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Productivity Commission

Econometric Modelling of R&D and Australia's Productivity

Staff Working Paper

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The views expressed in this paper are those of the staff involved and do not necessarily reflect those of the Productivity Commission.

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Preface

This Staff Working Paper presents the results of econometric modelling of the relationship between R&D and productivity growth in Australia. The project was initiated as part of the stream of research on Australia's productivity performance in the Commission's supporting research program.

The Commission is releasing this Staff Working Paper as a complement to a study recently commissioned by the Government. On 10 March 2006 the Government asked the Commission to undertake a research study on public support for science and innovation in Australia. The terms of reference request, among other things, that the Commission report on the economic impact of public support for science and innovation in Australia and in particular on Australia's recent productivity performance.

The Staff Working Paper should not be seen as necessarily foreshadowing or circumscribing the Commission's views. Any feedback on the Staff Working Paper will be considered in the context of this broader study.

The paper was developed and written by Sid Shanks and Simon Zheng under the direction of Dean Parham. The development of the paper was guided by Commissioner Mike Woods. Dr Trevor Breusch, an econometrics expert from the Australian National University, was engaged as a consultant to advise on modelling strategy and implementation. The project has also been assisted throughout by a Reference Group (see table 1.1), which provided external expertise and feedback on the project. A draft of the paper was also sent to the Reference Group for comment prior to finalisation.

Many people made significant contributions to the development of this paper. Paula Barnes constructed the infrastructure capital services measures used in the paper and wrote the associated appendix material. She also contributed to the construction of human capital indicators, undertook survey work on the productivity impacts of human capital and trade openness, and managed the editorial process. Damien Eldridge wrote the appendixes on international trends in R&D, transitional dynamics versus permanent impacts, and the calculation of an upper bound for the social return to R&D. He also undertook survey work on the effects of R&D on productivity, and contributed more broadly to discussions on many technical issues.

Tony Kulys made valuable contributions to the construction and management of datasets — a large task. He also produced many of the charts and tables used in the paper. Paul Roberts and Matthew Johnson contributed to the early stages of the research. Tracey Horsfall provided administrative and production support.

The Australian Bureau of Statistics provided vital assistance in the construction of datasets and measures based on unpublished data. The paper also benefited from comments from Ralph Lattimore and Garth Pitkethly of the Productivity Commission. Professor Steve Dowrick provided valuable referee comments on parts of the paper. The views in this paper remain those of the authors and do not necessarily reflect the views of the Productivity Commission.

Abbreviations

ABARE	Australian Bureau of Agricultural and Resource Economics
ABS	Australian Bureau of Statistics
ACCI	Australian Chamber of Commerce and Industry
ADF	Augmented Dicky-Fuller
AE	Electronic equipment; and Electrical equipment & appliances
AFF	Agriculture, forestry and fishing
AIC	Akaike’s information criterion
ANBERD	Analytical Business Enterprise Research and Development
ANSTO	Australian Nuclear Science and Technology Organisation
ANZSIC	Australian and New Zealand Standard Industrial Classification
AR	autoregressive
ARDL	autoregressive distributed lag
ASIC	Australian Standard Industrial Classification
ASNA	Australian System of National Accounts
BEC	Broad Economic Categories
BERD	business expenditure on research and development
BIC	Bayesian information criterion
BIE	Bureau of Industry Economics
BLS	US Bureau of Labor Statistics
BMP	Basic metal products
BRD	business research and development
CES	constant elasticity of substitution
CIPO	Canadian Intellectual Property Office
CITR	corporate income tax rate
CPI	consumer price index
CRS	constant returns to scale
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CUSUM	cumulative sum

DEETYA	Department of Employment, Education, Training and Youth Affairs
DFAT	Department of Foreign Affairs and Trade
DITAC	Department of Industry, Technology and Commerce
DITR	Department of Industry, Tourism and Resources
DOCITA	Department of Communications, Information, Technology and the Arts
DSTO	Defence Science and Technology Organisation
DW	Durbin-Watson
EPO	European Patent Office
ERA	effective rate of assistance
ETM	Elaborately Transformed Manufactures
FBT	Food, beverages & tobacco
FDI	foreign direct investment
FDL	finite distributed lag
FE	fixed effects
FGLS	feasible generalized least-squares method
FRBSF	Federal Reserve Board of San Francisco
GDP	gross domestic product
GERD	gross expenditure on research and development
GLS	generalised least squares
GNP	gross national product
GRD	gross research and development
H-P	Hodrick-Prescott
IC	Industry Commission
ICT	information and communications technology
IME	Industrial machinery & equipment
IO	input-output
IOM	Industry of Manufacture
IP	intellectual property
IPC	International Patent Classification
IPD	implicit price deflator
ISDB	International Sectoral Data Base

ISIC	International Standard Industrial Classification
IT	information technology
KPSS	Kwiatowski, Phillips, Schmidt and Shin
LP	labour productivity
MCC	marginal cost of capital
MFP	multifactor productivity
MNE	multinational enterprise
MP	Metal products
MRR	marginal rate of return
MSTI	Main Science and Technology Indicators
NMP	Non-metallic mineral products
OCE	other current expenditure
OECD	Organisation for Economic Co-operation and Development
OLS	ordinary least squares
OM	Other manufacturing
OTC	OECD Technology Concordance
PBS	Property & business services
PC	Productivity Commission
PCCAP	Petroleum, coal, chemical & associated products
PCSE	panel corrected standard errors
PCT	Patent Cooperation Treaty
PIM	perpetual inventory method
PPP	purchasing power parity
PPRM	Petroleum, coal, chemicals & associated products
PSE	Photographic & scientific equipment
QALI	quality-adjusted labour input
R&D	research and development
RDC	Research Development Corporation
RE	random effects
RMSE	regression mean squared error
SC	Schwarz's information criterion
SCORE	Survey and Comparisons of Research Expenditure
SEO	socio-economic objective

SITC	Standard International Trade Classification
SME	small and medium sized enterprises
SOU	Sector of Use
SR	Scientific research
SSMP	Structural & sheet metal products
SURE	seemingly unrelated regression equations
TAFE	Technical and Further Education institutions
TCF	Textiles, clothing, footwear & leather
TE	Transport equipment
TFP	total factor productivity
TKH	technical know-how
TRYM	Treasury Macroeconomic Model
TSP	trend stationary process
USPTO	United States Patent and Trademark Office
VA	value added
WIPO	World Intellectual Property Organisation
WPP	Wood and paper products; and Printing, publishing & recorded media
WRT	Wholesale & retail trade
ZA	Zivot and Andrews test

OVERVIEW

Overview

To what extent can econometric modelling clarify the relationship between R&D and productivity growth in Australia?

There is a lot of interest in new quantitative analysis that would provide updated estimates to help address the question of what effect R&D has on Australia's productivity. Policy advocates and policy makers have drawn upon major econometric studies conducted in the mid-1990s by the Industry Commission and Professor Steve Dowrick for evidence. These studies are now somewhat dated as the observation period can be extended at least 10 more years. The additional period covers considerable change in both R&D activity and economic performance. Further developments in the understanding of R&D impacts can also be exploited.

The objective of this study was to undertake a series of modelling exercises that took advantage of the additional available data to explore the effects of R&D on Australian productivity.

However, despite the advances in data and methods, our research was unable to find a consistent robust measure of the impact of R&D on productivity. In addition to core data measurement issues, the most likely explanation is that the extra data period includes disruptions or 'shocks' to the relationship between R&D and productivity performance in Australia. This has frustrated attempts to clearly determine the magnitude of any long-term relationship between R&D and Australian productivity.

As it progressed, the study became much more than a simple updating exercise. It has covered a large expanse of modelling territory and has tested the limits of standard models to explain the effect of R&D on Australia's productivity. It has also explored a promising approach that deals with influences on R&D and on productivity in separate models, but within a simple related system. However, whilst it has provided some clear and plausible results, uncertainties about magnitudes of some effects remain.

A major message from all the analysis is that, at least for the time being, empirical estimates of the effects of R&D on Australian productivity are unreliable. Any assessment therefore requires a high degree of judgment.

The context: change in the Australian economy

The analysis of the effects of R&D on productivity covers a period of marked change in the Australian economy. In very broad terms, an economy that, three decades ago, was domestically-oriented and resistant to change has become an economy that is more outward-oriented and innovative.

A number of ‘shocks’ have affected the climate for investment at different times. A generally adverse environment for investment in the 1970s turned around in the 1980s, with financial liberalisation and with lower wage costs under the Prices and Incomes Accords. Investment was also strong in the 1990s, but there was a switch away from property and toward machinery and equipment.

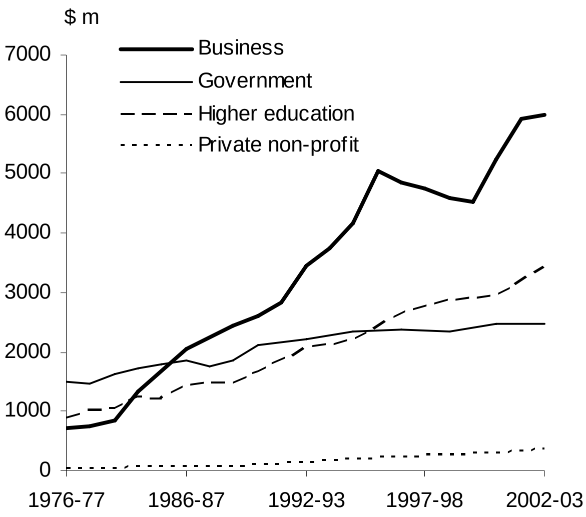
The climate for investment specifically in R&D has also changed — some of it broadly in line with the general investment trends, but also under some other influences. Business R&D expenditure surged between the mid-1980s and mid-1990s (box 1). The R&D tax concession lifted expenditure, although some of the increase is considered to be more ‘phantom’ than real. Competitive pressures, which heightened the incentives to undertake R&D, increased in the 1980s, especially in the manufacturing sector due to the rise of Asian competition and to reductions in trade barriers. Business R&D expenditure switched more heavily into services areas in the 1990s (box 1). To some extent, this may have reflected the general resource shift toward services. But there was also an expansion in technological opportunities as services provided more scope for innovation, particularly through application of information and communications technologies (ICTs).

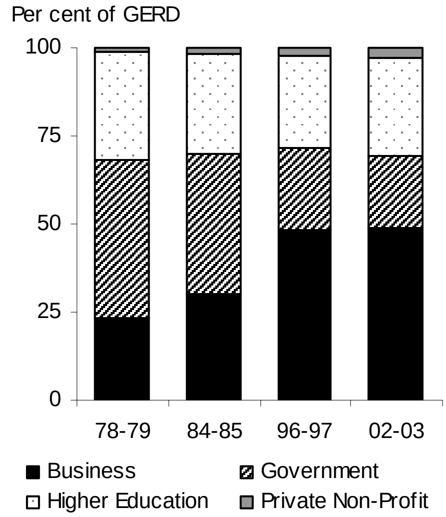
A number of shocks had strong effects on productivity. A series of microeconomic reforms contributed to Australia’s improved productivity performance, notably the record rates of productivity growth in the 1990s. A large part of the improved productivity performance was independent of influence from changes in R&D. Some, for example, came from reductions in excess manning and the reallocation of labour and investment. Adoption of technologies developed overseas (specifically ICTs) also played a part.

Box 1 **Trends in Australia's R&D activity**

Australia's R&D effort has increased about fourfold in real terms over the past three decades. By far the biggest increase has been in R&D undertaken in the private business sector, which now accounts for around one in two dollars spent.

R&D expenditure by institutional sector and shares in total expenditure

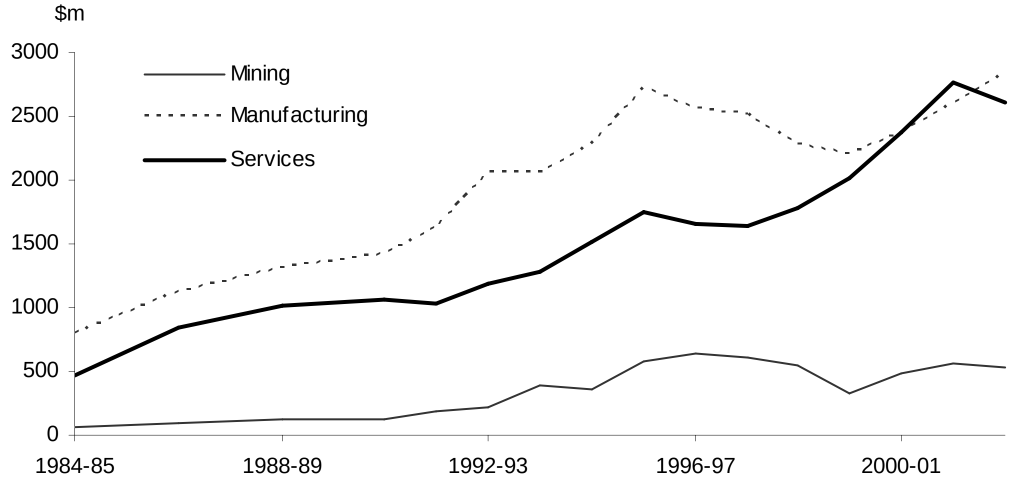




With the increase in business R&D, Australia's R&D effort has become much more commercially oriented. Business R&D is more skewed toward experimental development and applied research than is R&D activity in the other institutional sectors.

The industry structure of business R&D has also changed. Whilst manufacturing was the traditional locus of business R&D, services R&D has grown relatively much stronger since the mid-1990s. It is now on a par with manufacturing R&D.

Business R&D expenditure by industry sector, 1984-85 to 2002-03



The strategy in this study

The analysis in this study has been in the 'time series' rather than the 'cross country' mould. The time series approach models the effects of R&D on Australia's productivity over time. The cross country approach investigates the R&D and productivity relationship across countries (and, in some cases, with a time dimension as well). With some risk of oversimplification, cross country studies produce more precise estimates of general tendencies, given the many more observations usually available, but they do not give such a clear or unambiguous picture of the relationships specific to Australia. The time series approach puts the focus directly on Australian relationships, but limitations on the number of observations usually prevent a comprehensive and high-resolution view.

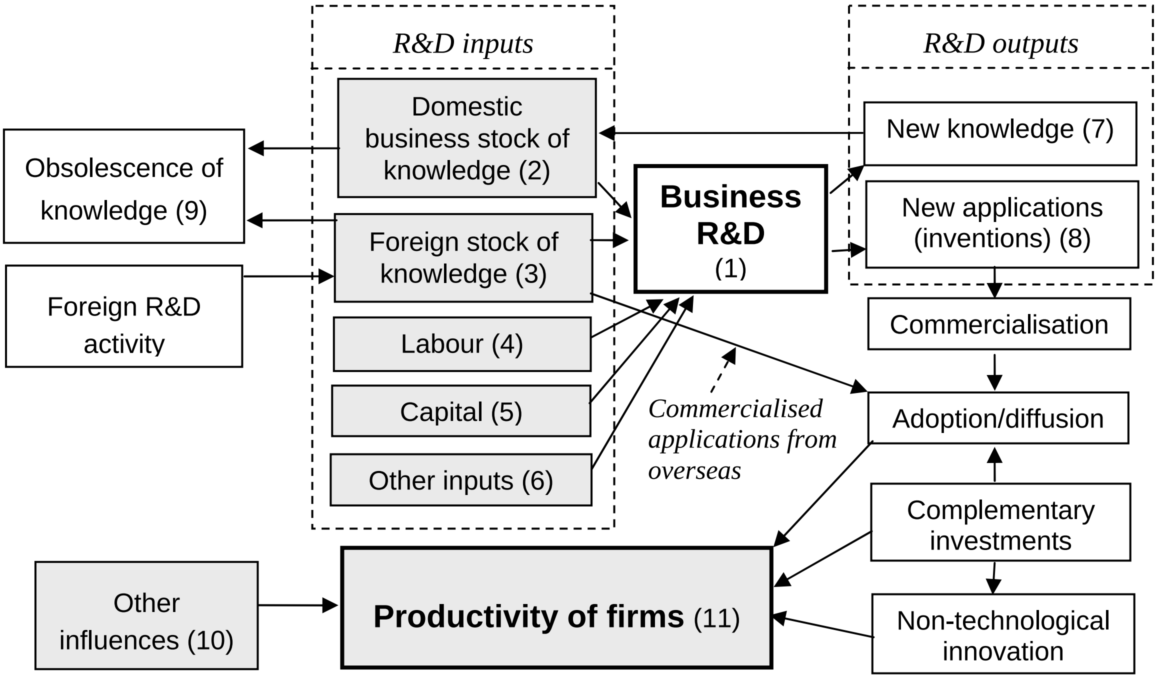
The approach in this study combined a strong grounding in theory, but took account of the fact that theory does not provide a great deal of guidance on a range of issues that prove to be important empirically (for example, appropriate lag structures). The reliability of results was thoroughly tested.

- The modelling was not driven by a particular view of the world. A number of alternative models, which drew on elements of neoclassical and endogenous growth theory, were used and tested.
- Many of the models included non-R&D variables in order to identify the effects of R&D, controlling for the possible influence of other factors on productivity. However, the relatively small number of observations placed severe limitations on the number of controls that could be tested comprehensively in any single model. A pragmatic approach was taken. Whilst theory guided the initial selection of potential influences, a process of eliminating 'weak' explanators and retaining 'strong' explanators was employed.
- Results were also tested thoroughly with a battery of statistical diagnostic tests to determine the reliance that could be placed on them. The sensitivity of key estimates to model and variable specification, and the stability of estimates over time, was also examined.

Model frameworks

The econometric models used were inevitably a simplification of a very complex system of relationships and interactions that link R&D and productivity (box 2). Various science, innovation and economic models are able to capture more of the complexity of parts of the system. But a model of the whole system inevitably requires compromises on the relationships that can be included.

Box 2 **Stylised links between R&D and productivity**



This chart is a highly simplified representation of the system of relationships that govern R&D activity, innovation and productivity growth. It helps to convey some of the major assumptions underlying the modelling.

R&D activity (1) is viewed as a knowledge accumulation process. Inputs of the existing stock of knowledge (2, 3), together with systematic investigation (4, 5, 6), create outputs of new knowledge (7) and new applications (technological inventions) based on the existing stock of knowledge (8).

Formation of knowledge stocks. The common practice is to assume that R&D inputs yield a constant amount of output (and constant ratio of new knowledge to new applications) over time. Accumulated R&D expenditure can then represent the stock of 'effective' knowledge, once allowance is also made for some knowledge becoming obsolete (9).

Econometric models. The models include the variables identified by the shaded boxes. The knowledge stocks (2, 3) and other influences (10) are related to productivity (11). (If other R&D inputs (4, 5, 6) are included in the measures of inputs to all production there is an element of double counting because they are also reflected in accumulated R&D expenditure — see chapter 5). The other variables identified in unshaded boxes, as well as many other features, are not included in the models.

The diagram also serves to illustrate that R&D is not the same as innovation. While R&D is the foundation for technological innovation, there is also non-technological innovation (for example, in management and organisational arrangements). Furthermore, R&D does not necessarily result in new technologies but, even when it does, other investments must be made, for example, in commercialisation, acquisition of technologies, and new skills (see chapter 2).

R&D activity is assumed to form knowledge assets that generate a flow of services into production, similar in that sense to traditional capital assets. However, depending on the theory underlying the model, knowledge can have different effects on productivity.

The models used in the study had their foundation in neoclassical economic theory, with various elements of endogenous growth theory built in. Even in that regard, there were simplifications. Endogenous growth theory emphasises increasing returns to knowledge accumulation. Theorists have emphasised different mechanisms for knowledge accumulation — R&D, human capital and physical capital (with embodied knowledge) — and interactions between them. The approach used here, however, focuses exclusively on R&D as a driver of knowledge accumulation. Whilst the input of human and physical capital into innovation activity is taken into account elsewhere in the models, their broader interactive role in knowledge accumulation is not.

Formation of knowledge stocks

Most of the models specify that it is the stock of knowledge (or, more precisely, the stock of R&D-based knowledge) that influences productivity. The stock of knowledge is represented by the accumulation of R&D expenditure, with allowance made for the 'decay' or obsolescence of knowledge (box 2). Domestic and foreign R&D stocks are separately identified.

The study focused on modelling the productivity effects of R&D undertaken in the private business sector. The study did not focus on returns to public sector R&D (by, for example, CSIRO and universities). Public sector R&D was included in some models, but only in an incidental fashion. The modelling downplayed this area of R&D activity, not because it is of lesser importance, but because it would require a different framework in order to be analysed properly.

Level of aggregation and data

Most of the modelling investigated relationships between R&D and productivity at a high level of industry aggregation. The desire to match the measure of productivity performance with the measure of R&D activity for the same area of the economy was a strong consideration. The 'market sector' scope of the prime productivity measures suggested that the measurement of R&D knowledge also be confined to the market sector of the economy. The market sector covers those parts of the economy in which outputs are relatively well measured and excludes areas such as public administration, defence, health and education where the output measure is effectively based on expenditure on inputs. Sensitivity testing also included a broader measure of the aggregate economy (the 'expanded' market sector). Separate modelling of a number of industry sectors was also conducted.

Box 3 briefly describes the data used in the modelling.

Box 3 **The sources and quality of data**

The data sources and quality for the main R&D and productivity variables are briefly described here. Further details and information on control variables are provided in chapter 5 and appendix A.

R&D data

Data on R&D expenditure in Australia were drawn from ABS sources. The ABS's R&D surveys are intended to be a complete enumeration of expenditure by R&D-performing businesses and institutions. Early expenditure data (in the 1970s) was complied by other government agencies. There have been various efforts to improve the quality of the early data so as to improve the assessment of trends. Nevertheless, there are likely to be some errors in trends, especially over long periods. Errors are likely to be even larger in structural dimensions of R&D expenditure over long periods.

Data on foreign R&D expenditure were drawn from OECD sources.

Productivity data

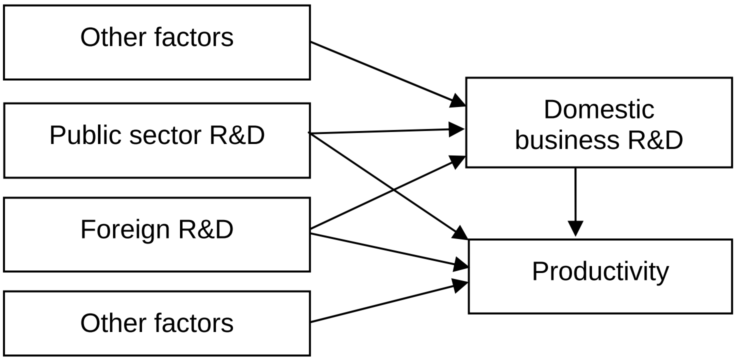
Productivity estimates for the market sector are the official estimates from the ABS's national accounts.

Productivity estimates for the expanded market sector are from Diewert and Lawrence (2005).

The estimates of productivity in industry sectors are compiled and published by the Productivity Commission. They are likely to be subject to more error than the aggregate estimates, for various reasons including doubts about how precisely industry of work is identified in ABS household surveys.

Analysis of influences on business R&D investment

An investigation of the influences on private investment in R&D was undertaken within a simple two-equation model where the influences on both R&D investment and productivity are estimated as a related system. R&D investment was also modelled as a separate equation for closer comparison to overseas studies.



The international context

International investment in R&D should have a large impact on the incentives facing Australian businesses to invest in R&D through a combination of the provision of new areas of technological opportunities, knowledge spillovers and competition effects.

During the 1970s, business R&D investment was very weak in absolute terms and when compared with overseas investment. Since the early to mid-1980s, the stock of Australian business R&D capital has grown much faster than the stock of foreign R&D capital. Net growth in the knowledge stock as a proportion of output was very weak or non-existent in the 1970s and into the 1980s. By the 1990s, the rate of accumulation of knowledge from business investment in R&D was roughly the same as for foreign OECD businesses (with or without the inclusion of United States and Japan). It was higher in the first half of the 1990s, and lower in the second half, with rates equal at 2001-02.

Factors associated with increased business R&D investment

Foreign R&D is strongly positively associated with increased domestic own-financed business expenditure on R&D.

A lower and more stable cost of capital, reductions in industry protection, government-financed R&D performed by businesses, and government-performed R&D were all found to be highly positively associated with increased business expenditure on R&D.

There was some evidence that university-based R&D tends to ‘crowd-out’ business R&D. Given the very strong increase in business demand for R&D since the mid-1980s and the impact this may have had on wage costs, a negative relationship is possible. However, it may not take account of some of the complex, longer term relationships between private and public R&D (such as the role of universities in training future scientists and engineers).

The robust positive association between domestic business R&D and foreign R&D is consistent with domestic R&D being undertaken in order to absorb overseas knowledge, overseas knowledge helping to reduce the costs of domestic R&D activity, and overseas knowledge establishing the boundaries of technological opportunity.

Productivity and the demand for R&D experienced common 'shocks'

The estimation strategy undertaken for the separate models within a related system is able to produce more precise estimates of the effect of R&D and the control variables on productivity, compared with the many single equation productivity models, because it exploits information in the error terms of the two equations. The two sets of error terms will be correlated when R&D investment and productivity have been subjected to common shocks that are not captured in each equation's set of explanatory variables. It is the information in the correlation of the errors that is used to improve results.

It is likely that important shocks such as economic reforms are not well controlled for in the models. Indexes of the level of industry protection and the degree to which wages are centrally determined are used as controls in the models, but are partial measures. It is particularly difficult to incorporate the changes in investment incentives pre and post-reform, but the different incentive structures may be very relevant to understanding both R&D investment patterns and productivity performance.

A hypothesis of a stronger link between firm profitability, innovation performance, and the private demand for R&D pre and post the mid-1980s helps explain the starkly different periods of R&D investment in Australia.

The effect of R&D on productivity: modelling strategy

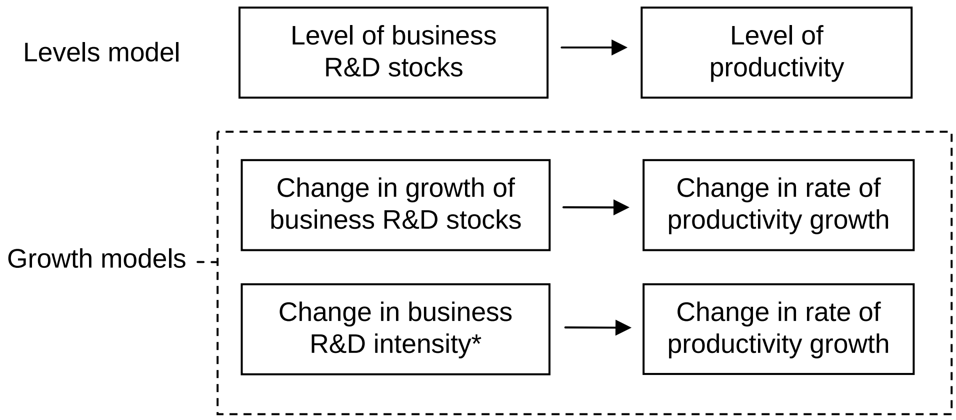
The 'standard' approach in the R&D-productivity literature has been to specify a single equation model that either represents an aggregate production function (that relates output to inputs, including R&D, and productivity) or represents a derivation from a production function that relates productivity to R&D. The second approach has the advantage that it requires estimation of fewer model parameters — restricted to those of prime interest — and this can mean that those parameters are estimated more precisely from the limited number of observations available.

The standard approach also specifies the relationship in a form that is linear in the logs of variables. In this study, this is referred to as the 'levels' model, in which the (log) level of R&D and other variables affects the (log) level of productivity. In some studies there have been limited or no control variables. It is common to control for at least the effects of the business cycle and time-varying influences on productivity.

Levels models are estimated as single equation models and as part of the two-equation model described above.

In addition to the levels models, three alternative theories of how R&D (or knowledge) affects productivity growth guided regressions at the level of the market sector and expanded market sector. These theories point to different specifications of the long-run relationship between R&D and productivity, with a focus on *growth* in productivity. In one version, growth in R&D affects growth in productivity and, in another, R&D intensity (the size of R&D in relation to GDP) affects productivity growth.

The productivity growth models were also estimated as single equations and as part of the two-equation system.



* R&D intensity is measured as R&D stocks or changes in R&D stocks in proportion to GDP.

The importance of foreign R&D to Australian productivity

Previous Australian studies have tended to find a relatively weak effect of foreign R&D on Australian productivity. Some cross-country panel studies even suggested a negative effect.

This study found that a negative relationship between foreign knowledge stocks and Australian productivity is readily obtained in models based on the 'standard' framework, when estimation does not take account of lags in R&D, transitional effects, and/or the possibility that the relationship between domestic R&D and productivity is not strictly linear in logs. Foreign patent measures were less likely to produce a negative effect.

However, at the level of the market sector and expanded market sector, the effect of foreign R&D is positive and highly significant when one or more of these features (depending on the specific model) are incorporated in the regressions. Both foreign knowledge stocks and patent measures are shown to have a large positive impact on Australian productivity. Results based on manufacturing subdivisions tend to support this finding, whereas other industry results have difficulty detecting an economically or statistically significant effect of foreign R&D.

An investigation into whether the effect of foreign R&D had changed over time produced inconclusive results. The dramatic increase in measured business R&D investment, rising education levels, increased openness to imports, and reductions in industry protection, are all trends that may have altered how important foreign R&D is to Australia. Some models supported an increasing partial effect due to either increased 'absorptive capacity' or greater incentives to exploit relatively low cost technology. However, other empirical specifications or regressions at different levels of aggregation did not.

Robust estimates for some 'control' variables

Significant improvements were made to the quality of the set of control variables used in the modelling. Some improvements relate to new data that has become available from the ABS, while others relate to measures constructed specifically for the study.

Although other influences on productivity, such as the level of education and industry assistance, were not a prime focus of the study, the estimates of their effects were generally more robustly estimated than was the effect of R&D on productivity.

Human capital

The effect of rising post-secondary school qualifications was generally positive and significant. Better controls for changes in human capital were constructed. Separate series of unpublished ABS data on post-secondary school qualifications were spliced together to create time series from 1974. In addition, the ABS's Quality Adjusted Labour Index (QALI) was tested in regressions. This recent index attempts to take account of changes in human capital both from formal education and work experience.

In models which produced a strong and positive effect of Australian business R&D on productivity, attempting to control for changes in the quality of labour did not reduce the coefficient on business R&D.

Influence of communication infrastructure and IT capital

Capital services measures were constructed for communication infrastructure, private IT capital, and general government infrastructure. Services measures are used by the ABS in its construction of MFP estimates for the market sector and offer improvements over net capital stock measures for productivity analysis.

Advances in ICT technology, especially since the early 1990s, appear to have raised, or at least shifted, the technological opportunities for R&D activity. The Australian economy appears to have benefited from the strategy of importing some technologies (ICT equipment) and investing in R&D (software development) to create complementary products in adapting these technologies to local use. Australian businesses have also been successful in providing ICT-related services to overseas niche markets. Much of the increased R&D activity has taken place in the services sector and a number of services industries (as well as industries in mining and manufacturing) have been able to gain from ICT-based innovation.

Previous research has demonstrated the potential for productivity gains due to innovations that users of ICT can base on an ICT platform. Although it was not thoroughly investigated, there was some evidence that the communications network had positive productivity effects at the level of the market sector; and that, having controlled for the effect of the communications network, there was no positive effect from ICT equipment itself. This would align network effects — externalities (productivity gains from, for example, better organisation of supply and distribution) due to the network of communication links between ICT equipment in different organisations and locations — with the communications network, rather than ICT equipment. In the expanded market sector, both tended to have positive impacts.

Industry protection and centralised wage determination

As well as being associated with rising business R&D investment, reductions in industry assistance had a highly significant positive impact on productivity. Reductions in the degree to which wages are centrally determined also appear to have had a positive impact. Industry protection is particularly robust to the many different empirical specifications, alterations to models and sensitivity testing that was undertaken to improve the results for the R&D variables.

In the case of the R&D equations, the positive association between increased R&D investment and reduced industry protection was robust to controlling for Manufacturing's declining share of output. This suggested that the effect was more likely to be a competition or incentive effect rather than reflecting a decline in technological opportunities in Manufacturing relative to other industries.

The uncertain estimated effect of Australian business R&D on productivity

Unreliable, fragile or implausible results were encountered in the early stages of investigation. This prompted a thorough canvassing of alternatives and an extensive search for specifications that might generate more reliable, robust and plausible results of the effect of Australian business R&D on productivity. However, the search did not result in a single preferred model that gives *the* rate of return to R&D.

Why the imprecision and fragility?

The econometric analysis of the effects of R&D seems to be especially fraught, with modelling difficulties including:

- problems in adequately capturing the complexity of R&D and innovation processes and their effects on productivity;
- transitional effects impairing the identification of a permanent effect;
- similarity in trends in key R&D and other variables — multi-collinearity — making the accurate attribution of productivity changes to different determinants problematic in the absence of strong long-run relationships;
- the relatively few observations, relative to the number of parameters of interest, brings lack of precision to estimation; and
- a number of shortcomings in the data in constructed variables and especially in the constructed knowledge stock variables.

In addition, there appear to be problems specific to the quantitative analysis of R&D and productivity based on Australian data. Various strands of evidence from the modelling indicated that the relationship between R&D and productivity has changed over the observation period:

- extension of the observation period beyond that used in previous studies (that is, extension from the early 1990s to 2000-03) resulted in increased instability and unreliability of results;
- analysis was beset with problems in establishing a clear long-run relationship between R&D and productivity;
- investigation often indicated instability in the estimated parameters; and
- formal testing provided some evidence of structural breaks in relationships (although the imprecise nature of the estimates means that the tests themselves cannot be firmly applied).

Estimates from the standard framework

Testing did not support the existence of a strong long-run relationship between the level of R&D and productivity in the market sector. This means that there is a risk that the estimated effect of R&D, which is positive and large in some models, is spurious. In response to data that exhibits strong trends, the common practice is to 'difference' the data and run a regression in growth rates. When this was done, results did not find a strong, positive effect of business R&D on productivity.

The precision and even the sign of the estimate on business R&D is sensitive: the inclusion of lags in the regressions; whether foreign R&D is represented by foreign knowledge stocks or patent indicators; and the inclusion of 'unexplained' technology shift parameters.

Models were also formulated that produced estimates for individual industry sectors — Agriculture, Mining, Manufacturing, and Wholesale & retail trade. The estimated effects of R&D on productivity were positive in all industry sectors, but the magnitudes varied widely. Overall, the modelling results were questionable on the grounds of plausibility and robustness. Industry estimation is beset with additional specific problems (for example, data quality — see box 3). Panel estimates for manufacturing subdivisions failed to produce reliable results using the standard framework, in part, because production technology parameters differ across industries (that is, the manufacturing subdivisions were not 'poolable' in levels).

Alternative frameworks: productivity growth models for the market sector

The growth models generally do not support a positive effect of continued rises in R&D intensity on productivity growth. When foreign knowledge stocks are used in the two-equation regressions, the sign on own-financed business R&D is generally a small negative, which is not statistically significant. When the foreign knowledge stock is replaced with a patent indicator, the effect remains negative, but it is more precisely estimated. The results from these models suggest that, were R&D intensity to rise further, a positive impact on the rate of productivity growth should not be expected.

The results for foreign R&D and the suite of control variables are generally consistent between the regressions based on the standard framework and regressions using the alternative frameworks. It is in the effect of Australian business R&D that results differ and are the most fragile. However, while an increase in R&D intensity may not lead to a 'permanent' increase in the growth rate of productivity, there may be important transitional effects that raise the level of productivity.

Is there a stable structural relationship between R&D and productivity?

Various tests indicated that there may have been changes in the relationship between R&D and productivity over the period examined. A number of different ways of allowing estimated elasticities to vary over time were tested in regressions. The standard framework with slope shifts in basic systems models indicated a significant decline in the average effect of R&D on productivity post the mid-1980s, but with the effect remaining strongly positive. The growth specifications also indicated a declining partial effect on productivity growth of continued increases in R&D intensity.

A changing relationship and implications for the measured return to R&D

There are a number of complications in defining and measuring the social return to R&D, which are discussed in the paper. For the purposes here, what is important is that business investment in R&D can lead both to private benefits, which are appropriated by the business, and external effects on other businesses. In the broadest sense, the social return captures both the private and external effects. Most studies find that the social return is greater than the private return because the external effects are dominated by the positive effects of spillovers on the productivity of other businesses.

While there is significant uncertainty surrounding the estimated return to R&D, the results referred to in the previous section suggest that the difference between the social and private returns to R&D may have become much less after the mid-1980s.

Applying a constant elasticity to observed R&D intensities also suggests a diminished return to R&D.

A possible explanation is that, prior to the mid-1980s, very weak private investment in R&D resulted in the social return to R&D being significantly greater than the private return — business was underinvesting in R&D from a social perspective. With changes in the incentives to innovate from the mid-1980s, business invested heavily in R&D, and this likely contributed to the improved productivity performance of the 1990s, as well as leading to a reduction in the gap in the social return over the private return. How much of a reduction remains very unclear.

Post the mid-1980s, it is believed that R&D and innovation came to play a more central role in determining firm profitability and productivity.

Other potentially important influences on the return to R&D include: rising complexity; an expansion in the number of product varieties that require R&D to improve their quality; duplication externalities and 'creative destruction' effects between firms; changes in technological opportunities; changes in the fraction of the knowledge stock that can be characterised as a public good and, hence, changes in the volume of spillovers for a given measured stock; high real interest rates; the degree of quality adjustment in the national accounts; and the very large increase in the service sector's share of output. Some of these influences diminish the social return to R&D, while others work to offset the tendency to diminishing returns.

The productivity of R&D

What matters is the productivity of R&D (the extent to which R&D inputs generate R&D outputs — see box 2) as well as the amount of R&D. The productivity of R&D is affected by changes in technological opportunity, the cost of inputs to R&D, and how well R&D effort is organised at firm, industry, national and international levels.

Changes in the productivity of R&D can decrease the robustness of estimates of the effect of R&D because, in part, the construction of knowledge stocks assumes a constant relationship between the resources consumed in R&D and the knowledge obtained from R&D.

Concluding remarks

The study has generated an array of empirical results that should contribute to furthering an understanding of the role that R&D has played, and continues to play, in the Australian economy.

However, the body of work in this study has also highlighted many challenges in the quantitative analysis of the effects of R&D on productivity. The paper presents the strengths and weaknesses (‘warts and all’) of different approaches. Quantitative analysis, carefully conducted and interpreted, can assist the assessment of the economic returns to investment in R&D in Australia. But it cannot supplant the need for judgment about what is adequately and reliably captured and what is not. This report presents an extensive information base to assist in the assessment of the returns from R&D investment and to contribute to a firmer foundation for future judgments.

At this point in time, there remains no precise, robust estimate of the effect of increases in domestic business R&D on Australia’s productivity performance. Standard models and estimation methods, grounded in theory, tended to generate unreliable results, as well as estimates that were sensitive to seemingly modest changes in specification. A comprehensive investigation of alternative specifications and estimation techniques brought new insights, but proved unable to arrive at any definitive estimate.

An economy in transition

The lack of robustness in the econometric modelling is partly due to fundamental measurement and analytical challenges. But it is also likely that sizeable ‘shocks’ to R&D and productivity in Australia over the past two decades have obscured, if not disrupted, the statistical relationship between them. Allowing for periods of adjustment to these shocks, there still may not be enough observations to determine any ‘new’ long-term relationship with precision.

While R&D-based theories emphasise a long-run structural relationship between R&D and productivity, it may be that the relationship is subject to such frequent shocks or random processes that there is no stable long-run or permanent effect. The average effect found in regressions is the average effect for the period under observation, which may not be a good measure of what the marginal effect would be from increasing R&D, say, over the next 10 years.

1 About the project and this paper

1.1 Background to the project

This investigation into the relationship between research and development (R&D) and productivity growth has three main motivations. First, it is part of a stream of work in which the Productivity Commission has monitored trends in Australia's productivity performance, analysed their causes and assessed their consequences for the living standards of Australians. R&D, technological change and innovation are major contributors to Australia's productivity growth that warrant investigation.

Second, there is some uncertainty and debate about the role of Australian R&D in the economy's performance. It is common ground that R&D plays a central role in long-term innovation and productivity growth among high-income countries. However, there are some specific issues that attract debate in the Australian context. Some of the divergent views expressed are as follows.

- A marked improvement in Australia's productivity performance since the early 1990s is associated with an increase in R&D activity and with other developments that have led to Australia becoming a knowledge-based economy.
- The increase in R&D activity is more apparent than real. Government incentives to increase R&D activity have done more to lift R&D spending on paper than they have to raise the delivery of commercially-relevant R&D outputs.
- Australia's R&D effort remains inadequate to sustain strong economic performance in the long term. The 1990s productivity gains were primarily due to factors other than R&D; and have obscured deficiencies in Australia's R&D capability and effort.
- Australia is a 'technologically-small' and geographically-isolated country. In general, Australia should rely on technologies developed elsewhere.

Further, analysis could shed light on some of the underlying issues and might help to narrow areas of debate.

Third, the Australian economy has undergone significant structural change over the past two decades. There has been an increased emphasis on innovation and on directing more of Australia's R&D effort toward commercial implementation. The changing patterns of R&D activity could themselves be significant and worth highlighting.

The dearth of available quantitative studies of Australia's R&D activity provided a very limited basis upon which to address these issues. Whilst the evidence of a link between R&D and performance is plentiful, it tends to be based on overseas and cross-country analysis. There is little analytical evidence that specifically addresses the economic effects of Australia's R&D effort in recent times. Studies since the mid-1990s that specifically focus on the broader economic effects of Australia's R&D effort are limited.

1.2 The R&D project

The Productivity Commission embarked on this research project with the aim of helping to fill that gap. The project was initiated as part of the Commission's supporting research program. It does, however, now have relevance to the Commission's formal study into Science and Innovation in Australia that was initiated through terms of reference from the Government on 10 March 2006.

Objectives

There were two principal objectives in undertaking the project:

- to identify trends in R&D activity that are likely to have had a significant influence on Australia's economic performance; and
- to quantify the effect of R&D activity on Australia's past economic performance.

Scope and focus

As a supporting research project, the purpose of the study has been to assemble useful information and analysis. Assessment of optimal levels and types of R&D activity, evaluation of policy measures or recommendations for government action are not part of its scope.

Quantitative analysis, directed at assessing the broad economic effects, has been the prime focus. Consequently, many important dimensions and contributions of R&D are not covered.

The analysis focuses primarily on the economic effects of R&D undertaken in the business sector. This is where R&D activity could be expected to relate most directly and immediately to economic performance. Trends in, and effects of, R&D activity in different industries is also of particular interest, but the measurement of the effects of R&D at the industry level is severely constrained by available data.

R&D undertaken by publicly-funded institutions is also included in the analysis. However, its contribution to the advancement of knowledge and the economy over the long term have not been thoroughly investigated.

R&D undertaken overseas is potentially a major source of knowledge for Australian businesses. Whilst a significant amount of effort has been devoted to identifying the effect of overseas knowledge on Australian productivity, the diverse impacts it can have on the accumulation of knowledge in Australia and Australia's economic performance, means that much more work could be done.

In order to assess the effects of R&D on economic performance, it is essential to isolate the effects that other factors have on economic performance. There are limits on the extent to which this can be done in practice. But, as a by-product, the analysis can give some preliminary insight into other influences on economic growth.

Processes

The project has covered a lot of territory. In part this was due to some basic data and estimation issues that confront this area of analysis. Modelling tends to be 'fragile', with results showing a fairly high degree of sensitivity to changes in specification. In this light, and given the importance of the objectives, a lot of effort has been put into thoroughly testing alternative frameworks and model and data specifications. This has been done at various levels of data aggregation.

Dr Trevor Breusch, an econometrics expert from the Australian National University, was engaged as a consultant to advise on modelling strategy and implementation.

The project has been assisted throughout by a Reference Group (table 1.1). The objective in forming the Group was to tap into external expertise, to ensure that the project was directed as far as possible at issues of relevance, and to get feedback on the project as it progressed. A draft of the report was also sent to the Reference Group and others for comment prior to finalisation.

Progress on the implementation of the project was also presented at various stages to broader audiences at conferences and meetings of groups involved in research and development.

Table 1.1 **Membership of the R&D project Reference Group**

Government agencies	
	Australian Bureau of Statistics
	Australian Tax Office
	Australian Treasury
	Department of Communications, Information Technology and the Arts
	Department of Education, Science and Training
	Department of Industry, Tourism and Resources
Research sector	
	Dr Ian Elsum — CSIRO
Academics	
	Dr Trevor Breusch — Australian National University
	Prof. Steve Dowrick — Australian National University
	Prof. Peter Hall — Australian Defence Force Academy

1.3 This paper

The documentation is organised in a way to facilitate access to material by people with different levels of interest.

- The Overview provides a non-technical discussion of the study and its outcomes.
- The chapters provide detailed documentation of the conduct of the study and its results and discussion of its conclusions and implications. Some chapters delve into technical issues more than others. Summary discussion is designed to remain accessible to those with a general understanding of statistical and econometric issues.
- The appendixes provide supporting details, and some of them are at a technical level. Appendixes have not been reproduced in this volume, but are available on CD (inside cover or by request to the Commission) and on the Commission's website (www.pc.gov.au/publications).

The remaining chapters document the study in the following fashion.

- The next two chapters provide non-technical overviews of:
  - how R&D affects productivity and issues that arise in the analysis of R&D and productivity (chapter 2); and
  - trends in R&D activity and productivity (chapter 3).

- Two chapters then set out the framework for quantitative analysis:
  - a review of empirical models, previous estimates and common estimation challenges (chapter 4); and
  - description and analysis of data assembled for this study (chapter 5).
- Three chapters then present the results from three types of analysis:
  - basic regressions involving aggregate R&D and productivity (chapter 6);
  - extensions of these regressions to include controls for other influences on productivity (chapter 7); and
  - regressions at the industry sector level (chapter 8).
- Two chapters examine two particular areas that warrant further investigation:
  - the effect of foreign R&D on performance in Australia (chapter 9); and
  - factors affecting the amount of R&D undertaken in Australia (chapter 10). This chapter also advances the analysis of the effects of R&D on productivity undertaken in chapters 6, 7 and 9.
- The implied rates of return to R&D, conclusions and policy implications are discussed in chapter 11.

2 How does R&D affect productivity?

Innovation is universally regarded as the most important source of productivity growth over the long term. Technological advance, based on research and development (R&D), is seen by many as the cornerstone of innovation.

Yet the relationships between R&D activity and productivity growth are so complex that they defy straightforward description and empirical investigation. Plenty of scope remains to differ on how, and the extent to which, R&D affects productivity growth.

This chapter introduces key concepts, issues and theories that are pertinent to the quantitative analysis of the effects of R&D on productivity. The objective is to give a broad and largely non-technical overview of how R&D is thought to affect productivity, of how relationships are captured in quantitative analysis and of some of the limitations in the models that are used as the basis for quantitative analysis. The chapter:

- defines R&D and productivity for the purpose of quantitative analysis (section 2.1);
- identifies key stages that link R&D, innovation and productivity growth (section 2.2);
- explores some of the issues, relationships and institutional arrangements that govern the accumulation of knowledge through R&D activity (section 2.3); and
- outlines the theoretical basis for the quantitative models that investigate the links between R&D-based knowledge and productivity growth (section 2.4).

Many of the pertinent issues are introduced here, but are taken up in more detail in later chapters and the appendixes.

2.1 Clarification of concepts

The prime focus of this study is on the extent to which R&D is a source of change in the technology of production that improves productivity in economic activities.

The terms ‘R&D’ and ‘productivity’, whilst broadly understood, can have slightly different meanings or interpretations in different contexts. This section outlines the concepts of R&D and productivity that underlie the data available for quantitative analysis.

What is R&D?

Australian data on R&D are compiled by the Australian Bureau of Statistics (ABS). In keeping with international standards[1], the ABS defines R&D as systematic investigation that is undertaken in pursuit of new knowledge and new applications of existing knowledge.

The scope of measured business R&D mainly falls within the broad area of 'science and technology', whereas higher education R&D has a broader scope. Fields of science and technology cover: natural sciences, engineering and technology, medical sciences, agricultural sciences, social sciences and humanities.

R&D can have economic, social and environmental relevance and application. The introduction of new medical technologies, for example, brings both social and economic gains. From the economic viewpoint, R&D activity is ultimately directed toward the discovery of new goods and services, new inputs into production (materials and devices), and new methods of production, distribution and marketing.

There is one dimension of R&D activity that is not explicit in the ABS/OECD definition. It is increasingly recognised that R&D can enhance the capability of individuals, firms and R&D institutions to identify, assimilate and apply relevant knowledge. The ability to assist the absorption of knowledge and technologies developed elsewhere is sometimes referred to as the 'second face' of R&D (Cohen and Levinthal 1989).

The ABS collects data on four categories of R&D activity. The Bureau identifies three types of research — pure basic, strategic basic and applied — and a category of experimental development (box 2.1). Basic research has no particular application in mind, whereas applied research and experimental development are defined to have a particular application in prospect.

Trends in the four categories of R&D activity are reviewed in chapter 3.

[1] See the *Frascati Manual* (OECD 2003c, p. 67).

Box 2.1 **Types of R&D activity**

The Australian Bureau of Statistics follows international conventions in defining categories of R&D activity. In brief, these are:

- *pure basic research*: experimental and theoretical work undertaken to acquire new knowledge without looking for long term benefits other than the advancement of knowledge;
- *strategic basic research*: experimental and theoretical work undertaken to acquire new knowledge directed into specific broad areas in the expectation of useful discoveries;
- *applied research*: original work undertaken primarily to acquire new knowledge with a specific application in view; and
- *experimental development*: systematic work, using existing knowledge gained from research or practical experience, that is directed to producing new materials, products or devices, to installing new processes, systems and services, or to improving substantially those already produced or installed.

What is productivity?

Productivity is a measure of the quantity of output produced per unit of input(s) used.[2] More output per unit of input can be generated in two ways. Producers can introduce ways of using fewer inputs to produce a unit of output (efficiency of input use). Or they can change the nature of the output they produce in ways that yield more output per unit of input (effectiveness of input use).

The two most common measures of productivity are labour productivity and multifactor productivity (box 2.2). Labour productivity is measured as output per labour hour worked. Multifactor productivity (MFP) is measured as output per input of labour and capital combined.

There is a relationship between labour productivity growth and MFP growth that will come into use in later chapters. The relationship expresses growth in labour productivity as the sum of capital deepening (which captures increases in the capital-to-labour ratio) and MFP growth. The intuition behind the relationship is that increases in output per unit of labour input can come about by installing more capital per unit of labour input (for example, increased mechanisation) or by improving the efficiency and effectiveness with which inputs combine to produce

[2] Because more than one good is commonly embraced in productivity measures, output normally has to be valued to allow aggregation. In this sense, the real *value* of output enters the productivity calculation.

output (for example, increasing the number of shifts in which labour operates installed plant and machinery).

Box 2.2 **Measures of productivity**

Different productivity measures are distinguished by the input measure used.

Labour productivity measures output produced per unit of labour input, where labour input can be measured by the number of employees or, more usually and preferably, by the number of hours worked by all employees.

Capital productivity measures output per unit of capital input.

Multifactor productivity (MFP) uses a more comprehensive measure of inputs — usually both labour and capital (although, in principle, others can also be included). And so, typically, MFP is a measure of output of goods and services per combined input of labour and capital.

Which productivity measure is used depends on the context and on the availability of data. Growth in labour productivity is often used in a macro context to convey improvements in a nation's prosperity, because growth in labour productivity usually closely approximates growth in average income — a frequently-used indicator of a nation's prosperity. In a macro or micro context, labour productivity growth can also be used to indicate the affordability of wage increases. Labour productivity partly determines unit labour costs — a measure of the extent to which wage costs are matched by productivity improvements. Labour productivity is also sometimes used for purely practical reasons — the lack of available data on capital inputs.

MFP is a more comprehensive measure of the extent to which inputs are used efficiently and effectively. The way it is normally measured, MFP captures: movements of inefficient firms towards current 'best practice'; firms' adoption of new more-efficient production methods; firms' production of higher-quality output; and the shift of resources between firms and uses that have higher or lower levels of productivity.

In brief, R&D is a source of productivity growth when it leads to changes in technology that generate new or better-quality products (product innovation) or that improve techniques of production (process innovation).

Trends in Australia's productivity performance are reviewed in the next chapter.

2.2 A sketch of stages that link R&D, innovation and productivity

This section provides a broad overview of some key steps that link R&D activity, innovation and productivity growth. A highly simplified and 'linear' (stage-to-stage) progression is presented. This does not capture the complexity and systemic nature of the R&D-productivity links. Rather, it serves to highlight issues that have an important bearing on quantitative analysis. More of the complexity is built into following sections.

It is helpful to distinguish four components that link R&D and productivity:

- R&D activity that leads to increments in the stock of knowledge and to discoveries of new applications of knowledge — that is, new technologies for production activities;
- commercialisation activity that takes the invention of a new technology to the stage where it can be introduced into production;
- the diffusion of commercialised technologies; and
- other innovative activities (often of a non-technological nature) that can interact with new technologies to generate productivity gains.

R&D inputs and outputs

R&D activity can be characterised as a process of transforming R&D inputs into knowledge outputs (in particular, increments to the stock of knowledge and new technologies, but also enhanced absorptive capacity).

The existing stock of knowledge is one of the major inputs in this process. Thus, R&D activity can also be seen as a process of accumulating knowledge over time. Moreover, the directions that research takes and the type of knowledge gained are fundamentally related to pre-existing knowledge. For example, some fundamental research (nuclear physics) may lead to a knowledge breakthrough that spawns a stream of subsequent technological applications (weapons, energy generation, medical diagnostics and treatment, new materials, carbon dating). In other words, there can be a 'path dependence' to R&D activity.

Other major inputs into the R&D process are the expertise and creativity of researchers and supporting labour, capital items (such as buildings, structures and equipment), and materials and purchased services. (Expenditures on these inputs are reviewed in the next chapter.)

The type of R&D activity undertaken has an important bearing on the nature of R&D outputs and on the timing of their delivery. Basic research is oriented toward finding new knowledge and understanding. It can take many years to come to the point of 'discovery'. Applied research and experimental development, on the other hand, is directed at the discovery of specific usable technologies in a much shorter timeframe.

The delivery of outputs from R&D is subject to uncertainty. By definition, R&D explores the unknown. In basic research, particular outcomes cannot be anticipated. In applied research and experimental development, particular outcomes may be anticipated, but their delivery cannot be guaranteed. Not all R&D activity is 'successful' in reaching its initial objective or in generating a useful outcome. Some projects simply fail or generate an unforseen outcome.

Commercialisation

A technological invention cannot usually be introduced immediately into production activities. It normally requires further investment in pre-production or commercialisation activities (such as trial production and testing, market testing, regulatory approval and the establishment of methods of supply and distribution) to take inventions to the stage where they can be introduced into commercially-viable production and use.

Conceptually, R&D finishes where commercialisation starts.[3] This distinction is employed by the ABS in its collection of data on R&D expenditure.

There are two important implications that impinge on the analysis of the productivity effects of R&D. First, success in achieving an R&D output of a new technological application does not necessarily guarantee success in achieving a technology that can be introduced into commercial operation. Some inventions 'fall over' at the commercialisation stage and are not used.

Second, additional investments in commercialisation should share in the attribution of gains from the introduction of new technologies, because they are essential complements to the invention itself in generating productivity gains. Without the commercialisation investments, the R&D outputs would not, and could not, generate productivity gains.[4]

Diffusion

A further step that affects the magnitude of the economic benefits from R&D outputs is the extent and rate of diffusion of new commercialised technologies

[3] In practice, the distinction between R&D and commercialisation may not be precise. Furthermore, R&D does not necessarily lead in linear fashion to commercialisation. The commercialisation process can identify the need for further R&D work to make an application viable.

[4] They are jointly responsible for the gains because, without the R&D output, commercialisation too would not, and could not, generate productivity improvements.

among producers. Some technologies (such as specific pharmaceutical products) are usually confined to a small number of firms, whereas other technologies (such as computer hardware or software used in production processes) are widely diffused among a very large population of firms.

Firms incur costs, associated with the adoption of new technologies in order to derive benefits. Adopting firms usually have to pay for the technology itself, either through licensing fees or through the purchase price of the products in which the new technology is embodied. Adoption of some technologies also involves other adjustment costs, such as staff training and complementary investments in capital (other equipment or modifications to buildings).

The economic returns from the introduction of new commercialised technologies are the collection of net gains to individual adopting firms. The net gains are the benefits that come from additional productivity, less the adoption and adjustment costs.

The pattern of net gains can be quite different across firms, even in similar industry circumstances. Some firms have strategies that, by being active in R&D, put them at the forefront of developments in knowledge and application of technologies. The costs and the risks may be higher, but their expectation is that the market rewards will also be higher, especially over the long term. The strategy for other firms is to not engage actively in R&D, but to base their innovation strategy on adopting new technologies only when they are well refined and costs and benefits are clear. Costs and benefits of adoption are likely to be lower and the timing of uptake comes later.

The measured productivity gains, derived from ABS national accounts data, are more likely to be net gains than gross gains. In principle, the purchase of technology either through license fees or embodied in capital is taken into account in measured inputs. Adjustment costs that are manifest in additional labour or capital would also be included in input measures. However, in practice, there are likely to be some unmeasured costs. These could include unmeasured technological improvements in capital purchases, the diversion of management effort and the need to invest in organisational learning in order to adapt to a new technology.

R&D and non-technological innovation

There is another potential layer of complication. Some productivity gains associated with the introduction of a technology come not just from the adoption of technology alone, but also from complementary investments in related innovation. These investments are more than adjustment costs, and warrant different treatment.

The introduction of information and communications technology (ICT) is a prime example. The adoption of ICT often involves adjustment costs such as staff training.[5] The end result is an improvement in productivity (via capital deepening) and profitability, but the business continues in essentially the same fashion.

However, the use of ICT also has the potential to transform businesses in ways that generate additional productivity gains. ICT is considered to be a general purpose or enabling technology that provides a platform upon which business users can undertake their own innovations. They can develop new products and new methods of production, marketing and distribution. Some innovations may be technological and based on R&D investment — for example, to develop new software. But many of the investments are non-technological and do not require formal R&D activity. Examples are new management information systems and techniques, new work arrangements and new organisational boundaries, structures and linkages to suppliers and customers.

In terms of attribution of productivity gains, there is a parallel here with the treatment of investments in commercialisation. Investments in such activities as managerial and organisational change are essential complements and are jointly responsible, along with the use of ICTs, for any additional multifactor productivity gains.

The role of R&D in innovation and productivity growth

The above discussion puts the role of R&D activity in innovation into perspective. The terms 'R&D' and 'innovation' are sometimes used interchangeably, or R&D expenditure is sometimes used as a measure of innovation. It is clear from the above that R&D is neither necessary nor sufficient for innovation to take place. Innovation is about the introduction of new technologies or production arrangements into commercial operations. Some R&D activity does not lead to innovation, either in the short term or at all. It can be directed at discovery of 'deeper' knowledge, rather than short-term application. Some R&D activity fails to reach usable outputs. R&D activity is also insufficient for innovation in the sense that additional complementary investments, especially in commercialisation, are normally required. R&D is not necessary for innovation both in the sense that many firms do not have to undertake R&D in order to adopt new technologies and in the sense that other non-technological paths to innovation are possible.

5 Some adjustment costs, such as training, might be seen as indispensable. But they are more in nature of 'familiarisation' expenses than longer-term investments that change the nature of what the business does or how it operates.

To put R&D activity in perspective in expenditure terms, the results of the 2003 Innovation Survey (ABS Cat. no. 8158.0) revealed that R&D costs accounted for about one third of what businesses spent on innovation.

2.3 The accumulation of knowledge

With the above simplified overview now in place, this section returns to the stage at which R&D outputs are generated in order to highlight more of the range of issues that confront quantitative analysis. For convenience, the distinction between knowledge and applications of knowledge is now dropped and the term 'knowledge' is used in a more generic sense to cover both.

Characteristics of knowledge

R&D is territory rich in potential 'spillovers' — benefits to users (of knowledge in this case) that are not fully reflected in the compensation they pay to producers (of knowledge). There are two key characteristics of knowledge that underpin the presence of spillovers:

- *Non-rivalry.* Knowledge can be made available to a number of users simultaneously without extra costs to the supplier. Unlike a typical asset, such as a car, knowledge is not 'consumed' by those who use it. It can be used at multiple times and by multiple users.
- *Non-excludability.* There are many cases in which users of knowledge cannot be denied access to it (particularly in the absence of patent protection). For example, the act of seeing an application in use can be closely linked to the act of transferring the knowledge.

Box 2.3 gives more detail on the nature of knowledge spillovers.

Spillovers can have a 'cascading' effect on returns to R&D effort. The knowledge derived by one firm or organisation can form the basis for other firms to 'reuse' the knowledge to their benefit. If the subsequent users fully compensate the originator for their use, the gains from introduction of the new technology will be concentrated in the economic performance of the originator. But, if full compensation is not paid, the gains will be spread over a number of using firms. Because of spillovers, returns to R&D are often higher at an industry or aggregate level than they are for individual firms that undertake R&D.

The non-rivalry and non-excludability characteristics of knowledge also add an increasing returns dimension to the process of knowledge accumulation itself. The more knowledge that is created and diffused, the more scope there is for higher returns to further R&D effort (Dowrick 2002). This characteristic underpins growth models outlined in the next section.

The stock of knowledge generated in other countries is a major potential source of knowledge transfer and spillover to Australia. As spelt out in the next chapter, the bulk of the world's R&D activity is undertaken in the United States, Japan and Europe.

Box 2.3 **On the nature of knowledge spillovers**

Knowledge spillovers are benefits to users of knowledge that are not fully reflected in the compensation they pay to producers of knowledge.

Knowledge is 'stored' and transmitted in different ways. It can be embodied in physical capital and transferred along with the sale of the item of capital. It can be embodied in human capital, for example, in the minds of researchers. (Knowledge that cannot be fully articulated is known as tacit knowledge.) Or it can be disembodied, for example, in a set of blue-prints (codified knowledge) that is available for transfer to others. Some knowledge can be transferred by mere imitation.

The unintentional 'leakage' of knowledge is a major source of spillover. Non-excludability can be particularly acute in research. But problems also arise in the development of applications. Discoveries can be copied. Knowledge embodied in capital can be accessed, for example, through reverse engineering. Researchers can leave their organisations.

Private firms can take some steps to reduce the risks of leakage. They can maintain high levels of secrecy or, in some situations in which the number of potential beneficiaries is small, they can collaborate on R&D projects.

'Pecuniary' spillovers can also occur because of market circumstances. Purchasers of embodied technology may be able to pay below the level at which they value it, because competitive market conditions for the goods prevent sellers from raising their prices beyond a point. Technological advances embodied in information and communications technology equipment are a prime example.

Spillovers can also have a down side, when they reduce the incentives for private concerns to invest in worthwhile R&D. Non-excludability makes it difficult for the producers of knowledge to extract payments from users and this, in turn, may make it difficult for the R&D performers to make sufficient returns on their investment to make it worth undertaking. If they do not proceed with the R&D, the potential for higher collective returns is not realised.

Dealing with spillovers – different institutional performers

The existence of spillovers provides a broad rationale for government intervention — to bolster the conditions under which worthwhile R&D is not discouraged and knowledge spillovers do in fact occur to the benefit of the economy generally. The forms of intervention can include the establishment and enforcement of intellectual property rights (patent protection that makes the 'right to use' knowledge excludable), general incentives (for example, tax concessions for private R&D), specific grants for particular R&D projects and public funding of R&D organisations.

The public good character of R&D and the forms of government support give rise to some institutional specialisation in the conduct of R&D activity. Private firms that undertake R&D tend to give more emphasis to development rather than research in the pursuit of more immediate and certain returns.[6] The technological and economic risks of development activity are generally less or can be better managed.[7] A major form of government support for R&D comes through direct public funding of research organisations — government research agencies, such as the CSIRO in Australia, and universities in their research function. These publicly-funded agencies are well placed to focus more on research and to undertake more of the type of research that generates diverse and diffuse benefits through knowledge spillovers.

Trends in the levels and types of R&D undertaken in these institutional sectors are reviewed in chapter 3.

The productivity of R&D activity

The degree of cohesion and coordination between the activities of different R&D performers is one influence on the amount of knowledge output that can be generated through available R&D inputs — that is, the 'productivity of R&D'. This concept encompasses the productivity R&D activity alone, and is quite distinct from the effects that R&D (outputs) may have on productivity in the economy at large. Since the productivity of R&D determines the amount of knowledge output generated, for given resource inputs, it also determines the potential for productivity gains in the economy generally.

[6] Many large R&D-performing firms have a mix of research and development activities.

[7] For example, the risk of leakage of knowledge can be limited by a combination of secrecy and speed to market (for example, software development) or by patent protection (for example, in pharmaceuticals).

Two broad factors affect the productivity of R&D in a given period:

- the inherent ‘ease’ of making a discovery or what are referred to as ‘technological opportunities’; and
- the organisation of R&D, or the ways in which resources are organised in order to achieve advances in knowledge effectively and efficiently.

Greater technological opportunities implies that more knowledge can be generated per R&D dollar spent. The existing stock of knowledge plays a vital role. For example, complex and early-stage technologies can provide more opportunity for advancement and can display increasing returns to R&D effort. On the other hand, as technologies ‘mature’, they tend to display diminishing returns to R&D effort.

For given technological opportunities, the organisation of R&D effort can also affect the amount of knowledge generated per dollar spent. In broad terms, R&D effort is optimised in an organisational sense if gains from specialisation by R&D performers can be married with the benefits of coordination and interaction among them (that is, spillovers); and the development of technological capabilities (‘technology push’) can be integrated with market needs and opportunities (‘demand pull’). Key levels of organisation of R&D activity are as follows.

- *Firm*. At this level, the organisation of innovation system, including its R&D includes: the management of an R&D program (for example, project selection and risk management); the location of R&D activities (in order to access any advantages that might come from specific locations or agglomeration of activities); and the position of the R&D activity within the structure of the firm (for example, to facilitate the inclusion of commercial considerations in directions for technology development).
- *Industry*. The organisation of R&D across firms within an industry can affect the access of individual firms to gains from scale and specialisation, the pooling of risks in some R&D endeavours and the degree to which R&D outputs are transmitted to other firms.
- *Nation*. The organisation of a nation’s innovation system, including its R&D resources — how it develops skills and competencies, the quality of its R&D institutions and how it coordinates and integrates the knowledge generated by different bodies and so on — has a major influence on the productivity of R&D over the long term (box 2.4).
- *International*. R&D activity is increasingly being ‘internationalised’, with different specialisations in different countries, integration of R&D effort across countries and international outsourcing of R&D effort to other countries. The degree to which countries take advantage of international trends in knowledge accumulation affects the productivity of their own R&D effort.

Changes in selected aspects of the organisation of Australia's R&D effort are reviewed in the next chapter.

Technological opportunities and the 'optimum' organisation of R&D are not entirely separate. For example, the technological opportunities that can be realistically pursued by a country are a function of its research infrastructure and competencies, which are part of the organisation of its national innovation system. Similarly, the 'optimum' organisation of a national innovation system depends in part on the changing patterns of technological opportunities.

Box 2.4 **The national innovation system**

R&D activity and research infrastructure are central elements of what has come to be called the 'national innovation system'.

This concept recognises that the ability of a nation to generate, diffuse and use knowledge depends on more than the mere sum of its knowledge-based activities. It is also determined by a nation's 'learning' — what and how it learns. Learning is influenced by: the science and technology base in higher education and public research organisations, the development of human capital and specific skills, networks and interactions among R&D performers and between performers and the ultimate users of knowledge in business; and institutions such as the policy environment, the financial system, culture and the competencies and specialisations that may be shaped by history and resource endowments. Importantly, the system is not 'closed'. How and the extent to which a nation draws on the knowledge generated in other countries also affects the productivity of its innovation system.

Explanations of the concept of the national innovation system can be found in, for example, Lundvall (1992), Industry Commission (1995) and Balaguer et al. (2003). The latter two references explore the characteristics of Australia's system.

Formation of knowledge stocks

It is clear that a measure of the stock of knowledge is required for quantitative analysis. In most models, the existing stock of knowledge determines the rate of technological advance.

Measurement of knowledge outputs

R&D outputs are assets that can deliver a stream of knowledge and economic benefits over time. In general, they are intangible assets that cannot be directly observed or measured. Patents can provide a degree of tangibility, but the use of patents granted as a measure of R&D outputs is less than ideal. A good measure for economic purposes would capture the value of the outputs generated. However, there is no reliable way to establish the value of the range of knowledge and applications produced (box 2.5).

A common alternative is to use data on R&D expenditures as a proxy measure of the outputs generated. However, variations in inputs used will only accurately measure variations in outputs generated if the productivity of R&D remains constant over time (considered in the next chapter).

As spelt out in chapter 5, the analysis in this study uses an input-based measure of knowledge stocks.

Box 2.5 **Measurement of R&D outputs**

Patent data can provide a measure of some outputs, but they also have some significant limitations. Patent protection tends to be used more for product advances than for process advances. Many contributions to the stock of knowledge simply cannot be patented. Some R&D-performing industries (such as software development) do not make significant use of patents, because the net benefits from costly and slow processes of being granted intellectual property rights are outweighed by the gains to be had from speed of new products to market. Furthermore, simple patent count measures do not take account of the wide variation in the value of patents — which is very low in many cases.

Markets for knowledge are also too thin to provide sufficient and reliable valuations on heterogeneous R&D outputs. Some knowledge can be marketed, for example, through license fees. But a lot of privately-generated knowledge is retained within individual firms in order to preserve technological and market advantage, while publicly-generated knowledge tends to be more 'freely' distributed as a base for further R&D activity.

Because of the difficulties in measuring R&D outputs, R&D is often measured in terms of expenditure — that is, inputs consumed. The implicit assumption is that a (real) dollar of expenditure delivers a constant rate of output over time.

Lags

The lags between R&D activity and the realisation of R&D outputs can pose particular challenges for quantitative analysis of R&D. Lags vary broadly with the type of R&D activity — longer projects for basic research and shorter projects for applied research and experimental development. But lags can also vary within types of activity and over time, depending on such factors as technological opportunities and the field of investigation.

Lags can be handled in a number of ways in quantitative analysis. If a direct output measure, such as patent counts, is used there is no need to account for lags in the formation of knowledge. However, if an input-based measure is used, lags do become an issue. A lag structure can be assumed or specified in an empirical model. However, the lack of information on lags and the limitations on available data usually dictate a more pragmatic approach. It is common to ignore lags for the purpose of forming knowledge stocks, and to subsume them in the specification of lags between the formation of knowledge and the ensuing productivity effects. Knowledge stocks are estimated by accumulating R&D expenditures, based on assumptions of a constant productivity of R&D, a constant structure of R&D by type of activity and a constant structure of lags within types of activity. As has already been discussed, these assumptions are open to question.

The sensitivity of estimates to the specification of lags (between knowledge formation and productivity) is examined, for example, in chapter 7.

Depreciation of knowledge

The 'depreciation' of knowledge is another factor that impinges on the measurement of available knowledge. As noted above, areas of knowledge tend to have a cycle, with scope for increasing returns at the start of the cycle but diminishing returns toward the end of the cycle. At the end of the cycle, the knowledge still exists, but its value as a foundation for further technological advance is greatly diminished. Of course, the length of the effective life, and the associated depreciation rate, vary greatly between areas of knowledge — from a few years in narrow specific areas to centuries in the case of some fundamental knowledge breakthroughs.

Knowledge does not necessarily depreciate in smooth fashion. There are interactions between existing and new knowledge. Just as success in discovery of new knowledge can be contingent upon the existence of other knowledge, the value of existing knowledge can depend on the development of new technologies.[8] Some knowledge can remain 'dormant' for some time, until its value rapidly appreciates when further discoveries come along to complement it; or the value of some knowledge can depreciate sharply when new discoveries render it obsolete.

The approach used in this study to estimate knowledge stocks is set out in chapter 4.

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8 The value of existing knowledge can also depend on the prevailing economic circumstances — whether potential markets exist.

2.4 Knowledge accumulation and growth

This section clarifies type of effects that knowledge can have on productivity and outlines the broad nature of the economic models that are drawn upon in quantitative analyses to investigate the links between knowledge and productivity.

Effects on labour and multifactor productivity

The introduction of commercialised knowledge-based innovations can lift both multifactor productivity and labour productivity. The nature of the effect depends on the nature of the innovation and how it is diffused.

The effects of product innovations are seen in MFP. Product innovation yields more (higher-quality) output for given use of inputs. MFP gains would be available to all those producers who adopt the technology for making the new product.

However, one producer's product innovation can also form the basis for another producer's process innovation. For users, the technology is embodied in the new and improved products that they purchase and, if properly measured, is reflected in increased inputs of materials or capital.[9] Purchase of more-advanced equipment can often lead to capital deepening (increases in the capital-labour ratio). For example, the adoption of robotics in a production process will increase the use of capital relative to labour. Capital deepening is a source of growth in labour productivity.

There can also be further MFP gains through innovations based on the use of new technologies. As previously noted, users of ICT can use the embodied technology as a platform for developing and introducing their own product and process innovations.

Whilst these are illustrative of the types of effect that R&D has on productivity, it is necessary to go to knowledge-based growth models to investigate how, and to what extent, R&D affects productivity.

[9] In principle, quality improvements can be taken into account in constructing volume measures by using quality-constant or hedonic price deflators. Quality improvements are then reflected in increased volumes of capital inputs. In practice, hedonic deflators tend to be used only where there are large changes in quality, such as in ICT equipment. Where quality improvements are not taken into account, capital inputs are understated and the MFP growth of commercial users is commensurately overstated.

R&D-based growth models

There is a spectrum of models that relate knowledge to economic growth. At one end, there is the neo-classical growth model in which technological advance appears exogenously as ‘manna from heaven’ and without any explicit link to the formation of knowledge. Evolutionary models are at the other end of the spectrum. They focus on the nature of advance in areas of knowledge and technology and seek to capture technological trajectories and long cycles in technological opportunities. Whilst the basis of these models has some appeal, they are not well-established in terms of empirical investigation of links to economic performance.

Models in this study are based on the neo-classical framework. Some specifications use the long-run relationships identified in endogenous growth models. Endogenous growth theory emphasises increasing returns to knowledge accumulation that can offset diminishing returns to physical capital accumulation. In some models the long-run equilibrium rate of growth can be influenced by policy interventions.

Whilst these models seek to explain output growth, they can also be taken to explain productivity growth. If inputs of labour and capital are identified in the models, the output growth attributable to these inputs is identified. Other factors seek to explain the remaining output growth — that is, the MFP growth residual. Alternatively, a model of output can be transformed by dividing through by the labour variable to become a model of labour productivity. (Model specifications are set out in chapter 4.)

Romer (1990) introduced an R&D-based endogenous growth model which allowed for increasing returns to knowledge accumulation within an overall balanced-growth or equilibrium framework. The underlying framework has also been used in growth models in which human capital or learning-by-doing are sources of increasing returns. In this case, R&D produces new ‘designs’, which both contribute to an expansion in the continuum of intermediate inputs and raise the productivity of the research sector. In Grossman and Helpman (1991) and Aghion and Howitt (1992), R&D improves the quality of inputs.

These early models predicted productivity growth in proportion to an increase in the level of resources devoted to R&D — that is, a doubling in the level of resources devoted to R&D would lead to a doubling of the growth rate.

The source of the scale effect was two-fold:

> In many research and development-based endogenous growth models (e.g., Romer 1990; Grossman and Helpman 1991; Aghion and Howitt 1992), as the population rises, so does the rate of technological progress [which is synonymous with productivity growth and growth in knowledge] and the growth rate of output per person. A larger

> population stimulates not only the supply of potential R&D workers but also the demand for their services, by increasing the size of the market that can be captured by a successful innovator. The combined effect of these two forces on growth is usually referred to as the “scale effect”. (Howitt 1999, p. 715):

Jones (1995a) highlighted that the scale effects predicted by these early endogenous models were at odds with US macroeconomic time-series data:

> … according to the National Science Foundation (1989), the number of scientists and engineers engaged in R&D in the United States has grown from under 200,000 in 1950 to nearly 1 million by 1987; per capita growth rates in the United States exhibit nothing remotely similar to this fivefold increase. The prediction of scale effects is clearly at odds with empirical evidence. (p. 760)

Jones stated that:

> … apart from this problem, the R&D-based models are intuitively very appealing. Growth arises as a result of intentional innovation by rational, profit-maximising agents, and the models have strong microfoundations. Because of this appeal, it is desirable to find a way to maintain the basic structure of these models while eliminating the prediction of scale effects. (p. 764)

A variety of mechanisms have since been introduced which eliminate the prediction of proportional scale effects (while still allowing for increasing returns).

- *Semi-endogenous models*: Jones (1995a) developed a model which restricted the scale effects by exogenously imposing diminishing returns to R&D investment. The idea is that as more and more R&D is undertaken the returns to the R&D are subject to ‘fishing-out’ — the exhaustion of technological opportunities. Diminishing returns to R&D constrains growth akin to diminishing returns to physical capital investment. The Jones formulation removed a key implication of the endogenous growth literature that policy (for example, R&D subsidies) can influence the long-run growth rate. Growth would converge to zero in the absence of population growth.
- *Schumpterian (fully endogenous) R&D-based model adjusted for scale effects*: Young (1998) introduced an alternative and endogenous mechanism to remove the scale effects of earlier models. He posited that any increase in the reward to innovation resulting from a larger population will be dissipated in the long run by the product proliferation it induces. Furthermore, the larger economy will have to allocate a larger number of workers to the innovation process in order to maintain a constant rate of productivity growth because those workers must improve a larger number of products. Improving the quality of an ever increasing range of products requires increasing R&D inputs just to maintain a constant rate of growth (in these models, growth is synonymous with the rate of product quality improvement).

- *Howitt (1999)*: Young's model implies that a broadly based subsidy to innovation will have no long-run effect on the rate of growth since product proliferation will dissipate the increased reward to innovation from a subsidy in the same way as it dissipates the increased reward from a larger population. He incorporates Young's product proliferation mechanism into a model which yields a steady-state with constant growth in output per person, even though both population and R&D inputs are growing steadily over time. The steady-state intensity of R&D is determined through a process of equalising the marginal value product of vertical R&D (quality improving) and horizontal R&D (expansion in the number of products). Rising R&D inputs has the potential to increase the productivity of R&D (as per Romer), but this potential scale effect is diminished by the rising number of products and a decline in the fraction of the R&D-related knowledge stock which is of value to any particular product (the spillover parameter).

The alternative approaches to removing the scale effect results in differences in predictions concerning the relationship between R&D and productivity growth, and point to different empirical models. The long-run relationships are between productivity growth and either the growth rate of investment in R&D or the fraction of an economy's resources devoted to R&D:

- *Jones (1995a)*: the growth rate in productivity (MFP) will track the growth rate in the level of resources devoted to R&D;
- *Young (1998)*: the growth rate in productivity (MFP) will track the fraction of GDP spent on R&D; and
- *Howitt (1999)*: steady growth in output per person (labour productivity) will be maintained with a constant R&D intensity.

These models provide alternative foundations for quantitative analysis in this study.

Whilst the theoretical models provide alternative ways to think about the role of R&D in productivity growth, it may be overambitious to attempt to discriminate between alternative long-run predictions of theoretical models. Temple (2003) stated:

> Unfortunately it is difficult to see how we could ever conclude in favour of one type of model or the other. We do not observe the long-run growth rate, and there is a considerable distance between other key theoretical concepts and observable variables … This analysis will typically have to assume that variables such as the average quality of ideas, or the productivity of researchers, or even the whole process by which ideas are generated, are constant over time. This is not an attractive set of assumptions, and it is therefore hard to see how predictions about long-run outcomes can be tested in a genuinely rigorous way … As a result, it will be virtually impossible to test the long-run predictions of growth models against the data. (p. 503)

Other mechanisms: Interactions between knowledge and other factors

Knowledge can interact with other factors. As has been discussed, R&D activity depends on and influences the development of research skills, the absorption of technologies developed elsewhere and the acquisition of capital equipment.

The standard framework for analysing the effect of R&D, and the early endogenous models, maintain a strict separability between R&D and capital. Hall (1994, p. 339), for example, noted that this approach:

> … relies on an aggregate production function in which knowledge and physical capital make separate and distinct contributions to output. But so much new knowledge is embodied in new capital that it may make little sense to separate the knowledge from the equipment and more sense to focus on the act of investment in physical capital.

The models in this paper do not explicitly recognise the interactions between physical investment and R&D.

Causality

The discussion to this point has been based on the premise that R&D leads to productivity growth. But causality can also run in the other direction — in good economic times, firms are in a better financial position to undertake R&D and the risks of introducing a new technology into the market are less. This feedback from growth to R&D is sometimes referred to as the ‘endogeneity’ of R&D and the (possible) existence of the two directions of causality is sometimes referred to as the ‘simultaneity of R&D and growth’. The presence of simultaneity will bias the estimated effects of R&D. Therefore, it is common practice to test for simultaneity and adopt empirical approaches that remove the bias in estimated returns (see chapter 4).

One of the ways to address simultaneity is to estimate a recursive system of equations which is undertaken in chapter 10. This approach provides the added benefit of supporting a preliminary investigation into the factors associated with rising business expenditure. It may also improve the precision of the estimated effect of R&D on productivity.

3 An overview of trends in R&D and productivity

This chapter reviews major changes in Australia's R&D activity and productivity over the past three decades. It sets out:

- the trends in R&D activity, particularly in business sector R&D, which is the focus of later quantitative analysis (section 3.1);
  - the business sector has been the main source of a substantial increase in R&D spending;
- changes in the type of R&D activity and the industry mix of business R&D (section 3.2);
  - Australia's R&D effort has become more commercially and services oriented;
- changes in the productivity of Australia's R&D effort (section 3.3);
  - there are signs that Australian R&D is generating more knowledge output per dollar spent; and
- trends in aggregate and industry productivity (section 3.4);
  - Australia's productivity growth has also increased since the 1980s, but the timing of increases does not correlate highly with changes in R&D activity — at least at the aggregate level.

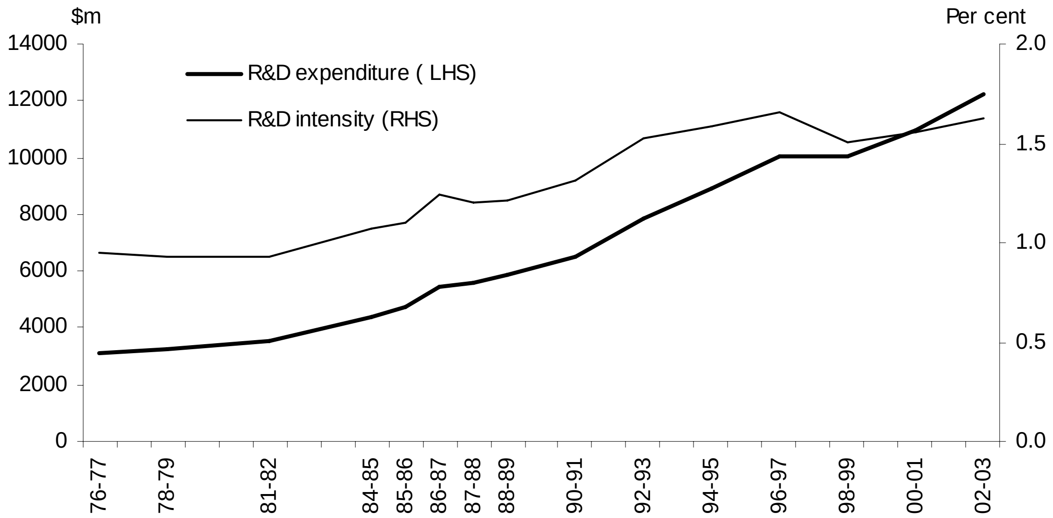
3.1 Trends in R&D activity

The presentation of R&D trends comes with a measurement warning. Whilst the information collected by the ABS provides a generally sound basis for assessment and analysis of trends in R&D expenditure, there is potential for measurement errors to intrude, particularly in some structural dimensions over long periods. Details on the data and its limitations are provided in appendix A.

Australia's investment in R&D has increased substantially. According to available estimates, total spending has quadrupled in real terms over the past three decades, from $3.1 billion in 1976-77 to $12.2 billion in 2002-03 (figure 3.1).[1] The average annual rate of growth has been 5.2 per cent.

The magnitude of the increase reflects not just an expansion in the economy, but also a diversion of more resources into R&D activity. R&D intensity — R&D expenditure as a proportion of GDP — has increased from 0.95 per cent to 1.63 per cent over the period.

Figure 3.1 **Real gross expenditure on R&D[a] and R&D intensity[b], 1976-77 to 2002-03**



a At 2002-03 prices. **b** Gross expenditure on R&D in proportion to GDP.

Data sources: Commission estimates based on ABS (*Research and Experimental Development, All Sector Summary, Australia*, Cat. no. 8112.0, various issues); ABS (*Australian System of National Accounts*, Cat. no. 5204.0).

Although there has not been marked volatility in R&D activity, there have been discernable trends in different periods.

- R&D expenditure and intensity changed relatively little over the late 1970s and early 1980s.
- The mid-1980s to the mid-1990s was a period of strong growth. Of the $9 billion increase in expenditure, around 60 per cent took place between 1984-85 and 1996-97.[2]

[1] Although continuous lines are presented in figure 3.1, estimates are only available for the years indicated on the horizontal axis.

[2] It is most probable that total expenditure was higher in 1995-96 than in 1994-95. Data on R&D in higher education, government and private non-profit organisations are not available for 1995-96. However, business expenditure was at a temporary peak in that year and available data for the other sectors suggest that their expenditure was at least maintained through the 1990s.

- Expenditure levelled off for several years after the mid-1990s peak. R&D intensity dropped, owing to the combination of slower growth in R&D expenditure and faster growth in GDP.
- The most recent estimates suggest that there has been a return to stronger growth — at least since 2000-01.

The biggest increase has been in business R&D

R&D is performed in four institutional sectors:

- business — private businesses that perform R&D primarily for their own purposes;
- government — organisations, such as the CSIRO, Defence Science and Technology Organisation (DSTO) and Australian Nuclear Science and Technology Organisation (ANSTO), that are (predominantly) publicly funded and undertake R&D;
- higher education — universities, the R&D of which is also predominantly publicly funded; and
- private non-profit — private or semi-public incorporated organisations that do not (directly) serve the business sector.

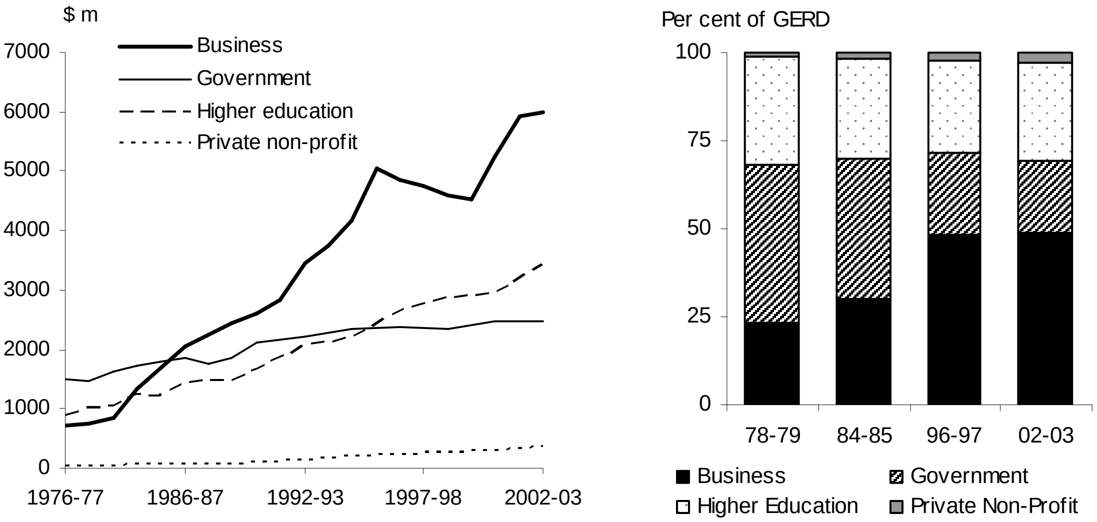
The business sector stands out in figure 3.2 as showing the strongest increase in R&D spending. Real business expenditure on R&D (BERD) grew at an average annual rate of 8.1 per cent (table 3.1), compared with 5.2 per cent for total or gross expenditure on R&D (GERD). Business increased its share in the total spend from around one in four dollars to one in two dollars (figure 3.2).

Businesses were also mostly behind the two major deviations in R&D spending during the 1990s. BERD rose to a peak, well above trend, in 1995-96 and then descended to a trough, well below trend, in 1999-00. These deviations largely account for the movement of GERD in the 1990s.

With the increased prominence of businesses in Australia’s R&D effort, the earlier prominence of government agencies has declined. R&D activity in government agencies has increased, with expenditure growing in real terms at a rate of 2.0 per cent a year since the 1970s. But, because that rate was slower than BERD, the government-agency share of GERD declined from 48 per cent to 20 per cent.

The university sector has maintained its share, accounting for around 28 per cent of GERD. The private non-profit sector share has increased from a small base and now accounts for 3 per cent of R&D.

Figure 3.2 **Real R&D expenditure[a] and shares in total expenditure, by institutional sector, 1976-77 to 2002-03**



[a] At 2002-03 prices.

Data sources: Commission estimates based on ABS (*Research and Experimental Development, All Sector Summary, Australia*, Cat. no. 8112.0, various issues); ABS (*Australian System of National Accounts*, Cat. no. 5204.0).

Table 3.1 **Rate of growth in real R&D expenditure and contributions to total expenditure, by institutional sector, various periods**

	1976-77 to 1984-85	*1984-85 to 1996-97*	*1996-97 to 2002-03*	*1976-77 to 2002-03*
Growth in R&D expenditure (per cent per year):				
Business	7.6	10.8	3.5	8.1
Government	1.9	2.5	0.8	2.0
Higher education	4.4	6.2	4.4	5.3
Private non-profit	9.1	8.2	8.8	8.6
Total (GERD)	**4.3 (100)**	**6.9 (100)**	**3.3 (100)**	**5.2 (100)**
Contributions to growth in GERD (percentage points[a]):				
Business	1.9 (44)	3.6 (53)	1.7 (53)	2.2 (43)
Government	1.0 (23)	1.1 (16)	0.2 (6)	1.1 (21)
Higher education	1.3 (31)	2.0 (29)	1.2 (36)	1.8 (33)
Private non-profit	0.1 (3)	0.2 (2)	0.2 (6)	0.1 (2)

[a] Percentage point contributions add to the growth rate in GERD. Numbers in brackets refer to the percentage contributions. May not add to totals due to rounding.

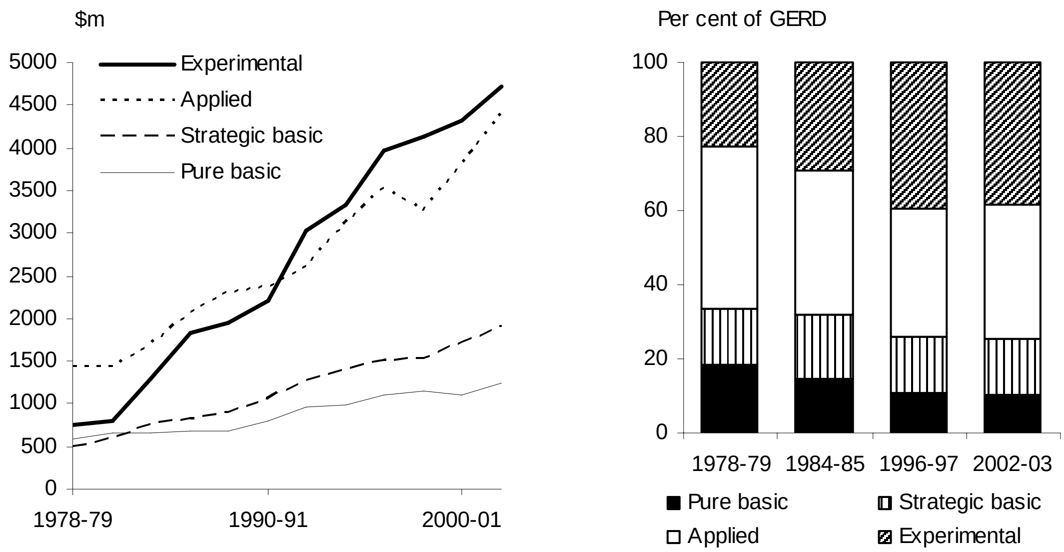
Sources: Commission estimates based on ABS (*Research and Experimental Development, All Sector Summary, Australia*, Cat. no. 8112.0, various issues); ABS (*Australian System of National Accounts*, Cat. no. 5204.0).

3.2 Changes in the structure of R&D activity

Chapter 2 noted that changes in the mix of R&D activity can affect the amount and timing of R&D outputs. This section reviews changes in the structure of R&D activity, in general, and then examines changes in the structure of business R&D.

Most of the growth in R&D spending has been in applied research and, especially, experimental development (figure 3.3 and table 3.2). Experimental development has stepped up from 23 to 39 per cent of total R&D (figure 3.3), largely due to the rapid growth in business sector R&D, which is heavily oriented toward experimental development (figure 3.4). The growth in applied research has been just below the whole-period average, although it has shown above-average growth since the mid-1990s. Its growth has been boosted by the strong growth in business R&D; and the combination of growth and reorientation of university R&D toward applied research (figure 3.4).

Figure 3.3 **Real R&D expenditure[a] and shares in total expenditure, by type of R&D activity, 1978-79 to 2002-03**



[a] At 2002-03 prices.

Data sources: Commission estimates based on ABS (*Research and Experimental Development, All Sector Summary, Australia*, Cat. no. 8112.0, various issues); ABS (*Australian System of National Accounts*, Cat. no. 5204.0).

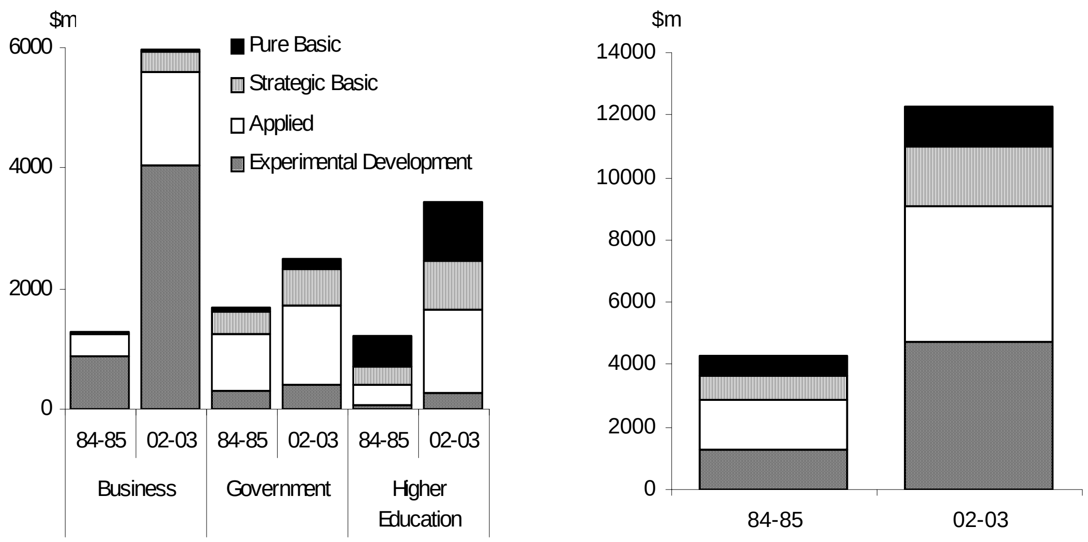
Table 3.2 **Rate of growth in real R&D expenditure, by type of R&D activity, various periods**

	1978-79 to 1984-85	*1984-85 to 1996-97*	*1996-97 to 2002-03*	*1978-79 to 2002-03*
Growth in R&D expenditure (per cent per year):				
Experimental development	9.1	9.4	2.9	7.7
Applied research	2.9	6.1	3.6	4.7
Strategic basic research	7.1	5.7	4.0	5.6
Pure basic research	1.5	4.3	2.1	3.1
Total (GERD)	**5.0**	**6.9**	**3.3**	**5.5**
Contributions to growth in GERD (percentage points[a]):				
Experimental development	2.2 (44)	2.8 (41)	1.2 (36)	1.9 (34)
Applied research	1.3 (27)	2.4 (35)	1.3 (39)	2.2 (39)
Strategic basic research	1.1 (23)	1.0 (15)	0.6 (18)	0.9 (16)
Pure basic research	0.3 (6)	0.7 (10)	0.2 (7)	0.6 (11)

a Percentage point contributions add to the growth rate in GERD. Numbers in brackets refer to the percentage contributions. May not add to totals due to rounding.

Sources: Commission estimates based on ABS (*Research and Experimental Development, All Sector Summary, Australia*, Cat. no. 8112.0, various issues); ABS (*Australian System of National Accounts*, Cat. no. 5204.0).

Figure 3.4 **Real R&D expenditure[a], by institutional sector and type of R&D activity, 1984-85 and 2002-03**



a At 2002-03 prices.

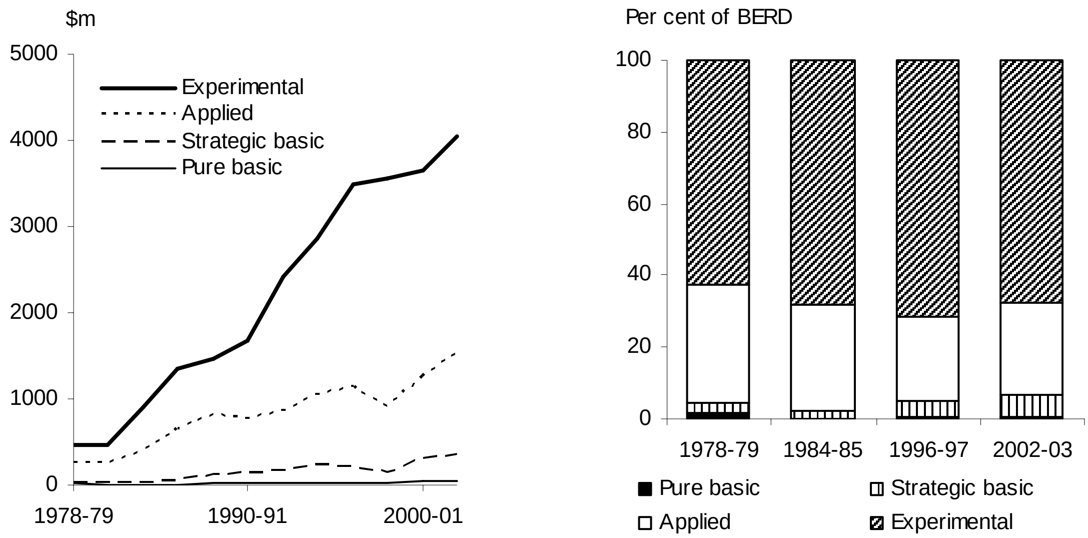
Data sources: Commission estimates based on ABS (*Research and Experimental Development, All Sector Summary, Australia*, Cat. no. 8112.0, various issues); ABS (*Australian System of National Accounts*, Cat. no. 5204.0).

The structure of business R&D has shifted toward services

A greater orientation toward experimental development

Most of the growth in business R&D spending has been in experimental development, which has increased from 63 to 68 per cent of real BERD (figure 3.5). Most of the balance of BERD is in applied research, with only around 5 per cent in basic research.

Figure 3.5 **Real BERD expenditure[a] and shares in total expenditure, by type of R&D activity, 1978-79 to 2002-03**



[a] At 2002-03 prices.

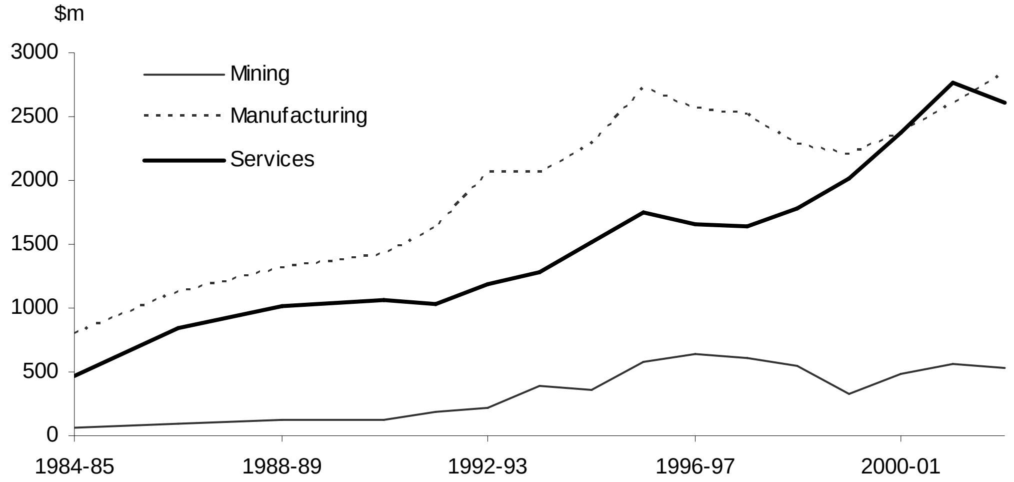
Data sources: Commission estimates based on ABS (*Research and Experimental Development, All Sector Summary, Australia*, Cat. no. 8112.0, various issues); ABS (*Australian System of National Accounts*, Cat. no. 5204.0).

A greater orientation toward R&D in services industries

Three industry sectors can be readily identified in ABS data on R&D — mining, manufacturing and services. Information on any formal R&D undertaken by businesses in agriculture (that is, on farms) is not collected. Of course, considerable R&D is undertaken for agricultural application and this is performed by government sector research agencies, by universities and by businesses in manufacturing and services.

Whilst manufacturing firms have traditionally been the main locus of business R&D, services R&D has grown so strongly since the early 1990s that its expenditure level is now on a par with manufacturing R&D (figure 3.6).

Figure 3.6 **Real business R&D expenditure, by industry sector, 1984-85 to 2002-03**



Data sources: Commission estimates based on ABS (*Research and Experimental Development, Businesses, Australia*, Cat. no. 8104.0, various issues); ABS (*Australian System of National Accounts*, Cat. no. 5204.0).

Manufacturing R&D has grown with reasonable strength over the long term, but was mainly responsible for the peak and trough in business R&D activity in the 1990s. R&D by manufacturers grew at 4.3 per cent a year on average over the whole period, contributed over half the growth in BERD during the high-growth years from 1984-85 to the 1995-96 peak, and slumped by over 5 per cent a year from the peak to the trough in 1999-00. It has returned to strong growth in recent years (table 3.3).

However, not all manufacturing industries have followed this pattern. There have been stronger and steadier increases in activity in major R&D-performing industries. Transport equipment ($730 million spent in 2002-03) and Petroleum, coal & chemical products ($500 million) were prime examples. Other industries with less involvement in R&D activity have tended to follow the peak and trough path, with strong growth to the mid-1990s, followed by stagnation or decline and little subsequent recovery.

Growth in services R&D has been both strong and (relatively) steady. It grew at 9.4 per cent a year on average for the whole period. Services R&D took off in the early 1990s, although it too had a slump from a mid-1990s peak. That slump was milder and shorter-lived, than in Mining and Manufacturing, and services R&D took off again after 1997-98.

Table 3.3 **Rate of growth in real R&D expenditure and contributions to growth in business R&D expenditure, by industry sector[a], various periods**

	1984-85 to 1995-96	*1995-96 to 1999-00*	*1999-00 to 2002-03*	*1973-74 to 2002-03*
Growth in R&D expenditure (per cent per year)				
Mining	21.3	-14.7	12.8	8.2
Manufacturing	11.1	-5.2	6.2	4.3
Services	11.8	3.6	6.5	9.4
Total (BERD)	**12.1 (100)**	**-2.6**	**6.9 (100)**	**6.1 (100)**
Contribution to growth in BERD (percentage point[b]):				
Mining	0.9 (8)	-1.3	0.9 (13)	0.4 (7)
Manufacturing	6.8 (57)	-2.2	3.1 (44)	3.9 (64)
Services	4.3 (36)	1.0	2.9 (42)	1.8 (29)

a More disaggregated industry data is provided in appendix N. **b** Percentage point contributions add to the growth rate in BERD. Numbers in brackets refer to the percentage contributions. May not add to totals due to rounding.

Sources: Commission estimates based on ABS (*Research and Experimental Development, Businesses, Australia*, Cat. no. 8104.0, various issues); ABS (*Australian System of National Accounts*, Cat. no. 5204.0).

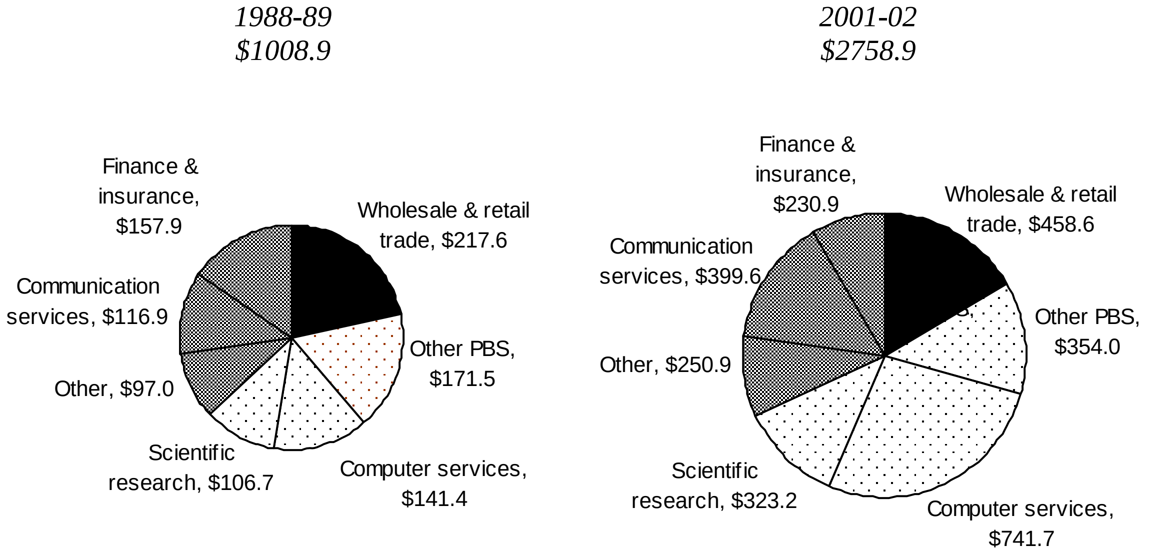
The faster growth in services R&D, which has also featured in other countries[3], can be put down to at least three factors.

- There has been relatively strong growth in the services sector.
- At least some services industries have become more R&D intensive and innovative.
  - Property & business services has been the main R&D growth area (figure 3.7). There has also been very strong growth in R&D activity (at different times) in Wholesale & retail trade, Finance & insurance and Communication services.
- More R&D activity has been undertaken by specialist service providers on behalf of a range of services and non-services industries.
  - The two main areas come within Property & business services. The Computer services industry has undertaken rapidly increasing amounts of R&D ($740 million in 2001-02). The Scientific research industry undertakes R&D for other industries, often on a contract or collaborative basis.

[3] Stronger growth in services R&D has been a feature in a number of countries in which English is the dominant language.

Figure 3.7 **Business expenditure on R&D, service industries, 1988-89 and 2001-02**

$million



Data sources: Commission estimates based on ABS (*Research and Experimental Development, Businesses, Australia*, Cat. no. 8104.0, various issues); ABS (*Australian System of National Accounts*, Cat. no. 5204.0).

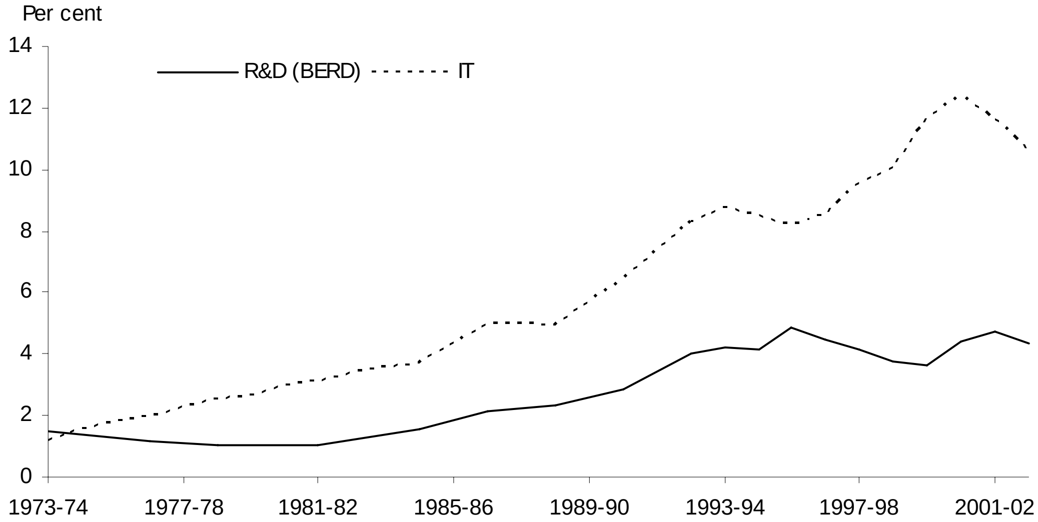
It is likely that part of the uplift in services R&D, especially in the Computer services industry, is ICT-related (box 3.1). This is consistent with the phenomenon noted in the previous chapter, whereby knowledge is imported into Australia, embodied in ICT equipment, and local R&D-based and non-technological innovation is developed upon the ICT platform.

Mining R&D, which now accounts for around 10 per cent of BERD, reinforced the manufacturing trends. Expenditure increased substantially between 1990-91 and 1996-97 (a year after the manufacturing peak), but has essentially stagnated since.

Box 3.1 **R&D and ICT**

An acceleration of investment in information and communications technology (ICT) coincided with the decline in R&D from the mid-1990s (see figure below). These trends would be entirely unrelated if R&D expenditure has been driven by other factors. But it is also possible that they are related — either as a lagged effect of earlier ICT-related R&D leading to an increase in ICT investment or as a contemporaneous trade-off between investment in R&D and investment in ICT within constrained budgets.

BERD and IT investment as a proportion of non-residential investment, 1973-74 to 2001-02



Data source: Commission estimates based on ABS (*Research and Experimental Development, Businesses, Australia*, Cat. no. 8104.0, various issues).

They could also be more directly related. First, for many firms, the advent of new ICTs could have meant that innovation strategies based on the acquisition of ICT could deliver larger and more certain gains than further investment in R&D. This is consistent with the pattern of ICT and R&D investment observed in Manufacturing. Second, and in the opposite direction, the increase in ICT use could have formed the basis for more ICT-related R&D activity. This is consistent with the pattern in a number of services industries.

3.3 Changes in the productivity of R&D

The concept of the ‘productivity of R&D’ was discussed in the previous chapter. It captures the extent to which R&D activity (expenditure) generates R&D outputs (knowledge). The degree of stability in the productivity of R&D over time has implications for the construction of knowledge stocks to be used in the quantitative analysis.

Technological opportunities and the organisation of R&D were put forward in chapter 2 as two broad factors that can affect the productivity of R&D. Based on readily-available data, there are signs that the productivity of Australia’s R&D effort has increased.

New technological opportunities

Australia is a small R&D performer in world terms, accounting for a little over 1 per cent of OECD R&D activity (box 3.2). Size (small domestic market), history (not the same size and depth of research infrastructure) and geography (lack of ready access to large markets) have put constraints on Australia’s ability to become a leader in mainstream R&D activity — irrespective of the quality of its science base. Of course, Australia is at the forefront of some technological advances in agriculture, mining, medical science and niche areas of manufacturing. But it is not involved, on a world scale, in the major areas of R&D activity — transport equipment (including aerospace), chemicals (including pharmaceuticals) and electronics and office equipment (including ICT equipment).

The patterns of expenditure suggest that global technological opportunities increased from the mid-1990s.[4] The increase came after a period of decline from the mid-1980s to the mid-1990s (appendix G). R&D in the United States and R&D related to ICT equipment and to services industries were prominent in the recovery.

Expenditure patterns suggest that the incentives to invest in R&D in Australia were detached from the overseas pattern up until the mid-1990s. This may be partly due to differences in technological opportunities, but other factors likely played a much stronger role (see chapters 10 and 11). These factors include government policies and the ‘opening-up’ of the economy, as well as perceptions of technological opportunities. During the period of overseas decline, from the mid-1980s to the mid-1990s, Australia’s R&D effort was on the ascent. Traditionally, the detachment between foreign and domestic patterns has been reinforced by Australia’s relatively

[4] Greater technological opportunities would induce more R&D expenditure, as well as increase the amount of R&D output from a given amount of expenditure.

small engagement in business sector R&D and in manufacturing-related R&D (appendix G).

It would appear that accelerating technological advances in overseas ICT equipment have opened up new technological opportunities for Australia. As noted in the previous section, R&D activity increased in services in the 1990s, particularly in relation to ICTs and the adaptation of ICTs to innovative Australian uses.

Box 3.2 **Australia's R&D effort in international perspective**

World R&D is highly concentrated in a few countries. The United States is by far the largest R&D performer, accounting for 44 per cent of OECD expenditure on R&D. Just four countries — the United States, Japan, Germany and France — undertake three quarters of OECD R&D. Add four more countries — the United Kingdom, South Korea, Canada and Italy — and the coverage runs to 87 per cent.

Australia is in the next group of four countries — Sweden, the Netherlands, Australia, Spain — that each performs between 1 and 2 per cent of OECD R&D. Australia ranks 11 in size of R&D spend, accounting for about 1.3 per cent of the OECD total.

Business R&D overseas is on a scale that dwarfs Australian activity. The Ford Motor Company alone spends US$7.5 billion every year — roughly two thirds more than Australia's entire BERD. The five biggest spending companies worldwide have R&D budgets totalling US$34 billion — more than five times Australia's BERD.

Much is often made of the fact that Australia's R&D intensity is below the OECD average. According to OECD data, Australia's R&D intensity of 1.5 per cent compares with an OECD average of 2.3 per cent.

However, the relatively high intensities of the dominant R&D-performing countries have a large effect on the OECD average. R&D intensities among the smaller performing countries vary widely, seemingly across geographic groupings (for example, high intensities in northern Europe and low intensities in southern Europe). In the context of smaller performers, Australia does not stand out as atypical. Its R&D intensity is around the OECD average when the top four R&D-performing countries are excluded.

Business R&D and experimental development are less prominent in Australia than on average in other countries; and government-agency and university research are commensurately higher. Again, the large R&D-performing countries have a big influence on the OECD average. Australia is more typical of smaller performing countries.

(continued on next page)

Box 3.2 **(continued)**

Size of economy, geography (access to markets) and technological infrastructure are some of the influences on the amount and nature of R&D that a country undertakes. Particularly when basic research is involved, R&D often takes place in large-scale operations that can take advantage of economies of scale and scope and can spread the risks of failures. Ready access to large markets is a distinct advantage in order both to provide a source of funds for R&D and to reap the rewards from successful R&D outcomes. Often competencies and specialisations develop in different countries depending on their history of R&D effort, the technological infrastructure they have developed and the uniqueness of their resource endowments.

In world terms, Australia is not favoured by market size, geography or history of industrialisation and R&D. But it has developed leading technological expertise through R&D in agriculture, mining and niche areas of manufacturing and services.

R&D in Australia is also important in absorbing technologies developed overseas. The application of ICT provides a recent demonstration. The principal hardware technologies have been developed overseas, but R&D effort has been undertaken to develop software and information and communications systems suited to Australia's circumstances.

Source: Appendix G.

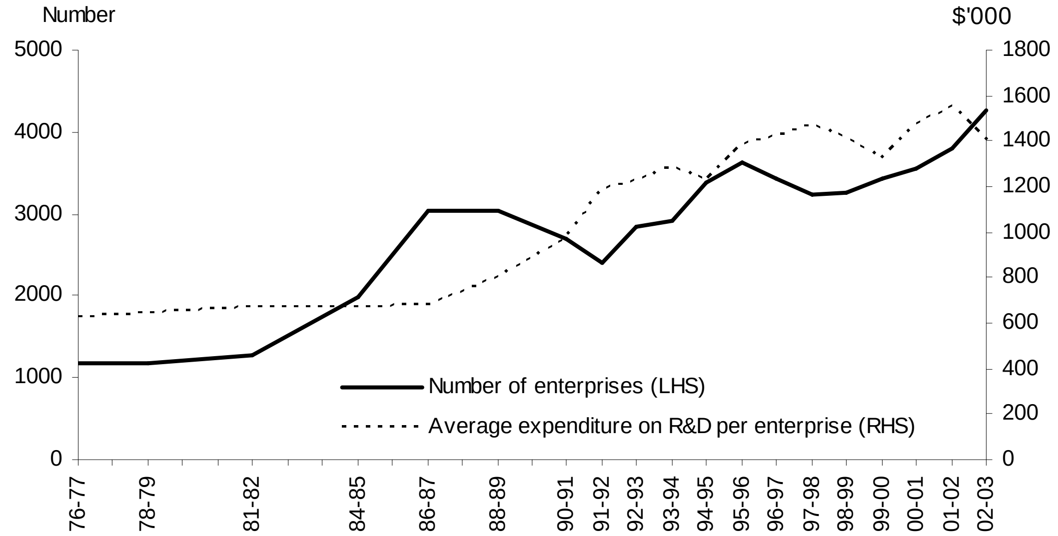
There have been changes in the organisation of R&D

As noted in chapter 2, changes in the way R&D activity is organised at the firm, industry, national and international levels can also influence the productivity of R&D. A brief examination of available data suggests that there have been some organisational changes of relevance. However, a comprehensive assessment of the organisation of R&D, which covers the national innovation system, is well beyond the nature and scope of this study.

Entry and scale

Some of the characteristics of firms undertaking R&D are examined in appendix I. It appears that more of the variation in BERD has come through the entry and exit of firms into R&D activity — over the long term and especially over shorter periods — than increases in the average scale of R&D operations (figure 3.8). For example, the rapid growth in R&D expenditure in the early to mid-1980s came primarily through firm entry, with little change in average expenditure per firm. And business numbers dropped in the second half of the 1990s — particularly among medium and large manufacturing firms. To the extent that the productivity of R&D is related to scale of operations, it appears that there would have been scope for scale-based productivity improvement, on average, but perhaps more limited than the aggregate expenditure might suggest at first glance.

Figure 3.8 **Number of firms and average real R&D expenditure per firm in the business sector, 1976-77 to 2002-03**



Data sources: Commission estimates based on ABS (*Research and Experimental Development, Businesses, Australia*, Cat. no. 8104.0, various issues); ABS (*Australian System of National Accounts*, Cat. no. 5204.0).

Outsourcing and collaborations

There have been trends toward greater outsourcing (appendix B) and collaborations in Australia, both within and between institutional sectors. Outsourcing can foster greater specialisations in R&D and better management of risks. Collaborations can bring together technical and commercial expertise and allow organisations to pool risks, share costs and develop technical capabilities and market awareness.

It appears that a pattern has developed in which in-house R&D is relatively stable and externally-performed R&D is more variable. Data on the structure of costs of business R&D show a steady increase in in-house labour costs. There is also evidence that the number of R&D workers per firm has settled down to a quite stable 'core'. Data on the amount of R&D performed internally and externally suggest that outsourcing and collaborations increased in the early 1990s, but declined in the latter part of the 1990s. This pattern is corroborated by data on other current expenditures in business R&D, which would capture payments to outsourced providers (appendix B).

Institutional linkages

Business, universities and government agencies have strengthened their R&D links in order to enhance the focus on business application and the publicly-funded agencies have put greater emphasis on commercialisation of their R&D outputs.

Business has not only funded the increase in its own spending, but has become a more important source of funds for the other institutional sectors. Although business funding for university and government-agency R&D still only accounts for about five per cent, it increased substantially between 1992 and 1996. Business now funds about 46 per cent of total R&D (excluding indirect contributions from government grants and subsidies).

A higher proportion of funding now also comes from the private non-profit sector and from overseas. Both provide a little under 5 per cent of funds.

The relative importance of direct government funding of R&D has declined. Government funds for organisational budgets (excluding grants and subsidies) have grown in real terms and have contributed a third of the increase in total R&D activity. However, as a proportion of total funds, they have declined from 76 per cent in the 1970s to 44 per cent in 2002-03 (see table G.2).

International linkages

Australian businesses also gain from R&D undertaken overseas. R&D undertaken in other countries is the major source of worldwide knowledge accumulation (box 3.2) and is a very large potential source of knowledge spillovers for Australian application.

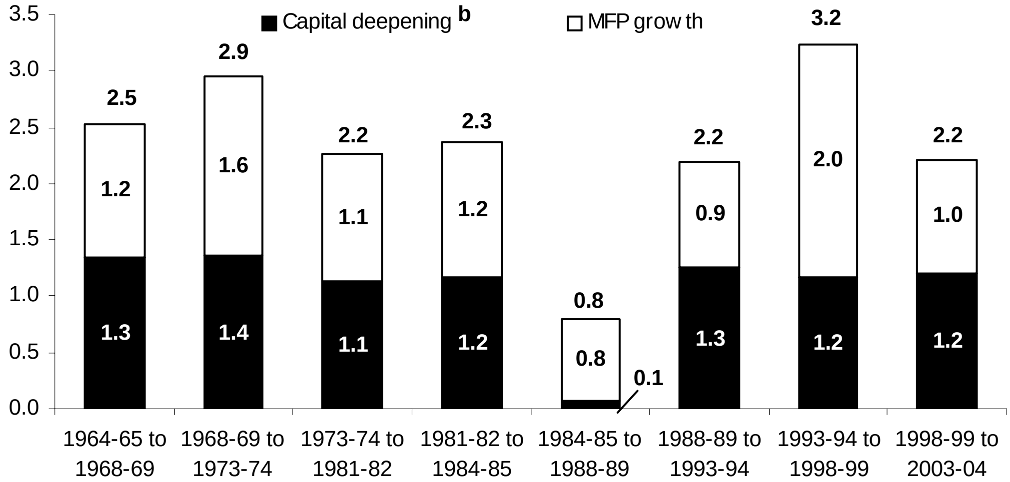
The integration of Australia's R&D with the rest of the world has strengthened, particularly business R&D, albeit from a low base. Stronger linkages are reflected in the growth in funding from overseas, growth in two-way trade in knowledge, export of R&D services from Australia and a step up in lodgements of Australia-linked patent applications in overseas offices (see appendix G).

3.4 Trends in industry and aggregate productivity

As is well known, Australia experienced a productivity resurgence in the 1990s. Productivity growth was historically slow in the 1980s, but surged to record highs in the 1990s (figure 3.9). It was particularly high, and consistently so, between 1993-94 and 1998-99.

Figure 3.9 Labour productivity growth[a] in Australia's market sector, 1964-65 to 2003-04

Per cent per year



[a] Components may not add to total due to rounding. [b] Capital deepening is the growth in the capital to labour ratio multiplied by the average capital income share for the period.

Data sources: ABS (*Australian System of National Accounts*, Cat. no. 5204.0); Commission estimates.

Since the late 1990s, productivity growth has slipped back to rates around the long-term average. The slowdown appears to be a combination of: a drop in underlying productivity growth from previous record highs; and a number of short-term one-off factors that have held average productivity growth below the 'true' underlying rate (Parham 2005).

Although R&D expenditure and productivity growth have both increased over the past three decades, the correlation is not all that strong within each period.

- The major growth in R&D activity was from the mid-1980s to mid-1990s, whereas the highest productivity growth was from the mid- to late-1990s.
- R&D expenditure declined in the mid- to late 1990s, when productivity growth was at its peak.
- In the 2000s, R&D expenditure has picked up again, while productivity growth has slowed.

There are a number of possible explanations for the lack of correlation, including: lags between the R&D performed and the productivity response; and the influences of other factors on productivity growth.[5] But it may also be that the aggregate view

[5] Note also that the stock of knowledge, rather than the flow of expenditure, is most important.

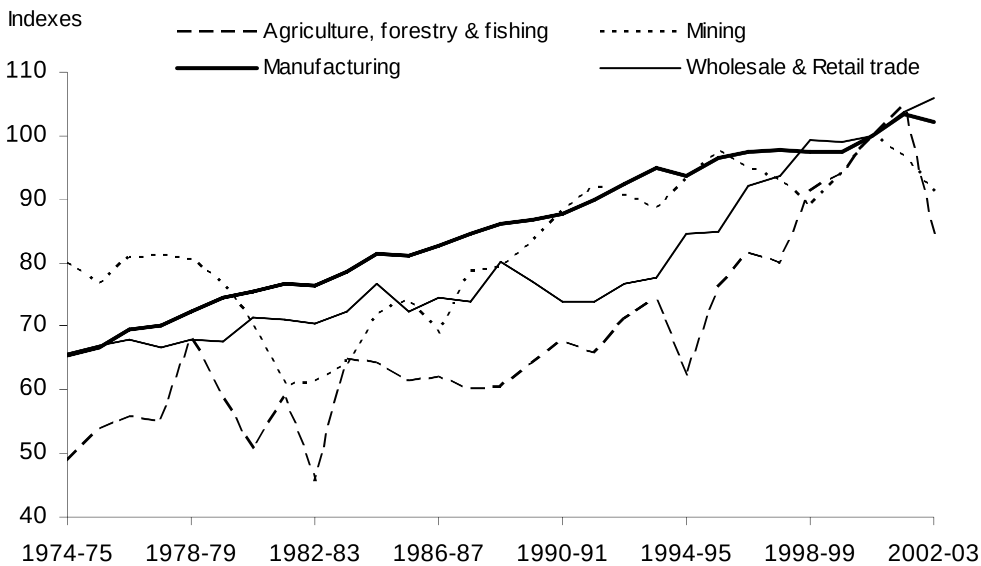
obscures some closer associations between R&D spending and productivity growth at the industry level.

Services industries have been prominent in both the increase in R&D expenditure (section 3.2) and the acceleration in productivity growth in the 1990s. The substantial increase in Computer services R&D would have served a range of using industries. R&D and productivity growth both increased in Wholesale trade.

The industry focus in this study has been dictated by the availability of R&D data. Four industry sectors have been identified for investigation — Agriculture (based on non-farm R&D), Mining, Manufacturing and Wholesale & retail trade. MFP estimates for these industries are displayed in figure 3.10. Average annual rates of MFP growth over various periods are shown in table 3.4. It should be noted that productivity estimates are less accurate at the industry level than at the aggregate level.[6]

Figure 3.10 **MFP index for the four market-sector industries, 1974-75 to 2002-03**

Indexes 2000-01 = 100



Data source: Commission estimates based on unpublished ABS data.

6 Any bias in use of a value-added basis of measurement, rather than gross output, is more severe at the industry level (Cobbold 2003). There is uncertainty about the industry allocation of hours worked. And there may be issues about the precision of estimates of industry output (Zheng 2005). Services outputs present more severe measurement challenges, especially where there are changes in quality to take into account.

Table 3.4 **MFP growth rates, industry and market sector, ABS growth cycles[a]**

Average annual rate of growth, per cent

	1974-75 to 1984-85	*1984-85 to 1993-94*	*1993-94 to 2002-03*	*1974-75 to 2002-03*	*Std. Deviation*
Market sector	**1.0**	**0.6**	**1.2**	**0.9**	**0.3**
Agriculture, forestry & fishing	2.7	1.6	1.4	1.9	0.7
Mining	-1.0	2.3	0.3	0.5	1.7
Total manufacturing	2.2	1.7	0.8	1.6	0.7
Wholesale & retail trade	1.5	0.1	3.5	1.7	1.7
Other n.e.c.	2.2	2.3	2.6	2.4	0.2

a These are compressed growth cycle periods based on ABS growth cycle peaks. According to ABS Cat. no. 5204.0 (Nov 2004), 'Growth cycle peaks are identified by considering the distance between the MFP estimate and its long term trend as well as general economic conditions'.

Sources: Commission estimates based on unpublished ABS data; ABS (Australian System of National Accounts, Cat. no. 5204.0, November 2003); Updated estimates from Gretton and Fisher (1997) in PC (2003).

In brief, productivity growth has been strongest overall in Agriculture although with climatic variations it has also been the most volatile. The 1990s productivity acceleration was greatest in Wholesale & retail trade. Mining showed little overall productivity growth from the early 1990s. Finally, productivity growth in Manufacturing has been reasonably strong, and comparatively very steady, over the entire period.

Trends in R&D (knowledge) *stocks* in relation to productivity are examined in chapter 5.

4 The platform for quantitative analysis

The purpose of this chapter is to outline the empirical framework adopted for this study and to introduce a range of specification, data and interpretation issues which have a bearing on the modelling in later chapters.

4.1 Specification of empirical frameworks

Following common practice, the strategy for specifying an equation for estimation is to start from a theoretical model and augment it with the most relevant control variables. The theory underlying the analysis is a conventional one, which is based on production economics.

The production function method

In particular, the stock of knowledge or R&D capital is regarded as one of the inputs in production. Conventional capital is treated as another input.

The Cobb-Douglas production function is the most popular form used in the empirical work on R&D and productivity (Griliches 1998). A Cobb-Douglas production function can be written as

$$Y = Ae^{\lambda t} C^{\alpha} L^{\beta} K^{\gamma} \prod_{j=1}^{q} Z_j^{\omega_j} \qquad (1)$$

where A is a constant, e is the base of natural logarithms, $e^{\lambda t}$ can be considered as a neutral technology term, and Y, C and L are output, the stock of conventional capital and labour, respectively. K is the R&D capital stock. Z_j (*j = 1 to q*) are other inputs that determine the level of output.

All inputs and output are in quantity (real) terms.[1] All the exponential coefficients associated with the variables are elasticities of output with respect to the corresponding inputs.

The Cobb-Douglas production function is somewhat restrictive, since it imposes an elasticity of substitution between each pair of inputs equal to one. Interaction terms can be included that allow relationships between inputs (for example, between the domestic and foreign knowledge stocks where K is expanded to include multiple stocks). Other more sophisticated forms, such as the constant elasticity of substitution (CES) or the translog production functions can also be used. Cost functions have also been used for estimating the relationship between R&D and productivity. These alternative approaches describe more complex production processes, but will introduce more parameters to be estimated compared with the Cobb-Douglas production function. This is a disadvantage when degrees of freedom are restricted by the small numbers of observations (as is the case in this study).

Taking the natural log of (1), the Cobb-Douglas production function is specified as

$$\ln Y = \ln A + \lambda t + \alpha \ln C + \beta \ln L + \gamma \ln K + \sum_{j=1}^{q} \omega_j \ln Z_j \qquad (2)$$

Adding an error term and using the appropriate measures of output and inputs, equation (2) can be used directly for estimation.

The parameter of primary interest is γ as it provides an estimate of the elasticity of output with respect to the R&D capital (or knowledge) stock.

The two-step method

Assuming constant returns to scale in capital and labour (that is, $\alpha + \beta = 1$) and competitive equilibrium in both input and output markets (so that observed factor prices can be used in place of unobserved marginal products), equation (2) can be written as

$$\ln MFP = a + \lambda t + \gamma \ln K + \sum_{j=1}^{q} \omega_j \ln Z_j \qquad (3)$$

[1] Ideally, the measures of outputs and inputs should be based on the 'flows' concept, that is, it is the *services* of inputs that are used to produce the flows of outputs, while the services of inputs are derived from the stocks of inputs. Therefore, measures of capital services rather than stocks should be used in productivity analysis. Capital and infrastructure services measures were constructed for this study based on unpublished ABS data (see appendix D).

where $\ln MFP = \ln Y - \alpha \ln C - (1-\alpha)\ln L$, $a = \ln A$ and represents the state of technology. The left-hand-side variable is the conventional multifactor productivity (MFP) index based on value added (sometimes referred to as total factor productivity (TFP)).[2] Equation (3) contains two less right-hand-side variables than equation (2), which can be an advantage when estimating models on small samples.

MFP is often referred to as a measure of technological progress. However, 'measured' MFP is a 'residual' and will reflect various influences on the rate of growth of outputs over inputs in addition to technological change (box 4.1).

Box 4.1 **Technological change and the residual**

Typically, there are multiple, heterogeneous outputs produced and inputs used by a production unit. Index number theory is used to aggregate the outputs and inputs to derive the MFP index. The index shows the growth or change in MFP.

MFP growth is derived as a 'residual', that is, the amount of real output growth not explained by the amount of real input growth. Under the framework of growth accounting in production economics, the change in MFP is closely linked to the concept of Hicks neutral technological progress. Thus, the MFP measure is often thought to be a 'technology index' that measures the amount of technological change.

However, measured MFP not only reflects technological progress in a production unit, but also other factors that may not be related to changes in technology. This is the result of the 'residual' nature of the MFP index. Some of these factors include scale economies, spillover effects, efficiency change, variation in capacity utilisation and measurement errors in either outputs or inputs.

Despite these qualifications, an improvement in MFP does reflect the fact that measured outputs grew faster than measured inputs. Over long periods of time, MFP growth is an important determinant of improvement in living standards.

For a discussion of the methodology and issues which arise in constructing estimates of aggregate and industry MFP, see Diewert (2000) and OECD (2001), with Aspden (1990) and Zheng (2005) providing a discussion in the Australian context.

2 If the intermediate inputs are also included in the industry-level production function, which usually is the case at the firm level to reflect the actual production process, the appropriate measure of output should be gross output and the corresponding MFP index will have a somewhat different interpretation from the productivity index based on value added. See OECD (2001) for a further discussion of the difference between the value added and gross output based MFP indexes. See also Jorgenson et al. (1987) for deriving the MFP index based on production economics, and Balk (2003) for an index number approach to deriving the two MFP indexes without relying on production functions.

Since the MFP index is derived independently prior to estimation, this method of estimating the effect of R&D on productivity is referred to as the two-step method. Many empirical studies and most of the results in this paper are based on this method. However, models are also estimated based on equation (2) specified in labour intensive form (that is, divided through by L so that measures are per hour worked) and seek to explain labour productivity.

The stock of knowledge capital can be expanded to separately identify knowledge capital resulting from Australian R&D or international R&D. The stocks can be constructed at different levels of aggregation, for different institutional sectors and/or for different types of R&D.

The R&D capital (knowledge) stock

The prevailing measurement framework used to derive estimates of the knowledge stock is the perpetual inventory method (PIM). PIM can be represented by

$$K_{t+1} = (1-\delta)K_t + R_t$$

where δ is the geometric constant depreciation or obsolescence rate of knowledge, and R_t is the flow of research and development investments (expenditures in constant prices) at time t.[3] The perpetual inventory method (PIM) assumes a geometric depreciation schedule and is directly analogous to forming a *structure capital stock.*

Assuming that preceding the initial observation, there was a long period of real investment growth at a constant rate of g, the initial stock of knowledge capital can be calculated using

$$K_o = R_o /(g + \delta)$$

where K_o is the initial stock of knowledge capital from investments in R&D (t = 0). It is the stock at the beginning of the first period for which R&D expenditure data are available; R_o is the expenditure on R&D (in constant prices) during the first year for which it is available; and g is approximated by the average annual logarithmic growth of R&D expenditures (in constant prices) over the period for which published R&D data are available.

The PIM methodology is used in the construction of all knowledge stocks in this paper. While referred to as a 'knowledge stock' it only includes knowledge that is

3 In the capital measurement literature, this form of PIM corresponds to the geometric age-efficiency profile for the productive capital stock.

the outcome of R&D. Other sources of learning, such as formal education and learning-by-doing, are not included. Other limitations of the PIM are discussed below.

Analysis using the 'rate of return' framework

Empirical work often uses the growth or 'rate of return' framework. The motivation for this is that it can be used to directly estimate the rate of return, rather than convert an elasticity into a rate of return. It may also be used to avoid some of the complications from constructing R&D stocks, particularly where there are concerns about the length of the expenditure time series and the ability to construct the initial stock of knowledge capital.

The rate of return framework is derived from the specifications of equations (2) and (3) where the variables are in (log) levels. Differentiating both equations with respect to time gives

$$y = \lambda + \alpha c + \beta l + \gamma k + \sum_{j=1}^{q} \omega_j z_j \qquad (2')$$

$$mfp = \lambda + \gamma k + \sum_{j=1}^{q} \omega_j z_j \qquad (3')$$

where lower case letters signify growth rates; $mfp = \frac{d \ln MFP}{dt} \approx \ln MFP_t - \ln MFP_{t-1}$; and $x = \frac{d \ln X}{dt} = \frac{\dot{X}}{X}$ is the rate of growth for R&D capital and the control variables, and it is approximated by $\ln X_t - \ln X_{t-1}$.

Differencing removes the time trend from the equations. Despite the same coefficient, γ, appearing in equations (2), (3), (2') and (3'), the estimated γ from these different specifications will generally not be identical because of different forms of the variables involved in estimation.

The reference to 'rate of return framework' comes from the transformation below and the relationship between the elasticity γ and marginal product ρ

$\gamma = \frac{\partial Y}{\partial K}\frac{K}{Y} = \rho \frac{K}{Y}$ (where $\rho = \frac{\partial Y}{\partial K}$), therefore

Net change in stock ↓   Gross expenditure ↓

$$\gamma k = \gamma \frac{\Delta K}{K} = \rho \frac{K}{Y}\frac{\Delta K}{K} = \rho \frac{\Delta K}{Y} = \rho \frac{(1-\delta)K_{t-1} + R_t - K_{t-1}}{Y_t} = \rho \frac{R}{Y}$$

The differenced specifications (2') and (3') can be re-specified using either the net change in the knowledge stock over output or gross R&D expenditure over output in place of the growth rate of the knowledge stock (γk). Gross R&D expenditure might be used if it is believed that the decay rate of knowledge approximates zero (δ=0), but this is not supported by studies that have sought to estimate it (discussed later).

Alternatively, and without relying on a zero decay rate assumption, gross expenditure might still be used noting that the term $-\rho\delta(K_{t-1}/Y_t)$, which is dropped in moving from the net change in stock specification to the gross expenditure specification, can be treated as constant (and would be absorbed in the intercept of a regression) if the theoretical framework in mind is defined by a steady state in which the knowledge capital to output ratio is constant.[4]

The 'rate of return' intensity specifications with a knowledge stock are

$$y = \lambda + \alpha c + \beta l + \rho \frac{\Delta K}{Y} + \sum_{j=1}^{q} \omega_j z_j \tag{4}$$

$$mfp = \lambda + \rho \frac{\Delta K}{Y} + \sum_{j=1}^{q} \omega_j z_j \tag{5}$$

The above methods are subject to a range of criticisms that are discussed at various points in the paper and, for example, in Griliches (1995), Greenwood and Jovanovic (2001), and Diewert (2005).

Interpreting elasticities and rates of returns

Once the coefficient for the elasticity of output with respect to the R&D capital stock is obtained (γ), the rate of return is computed as

$\rho = \gamma \frac{Y}{K}$, where ρ is the *gross* rate of return, or

[4] The latter justification was pointed out by Professor Steve Dowrick in his comments on the paper.

$$\rho = \gamma \frac{Y}{K} - \delta$$, where δ is the decay rate, and ρ is the *net* rate of return.

The concept of the net rate of return is more meaningful than its gross counterpart, because it is the net rate that profit-maximising/cost-minimising firms use to equate with the net rate of return to other assets and the cost of funds in making their investment decisions.

The rate of return can be calculated at the mean of output (*Y*) over the mean of the knowledge stock (*K*) or it can be applied to sub-samples of the data to, for example, infer changes in returns over time.

Private, social and excess returns

The interpretation of measures of the rate of return depend on the level of aggregation of the analysis (table 4.1). Higher levels of aggregation capture more of the external effects of R&D.

The rate of return is based on the marginal product of R&D — the extra output that results from incremental R&D expenditure (or a change in the knowledge stock). Appendix P discusses why it can also be considered the internal rate of return. The internal rate of return is the social rate of time preference that would equate the present value of the benefits of R&D investment with the present value of the costs of the investment.

Studies of R&D and productivity are interested in the aspects of R&D that generally distinguish it from other forms of capital and labour. The studies can be separated into those that seek to understand the private return to R&D and why it does or does not differ from the return to conventional inputs, and those that seek to understand the external aspects of R&D and its importance in terms of productivity growth. In the case of business R&D, the external effects are those aspects of R&D undertaken by a firm that affect other firms.

Studies often estimate returns to R&D from productivity measures that have been constructed from capital and labour data that implicitly include R&D capital and labour. Adjusting the conventional inputs to separately identify R&D inputs often cannot be done or it requires messy ad hoc assumptions. If a study is based on data that do not net out R&D inputs from conventional inputs, then the return to the conventional inputs is also implicitly applied to the R&D inputs when these inputs are subtracted from output to arrive at a measure of productivity. If the private return to R&D is in fact higher than conventional inputs, then the estimated return will include this extra return.

Table 4.1 **The interpretation of R&D coefficients as aggregation increases**

Return is marginal product

Level of aggregation	*Effects captured*	*Return to business R&D*
Economy-wide	Market sector + Non-market sector	Social return to business R&D in the broadest sense, given the definition of 'return' being based on the marginal product of R&D.
Market-sector	Inter-industry + Intra-industry	Social return. Captures intra and inter-industry external effects, but excludes effects on non-market sector activity.
Industry-level	Within or intra-industry	Industry 'internal' return. Captures external effects among sub-industries and firms within the industry only.
Firm-level	Private 'excess' return +	Private return to R&D. This *excess* return to R&D represents either a risk premium or a supranormal rate of profit on R&D investments, relative to traditional capital.
	Return to traditional capital	In deriving rental prices or user costs of capital services, the net rate of return (or real interest rate) of 4 per cent, together with the information on rates of depreciation, capital gain or loss and effects of net taxes, have been used in several industries in the Australian National Accounts.

The alternative is to estimate the return to a knowledge stock by regressing it against a MFP measure that includes 'double counting', but to give a different interpretation to the estimated coefficients. It is common practice to interpret the coefficient as an 'excess' return. The 'excess' return is a measure of the output response to R&D capital over and above the normal return to conventional labour and capital.

In firm-level studies, the excess is conventionally thought of as either a risk premium or a supranormal rate of profit on R&D investments. In studies at higher levels of aggregation, the estimated return incorporates external effects. The estimates from studies at higher levels of aggregation are often referred to as a 'social' return which, depending on how data have actually been constructed and the level of aggregation of the analysis, can be misleading for two reasons.

- The 'social' return includes the private excess return, except in the few cases where specific adjustments have been made to the data.
- The 'social' return may be incomplete. For example, industry level studies will estimate the effect on productivity of the industry's own R&D knowledge stock. This will give an estimate of the return which incorporates intra-industry

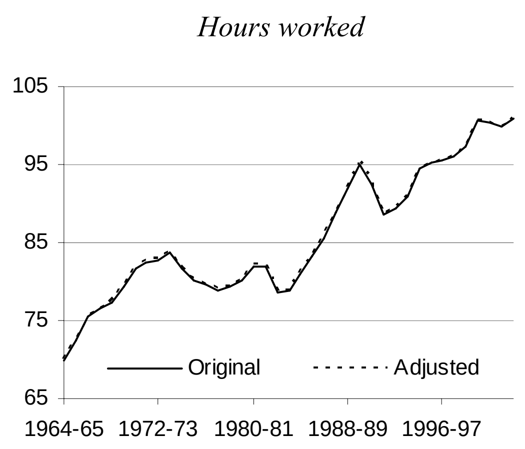
external effects related to R&D, but it will not capture inter-industry effects. Some studies will include a separate knowledge stock representing the sum of R&D undertaken by other industries in which case an estimate of the importance of spillovers to the industry under study is obtained.

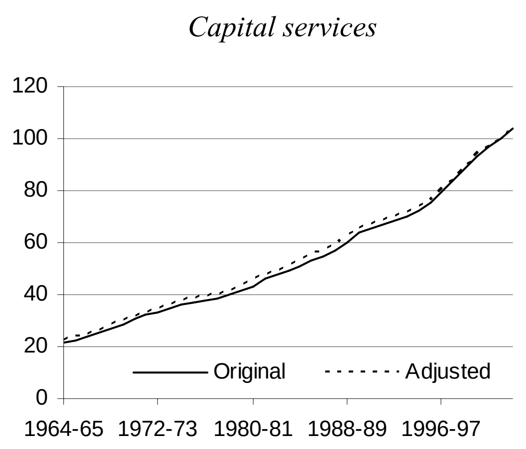
The validity of the 'excess' interpretation partly depends on how value added is measured in the national accounts. As R&D is treated as an intermediate expense rather than as a capital asset, an 'expensing' bias is introduced, which may partially offset or add to the double counting bias. Further discussion of these issues is provided in appendix K. The appendix also sets out a methodology for gauging the effects of double counting and expensing within an econometric model specification.

In Australia, it is possible to directly adjust the capital services and labour input measures used in the calculation of MFP measures, subject to a range of assumptions (see the footnotes to figure 4.1). Removing R&D hours worked from total market sector hours worked and R&D capital from total capital services for the market sector has a very minor impact on the market sector indexes (figure 4.1). As a percentage of the market sector or economy as a whole, the fraction of resources committed to R&D is very small.

Figure 4.1 **Hours worked and capital services indexes, adjusted for 'double counting', market sector[a], 1964-65 to 2002-03**

Indexes 2001-02 = 1000





a For hours worked, an estimate of hours worked conducting R&D was subtracted from total hours worked The R&D hours worked estimate was based on person-years in R&D data collected in the ABS R&D survey of businesses. The estimate was multiplied by economy-wide average hours worked per person per year. For the construction of an adjusted capital services measure, R&D capital was weighted by the non-IT rental price multiplied by 2.5 (reflecting the higher level of risk of R&D investment).

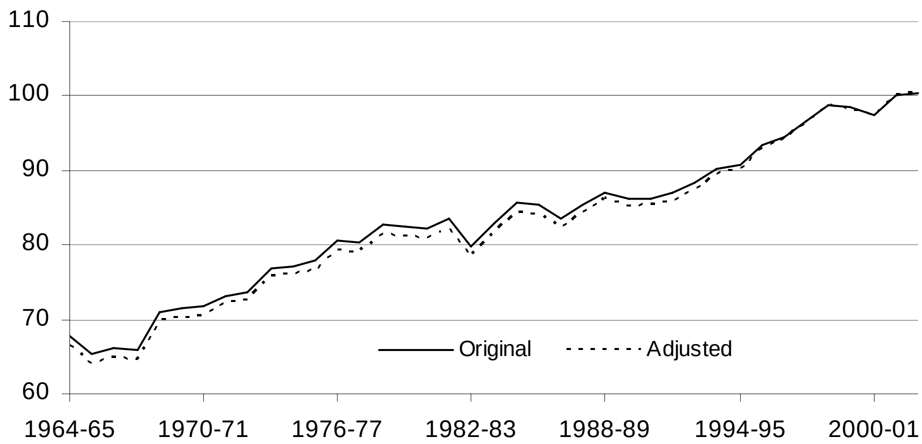
Data sources: ABS (*Australian Systems of National Accounts,* Cat. no. 5204.0); ABS (*Research and Experimental Development, Businesses,* Australia, Cat. no. 8104.0); Commission estimates.

The impact of netting out R&D labour and capital on MFP growth rates is to raise the growth rate of MFP (figure 4.2). Across the productivity cycles, growth rates were approximately 0.1 of a percentage point higher when MFP was adjusted for double counting. This is an outcome of the fact that the MFP index is a measure of the rate of growth of output (the denominator) over inputs (the numerator). The R&D adjustments reduce inputs, but output remains constant. R&D inputs have grown faster than the average of all other inputs, so removing them reduces the rate of growth in total non-R&D inputs.

While visually there appears to be little difference in the indexes, the adjustments do produce differences in estimated market sector elasticities (appendix K). The elasticities are larger and statistical significance is slightly higher. However, with the imprecision in the estimates on both the unadjusted and adjusted data, tests cannot confirm that the difference in the coefficients is statistically significant.

Figure 4.2 **Growth in MFP, adjusted for 'double counting', 1964-65 to 2002-03[a]**

2001-02 = 100



a The methodology used to calculate the MFP index was to estimate annual changes for each of the components of output. Output changes are assumed to remain the same. Given this, then annual changes for MFP as a residual can be calculated. This comes from the decomposition of output into its components, capital, labour and MFP. Changes were made to capital and labour indexes as per the above, with extra indexes included. Given these small changes, there was little change to levels in MFP. The use of standard index number methodology contains the implicit assumption that levels are equal in a base year. Therefore, the indexes cannot be used to compare levels with and without the R&D adjustments.

Data source: Commission estimates.

The coefficient on the knowledge stock when regressed against the adjusted MFP index effectively includes more of the return to R&D as it incorporates the component of the private return to R&D that was being treated symmetrically with conventional capital and labour in the calculation of the MFP index. However, the assumptions made in adjusting conventional capital and labour inputs could have been done differently. For example, a lower or higher rental price of R&D capital could have been assumed.

For consistency with other studies, and given the assumptions that need to be made in adjusting the data, market sector results are based on data that have not been adjusted for double counting (except for sensitivity testing in appendix K). The issue of double counting is not important to the key problems and findings identified at the market sector level.

The alternative productivity-R&D intensity long-run relationships

The models which postulate a long-run relationship between MFP or labour productivity growth and R&D intensity take one of two forms (suppressing controls, the error term, and the constant, and the capital to labour ratio for the labour productivity models):

$$\Delta \ln(MFP_t) = \ln(\frac{K_t}{Y_t}) \text{ or } \Delta \ln(MFP_t) = \ln(\frac{K_t - K_{t-1}}{Y_t}) \quad (6)$$

$$\Delta \ln(LP_t) = \ln(\frac{K_t}{Y_t * hrs}) \text{ or } \Delta \ln(LP_t) = \ln(\frac{K_t - K_{t-1}}{Y_t * hrs}) \quad (7)$$

These relationships are from the R&D-based endogenous models introduced in chapter 2. The models are not based on the production function specified above in equation (1).

The intensity is specified as either the knowledge stock over output or change in the knowledge stock over output. For the latter measure, the assumption of a log-linear relationship between productivity growth and R&D intensity imposes the restriction that the change in the knowledge stock is greater than zero (that is, the knowledge stock does not decline).

Estimation of (6) and (7) entails significant simplifications of the theoretical models of Young and Howitt introduced in chapter 2. The predicted long-run relationships are outcomes of more complete models. The theoretical models have a number of equations which jointly determine the growth rate (for example, a growth equation and an equation which governs the amount of resources devoted to R&D versus other economic activities). And, they may include theoretical constructs for which data are not available (for example, R&D which expands the range of inputs/goods (horizontal R&D) versus R&D which improves the quality of existing inputs/goods (vertical R&D)).

Further, knowledge may not accumulate as modelled by the PIM. However, the PIM has been used to form all knowledge stocks used in these models due to the difficulties of empirically implementing a more flexible approach.

As such, the empirical results from models based on the standard framework benefit from a tighter linkage between theory and empirics than do results based on (6) and (7).

Returns to scale

The assumption of constant returns to scale (CRS) is often used to derive the MFP index. However, this assumption is not a property associated with any particular type of production function, and thus it is also not required to estimate the MFP index if *independent* estimates of input cost shares are available.[5] Nevertheless, CRS is often imposed in the applied work to give more structure to the production function and ease in interpretation and exposition.

It is also worth noting that constant returns to scale is implied by the accounting identities relating the value of outputs to the value of inputs in an industry or economy where profit is not identified as a separate item in the production process. The cost shares of inputs can then always be added up to be equal to one. Thus, the assumption of constant returns to scale is naturally built into the estimated MFP index using Australian System of National Accounts (ASNA) data.

The assumption of constant returns to scale can be tested using econometric models. For example, the studies by Hall (1988, 1990), Morrison (1992) and Basu and Fernald (1997) all find evidence of increasing returns to scale at the aggregate manufacturing and private economy levels in the United States. Based on an improved functional specification for econometric estimation and using the ABS productivity database, Fox and Nguyen (2005) find that the returns to scale in the aggregate market-sector are constant or decreasing on average for the period 1966-2004, while technological progress appears to have been the dominant force driving productivity growth in Australia. van Pottelsberghe (1997, p. 38) discusses the difficultly in separately identifying increasing returns to scale from technological change:

[5] This is due to the fact that the MFP index can be derived using a general form of a production function under the non-parametric approach (Hulten 2001). Using an econometric approach, MFP can be also estimated without imposing the assumption of constant returns to scale. Based purely on an index number approach, the MFP index can also be derived from accounting identities without relying on production functions (Balk 2003).

What can we conclude about this 'returns to scale' issue? The algebraic development demonstrates that it might be difficult to distinguish empirically the effect of increasing returns to scale from the effects of technical progress. And this distinction might become even more puzzling if increasing returns to scale are considered to be partly due to technical change.[9] Empirical works at the firm or industry levels generally reach the conclusion that there are decreasing returns to scale and that relaxing the hypothesis of constant returns to scale reduce the estimated impact of R&D (or the output elasticity with respect to R&D). They confirm in some respects that there is a close link between the two forces at work. Yet, some single industry studies do not reject the constant returns to scale hypothesis, and therefore validate the majority of studies at the firm and industry level that explicitly rely on this apparently not too restrictive hypothesis.

[9] Intuitively, increasing returns to scale may be due also to technological characteristics of the production process that would make firms or industries more productive with larger output levels, independently of technical change.

The market sector MFP index used in this study is the index published by the ABS based on ASNA data. The industry level and manufacturing subdivision level MFP indexes are based on unpublished ANSA data using the same methodologies as the ABS uses for the market sector.

The MFP models in the following chapters are estimated using the two-step method. As the derivation of MFP already incorporates the CRS assumption, CRS is tested by re-entering capital and labour variables into the MFP regressions to test for non-constant returns (in particular, certain types of infrastructure, such as communications and general government infrastructure). CRS is also tested by entering the product of the labour and capital growth rates into a first-differenced MFP equation using the methodology set out in van Pottelsberghe (1997, p. 39).

4.2 Issues in empirical implementation and interpretation

The level of aggregation and type of analysis

The above frameworks are used for analysis at various levels of aggregation, including: the market sector as defined by the ABS; an 'expanded' market sector as constructed by Diewert and Lawrence (2005); four ANZSIC one-digit level industries; and eight manufacturing subdivisions.

Time series techniques are used for the market sector models and industry models. This poses a number of estimation and interpretation challenges as most variables possess strong trends (see appendix E for unit root testing and the discussion on identifying long-run relationships below). Most models are estimated as static models by simple Ordinary Least Squares (OLS). Dynamics are introduced by specifying some models as Finite Distributed Lag (FDL) models and Autoregressive Distributed Lag (ARDL) models.

Some studies (such as Coe and Helpman 1995) investigate the relationship between R&D and productivity by including only variables from the long-run relationship being investigated. This approach is adopted as the starting point for modelling in the market sector models. Regressions of the basic long-run relationships from chapter 2 are undertaken and tested thoroughly (chapter 6) before incorporating other controls and sources of growth (chapters 7 and 8). A large range of variables are tested including various capital and infrastructure measures, controls for changes in human capital, and indicators of labour market wage determination processes and the level of industry assistance.

The first observation for the models lies between 1968-69 and 1976-77 and the final observation between 2000-01 and 2002-03. Differences in sample period are driven by the length of available time series of the particular variables included in the models and the inclusion, or not, of lags in the variable's effect on productivity. Most models have between twenty-four and thirty observations which, in the context of identifying permanent or long-run relationships, may be insufficient to produce efficient, robust parameter estimates of the effect of R&D, particularly if the effect has not been stable.

Deflating R&D expenditure

Current-price R&D expenditure data are deflated to remove the effects of pure price inflation to obtain time series of the real volume of resources utilised in R&D activity. In principle, the deflated expenditure series shows the sum of changes in the quantity of resources utilised and their quality (although these two components are difficult to separately identify).

Overseas studies find that aggregate generic deflators, such as the GDP implicit price deflator (GDP(IPD)), tend to understate the true increase in R&D prices, as inflation in the cost components of R&D activity have risen faster than the average price inflation reflected in the GDP(IPD) (table 4.2). Labour costs form a large proportion of total R&D expenditure and wages have risen at a faster rate than prices reflected in the GDP(IPD).

Table 4.2 **Selected international evidence on the 'price' of R&D**

Study	*Data and methods*	*Key findings*
Mansfield, Romeo and Switzer (1983)	Constructs price indexes for R&D inputs for the period 1969 to 1979 for eight industries. Data obtained from surveys of thirty-two large R&D firms.	Compared with constructed indexes, the GNP deflator underestimated the rate of price increase for R&D inputs during 1969-79 in all eight industries
Mansfield (1987)	Constructed price index from random sample of 100 firms between 1969 and 1983. Collected data on expenditure and actual prices R&D inputs were classified into five categories: 1) engineers and scientists; 2) support personnel; 3) materials; 4) plant and equipment; 5) other inputs.	Compared with the constructed R&D price index, the GNP deflator tends to underestimate the rate of inflation in R&D.
Jankowski (1993)	Uses Mansfield (1987) data and official and non-official data sources to interpolate annual cost changes in R&D between survey years 1969 and 1983. Price indexes constructed for twelve industries based on the five factor inputs used in Mansfield (see above). An aggregate R&D index is calculated from a weighted average of the twelve indexes.	At an aggregate level and compared with the constructed index, the GNP IPD provides a reasonable approximation to the inflationary changes in R&D input costs. At a lower level of aggregation, there was significant variation in industry R&D cost changes, favouring the use of industry-specific R&D price indexes.
Cameron (1996)	Constructed R&D price indexes for eight UK manufacturing sectors and for manufacturing as a whole. The indexes were constructed using share weighted proxy price series for the individual cost components of R&D expenditure. Data are from various sources, but mainly based on the UK surveys of business R&D expenditure.	Compared with the constructed total manufacturing index, the GDP deflator tended to underestimate increases in R&D input costs. The cost of R&D in individual industries rose at significantly different rates from manufacturing as a whole.
Klette and Johansen (1998)	Norwegian plant-level manufacturing data linked to R&D survey data for the period 1980-92. Tests knowledge accumulation equation incorporating complementarity between current investments in knowledge and accumulated knowledge.	Appropriable part of R&D capital depreciates quite rapidly with an estimated annual depreciation rate of 18 per cent on average.
Haan and van Rooijen-Horsten (2004)	An input price index of R&D expenditure was derived using data on the compensation of employees (from the Dutch R&D surveys), intermediate consumption (an R&D-specific deflator was derived from the supply-use tables of the Dutch national accounts) and gross operating surplus (deflating using the GDP deflator).	The constructed input price index and the GDP deflator provide very similar estimates of the growth in R&D prices.

Mansfield (1984) found that the rate of inflation was well above that suggested by the GDP deflator. In providing comment on Mansfield's paper, Griliches noted that much of the apparent increase in R&D inputs between 1969 and 1979 may have been a 'statistical mirage' caused by the lack of better price indexes for R&D inputs.

Cameron (1996) constructed price indexes for R&D expenditure for eight sectors of UK manufacturing and for manufacturing as a whole for the period 1970 to 1992. The indexes were Divisia weighted averages of cost components deflated using proxy price indexes. He found:

> Trends in the cost of R&D and in the GDP deflator tend to be similar, as is to be expected, but differences still emerge. For example, our implicit R&D deflator shows that real manufacturing BERD rose by 7.3 per cent between 1983 and 1992, while the GDP deflator suggests a rise of 11.4 per cent. (p. 12)

The problem of insufficient deflation of nominal R&D expenditures appears to vary by country. Haan and van Rooijen-Horsten (2004) constructed a composite input price index to deflate R&D for the Netherlands and compared the resulting real expenditure estimates to those obtained using the GDP price index:

> … the specific R&D price index does not differ very much from the GDP price index. The most substantial differences show up in the early seventies, a period characterized by substantial wage increases and high inflation rates. Although in later years incidental differences in annual price changes do occur, the R&D and GDP price indexes follow almost similar patterns. In the case of the Netherlands, the GDP price index does not seem a very bad approximation for measuring R&D in constant prices. (p. 20)

The vast majority of productivity-R&D empirical studies deflate nominal R&D expenditure with their respective country's GDP(IPD). The *Frascati Manual* recommends that research agencies adopt such an approach, but notes that R&D specific deflators may be more appropriate:

> R&D [specific] deflators are justified if it is believed that the cost of R&D has moved in a way that is significantly different from general costs and/or if trends in the cost of R&D have varied considerably among sectors or industries. In general, over the long term, it is reasonable to suppose that the implicit GDP (output) deflator would tend to increase less rapidly than a "true" R&D (input) deflator because of productivity increases.
>
> The optimal solution is to calculate special R&D deflators based on weights and prices that are specific to R&D. The cost and complexity of carrying out the price surveys needed for this exercise rules out using them except for specialised analysis. The most common approach is to use weights derived from R&D surveys combined with proxy prices [generic deflators for each component]. (OECD 2003c, Annex 9, p. 218)

Lags and dynamics

Case studies have documented that the process of generating new knowledge from R&D is subject to lags between R&D investment and invention, between invention and development, and between development and commercialisation or production.

Griliches (1973) found that the average lag for applied and developmental research in industry was around two to three years, and five to eight years for basic research. Guellec and van Pottelsberghe (2001) in a cross-country panel study found that using a 'best fit' strategy suggested an optimum lag for domestic business R&D of around two years, and three years for foreign business R&D.

Rouvinen (2002), described in table 4.3, finds that the lag structure is bell shaped with a 'peak' lag of around four years for domestic business R&D:

> Productivity seems to respond to changes in R&D at a considerable lag. We include annual lags of R&D up to four in our ADL(1,4) specification: in most cases the fourth lag is significant at conventional levels and frequently the coefficient estimate of the fourth lag is the highest in absolute terms as far as R&D is concerned … Our findings suggest that the perpetual inventory method of constructing R&D capital stocks and the R&D-intensity approach to productivity analysis, both frequently applied in the literature, may have to be reconsidered. (p. 152)

The construction of a stock is meant to replace the series of collinear expenditures in a regression. In this paper, the R&D stocks were constructed so that expenditure in period (t) is fully reflected in the stock of period (t), rather than applying an assumed set of weights to recent R&D expenditures as they enter the stock (that is, rather than externally imposing a lag structure *a priori*).[6] This introduces a degree of measurement error as variation in the stock from recent earlier periods is likely to be significant to current period variation in output and productivity. If the rate of expenditure on R&D is constant, then the stock at period (t) or (t-1) only can be used. However, the rate of business investment in R&D has fluctuated widely. Therefore, better model estimates might be obtained where one or more lags of the stocks are also included in the models.

6 For example, the Alman polynomial lag structure can be imposed. It provides a bell shaped structure reflecting that R&D expenditures take some time before they contribute to output and that, as time passes, this contribution becomes less. For a recent application see Hall and Scobie (2006).

Table 4.3 **Empirical evidence on the lags associated with R&D**

Authors	*Data and methods*	*Key findings*
Ravenscraft and Scherer (1982)	Based on a unique micro dataset (Schaeffer 1977) of the US. Explores the lagged effect of industrial R&D on profitability. The dataset covers 1970 to 1979. It contains various numbers of businesses, depending on the year in the sample. A binomial lag and a form-free distributed lag technique are used to estimate the lag length.	Lag structure is roughly bell shaped with a mean lag of four to six years before R&D expenditures begin to generate profits.
Pakes and Schankerman (1984)	Based on data from Rapoport (1971) on 49 commercialised innovations, and Wager (1968) from survey data on process and product innovations from 36 firms.	Combined mean lag between project inception and completion (the gestation lag) and project completion to commercial application (the application lag) of between 1.2 and 2.5 years.
Hall, Griliches and Hausman (1986)	Panel from 1972 to 1979 of US manufacturing firms supplemented with patent applications data. Investigate the contribution of the firm's R&D history to the current year's patent applications to the USPTO.	Found a strong contemporaneous relationship between R&D expenditure and patenting, but did not find strong evidence of leads and lags in the R&D-patenting relationship.
Goto and Suzuki (1989)	Used Japan's Economy Planning Agency's survey of R&D activities of major firms to identify time lag for business R&D for each of seven industries between 1976 and 1984.	2 year time lag for electrical industrial machinery, parts for electronic appliances and communications equipment, and metalworking machinery. Five years for drugs and medicines. Three years for other industries.
Adams (1990)	The number of papers published in each science as measures of knowledge and data on employment of scientists by field and industry, data on (2-digit) manufacturing MFP from Bureau of Labor Statistics.	20 year lag between the appearance of research in the academic community and its impact on productivity. Academic technology and science takes roughly 10 and 30 years, respectively to filter through inter-industry spillovers.
Park (1995)	Panel of 10 OECD countries from 1970 to 1987. Successively lengthened lags and used best-fit strategy.	'Peak' lag length for private and foreign R&D was 2 and 3 years, respectively. Coefficients increased until the peak and then declined.
Ducharme and Mohnen (1996)	Industry level Canadian data (25 two or three digit industries) for 1964 to 1985.	Find an optimal lag of three to six years for the R&D capital stock.
Rouvinen (2002)	OECD Analytical Business Enterprise R&D Database (ANBERD) linked to the OECD International Sectoral Database (ISDB). Unbalanced panel of fourteen industries in twelve countries from 1973 to 1997.	The fourth lag in the ARDL(1,4) specification is significant and its coefficient estimate is the highest in absolute terms.

Models are sensitivity tested to various lag structures by including the R&D stocks contemporaneously or lagged by one or more periods. Distributed lag models start with a long lag structure and are tested down. This procedure tends to produce a lag structure which is shorter than the expected 'true' lag structure.[7] Many models were tested with both stock data and gross investment data.

In most of the market sector models, the default lag structure adopted for Australian business R&D and foreign business R&D is (t-1) and (t). Lagging Australian business R&D one period is done to address possible problems with the simultaneity of R&D and output and not to address lags in the R&D process. Results are also reported for some models using the lag structure (t-2) and (t-3). Park (1995) found that the effect of private research on productivity peaked at a lag of two years, while it peaked at a lag of three years for foreign R&D.

The estimation of a complete lag structure is hampered by the problem of multi-collinearity (box 4.2).

Adequacy of the PIM

Although the PIM methodology is adopted in this study and almost all other empirical studies of the effects of R&D which construct knowledge stocks, its application is subject to important criticisms:

- knowledge is extremely heterogeneous with much of it tacit[8], which raise concerns about the underlying concept and construction of a general knowledge stock;
- knowledge does not 'depreciate' in the same manner as physical capital; and
- use of the PIM imposes a linear accumulation methodology.

Use of the PIM is not entirely satisfactory because it does not take into account many special characteristics associated with knowledge accumulation and the stocks generated from the R&D activities. For details on this argument and the suggested alternatives, see Diewert (2005) and Bernstein (2002).

[7] Balcombe et al. (2005) find that the general-to-specific test down procedure tends to constrain the length of the estimated lag relationship between productivity and R&D. They are critical of the procedure when it is used to determine the appropriate lag structure between variables where the impact of one variable on another is delayed and highly dispersed. However, their alternative approaches seem to require much longer time series than is available in Australia.

[8] New technological knowledge can be embodied in improved or new capital equipment and intermediate inputs. Knowledge can also be tacit in the sense that it has not been explicitly recognised and articulated, but resides 'in the heads' of those who possess it. See for a discussion, Machlup (1980), Nelson and Winter (1982) and Cowan, David and Foray (1999).

Box 4.2 **The constraints imposed by multi-collinearity**

Econometric techniques rely on variation in data to estimate statistical relationships. However, the degree of variation between different types of R&D, between the R&D undertaken by different institutional sectors, and/or between observations over time may not be sufficient to give precise estimates of the effect of R&D.

> … there are two other serious econometric problems facing the analyst in this area: multicollinearity and simultaneity [the problem of inferring direction of causality]. Although both are common "garden variety" econometric problems, each has serious consequences. The problem of multicollinearity arises from the fact that many of the series we are interested in moved very much together over the period of observation. That being the case, it is then difficult (often impossible) to infer their separate contributions with any precision. There are no cheap solutions to this problem. It requires either less collinear data, more prior information, or a reduction in the aspiration level of the questions to be asked of the data. (Griliches 1979, p. 106)
>
> Mohnen (1996) suggests that the main reason why some studies often yield inconclusive or fragile results lies in the high collinearity between the various R&D intensity measures, combined with a low number of observations. This collinearity would arise because domestic and foreign R&D move in tandem; they are strategic complements or mutual inputs to each other. It is therefore difficult to disassociate their individual effects statistically. For instance, the studies by Coe and Helpman (1995) produce strongly significant output elasticities of foreign R&D thanks to the high numbers of observations and, consequently, to the large variations in the data. (Cincera and van Pottelsberghe 2001, p. 7)

The problem of multi-collinearity makes it more difficult to identify the separate contributions of different sources of spillovers and excess effects on productivity, and to identify lags in R&D.

The fallacy of aggregating 'private' knowledge stocks into a common 'public' knowledge stock

Cowan et al. (1999, pp. 10–2) outline important problems with the underlying concept of an aggregate 'knowledge stock':

> The "new growth theory" literature falls squarely within the tradition emphasizing the public-goods nature of knowledge. So, one may surmise that the world stock of knowledge surely has to be the union of private stocks of codified knowledge: anything codified for someone is thereby part of the world knowledge stock. Such reasoning, however, may involve a fallacy of composition or of aggregation. But if the contextual aspects of knowledge and codification … is to be taken seriously, the world stock of codified knowledge might better be defined as the intersection of individuals' sets of codified knowledge – that being the portion that is "shared" in the sense of being both known and commonly accessible. It then follows that the world stock of knowledge, being the intersection of private stocks, whether codified or tacit, is going to be very small.

> The foregoing suggests that there is a problem in principle with those models in the "new growth theory" which have been constructed around (the formalized representation of) a universal stock of technological knowledge to which all agents might contribute and from which all agents can draw costlessly. That, however, is hardly the end of the difficulties arising from the primacy accorded to the accumulation of "a knowledge stock" … The peculiarities of knowledge as an economic commodity, namely, the heterogeneous nature of ideas and their infinite expansibility, have been cast in the paradigm "new economic growth" models as the fundamental non-convexity, responsible for increasing returns to investment in this intangible form of capital. Heterogeneity implies the need for a metric in which the constituent parts can be rendered commensurable, but given the especially problematic nature of competitive market valuations of knowledge, the economic aggregation problem is particularly vexatious in this case.

The transfer, absorption and re-use of knowledge consumes significant resources, particularly where knowledge is tacit. The more that this is true, the less is knowledge instilled with the public good properties which underpin endogenous growth models:

> Furthermore, the extent to which the infinite expansibility of knowledge actually is exploited, therefore, becomes a critical matter in defining the relevant stock … Critics of these models' relevance have quite properly pointed out that much technologically relevant knowledge is not codified, and therefore has substantial marginal costs of reproduction and reapplication; they maintain that inasmuch as this so-called "tacit knowledge" possesses the properties of normal commodities, its role in the process of growth approaches that of conventional tangible capital. If it is strictly complementary with the codified part of the knowledge stock, then the structure of the models implies that either R&D activity or some concomitant process must cause the two parts of the aggregate stock to grow [in step or tandem]. Alternatively, the growth of the effective size of the codified knowledge stock would be constrained by whatever governs the expansion of its tacit component. (Cowan et al. 1999, p.12)

The 'depreciation' of knowledge

The application of a 'depreciation rate' to a knowledge stock is conceptually very different to depreciation of physical capital:

> The private rate of return in R&D investment is affected by the rate of decay of the private revenues accruing to industrially produced knowledge. However, except for the two studies by Pakes and Schankerman [1978; 1986] there are few estimates for the rate of decay of knowledge capital. Pakes and Schankerman correctly emphasize that the conceptually appropriate rate of depreciation of knowledge is the rate at which the appropriable revenues decline. The rate of decay in the revenues does not arise from any decay in productivity of knowledge but from reduction in market valuation, which arises due to inability to appropriate the benefits from the innovations and the obsolescence of original innovations by new ones. (Nadiri and Purcha 1996, p. 51)

> … the R&D "asset" is not like a "normal" reproducible capital asset that depreciates with use. The expenditures incurred in creating the R&D asset are sunk costs and they have no resale value as is the case with a purchase of a reproducible asset. However, a successful private sector R&D venture has created a new product or process that will give rise to a stream of profits in future periods. In many cases, the new technology can be licensed and the rights to use the new technology can be sold. Thus in the case of successful private R&D ventures, a new asset has been created: the rights to a (monopoly) steam of future incremental revenues. However, once a new successful technology has been created, expiry of patents, diffusion of knowledge about the innovation, even newer innovations by competitors and changing tastes all combine to reduce the stream of monopoly profits over time. (Diewert 2005, p. 6)

Although analysts assume a depreciation rate, this assumption is made in reference to the limited number of studies which estimate depreciation rates (surveyed in table 4.4) and what is common practice in the empirical literature. The arbitrariness reflects many unresolved measurement issues relating to the way in which the R&D capital stock is derived, and it also partly reflects the fact that R&D is not treated properly in the current version of the system of national accounts (SNA93) (Fraumeni and Okubo 2004).

There is some evidence that the depreciation rate of knowledge varies across industries, is not constant through time, and is not exogenous. In addition, it could be expected that rates would vary across countries. Therefore, the application of private depreciation rates based on overseas studies might not accurately reflect the rate of decay of appropriable revenues in Australia.

Using a 'best fit' strategy, a number of papers have tested their data to identify a 'preferred' rate of depreciation. Griliches and Lichtenberg (1984) found that their data favoured the no depreciation hypothesis. A zero rate of depreciation on R&D intensity provided the best model test statistics. The test statistics declined monotonically as the assumed rate of depreciation increased. Griliches (1980) undertook a panel study of US industries. Unlike the 1984 study, the choice of depreciation rate made little difference to the results. On a panel of US industries, Adams (1990) found that a depreciation rate of 13 per cent fitted the data best. Hall and Mairesse (1995) found that a depreciation rate of 25 per cent performed slightly better than lower rates of depreciation in a panel of French firms.

Table 4.4 **Empirical estimates of the private rate of depreciation of knowledge**

Authors	*Data and methods*	*Key findings*
Pakes and Schankerman (1978)	Patent renewal fees for France, UK, Netherlands and Switzerland for the period 1930 to 1939.	Depreciation rate of 25 per cent with a 95 per cent confidence interval from 0.18 to 0.36 per cent. Lower bound of confidence interval nearly twice the decay rate assumed in previous studies.
Pakes and Schankerman (1986)	Patent renewal fees	Depreciation rates of: 17-26 per cent (United Kingdom); 0.11 (France); and 0.11-0.12 (Germany).
Goto and Suzuki (1989)	Used Japan's Economy Planning Agency's survey data on the "life span" of technology. The life span is the length of time the firm's patents generated royalty revenues and/or the average length of time their products embodying the patented technologies generated profits.	Rates of obsolescence of R&D capital of: precision machinery (24.5 per cent per annum); communications equipment and related products (14.5 per cent); other transportation equipment including aircraft (14.2 per cent); food (6.0 per cent); stone, clay and glass (7.2 per cent); general machinery (7.2 per cent); and non-ferrous metals (7.5 per cent).
Nadiri and Prucha (1996)	Estimated a cost function for US total manufacturing over the period 1960-1988.	Depreciation rate of 12 per cent for R&D capital and 0.059 per cent for conventional plant and equipment.
Bosworth and Jobome (2001)	Uses patent renewal data for the United Kingdom to provide estimates of the hazard rate from cohorts of USPTO patents granted in each of the years from 1950 to 1975.	Average depreciation rates between 12 and 16 per cent, but not constant over time. The 'autonomous'[9] rate of decay roughly doubled over the period.
Ballester, Garica-Ayuso and Livnat (2003)	Cross-sectional and time series analysis of US firm-level data from the 2002 Compustat Annual Industrial and Research data files.	Amortization rate of 12-14 per cent.
Bernstein and Mamuneas (2005)	Econometric estimation of cost function for US knowledge intensive industries.	Chemical products (18 per cent average depreciation rate), non-electrical machinery (26 per cent), electrical products (29 per cent), and transport equipment (21 per cent). Results imply that R&D depreciates at 2-7 times the rate of physical capital in those industries.

9 By 'autonomous' the authors mean the rate of decay having controlled for competitive, spillover and other exogenous influences on the decision to renew patent protection. The authors note this is consistent with a number of trends: a high level of technological opportunity post-war which declined over time as there was 'catch-up' exploitation of the science and technology base; increased degree of global competition over the sample period; increases in foreign inventive activity (and the United States and Japan assuming increased importance); and increased accessibility of patent information associated with electronic access to patent information databases. They note it is also consistent with the declining rate of increase and eventual peak in patenting activity (United Kingdom).

Rather than assuming a rate and testing for best fit, there are a range of methods for estimating the private rate of knowledge depreciation.

- *The patent renewal fee method:* patent holders pay an annual renewal fee for continued protection of their intellectual property until expiry of the patent. This method uses information on the choice to pay or not pay this fee and let protection expire. It is assumed that the value of the innovation to the business is at least as great as the cost of the renewal fee where businesses choose to pay the fee. By analysing information on the rate at which businesses allow patent protection to expire, estimates of the rate of decay of appropriable revenues can be obtained.
- *Production, cost and profit functions:* rather than regressing on a knowledge stock (K_t), the expanded series of R&D investments with the rate depreciation identified as a separate parameter can be included directly in the estimation of a production, cost or profit function (see Diewert 2005 for a discussion).
- *Market valuation studies:* these studies use financial information on publicly traded firms to estimate the value of various intangible assets, with implications for unobserved depreciation rates.

Estimated depreciation rates are two to three times those of conventional physical capital:

> Many researchers have exploited the *q* relationship[10] to infer the value of intangible corporate assets or sources of rents … These studies have typically found valuations for R&D spending or stock which are consistent with a depreciation rate of about 15-20 per cent. (Hall 1993, p. 259)
>
> Some simple calculations using renewal data, based upon earlier studies suggested that depreciation rates are neither constant, nor exogenously given. However, some support was found for average rates of depreciation between 12 and 16 per cent per annum for at least part of the post-War period …, consistent with the 15 per cent per annum often assumed for the R&D stock in the market valuation (Tobin’s *q*) literature. (Bosworth and Jobome 2001, p. 78)
>
> These rates imply that R&D capital [stock of knowledge] depreciates in about three to five years. Moreover, since the depreciation rates for physical capital range from 4 percent to 8 percent, then R&D capital depreciates at 2 to 7 times the rate of physical capital … A common result among all studies finds R&D depreciating more rapidly than physical capital. (Bernstein and Mamuneas 2004, p. 9)
>
> The implication of this finding is that the appropriate private obsolescence rate for R&D investment is probably somewhat greater than 15 per cent, more in the neighbourhood of 20 to 30 per cent. (Czarnitzki et al. 2005, p. 15)

[10] The ‘*q* relationship’ refers to Tobin’s *q* theory which states that the long-run equilibrium market value of the bundle of assets which comprise a firm is equal to the book value of those assets, properly measured.

Depreciation rates are likely to be affected by many of the economic incentives that also impact on R&D investment and productivity. Using a model, which explicitly included the depreciation rate as an endogenous parameter, Bosworth and Jobome (2001) found that the rate of decay of knowledge was not constant through time. It responded to competition (from newer patents) and spillovers (from the accumulated stock of patents), as well as new investment activity in physical capital and the rate of growth in GDP.

For a small, fairly open economy like Australia, the assumption of an exogenous rate of depreciation may be reasonable if it is believed that the international environment has a large influence on many of the incentives acting to alter the rate of depreciation. For example, the rate of innovation — the rate of product quality increases and introduction of new products — might largely be driven by international rates through the mechanisms of technological opportunity and competition effects. Compositional changes in the capital stock based on technologies developed overseas might be another example where the increasing share of one form of capital (for example, information and communication technologies) raises the obsolescence rate of the knowledge associated with the use of other forms of capital.

The private depreciation rate of knowledge should ideally be based on the concept of the rate of decay of appropriable revenues. While the leakage of knowledge from a firm may negatively impact on appropriable revenues, the knowledge may provide benefits to other researchers and firms which are passed on to consumers. The continued benefits provided by the knowledge spillovers indicate that social rates of depreciation are likely to be lower than private rates.

There is some evidence that estimation of the rate of return to R&D is sensitive to the depreciation rate, but this appears to depend on whether output elasticities or rates of return are directly estimated. From a review of the literature, van Pottelsberghe (1997, p. 51–2) comments:

> These works confirm the idea … that the estimates of elasticities are more robust – e.g., less sensitive to the hypothesized depreciation rate – than the estimates of rates of return. … disregarding R&D depreciation in the measurement of R&D intensity may have serious implications on the estimated returns to R&D.

The estimation of depreciation rates does not appear sensitive to the choice of the depreciation rate used in the calculation of the initial stock:

> … we find that our estimates for the depreciation rates in particular are quite insensitive to alternative choices for the initial stocks. (Nadiri and Prucha 1996, p. 47)

Appendix K tests the sensitivity of the modelling results to the choice of depreciation rate. Most of the empirical work in this study is based on an assumed depreciation rate of 15 per cent.

A more flexible knowledge accumulation equation

Use of the PIM envisions a knowledge accumulation process where the volume of R&D expenditure each period is added to the sum of all previous periods' expenditure less accumulated 'depreciation'. A more flexible representation of the knowledge accumulation process can be specified as

$$K_{t+1} = (1-\delta)K_t + \gamma(R_t)^a (K_t)^b \quad (8)$$

This accumulation equation incorporate effects between current expenditure (*R*) and the existing stock of knowledge (*K*). Equation (8) defaults to the PIM when the parameters $a = 1$ and $b = 0$, which is a situation where knowledge is strictly a rival and fully excludable good, like physical capital.

Romer's (1990) specification sets both *a* and *b* equal to one, capturing the hypothesis that the greater the stock of existing knowledge on which researchers can draw, the greater the productivity of a given amount of current R&D in augmenting the stock. There is positive feedback between current and past expenditure (the 'Standing on Shoulders' hypothesis).

Jones (1995a) questions this formulation as it implies scale effects in the R&D-productivity relationship which he views as being very inconsistent with US historical data. He suggests that the coefficients *a* and *b* should be strictly less than one to capture the twin hypotheses of 'Stepping on Toes' (increasing *R* is likely to lead to duplicated efforts, hence ($a < 1$)), and 'Diminishing Returns' to the stock of knowledge ($b < 1$), or 'Fishing Out' (b < 0).

Jones and Williams (1998) investigate whether the estimates of the social return to R&D from the standard framework are biased, since they do not incorporate the sort of effects included in equation (8). They find that estimates are not significantly biased (box 4.3).

Another type of criticism of the linear accumulation methodology is that it implies economic incentives which are inconsistent with observed empirical regularities in micro-level data, in particular, the distribution of R&D intensities across firms within an industry (see Klette 1994 and appendix J). Klette's alternative accumulation methodology allows for complementarity between current expenditure and past expenditures. Firm behaviour is better understood when past expenditures on R&D are allowed to influence the return available to a firm from current investment in R&D.

Box 4.3 Biased returns from estimates based on the PIM?

Jones and Williams (1998) state that the standard framework is misspecified as it omits congestion effects, and it does not explicitly allow for intertemporal knowledge spillovers or diminishing technological opportunities.

They specify a production function linking new knowledge creation with R&D effort and the current level of knowledge in a semi-endogenous growth model. They derive an explicit expression for the steady state social rate of return to R&D. This 'true' social rate of return is then compared with the estimated coefficient from the standard framework used in the R&D-productivity literature.

They find that the social rate of return estimated from the standard framework captures only the dividend associated with the extra output from R&D (its marginal product), but omits the dynamic effects associated with intertemporal knowledge spillovers and the capital gain or loss associated with the change in the relative value of knowledge.

Intertemporal knowledge spillovers can have both positive and negative effects. Past research can raise the productivity of current research, but, on the other hand, past research may exploit the 'best' ideas first with the result that subsequent ideas are more difficult to discover (diminishing technological opportunity). A capital gain or loss to society occurs on the value of the existing stock of knowledge assets or ideas where there are changes in the cost of producing new ideas.

Despite the apparent importance of the omitted effects, the authors find that the magnitude of the omitted variable bias is quite small. The intertemporal knowledge spillovers and capital gain or loss effects may be individually large, but their sum is limited to a small magnitude.

Simultaneity and the direction of causation

Measurement error, significant omitted variables and explanatory variables which are simultaneously determined with the dependent variable can all result in inconsistent and biased estimates of the coefficients on the explanatory variables.

If current or prior-period values of output influence R&D investment, then R&D is endogenous:

> The simultaneity problem refers to the possible confusion in causality: future output and its profitability depend on past R&D, while R&D, in turn, depends on both past output and the expectation about its future. (Griliches 1998, p. 273)

There is mixed evidence on the extent to which the simultaneity of R&D biases estimated R&D elasticities and rates of return.

Griliches (1998) found that coefficient estimates of the effect of R&D capital were higher when estimates were based on the Olley and Pakes (1996) approach to addressing the problem of simultaneity, but the degree of bias was small:

> As far as the simultaneity problem is concerned, either it is of no great import in these data or the introduction of investment and the associated Olley and Pakes procedure does not fully adjust for it. (p. 279)

Hall and Mairesse (1995) estimated production functions based on firm-level data and sought to control for the simultaneity of the choice of labour and output levels. They found that there was an upward bias on the R&D coefficient when labour was incorrectly treated as predetermined, as it generally is when estimating conventional production functions.

Hall et al. (1986) analysed US firm-level data on R&D and patenting activity over the period 1966 to 1979. As noted earlier, they found a contemporaneous relationship between R&D expenditures and patenting:

> It seems reasonable to suppose that successful research leads both to a patent application and to a commitment of funds for development … the strong evidence of simultaneity in patents and R and D in our data conforms very well to this picture. (p. 282)

van Ophem et al. (2001), using firm-level data for 460 Dutch firms included in both the 1988 and 1992 Dutch innovation surveys, found that:

> … patents Granger-cause R&D in all specifications. One additional patent increases R&D four years later by 7.5%. The reverse causality from R&D to patents vanishes as soon as we depart in one way or another from the simple Poisson specification of patent counts. Although our result should be confirmed by analysing other datasets and by checking how sensitive our estimates are to other specifications … we might have uncovered a different causality from the conventional one estimated by other authors (p. 9)

Rouvinen (2002, p. 136) investigated the direction of causation between R&D and productivity and found evidence supporting causation running from R&D to productivity, but not in reverse:

> … [results] seem to suggest that R&D Granger causes TFP but not vice versa. With five and six lags, the tests for R&D causing TFP are nearly statistically significant at 1%. With four lags, the test just misses the mark at 10% level. With three lags, the test would be significant at the 15% level. Even in the most favourable case of six lags, the reverse causality test would not be significant even at 25% level … Feedbacks could possibly be observed, if firms used some kind of rule-of-thumb in determining R&D efforts, e.g., if a fixed percentage of profits, presumably closely related to productivity, were invested in R&D. (pp. 135–6)

Bodman (1998) adopts the Vector Autoregressive co-integration methodology of Johansen (1988) and Johansen and Juselius (1990) and finds some evidence of simultaneity:

> Reverse (bi-directional) causality is only established for public infrastructure, R&D capital, openness and migration and even then the sum of the lagged coefficients is small in each case. A 1% increase in the rate of output growth is estimated to only lead to around 0.09% increase in infrastructure capital and 0.14% increase in R&D capital in Canada and 0.12% and 0.09% increases in Australia. A 1% increase in output growth is estimated to increase the degree of openness (proxied by exports plus imports over GDP) by 0.02% in both countries. (p. 56)

Based on a survey of sixteen Australian R&D performing businesses, the Department of Industry, Tourism and Resources (DITR 2005) found that most businesses spend a fixed proportion of sales each year on R&D and that budgets are determined in the context of future sales projections:

> The finding that it is common for R&D budgets to be determined by sales projections raises some interesting challenges for the quantitative analysis of the relationship between R&D expenditure and economic growth. The case studies suggest that contemporaneous strong sales growth and the immediate prospect of further strong sales growth support more R&D expenditure. To the extent this holds in general, econometric estimates of the R&D expenditure/economic growth relationship will need to deal carefully with the technical issues of causality. (p. 4)

Part of the problem relates to adequately controlling for the effects of the business cycle on R&D expenditure plans. All models in the paper include some form of control. Usually the first or second derivative of market sector or industry value added is included in the models, but the sensitivity of results to alternative cycle measures is tested in appendix L.

A simple approach to addressing possible simultaneity bias used in this paper is to include a lagged value of the stock of Australian business R&D in the models and not the contemporaneous stock. The lagged value performs the role of an instrumental variable — having the property of being correlated with the contemporaneous stock in period *t*, but not the errors from the regression in period *t*. Most empirical studies which attempt to address simultaneity bias use an instrumental variables approach. Statistically significant coefficients were often much easier to obtain in market sector models when the contemporaneous value of Australian business R&D was tested in models rather than its lagged value.

Another approach to addressing simultaneity is to estimate a system of equations:

> With long time series and detailed lag assumptions one might be able to analyse a recursive equations system with current output depending on past R&D, and past R&D depending on past rather than current output. (Griliches 1995, p. 79)

In the longer term, if output is driven by many factors (including R&D), and nations demand more R&D as output rises, then there is a longer term relationship between R&D and output and productivity which runs both ways.

A two-equation system is estimated in chapter 10. Factors influencing R&D investment are modelled separately and can be thought of as those factors which alter the net profit from innovating through R&D investment versus not innovating, or innovating by means other than by performing R&D. Apart from addressing possible simultaneity bias, the factors influencing rising business investment are of interest in their own right. Further, Seeming Unrelated Regression Equations (SURE) estimation of the system can improve the efficiency of the estimates of the effect of R&D on productivity depending on the relationship of the errors between the two models.

5 Data assembly and analysis

This chapter highlights the assembly and characteristics of the data used in the quantitative analysis. It sets out:

- the coverage of aggregate and individual industry data (section 5.1);
- the formation of domestic business knowledge stocks (section 5.2);
- the formation of other (non-business) knowledge stocks (section 5.3);
- the formation of foreign knowledge stocks (section 5.4);
- the bi-variate relationships between knowledge stocks and productivity (section 5.5); and
- the nature of the data on control variables used in various regressions (section 5.6)

5.1 Industry scope

Modelling covers aggregate and individual industry sectors.

Compatibility of industry scope of R&D and productivity measures in the market sector

The Australian Bureau of Statistics (ABS) constructs and publishes multifactor productivity (MFP) indexes for the market sector of the economy. The market sector, which accounts for about 65 per cent of GDP, covers industry sectors in which inputs and outputs can be measured relatively well.[1] Non-market sector

[1] The market sector includes: Agriculture, forestry & fishing; Mining; Manufacturing; Electricity, gas & water; Construction; Wholesale trade; Retail trade; Accommodation, cafes & restaurants; Transport & storage; Communication services; Finance & insurance; and Cultural & recreational services. In these industry sectors, output can be measured in ways that do not merely reflect inputs used (for example, expenditures).

industries are excluded from the market sector because of particular difficulties associated with the measurement of capital inputs, outputs and productivity.[2]

Inclusion of these industries in an effort to model the whole-of-economy effects of R&D would require that assumptions be made about the rate of productivity growth in the non-market sector. Industry Commission (1995) presented estimates of the return to R&D under the assumptions of zero productivity growth in the non-market sector (the de-facto assumption made in the Australian System of National Accounts (ASNA)) and productivity growth equal to that of the market sector.

However, there are problems in obtaining R&D data based solely on the market sector. Non-market sector industries have historically been included by the ABS in published R&D statistics under the industry ‘Other n.e.c.’. Although unpublished data can be obtained from 1988-89, which would allow these industries to be split out, equivalent data are not accessible for any of the earlier years. The most important industry excluded from the market sector, in terms of the level and growth rate of R&D activity, is Property & business services (PBS).

The Scientific research industry (ANZSIC 781) is classified as part of Property & business services. It undertakes R&D principally for other industries. The R&D of this industry was distributed to other industries using a breakdown of the industry’s R&D expenditure by socio-economic objective. The distribution method is imperfect, but it was thought that this was a better option than leaving Scientific research out of the analysis altogether. The industries within Property & business services that are excluded are Property services, Technical services, Computer services, Legal and accounting services, Marketing and business management services, and Other business services.

The main implication is that the R&D knowledge stocks used in the market sector models have a broader industry scope than the labour input, capital services and productivity measures.

The former Department of Industry, Technology and Commerce (DITAC) maintained historical series of R&D expenditure. This series included various unpublished ABS revisions, and adjustments to the data, such as estimates for industries not included in the 1968-69 to 1973-74 surveys. The adjusted business expenditure on R&D (BERD) series was used in Industry Commission (1995) for its analysis of the relationship between R&D and growth.

2 The non-market sector industries are: Property & business services; Government administration & defence; Education; Health & community services; Personal & other services; and the special industry Ownership of dwellings.

Diewert and Lawrence database: and 'expanded' market sector

Diewert and Lawrence (2005) computed productivity estimates for an 'expanded market sector', including Property & business services, Education, Health & community services and Personal & other services. The dataset can be used to investigate the effects of R&D at the whole-of-economy level less Government administration & defence.

Apart from an expanded industry coverage, the database differs from the ABS market sector in a number of ways. An output measure is built up from final consumption components rather than sectoral gross value added. Outputs and inputs are expressed in terms of producer prices. An alternative methodology is used for the construction of capital and inventory input series (see appendix H for further details).

Individual industries

The industry level analysis focuses on the one-digit industries within the market-sector. There are 12 market-sector industries at the one-digit, ANZSIC divisional level. However, due to limitations of the available R&D expenditure data, the relationships between R&D and productivity could only be estimated in the following four industries: Manufacturing, Agriculture, forestry & fishing, Mining, and Wholesale & retail trade. As indicated earlier, the R&D data for Agriculture is based on public R&D and not on industry stock of R&D capital. The dataset for the four industries contains 29 years of data ranging from 1974-75 to 2002-03.

While the measures of outputs and inputs at the one-digit industry level have been published by the ABS, there are still various measurement issues associated with these measures, particularly in relation to measuring industry-level MFP (Diewert 2000). These issues will certainly have an impact on the results based on econometric estimation, which will be discussed in chapter 8.

5.2 Domestic business sector knowledge stocks

Surveys of business expenditure

The first surveys of business R&D activity were undertaken in the late 1960s and early 1970s by the former Department of Science and Department of Manufacturing Industry (table 5.1). The first publication by the ABS of business R&D activity was for 1976-77, which also included results from a survey undertaken for 1973-74.

Table 5.1 **Availability of time series data by institutional sector**

Years for which there were no surveys are omitted

Year	*Business*	*Higher education*[c]	*Government*	*Private non-profit*
1968-69	✓[a]			
1971-72	✓[a]			
1973-74	✓[a]			
1976-77	✓		✓	✓
1978-79	✓	✓	✓	✓
1981-82	✓	✓	✓	✓
1983-84	✓(s)[b]			
1984-85	✓	✓	✓	✓
1985-86	✓(s)[b]		✓	✓
1986-87	✓	✓	✓	✓
1987-88	✓(s)[b]		✓	✓
1988-89	✓	✓	✓	✓
1989-90	✓(s)[b]			
1990-91	✓	✓	✓	✓
1991-92	✓			
1992-93	✓	✓	✓	✓
1993-94	✓			
1994-95	✓	✓	✓	✓
1995-96	✓	✓		
1996-97	✓	✓	✓	✓
1997-98	✓			
1998-99	✓	✓	✓	✓
1999-00	✓			
2000-01	✓	✓	✓	✓
2001-02	✓			
2001-03	✓	✓	✓	✓
2002-03	✓			

a The 1968-69, 1971-72 and 1973-74 data were collected by the then Department of Science under the SCORE project (Survey and Comparisons of Research Expenditure) and the Department of Manufacturing Industry. The results of the 1973-74 survey of businesses were published with the results of the 1976-77 survey in the first edition of ABS Cat. no. 8104.0. **b** (s) represents years in which the survey was a stratified random sample of businesses previously identified as R&D performers. For all other years, the surveys cover all likely R&D performers. **c** Higher education data are collected on a calendar year basis (that is, 1978-79 in the table equals 1978).

Market sector

The Australian business R&D capital or knowledge stocks were constructed using the perpetual inventory method (PIM) (chapter 4) with assumed decay rates of between 5 and 30 per cent. Stocks for both total intramural R&D expenditure and ‘performed’ and own-financed expenditure were constructed.

Higher decay rates increase the amplitude of the stock growth rates (figure 5.1). At decay rates of more than 5 per cent, the stock of business R&D capital declined in real terms from the mid-1970s to the close that decade. It then rebuilt during the 1980s before declining again in the mid-1990s.

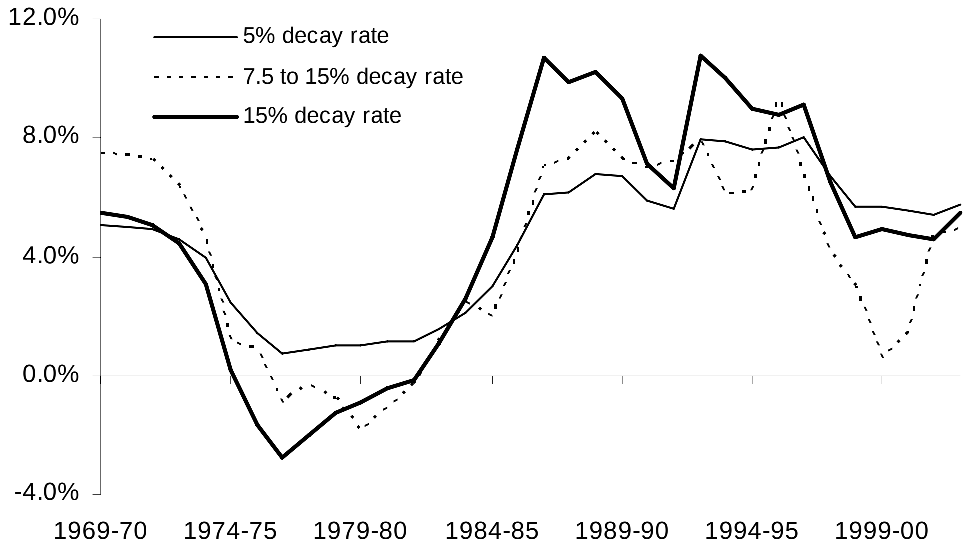
Most modelling results presented in the following chapters are based on a decay rate of 15 per cent, which tends to be at the low end of estimated rates (see chapter 4). This means that most models include observations where the stock of business R&D capital was declining in real terms, followed by a rapid acceleration and high rates of growth in the stock.

Sensitivity tests of modelling results were also undertaken under various non-constant decay rate scenarios. Figure 5.1 shows the effect of assuming a decay rate which begins at 7.5 per cent and ends at 15 per cent. The pattern of growth was guided by the change in the trade openness index under the assumption that increasing openness to new technologies and competition might have increased the decay rate of appropriable revenues.

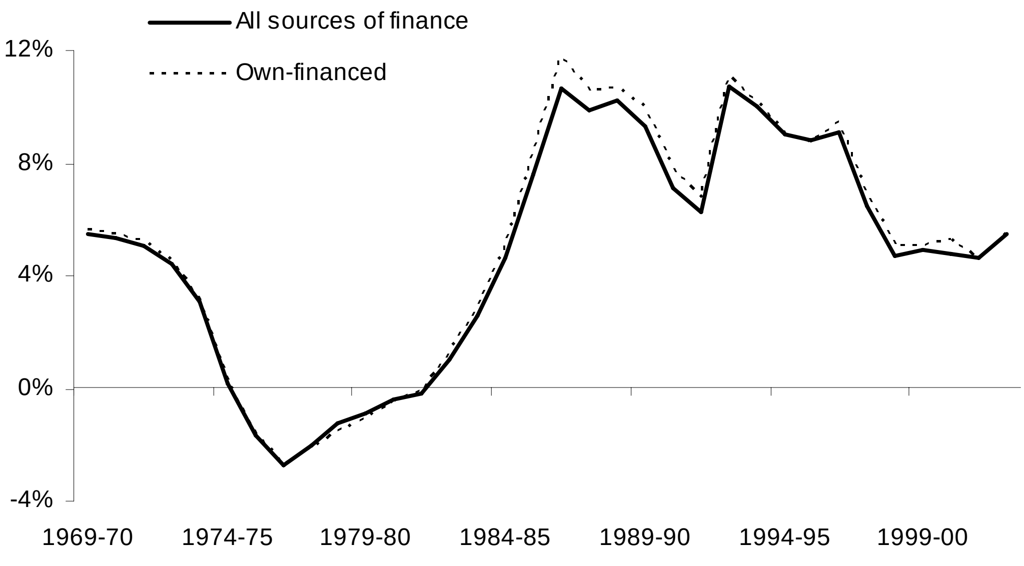
The growth rates of R&D capital stocks based on all sources of financed and own-financed expenditures are very similar. The similarity in the patterns reflects the fact that only a small proportion of the financing of business R&D expenditure is externally sourced.

Figure 5.1 **Growth in business R&D capital, 1969-70 to 2002-03[a]**
Excludes Property & business services other than Scientific research

Alternative decay rate assumptions



Growth in own-financed business R&D capital



[a] R&D capital stocks based on expenditures deflated using the GDP implicit price deflator (GDP (IPD)).

Data sources: ABS (*Research and Experimental Development, Businesses, Australia*, Cat. no. 8104.0); Commission estimates.

A decline in R&D capital in the 1970s

The decline in R&D capital in the 1970s does not appear to be the result of the methodology used to construct the initial stock of R&D capital (box 5.1).

Box 5.1 **Sensitivity of the growth pattern to the construction of the initial stock of R&D capital**

The methodology commonly used for construction of the initial stock of capital was outlined in chapter 4. The calculation of the initial stock assumes that the average annualised or trend growth rate of R&D expenditure is linearly extrapolated back in time. A high trend growth rate assumes lower levels of annual investment prior to the initial base year than does a lower growth rate. Hence, a lower growth rate means relatively higher levels of historical annual investment which accumulates into a larger initial stock. It also means that, for a given assumed decay rate, the 'volume' of the stock which decays or becomes obsolete is larger.

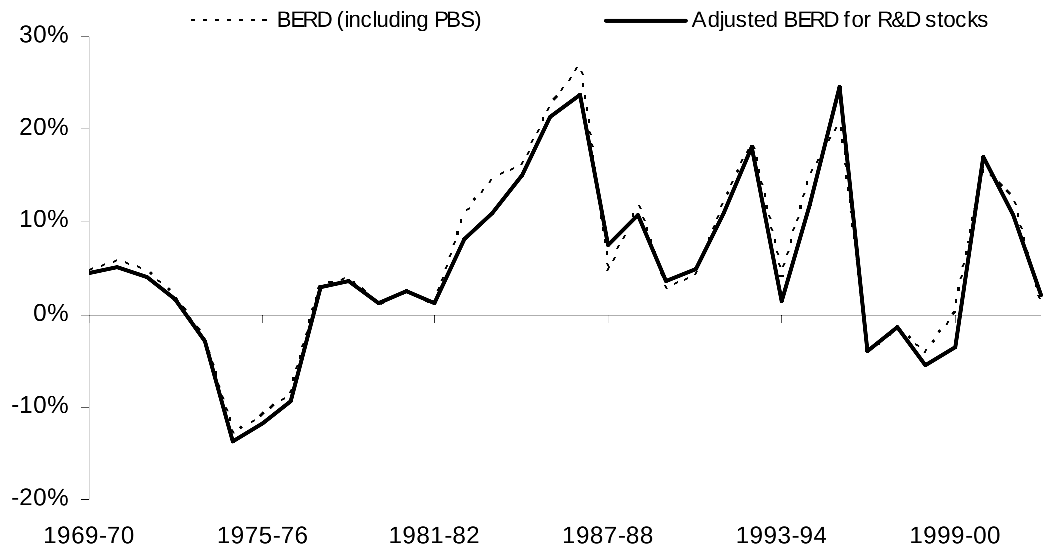
Appendix A canvasses a number of measurement issues which may have impacted on the measured growth rates in business R&D expenditure in Australia. In particular, the introduction of the tax concession and changes in accounting practises in the 1980s may have resulted in previously undertaken, but not recorded, R&D activities being included in the R&D statistics. The implication is that the strong increase in growth rates in the early to mid-1980s to a much higher and sustained rate of growth was not as dramatic as the data would suggest. However, it is impossible to know the magnitude of the distortion.

A further implication is that the initial stock may be larger than implied by the unadjusted data. If the expenditure data were adjusted to dampen the change in expenditure levels between the 1970s and the 1980s onwards, then the stocks would exhibit a dampened growth profile. However, they may still decline in real terms during the 1970s because higher levels of gross expenditure in the 1970s would be accompanied by higher levels of depreciation associated with a larger initial stock.

Even if it is believed that the pattern of expenditure growth is reasonably accurate, consideration could still be given to adjusting down the trend growth rate for the calculation of the initial stock if it is suspected that the high growth period from the mid-1980s is unsustainably high in the long run, and that this transition period results in implied levels of investment prior to the base year that are too low. In this case, the trend growth rate for the initial stock calculation might be arbitrarily lowered. However, with the way the initial stock calculation works, this would result in a downward shift in the profile of the growth rates with even larger real declines in the knowledge stock in the 1970s.

The source of the ‘problem’ is the weakness in business expenditure, which shows the same pattern (figure 5.2). As discussed in appendix A, previous studies have adjusted upwards historical business R&D expenditure data to improve the quality of the estimates. The adjustments are include in figure 5.2 and the construction of all business R&D stocks.

Figure 5.2 **Weak business R&D expenditure in the 1970s[a]**



a The adjustments to BERD for the purpose of construction of R&D capital stocks are discussed in appendix A. Deflated using the GDP(IPD).

Data sources: ABS (*Research and Experimental Development, Businesses, Australia*, Cat. no. 8104.0); ABS (*Australian System of National Accounts*, Cat. no. 5204.0); unpublished ABS data.

Industry

Each industry’s own R&D capital stock was constructed using the same methods as for the market sector, that is, use of the perpetual inventory methodology with a range of assumed rates of decay.

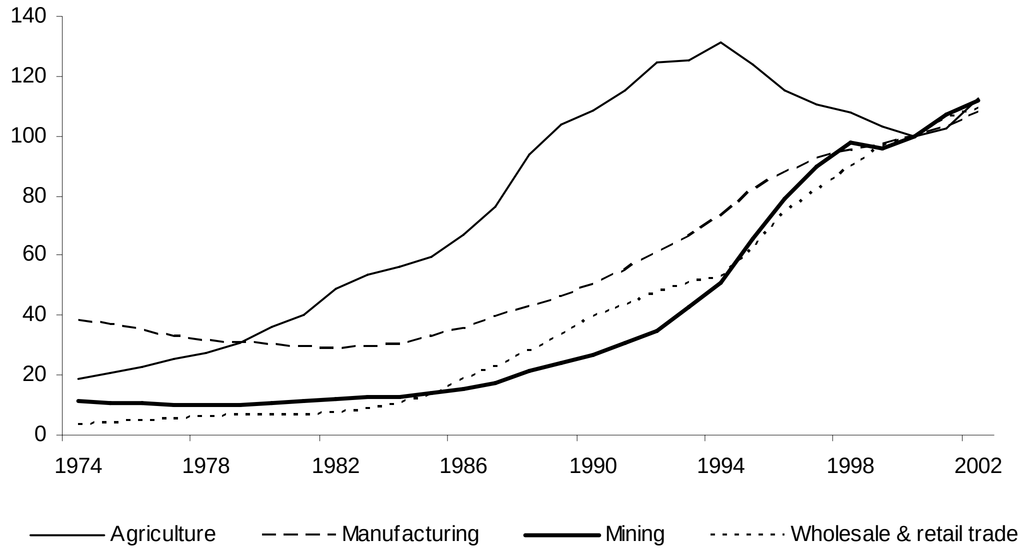
The ABS business enterprise R&D survey excludes enterprises mainly engaged in Agriculture, forestry & fishing (AFF). This is largely because such enterprises are believed to have very low levels of R&D activity, as R&D activity for this industry is generally carried out by specialised research institutions, such as state departments of agriculture, CSIRO and the agricultural faculties of universities (Mullen et al. 2000).

A partial measure of Agriculture’s ‘own-industry’ R&D capital can be constructed based on a decomposition of the Scientific research industry’s (ANZSIC 781) R&D

expenditure by socio-economic objective (SEO). Expenditures classified by SEOs related to AFF were used to form the stock. The stock peaked in 1994 and then declined until 2000, when it recovered to its 1989 level (figure 5.3).

Figure 5.3 **Industry's own R&D capital stock for the four market-sector industries, 1974-75 to 2002-03**

Indexes 2000-01 = 100



Financial years beginning 1 July of year specified.

Data source: Commission estimates.

The volatility in the industry's own R&D capital stock growth in Agriculture is similar to that in Mining and Wholesale & retail trade, but it is much less than the volatility in Agriculture's rate of growth in MFP (table 5.2). This may be due to the fact that there is no relationship between Agriculture's own R&D capital stock and weather conditions.

Table 5.2 **Summary statistics for the rate of growth (log difference) in industry's own R&D capital stock in the four industries**

Per cent

	Agriculture	*Manufacturing*	*Mining*	*Wholesale & retail trade*
Mean	6.4	3.7	8.2	12.4
Standard Deviation	0.074	0.054	0.077	0.074
Maximum	20.1	11.5	25.9	33.2
Minimum	-7.4	-5.6	-4.1	2.5

Source: Commission estimates.

5.3 Domestic non-business knowledge stocks

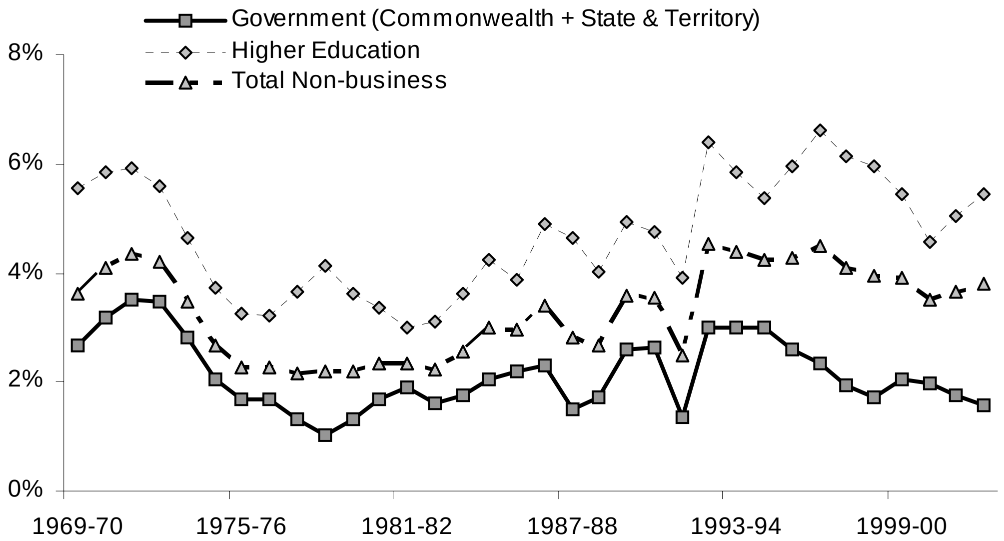
Differences in R&D expenditure patterns by institutional sector (chapter 3) translate into similar differences in the growth rates of the knowledge stocks. The Government, higher education, and total non-business R&D capital stocks show less volatility in their growth patterns than do the business stocks. Government performed R&D exhibits the steadiest growth rates (figure 5.4, upper panel). The business stock grew slower than the total stock prior to 1985-86, and more rapidly afterwards (bottom panel).

The modelling of the effect of R&D on productivity generally does not include non-business stocks in the regressions due to the relatively high degree of multi-collinearity (appendix E) with business R&D capital. Where included, rates of decay are assumed to be less than for business R&D capital reflecting the higher share of basic research in higher education and Government R&D expenditures.

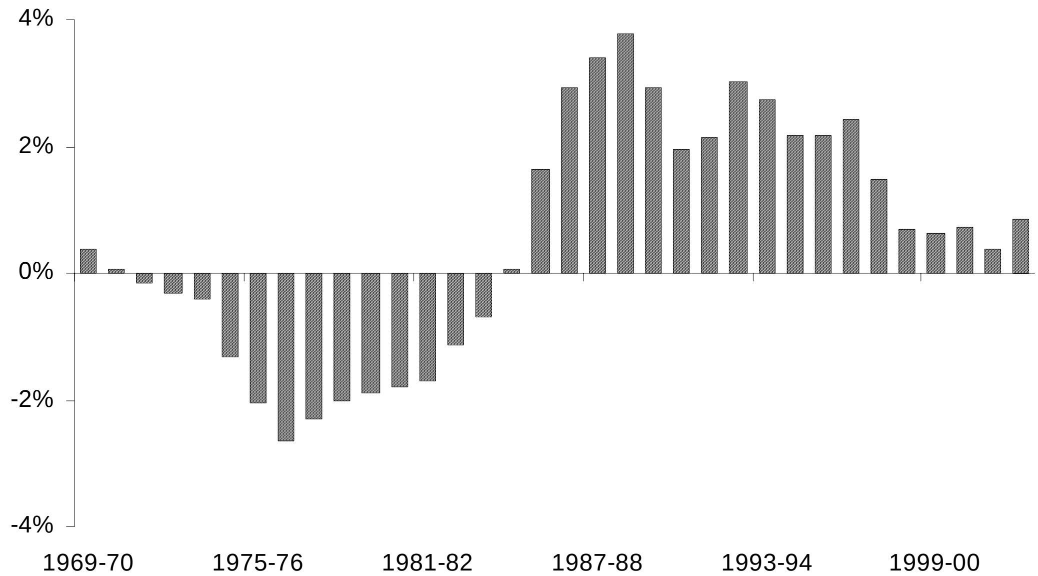
In the industry level models, a zero per cent decay rate was assumed for the non-business R&D stock. The stock of non-business R&D capital consists of knowledge at a more basic or fundamental level. It is expected that the value of this type of knowledge to economic production 'depreciates' at a rate that is much slower than the bulk of business R&D.

Figure 5.4 **Growth in the non-business knowledge stocks**

Assumed decay rate of 10 per cent



Business R&D capital (excl. PBS) growth rate minus Gross R&D capital growth rate



Data sources: ABS (*Research and Experimental Development, Businesses, Australia,* Cat. no. 8104.0); ABS (*Research and Experimental Development, All Sector Summary, Australia,* Cat. no. 8112.0); ABS unpublished data; Commission estimates.

5.4 Foreign knowledge stocks

R&D expenditure data from the OECD's Analytical Business Enterprise Research and Development database (ANBERD) was used to create time series of foreign knowledge stocks. The R&D expenditure of fourteen countries was included in the construction of the stocks, including: Canada; Denmark; Finland; France; Germany; Ireland; Italy; Japan; Netherlands; Norway; Spain; Sweden; United Kingdom; and the United States.

Various weighting schemes were used to aggregate the fourteen stocks into a single stock representing the potential spillover to Australia of knowledge from investment in foreign R&D. The different weighting schemes give different estimates of the growth in Australia's potential spillover pool from abroad.

As is the case with Australia, growth in the stock of foreign business R&D capital shows greater amplitude than foreign stocks (figure 5.5, upper panel). For this particular stock, the stocks of individual countries were weighted by their shares in Elaborately Transformed Manufactures (ETM) imports to Australia. Alternative weighting schemes are discussed in appendix F and tested in models in chapter 9.

Industry-specific potential spillover pools can be constructed if foreign industry level R&D expenditure data are used rather than country-level data. Aggregating up from industry-level data opens-up the possibility of taking account of both inter-industry and inter-country relationships, hopefully resulting in a more accurate indicator of the unobserved spillover pool. This might be important, for example, if there are significant differences in R&D expenditure growth rates across countries for a given industry.

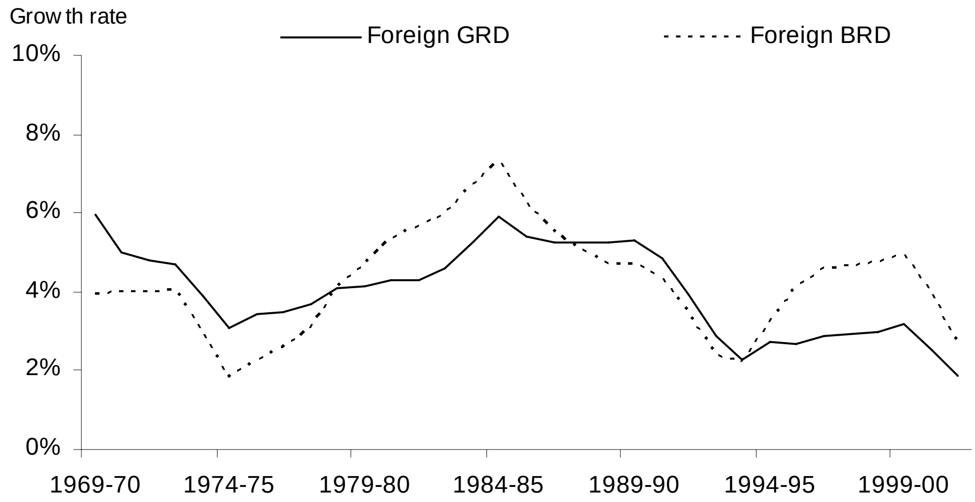
In the bottom panel of figure 5.5, "_seo" denotes inter-industry weights obtained by creating a technological proximity measure based on the expenditures of Australian industries decomposed by Socio-Economic Objective (SEO) (appendix C). "_io" denotes inter-industry weights obtained from the Australian System of National Accounts (ASNA) input-output tables. The relationships between industries in Australia, in terms of their relative importance as a potential source of spillovers, are assumed to approximate the importance of cross-industry relationships between foreign industries and each Australian industry.

The "etm-seo" and "etm-io" weighted international spillover pools for total manufacturing show that the alternative inter-industry weights do not have a large impact on the growth rates of the foreign stocks. Differences in growth rates are driven by the choice of country weights and not inter-industry weights (see appendix F which shows equivalent charts for all of the alternative country and inter-industry weighting schemes for total manufacturing).

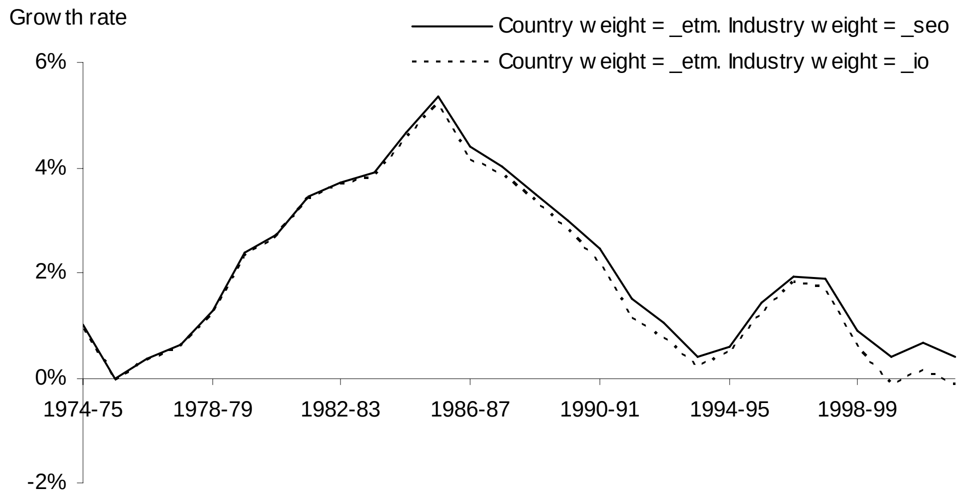
Figure 5.5 **Growth in Australia's potential spillover pool, 1963-64 to 2001-02**

Assumed decay rate of 15 per cent

ETM weighted spillover pool



Total manufacturing spillover pool built from foreign industry-level data



Data sources: OECD (Analytical Business Enterprise Research and Development (ANBERD) database); Commission estimates.

A comparison of the Australian business stocks and foreign stocks

The effect of netting out Property & business services (PBS) (less Scientific research) from the R&D data used to construct the Australian business knowledge stock is to lower the average annual growth rate of the stock from 5.33 per cent to 4.74 per cent (table 5.3, columns 1 and 2) over the period 1968-69 to 2002-03. The growth rates for the three different intensity measures are also lowered.

Table 5.3 **Summary statistics for knowledge stocks[a], 1968-69 to 2002-03**

Knowledge stocks based on PIM

	Aus. Business R&D capital (incl. PBS)	*Aus. Business R&D capital (excl. PBS)*	*Own-financed Aus. Bus. R&D capital (excl. PBS)*	*Aus. Gross R&D capital*	*Foreign Bus. R&D capital (ETM weights)*	*Foreign Gross R&D capital (ETM weights)*
Mean of ln(K)	3.5622	3.6581	3.6050	4.0383	3.9175	4.0160
Growth (%)	5.33	4.74	5.01	3.36	4.19	4.07
Std. deviation	0.042	0.041	0.043	0.010	0.014	0.011
Mean of (ΔK/Y)	0.0022	0.0017	0.0015	0.0087	-	-
Growth (%)	2.07	1.65	1.80	1.21	-	-
Std. deviation	3.236	2.335	2.535	0.110	-	-
Mean of ln(ΔK/Y)	-5.7943	-6.0404	-6.1626	-5.6412	-2.7358	-2.3547
Growth (%)	2.35	1.89	2.08	0.94	-0.06	0.26
Std. deviation	0.218	0.250	0.246	0.257	0.199	0.233
Mean of ln(K/Y)	-3.3621	-3.4433	-3.5969	-2.2962	0.5058	0.8932
Growth (%)	2.29	1.70	1.94	1.18	1.12	0.99
Std. deviation	0.044	0.043	0.045	0.027	0.029	0.028

a Stocks depreciated at 15 per cent, except for the intensity measure ln(ΔK/Y). For this intensity measure, Australian business R&D capital was depreciated at 5 per cent, while the stock of Australian gross R&D capital and the foreign stocks were depreciated at 10 per cent. For the calculation of intensities, output (Y) is Australian market sector gross value added. For the foreign intensities, Australian output is converted to PPPs to match the foreign stocks. All growth rates based on the average annual growth rate calculated as the log of the last observation minus the log of the first observation divided by the number of observations less one.

Sources: OECD (Analytical Business Enterprise Research and Development, ANBERD, database); ABS (*Australian System of National Accounts,* Cat. no. 5204.0); unpublished ABS data; Commission estimates.

Australian business R&D capital grew faster than the potential international spillover pool. The ETM share weighted stock of foreign business R&D grew at 4.19 per cent per year — 0.55 percentage points below the annual growth rate of Australian business R&D capital. Growth in the stock of foreign business R&D was less volatile (a lower standard deviation). Reducing the time period to 1985 and onwards increases the relative rates of growth of the Australian stocks and intensities.

Australian gross R&D capital has grown more slowly than the ETM weighted stock of foreign gross R&D capital at 3.36 per cent per year versus 4.07 per cent per year. However, the foreign intensity measures grow much more slowly (note that, for the intensity measure based on growth in the knowledge stock as a proportion of output, part of the reason the Australian business stock grows much faster is that it is depreciated at five per cent, whereas, the stock of Australian gross R&D and the foreign stocks are depreciated at ten per cent). The intensity measures show the level and growth in the foreign stock of knowledge relative to the scale of output of the Australian market sector (measured in purchasing power parity (PPPs)).

5.5 The bi-variate relationship between business R&D and productivity

Trends in Australia productivity were outlined in chapter 3. This chapter has highlighted key trends in the knowledge stocks used in modelling. This section investigates the bi-variate relationship between Australian business R&D and productivity.

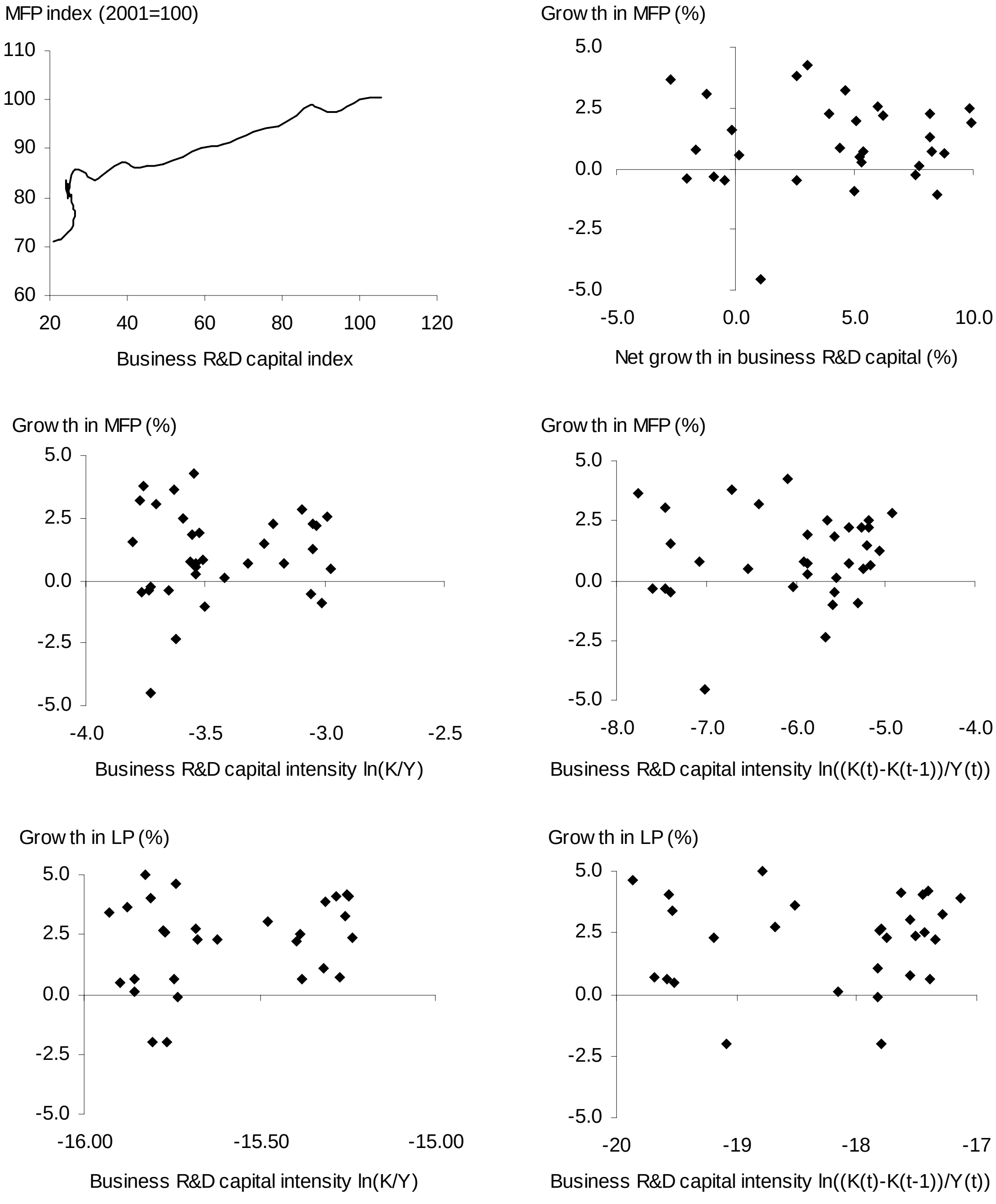
Market sector

The uppermost left-hand panel of figure 5.6 plots the MFP index against the index of the Australian business R&D stock. Both indexes are trending upwards over time which gives the appearance of a strong relationship. The other five panels do not show any clear relationship between growth in MFP or growth in labour productivity and the level of R&D stock or intensities. Higher levels of R&D activity are not clearly associated with higher productivity growth rates.

The scatterplots are of the contemporaneous relationship between R&D and productivity. Lagged effects of R&D on productivity, which could be obscuring relationships in the MFP and labour productivity (LP) growth panels, are not taken into account.

Figure 5.6 **Plots of the long-run relationship between R&D and productivity in the market sector**

Business R&D stocks for net accumulation intensity measure depreciated at 5 per cent. Other stocks depreciated at 15 per cent.



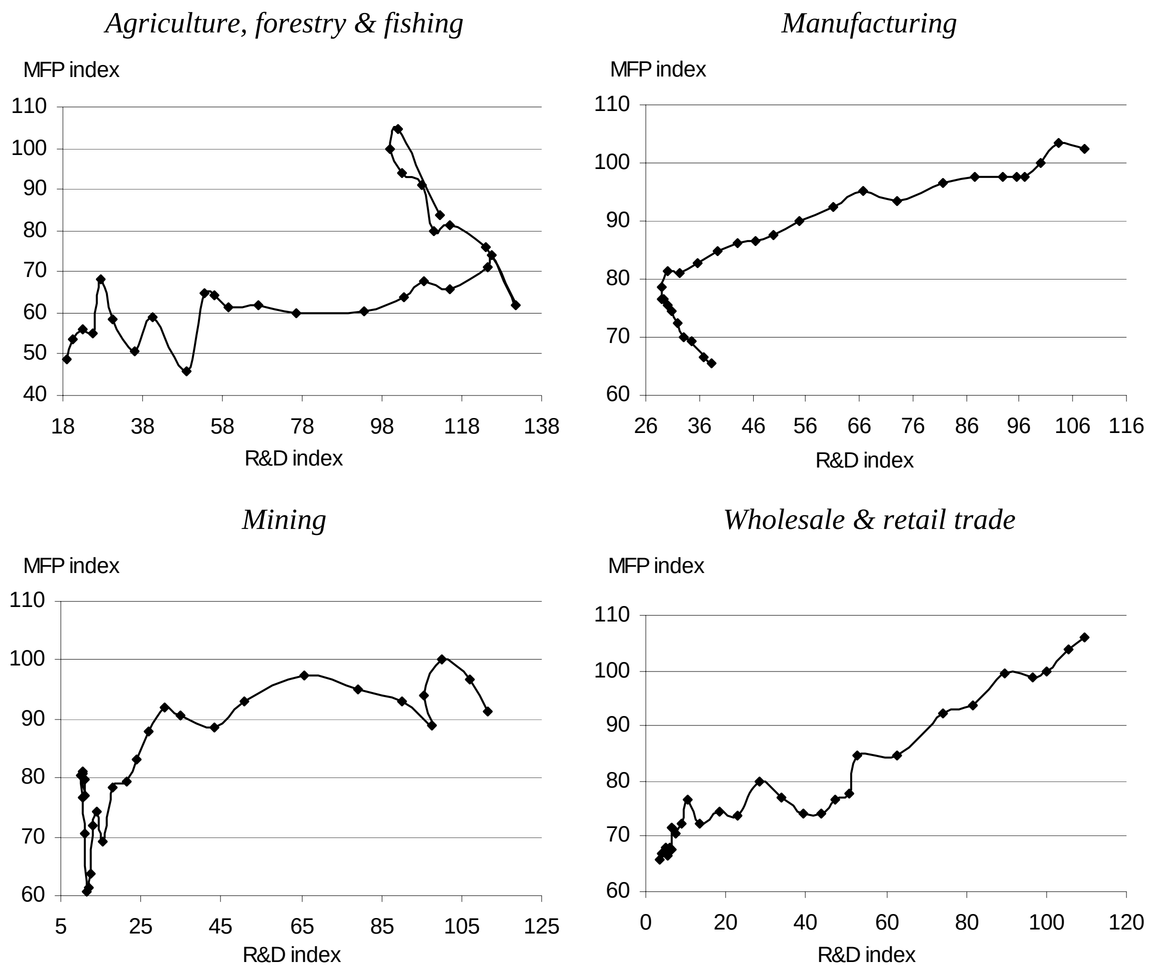
Data sources: ABS *(Australian System of National Accounts,* Cat. no. 5204.0); unpublished ABS data; Commission estimates.

Industry

While the bi-variate relationship between the level of R&D and productivity at the industry-level is not clear-cut when examining the co-movements of the two indexes, there is some evidence of a positive correlation between them (figure 5.7).

Figure 5.7 **MFP versus industry's own R&D capital for the four market-sector industries, 1974-75 to 2002-03**

Indexes 2001-02 = 100



Data source: Commission estimates.

The decline in Agriculture's own R&D stock during the six year period from 1994 to 2000 reverses the relationship between the industry's own R&D stock and its MFP from being positive to negative. The decline in R&D stock raises further questions about the assumptions used to construct the R&D capital stock.

The bi-variate relationship between MFP and Agriculture's own R&D capital is comparatively unusual and likely distorted by the 'partial' nature of the R&D

capital measure (discussed earlier). Given concerns about the quality of the 'own-industry' stock, the measure is not used in modelling productivity in Agriculture. Rather, the investigation of the effect of R&D in Agriculture relates solely to the effect of non-business R&D.

Manufacturing MFP has largely increased continuously since 1974 with only a small decline in 1994 and 2002. However, the industry's own R&D capital stock declined every year between the second half of the 1970s and early 1980s, reached its trough in 1983, and then exhibited a steady increase. This caused a negative correlation between R&D and MFP in Manufacturing in the early years, followed by a positive correlation thereafter.

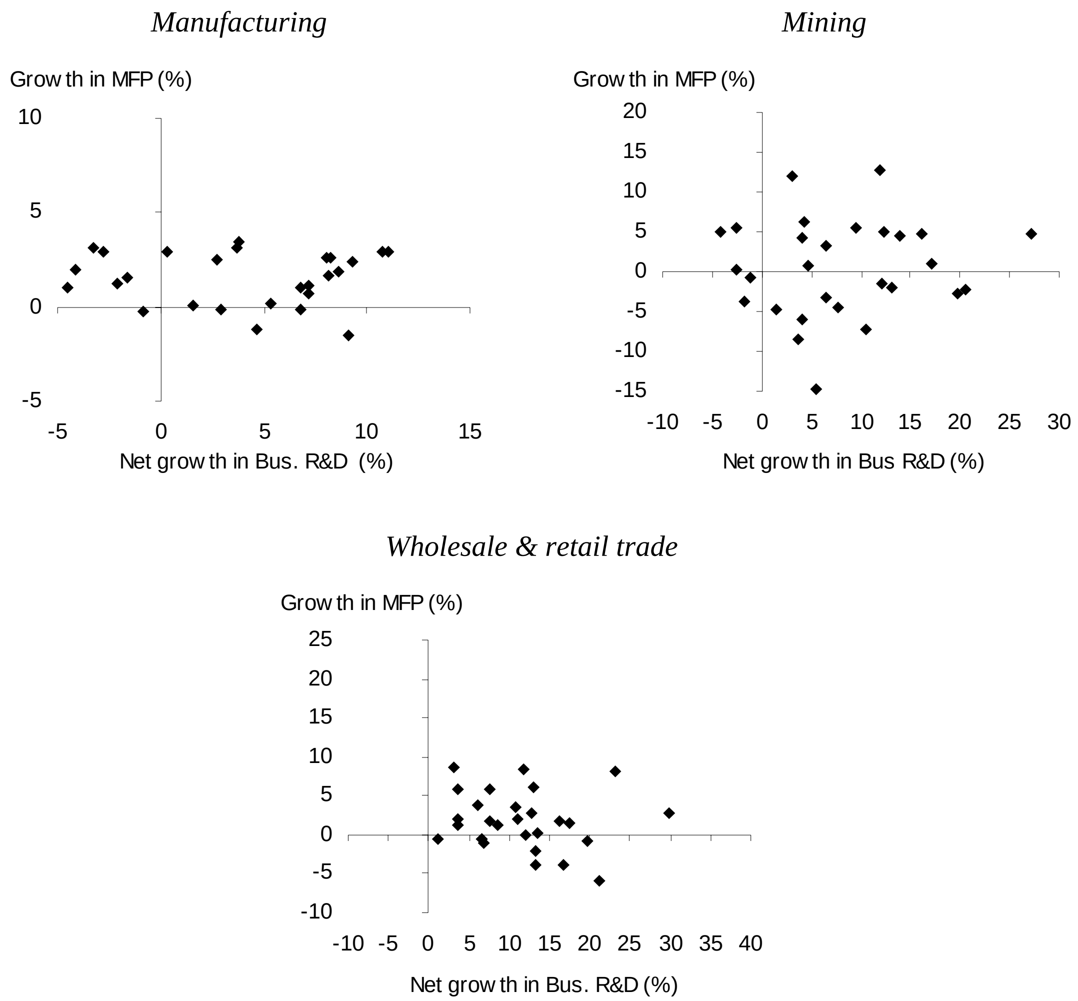
The bi-variate relationship in Mining is clearly non-linear. While a positive trend can still be seen to dominate the whole period, several negatively correlated segments are quite visible. This may be partly due to the fluctuations in the rate of MFP growth in the industry, although the magnitude of the fluctuations is much less than in Agriculture.

A positive linear trend is more readily apparent in the plot of MFP against R&D capital in Wholesale & retail trade. The positive correlation appears strongest in this industry.

There is no clear evidence of a contemporaneous correlation between the growth rates of MFP and own-industry R&D capital (figure 5.8). Higher growth rates in business R&D capital are not clearly associated with higher growth in MFP. However, lags and other influences on productivity could be obscuring a relationship.

Figure 5.8 **Growth in MFP versus industry's own R&D capital, 1975-76 to 2002-03**

Assumed decay rate of 15 per cent



Data sources: ABS (*Australian System of National Accounts,* Cat. no. 5204.0); unpublished ABS data; Commission estimates.

5.6 Control variables

There is a large body of studies of the determinants of productivity growth. Some of the factors generally seen as important are discussed below. The magnitude of some of the effects, and sometimes even the direction of the effects, is often debated.

- *Infrastructure*. Previous Australian studies of R&D have controlled for the effect of infrastructure using the official measure of the public net capital stock published by the ABS. This study goes significantly further by using capital services measures constructed from ABS unpublished data. Services measures were constructed for different types of infrastructure/capital and under different definitions, including: general government infrastructure; communications infrastructure; and IT capital. Measures were also constructed taking into account the usage of infrastructure by the market sector and/or individual industries.

- *Trade openness and international competitiveness*. Three measures of trade openness were constructed: the sum of imports and exports over GDP, where imports includes all imports of goods and services; an import intensity measure based on the imports of all goods and services; and an import intensity measure based more narrowly on ETMs.
- *Human capital*. Measures were based on the proportion of the labour force with post-secondary school qualifications, and the ABS's Quality Adjusted Labour Index (QALI). The index attempts to take account of changes in skill resulting from potential workforce experience and educational attainment.

Variables were constructed to control for these influences on growth with the objective of improving the parameter estimates of the R&D variables. The effects of the variables themselves were not of primary interest in the current context and were not subject to the same sort of testing as the R&D variables. However, attention was paid to whether results were within plausible ranges established in the literature. Appendix D provides further background on the data used for the control variables, the rationale for including the controls in terms of how they might affect growth, and briefly surveys results from the literature.

Infrastructure

Infrastructure can have three main effects on productivity.

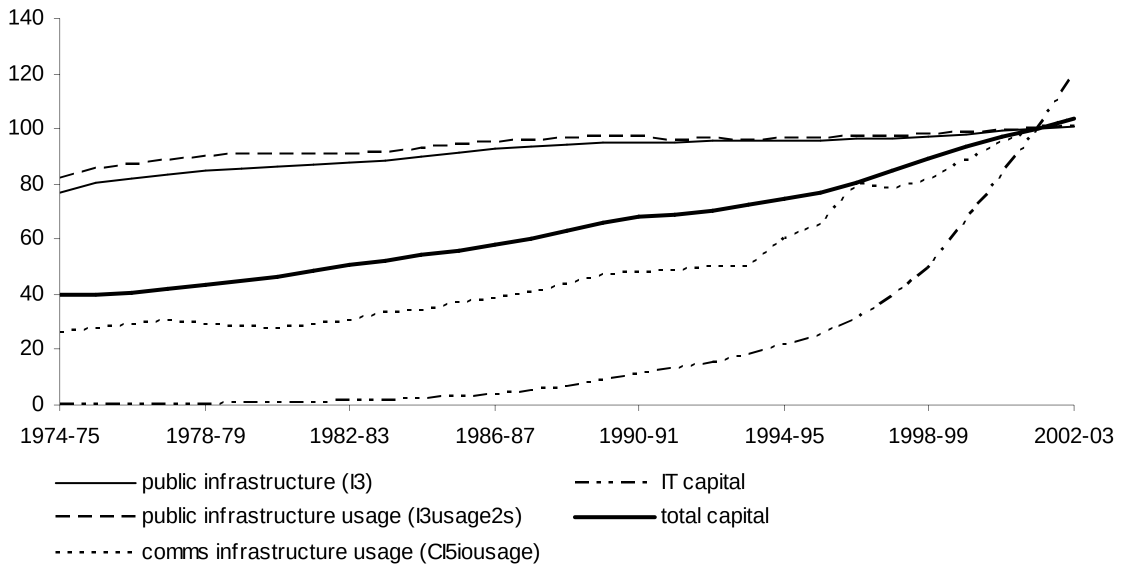
- Public infrastructure, which is not subject to user charges, is a free input into production and therefore directly affects private-sector output and productivity.
- Public or private infrastructure can have an indirect effect through its effect on other inputs — it can be a complement to or substitute for these other inputs and affect their productivity.
- Public or private infrastructure can have other spillover effects or externalities — it can, for example, be an enabler for innovation, allowing firms to do what they do now in a better way or to do new things.

In this paper, the first and third effects are examined by the inclusion of infrastructure variables in models of market sector and industry level MFP.

There are several measures of infrastructure. At the market sector level, the public infrastructure variables used are: the basic measure, which is general government infrastructure allocated to market sector industries; and the usage measure, which is the basic measure multiplied by the market sector's smoothed share of value added. The communications infrastructure variable is based on a subset of capital of the communications services industry (exclusions include IT capital) adjusted for the market sector's share of total usage based on input-output table data. Figure 5.9 shows the growth in these infrastructure variables for the market sector, in comparison to IT capital and total capital.

Figure 5.9 **Capital services indexes for components[a] of market sector capital, 1974-75 to 2002-03**

Indexes 2001-02 = 100



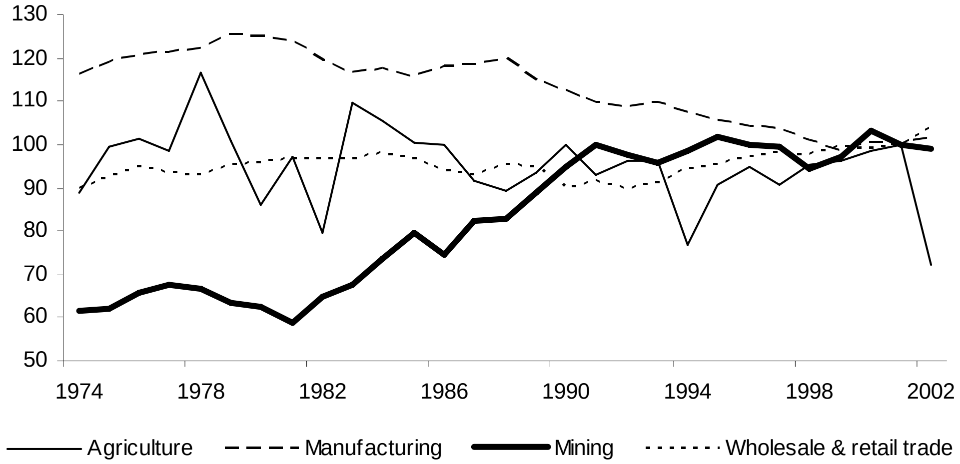
a Public infrastructure variables are based on capital services indexes for selected general government capital assets (non-dwelling construction plus all machinery and equipment except computer hardware) allocated by the ABS to the market sector. Communications infrastructure variable is based on capital services index for selected capital assets (non-dwelling construction plus all machinery and equipment except computer hardware, road vehicles and other transport equipment) of Communication services industry. IT capital is all computer hardware and software of the market sector (public and privately owned).

Data source: Commission estimates based on published and unpublished ABS national accounts data.

At the industry-level, the public infrastructure variable used is based on a measure of general government infrastructure for the market sector multiplied by the industry's share of value added. Growth in the usage of general government infrastructure varies significantly by industry (figure 5.10).

Figure 5.10 **Industry's usage of public infrastructure for the four market-sector industries, 1974-75 to 2002-03**

Indexes 2000-01 = 100



Financial years beginning 1 July of year specified.

Data source: Commission estimates.

The usage of public infrastructure is more volatile in Agriculture than other industries (table 5.4). Since the changes in general government infrastructure and aggregate market-sector value added are relatively stable, the volatility in this variable is largely determined by the fluctuation in the industry's value added in itself reflecting periods of drought in Australia.

Table 5.4 **Summary statistics for the rate of growth (log difference) in the industry's usage of public infrastructure**

	Agriculture	*Manufacturing*	*Mining*	*Wholesale & retail trade*
Mean	-0.7	-0.5	17.1	0.5
Standard Deviation	0.131	0.019	0.049	0.020
Maximum	32.1	2.7	10.1	3.7
Minimum	-32.6	-4.4	-6.5	-5.3

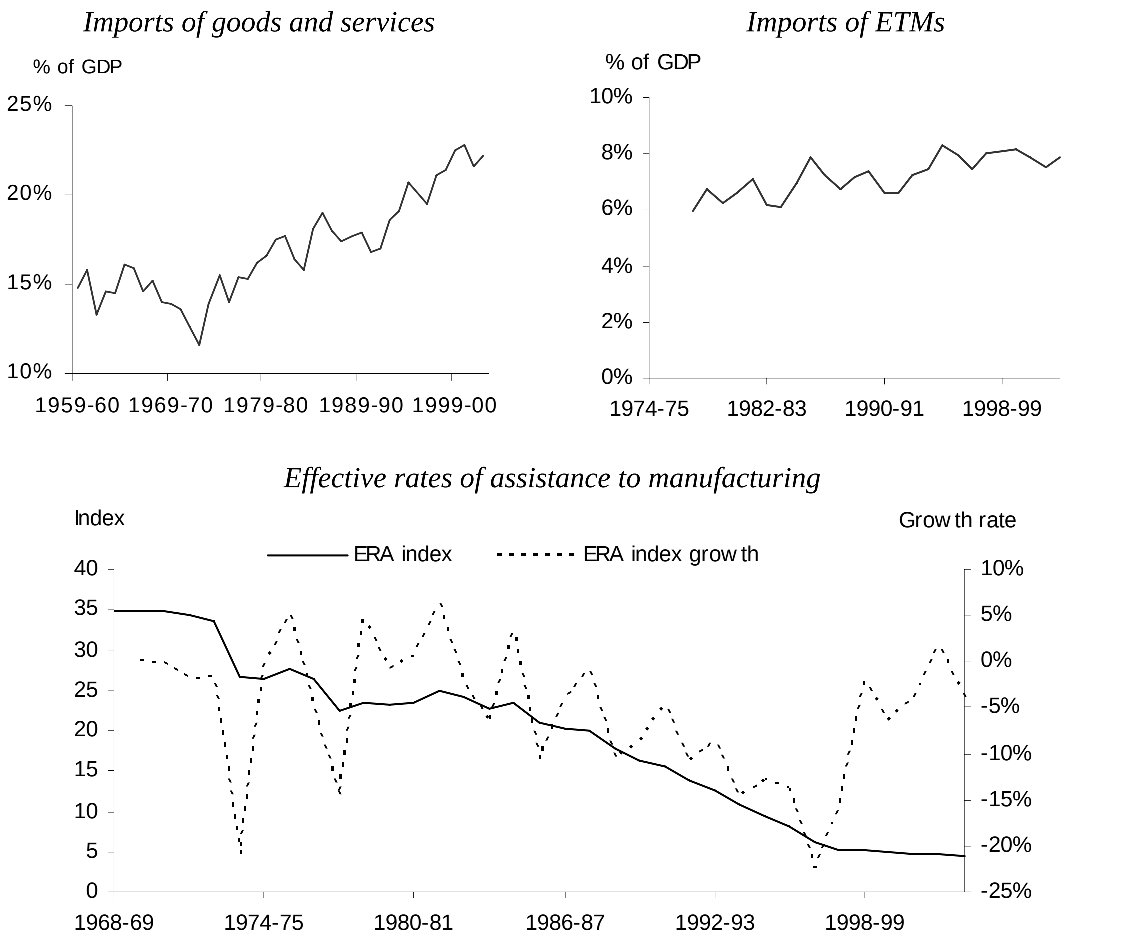
Source: Commission estimates.

Trade openness and international competitiveness

Australian imports of goods and services as a percentage of GDP have been rising since at least the early 1970s (figure 5.11). Imports of ETMs as a percentage of GDP have risen much more slowly. Country shares of the different categorisations of imports have also experienced some changes (discussed in appendix F in the context of constructing foreign knowledge stocks). These measures are based on economy-wide data.

After being relatively stable but declining from 1973-74 to 1984-85, the rate of decline in the effective rate of assistance (ERA) to manufacturing increased until roughly 1998-99.

Figure 5.11 **Trade openness and level of industry protection, various periods**



Data sources: ABS (*Australian System of National Accounts*, Cat. no. 5204.0), DFAT Stars database; Commission estimates.

Summary statistics for a range of other explanatory variables used in the industry models are shown in table 5.5. The variables are based on economy-wide or market-sector level data and are not industry-specific, except for the variable of farmers' terms of trade. The farmers' terms of trade variable is the ratio of prices received by farmers to prices paid by farmers and is used only in the regressions for Agriculture. It specifically takes account of the changes in prices of inputs and outputs that are only relevant to farmers in their production process (see ABARE 2003).

Table 5.5 **Summary statistics for the rate of growth in other control variables**

	Mean	*Standard deviation*	*Maximum*	*Minimum*
	%		%	%
Oil price index	3.0	0.240	64.0	-30.1
CPI	5.9	0.037	13.0	0.0
Goods terms of trade	-0.4	0.055	13.0	-11.0
Farmers terms of trade	-1.4	0.074	14.2	-16.4

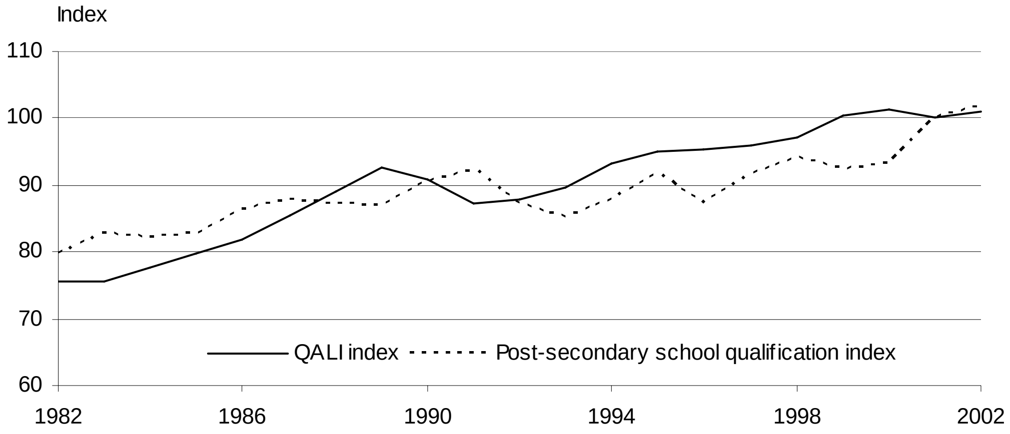
Source: Commission estimates.

Human capital

Human capital has been proxied in empirical studies using a variety of measures, including various educational measures and experience measures. For the R&D modelling two alternative measures have been used — the ABS QALI index, which is available only for the market sector in total, and the share of employed persons with post-school qualifications, which is available for the market sector and individual ANZSIC industries.

Both the QALI index and the proportion of the labour force with post-secondary school qualifications for the market sector in total have increased steadily from the early 1980s (figure 5.12).

Figure 5.12 **Controls for changes in the quality of labour**



Data sources: ABS (*Australian System of National Accounts*, Cat. no. 5204.0); unpublished ABS data, Commission estimates.

6 Basic regressions for the market sector

This chapter provides estimates of the effect of R&D on productivity in the market sector focusing on the long-run equilibrium relationships described in chapter 2.

Regressions cover:

- basic level models — effect of the level of knowledge on the level of MFP (section 6.1); and
- basic growth models — effect of R&D intensity or the growth in knowledge stocks on MFP or labour productivity growth (section 6.2).

6.1 The basic levels model

Many empirical studies have sought to measure the contribution of R&D to economic growth by investigating the relationship between the level of resources devoted to R&D and the level of multifactor productivity (MFP). This approach was adopted in the influential cross-country study of Coe and Helpman (1993, 1995); and was also used in Dowrick (1994b) and Rogers (1995). Additional control variables were added to the basic levels model in Industry Commission (1995) and Williams et al. (2003) to control for other sources of long-run productivity growth (for example, changes in human capital and infrastructure).

The analysis of the effects of R&D on productivity in Australia at the aggregate level has been undertaken with an industry scope corresponding to both the market sector and the whole-of-economy. It has also been investigated using state level data (Williams et al. 2003) (table 6.1).

All of the studies use econometric methods to obtain a measure of the magnitude of the effect of R&D on output or productivity. The exception is Chou (2003) who uses a growth accounting decomposition approach.

Table 6.1 **Australian aggregate studies of the effect of R&D**

Study	*Dependent variable, time period*	*Key findings*
Dowrick (1994b)	Ln(MFP), 1971-90	Domestic R&D stock elasticity equal to 0.066 with a return > 150 per cent. Foreign R&D elasticity equal to 0.065, which is much less than for other OECD countries. Australian elasticity of output with respect to domestic R&D similar to many other OECD countries.
Industry Commission (1995)	Ln(Y), 1976-77 to 1989-90	Output elasticities equal to 0.119 and 0.036 for domestic and foreign R&D stocks, respectively. Interaction of domestic and foreign R&D increases elasticities to 0.140 and 0.086, respectively, with a domestic return of 149 per cent.
Industry Commission (1995)	Ln(MFP), 1976-77 to 1989-90	Domestic R&D stock elasticity equal to 0.024 if assumed non-market sector productivity growth is zero and 0.040 if growth is equal to market sector growth (return equals 25 and 43 per cent compared with 149 per cent from the production function approach). Foreign R&D stock elasticities (for the same alternative assumptions) equal to 0.028 and 0.041, respectively.
Rogers (1995)	Ln(MFP), 1972 to 1990	Sign on domestic business R&D elasticity sensitive to specification. It is negative or insignificant if foreign R&D is not included, if business trips weighted foreign R&D rather than import share weighted stocks are included, or if a time trend is included. Foreign knowledge stocks proxied by both capitalised R&D expenditures and patent applications, with similar results (elasticities around 0.04). Import weighted foreign knowledge stocks more significant than business trip weighted stocks, suggesting embodied technological change, and the international spillovers associated with it, is more important to Australian than disembodied technological change.
Bodman (1998)	∆ln(Y), 1968 to 1996	Human capital, public infrastructure and R&D capital all have positive and economically significant effects on output growth.
Crosby (2000)	∆ln(Y/hrs) and ln(Y), 1901 to 1997	Increased patenting contributed to both labour productivity and output growth. Part of decline in productivity in the 1970s might be attributable to declines in innovation (proxied by patenting applications) from the late 1960s. A 1 per cent increase in overseas resident patent applications in Australia reduces domestic long-run applications by 0.36 per cent.
Williams et al. (2003)	Ln(MFP) by state, 1984-85 to 1999-00	State R&D stock elasticity equals 0.056. Rest of Australia elasticity equals 0.039. Some evidence of interstate spillovers. Average return to domestic R&D fell from 173 per cent in 1990-91 to 116 per cent in 1999-00.
Chou (2003)	∆Ln(Y/hrs), growth accounting, 1960-2000	42 per cent of Australian labour productivity growth attributed to rise in educational attainment, and 20 to 40 per cent to the increase in research intensity. Most of growth associated with ‘transitional dynamics’.

The studies are heavily reliant on the Australian System of National Accounts (ASNA) which provide data on industry, market sector and whole-of-economy inputs and outputs. Other ABS collections are the data source for most other control variables. Similar data problems confront all studies, such as the need to interpolate R&D for years in which there was no survey (see appendix A).

The studies use relatively short time series, for example, results from Industry Commission (1995) were based on a mere 14 years of observation. The longest sample period is Chou (2003) covering 1960 to 2000.

The estimated elasticities and implied rates of return to R&D vary widely across studies. Rogers (1995) finds that the estimated elasticity on domestic R&D is negative or insignificant in some models, while positive in others. In contrast, Dowrick (1994b) estimates a social return to R&D of roughly 150 per cent, consistent with some results in Industry Commission (1995) and Williams et al. (2003).

An update of the Coe & Helpman model applied to Australia

As an input to the Industry Commission's public inquiry into R&D, Dowrick (1994b) re-estimated the Coe and Helpman model on Australian data for the period 1970-71 to 1990-91. This provided Australian-specific coefficient estimates of the elasticity of MFP with respect to domestic business and foreign business R&D, whereas Coe and Helpman's estimates were averages for the OECD economies as a group.

For this project, the model was again re-estimated based on the longer time period 1968-69 to 2002-03 (table 6.2). The stock of Australian business R&D (BRD) was lagged one period to address possible endogeneity problems stemming from the simultaneous determination of output, productivity and R&D. Foreign R&D was treated as exogenous and was entered contemporaneously.

Table 6.2 **Estimation of the basic MFP and business R&D (BRD) model in levels**

Stocks depreciated at 10 per cent. Foreign business R&D stock is sum of bilateral import share weighted stocks multiplied by Australian import intensity.[a]

	Coe and Helpman's original results for OECD	*Update of Coe and Helpman*	*Test: add cyclical variable*	*Test: add time trend*	*Test: alternative lag structure*
Lag structure	*Aus.=(t-1)* *For.=(t-1)*	*Aus.=(t-1)* *For.=(t)*	*Aus.=(t-1)* *For.=(t)*	*Aus.=(t-1)* *For.=(t)*	*Aus.=(t-2)* *For.=(t-3)*
Dep. Var. = ln(MFP)	*CH1*	*CH2*	*CH3*	*CH4*	*CH5*
Aus. BRD stock	0.078*** (9.5)	0.040** (2.4)	0.038** (2.5)	0.023 (1.2)	0.069*** (4.0)
Foreign BRD stock	0.294*** (7.0)	0.128*** (8.3)	0.129*** (8.4)	0.014 (0.2)	0.098*** (5.2)
Cycle (growth of real GDP)			0.176* (1.8)	0.243 (2.50)	0.264*** (2.7)
Time trend				0.008* (1.7)	
Constant		3.821	3.819	4.116	3.841
Test statistics					
# of observations	440	34	34	34	32
R^2	0.630	0.951	0.954	0.958	0.948
Durbin-Watson (d)[b]		0.668	0.399	0.357	0.424
White test χ^2(p) for heteroskedasticity[b]		16.9 (0.005)	22.0 (0.009)	8.07 (0.886)	18.6 (0.029)
Residuals stationary?[b]		No	No	No	No

*** statistical significance at 1 per cent or greater. ** significance at 5 per cent or greater. * significance at 10 per cent or greater. [a] Heteroskedasticity-consistent t-statistic in brackets. [b] See table 6.3.

Source: Commission estimates.

The magnitude of the updated coefficients on Australian business R&D are robust to the inclusion of a cyclical variable (comparing 0.040 and 0.038 in models CH2 and CH3, respectively), which is included to control for the pro-cyclical nature of MFP (see appendix L). The inclusion of a linear time trend decreases the coefficient to 0.023 and both R&D variables are no longer statistically significant[1] (model

1 Statistical significance is a measure of the confidence that can be placed in the precision of the estimated parameter. If a parameter estimate is statistically insignificant, this does not mean that the true value of the parameter is zero. It means that the hypothesis that it might be zero cannot be rejected at the desired level of significance. The statistical insignificance of a point estimate may be due to the variable being economically insignificant or it might simply be due to the imprecision that is involved in estimating a population parameter from a small sample.

CH4). In Dowrick (1994b) and Rogers (1995), the inclusion of a time trend impacted severely on the significance of the domestic R&D stock.

The coefficient estimates for domestic business R&D are below that obtained by Coe and Helpman for the OECD as a whole and Dowrick's earlier estimates for Australia (0.078 and 0.066, respectively). For regression CH3, the estimate implies that a 1 per cent increase in the knowledge stock results in a 0.038 per cent increase in the level of MFP. Thus, according to the model, the 245 per cent increase in knowledge stocks from 1985 to 2002-03 would have led to a 9.3 per cent increase in the level of MFP.

The foreign knowledge stock was constructed by aggregating individual foreign stocks using bilateral import shares to Australia as weights and multiplying by Australia's import intensity, where imports are measured broadly to include all goods and services (refer to equation (F2), box F.1, appendix F). This particular approach to constructing foreign R&D knowledge stocks was used in Coe and Helpman, in Dowrick and in Rogers.

The scaling of the stocks needs to be taken into account when interpreting the coefficients. Using a mean value of import intensity of 0.18, the foreign elasticities for models CH2 to CH5 are 0.023 (0.128*0.18), 0.023, 0.003, and 0.018. Regression CH3, evaluated at the import intensity prevailing in 2002-03 of 0.22, produces an elasticity estimate of 0.028.

Evaluated at the 1990 import intensity, the elasticities for the foreign effect on Australian MFP from Coe and Helpman, Dowrick, Rogers and model CH3 are 0.055, 0.065, 0.042 and 0.022, respectively. At the time of these studies, Industry Commission (1995) speculated that the measured foreign effect for Australia would increase if Australia's import intensity continued to increase. At least in these basic regressions, the measured effect is lower. However, the results from these models are not reliable.

Robustness of the results

All of the regressions display very strong serial correlation in the residual (see the Durbin-Watson statistic at the bottom of table 6.2 and refer to the description of the statistical tests used in this paper in table 6.3). The estimates are not efficient and the usual ordinary least squares (OLS) standard errors and test statistics are not valid (Wooldridge 2003, p. 392).

Table 6.3 **Statistical tests for model robustness**

Test	*Description and interpretation*
Durbin-Watson (DW) 'd' statistic	Test for first order serial correlation in residuals using Durbin-Watson 'd' statistic. A statistic under 2 indicates positive serial correlation or persistence in the data. A test statistic greater than 2 indicates negative serial correlation.
Durbin-Watson (DW) 't' statistic	Test for serial correlation using Durbin-Watson 't' statistic for models which include regressors which are not strictly exogenous, for example, a lagged dependent variable. Prob > Chi^2 in brackets. A small probability rejects the null of no serial correlation.
White's test for heteroskedasticity	White's general test for heteroskedasticity or non-constant variance in the residuals. The null is homoskedasticity. P-values are in brackets. A small p-value rejects the null.
Test for functional form	Ramsey specification error test for omitted variables using powers of the fitted values. Null is no omitted variables. A failure to reject the null provides support for the chosen functional form. Prob > F in brackets. 'Z' is degrees of freedom calculated as number of observations less the number of explanatory variables less the number of fitted parameters.
Tests for stationary errors	Tests for non-stationary residuals included the Augmented Dicky-Fuller (ADF), Philips-Perron, and Dickey-Fuller generalised least squares tests. Rejection of the null of non-stationary errors was tested at a significance level of 5 per cent or greater. The Kwiatowski, Phillips, Schmidt and Shin (KPSS) test of a null of stationary errors was tested for rejection at a significance level of 10 per cent or greater.
AIC and BIC information criteria	Akaike's information criterion (AIC) and Bayesian information criterion (BIC). Comparisons across models take into account differences in the number of parameters estimated. Smaller scores indicate better model fit. As a rough guide, a BIC score difference of (0-2) provides weak support, (2-6) positive support and (>6 strong support). The BIC is preferred in small samples.

The inclusion of a time trend in model CH4 impacts severely on the statistical significance and magnitude of the variables. The purpose of a time trend in production function regressions is to represent exogenous technological change which shifts the production frontier outwards. For given capital and labour inputs, more output can be produced with a higher 'level' of technology. Direct measures of change are usually not available, so a linear time trend is used on the assumption that exogenous technological change is steady. These types of models are not well suited to considering technology cycles driven by the arrival and diffusion of technologies. To the extent that any such cycle does exist in the Australian data, and it is correlated with output, its effect will be subsumed in the business cycle control variable. The linear time trend will capture effects not controlled for in the model that result in steady growth.

For the Australian market sector, given its size relative to the rest of the world, exogenous technological change might be well represented by growth in the foreign knowledge stock. If so, there would be no need to separately include a time trend. However, while R&D expenditure is an important source of growth in the knowledge stock, it is not the only source. Therefore, the inclusion of a time trend should be considered even in models that include foreign knowledge stocks.

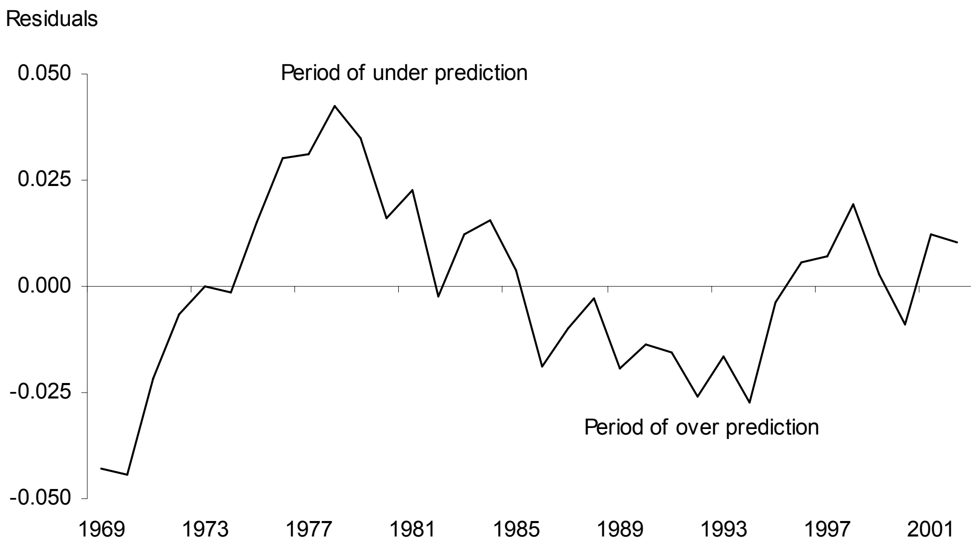
When a linear time trend was included in the extended market sector models presented later, it was usually not statistically significant. A common problem across model specifications was the difficulty in separately identifying the effect of foreign R&D from that of a linear time trend. This is related to the problem of using trending data in regressions and the resulting high degree of collinearity (see appendix E).

Misspecification and 'different periods'

There are time periods when the basic levels model consistently over and under-estimates measured MFP (figure 6.1). From the mid-1970s to the mid-1980s, MFP is higher than the prediction of the linear model (the residuals are greater than zero). From roughly the mid-1980s to the mid-1990s, MFP is lower than predicted (the residuals are less than zero). The high degree of serial correlation in the residuals is clearly evident, rather than the residuals being randomly distributed with an expected value of zero.

Figure 6.1 **Plot of residuals from basic, static model CH3, 1969-70 to 2002-03**

Actual MFP less predicted MFP



Financial years beginning 1 July of year specified.

Data source: Commission estimates.

The lack of a strong equilibrating relationship in the data between MFP and the R&D stocks variables is the source of the residual serial correlation problem in the levels model. The unit root testing and comparison of orders of integration in the long-run relationship indicated that the levels model would probably involve mixed orders of integration (appendix E). Formal testing for co-integration provided no support for co-integration. Tests indicated that the level of MFP is not co-integrated with either of the business R&D stocks individually, and that the R&D stocks are not mutually co-integrated. However, there is significant uncertainty around these test results due to the generally low power of unit root tests, relatively short time series, and the additional uncertainty that structural change introduces to unit root tests.

A more robust basic levels model

To improve the robustness of the models, a range of adjustments were tested:

- a different construction methodology for the foreign knowledge stock;
- the introduction of slope shift terms to test whether the partial effect of R&D changed over time;
- a quadratic functional form; and
- the introduction of dynamics.

The tests show that the introduction of dynamics significantly improves model results.

Respecification of foreign knowledge stocks

The models in table 6.4 include a foreign knowledge stock that is constructed by using bilateral import shares as weights, but without scaling by import intensity. The Australian and foreign knowledge stocks are depreciated at 10 per cent for easier comparison with the regressions in table 6.2. As foreshadowed in the previous chapter, the general approach to the construction of foreign knowledge stocks in this paper is to aggregate individual foreign country stocks using a variety of weighting schemes, to test the performance of the alternatively weighted stocks in regressions (chapter 9), and then to separately investigate whether interactions with Australia's import intensity or other economic characteristics alter the estimated effect of foreign R&D on Australian productivity (also chapter 9).

Table 6.4 **Dynamics improve the basic model**

Foreign business R&D stock is sum of bilateral import share weighted stocks. T-statistics in brackets. Stocks depreciated at 10 per cent.

	Static	*Static*	*Finite Dist. Lag*	*Finite Dist. Lag*	*Finite Dist. Lag*	*ARDL (1,3)*
Lag structure						
Australian =	*(t-1)*	*(t-1)*	*1*	*1*	*1*	*3*
Foreign =	*(t)*	*(t)*	*4*	*4*	*4*	*3*
Dep. Var. = ln(MFP)	*BL1*	*BL2*	*BL3*	*BL3q*	*BL3s*	*BL4*
Aus. BRD stock	0.055** (2.6)	0.082*** (3.0)	0.016 [a] (0.4)	-0.042 [d]	0.041 [a] (1.5)	0.021 [a] (0.6)
Aus. BRD stock squared				0.007 [d]		
Foreign BRD stock	0.155*** (5.2)	0.262*** (4.9)	0.217*** [a] (4.5)	0.171*** (4.0)	0.220*** [a] (5.4)	0.220*** [a] (5.5)
Cycle (growth of real GDP)	0.191 (1.5)	0.291* (1.9)	0.488*** (7.2)	0.475*** (5.5)	0.340*** (4.4)	
Intercept	3.627*** (68.2)	3.164*** (23.1)	3.584*** (78.9)	3.829*** (8.7)	3.449*** (53.1)	2.654*** (5.7)
Lagged dependent						0.256* (2.0)
Aus. BRD slope shift 1983		-0.019** (-2.3)				
Aus. BRD slope shift 1989		-0.013** (-2.7)				
Shift1973					0.036*** (4.5)	
Shift1982					-0.022* (-1.8)	
Shift1989					-0.024*** (-3.1)	
Test statistics						
# of obs.	34	34	31	31	31	32
R^2	0.929	0.956	0.986	0.988	0.993	0.978
Durbin-Watson	0.28 [b]	0.907 [b]	1.43 [b]	1.20 [b]	2.19 [b]	0.037 [c] (0.847)
White test χ^2(p) for hetero.	25 (0.003)	24 (0.116)	28 (0.267)	31 (0.381)	31 (0.415)	13 (0.936)
RESET F(3,Z)	30.96 (0.000)	9.52 (0.000)	3.30 (0.043)	2.93 (0.064)	1.15 (0.360)	2.37 (0.102)
Residuals stationary?	No	No	M [e]	M [e]	Yes	Yes

*** statistical significance at 1 per cent or greater. ** significance at 5 per cent or greater. * significance at 10 per cent or greater. [a] Coefficient, t-statistic and statistical significance is for long-run effect. Joint F-test on lags statistically significant at greater than 1 per cent. [b] Test for serial correlation in residuals using Durbin-Watson 'd' statistic. [c] Test for serial correlation using Durbin-Watson 't' statistic. [d] Primary and quadratic term each individually statistically significant with their lags at greater than 5 per cent. Terms jointly significant at greater than 1 per cent. [e] M is 'marginal' — result sensitive to test specification.

Source: Commission estimates.

Simply altering the construction of the foreign knowledge stock (by dropping the scaling by import intensity) does not improve the robustness of the model (model BL1). The inclusion of a linear time trend was significant, but the coefficient on the foreign effect changed to negative and significant (-0.445 with a standard error of 0.050, and Durbin-Watson statistic of 0.985).

Slope changes

The Australian economy has experienced significant structural change over the last thirty years (see chapter 10). These changes could have impacted on the relationship between R&D and productivity.

A model modification was introduced to allow the estimated elasticity to change at various points in time. Slope changes from 1983 and 1989 were significant (model BL2). The slope changes raise the primary coefficient, but show it declining over time. For the period from 1989, the coefficient is 0.050 (0.082 less 0.019 less 0.013). The modification improves the residuals, but there is still significant residual serial correlation. Piece-wise linear regression techniques also suggested significantly differing slope coefficients by period (parameter stability is discussed at various points in the following chapters and appendixes).

Dynamics and test of a quadratic functional form

Investment in R&D, the ‘arrival’ of new knowledge, and the impact of that knowledge on economic performance takes time. The introduction of lags into the models recognises that there may be important differences between initial, short-run or transitionary effects and the permanent or long-run effect of business R&D investment. Lagging stocks recognises that the construction of the stocks did not take lags into account (as discussed in chapter 4). Chapter 4 listed empirical studies which have found evidence of significant lags. Not taking lags into account could result in the static models being misspecified.

Regression BL3 was estimated as a finite distributed lag model (FDL). The contemporaneous value of Australian business R&D was again replaced with (t-1). The lag structure was determined by successively dropping the longest lag until it was statistically significant, whilst also having regard to overall model fit (based on information criteria). This resulted in the inclusion of a single additional lag for Australian business R&D at (t-2), and the inclusion of four lags in addition to the contemporaneous value for foreign R&D. Providing separation of short-run from long-run effects substantially improved results (model BL3).

Introducing shift terms to model BL3 resulted in reliable standard errors and test statistics (model BL3s). The shift terms impact on the constant and are interpreted as ‘unexplained’ shifts in the state of technology.

Model BL1, BL1s, BL2 and BL3 all fail the Ramsey RESET test for functional form. If the absorptive capacity role of R&D is important or there are other scale effects associated with the production of knowledge, then a quadratic or higher polynomial term may be significant.

Specifying MFP as a quadratic function of Australian business R&D results in a statistically significant quadratic term suggesting that the partial effect of R&D may be positively related to the level of R&D activity in Australia. However, evaluation of the total effect at the mean of the full sample (a coefficient of 0.010 with a standard error of 0.033), or the mean of the sample prior to or after 1985, does not produce a statistically significant estimate of the permanent effect of R&D. The model continues to exhibit significant residual serial correlation.

In the FDL models, a joint F-test on the lags of the stock of Australian business R&D indicated statistical significance at greater than 1 per cent. However, the long-run effect was not statistically significant at 10 per cent. The difference between the tests indicates that statistically significant ‘short’ term or transitionary effects of business R&D capital can be found, but that the estimated long-run or permanent effect cannot be estimated with precision. For example, in model BL3s, the 95 per cent confidence interval ranges from -0.012 to 0.094. The long-run or permanent effect can be thought of as the sum of the accumulated changes in output from a permanent change in an explanatory variable (box 6.1).

Model BL4 was estimated as an autoregressive distributed lag model (ARDL) with a lagged dependent variable included with the contemporaneous values and three lags of both R&D variables (ARDL(1,3)). This specification produced randomly distributed errors (sometimes referred to as errors which are ‘white’) with both sets of lags being jointly significant at greater than 5 per cent. The estimated long-run effect of Australian business R&D at 0.021 per cent is low compared with the referenced studies above. However, similar to the FDL models, the long-run effect is poorly estimated and not statistically significant at 10 per cent.

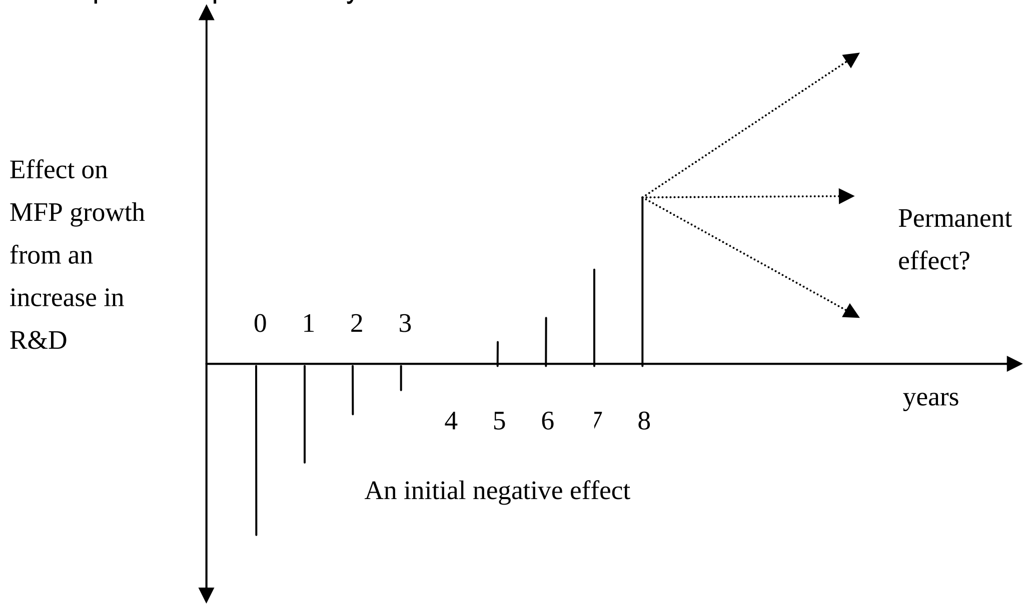
The ARDL model implies a transitionary period of 21 years with most of the distance covered to the new steady-state after about 10 years (appendix M).

Box 6.1 Transitional versus permanent or long-run impacts

The benefits from R&D activity often accrue over a number of periods, while the costs are typically incurred early on in the process. As such, the short-run impacts of R&D can look very different to the long-run impacts. Indeed, the immediate impact of R&D activity is likely to be negative.

R&D activity requires labour and capital resources, but does not immediately result in any productivity improvements. Productivity improvements will not occur until the innovations that result from the R&D can be incorporated into production processes used by firms in the economy. Thus the immediate impact of R&D is to increase inputs and leave output unchanged. Over time, output will gradually grow.

The need for firms to adjust their production processes to incorporate the new innovation will tend to delay the realisation of the full benefits of the innovation. In some instances, these adjustment costs may be sufficiently large to generate further negative impacts on productivity in the 'short run'.



The foreign effect can be read directly as an elasticity as it has not been scaled by import intensity. The coefficients are large, positive and statistically significant at 10 per cent or less in each of the models. The estimates are more in line with the average estimate for OECD countries at 0.294 per cent (model CH1). In the models with dynamics, a joint F-test on the lags and evaluation of the long-run effect were both statistically significant at greater than 1 per cent.

Entering single values of Australian business R&D lagged two periods and foreign business R&D lagged three periods (that is, picking an 'optimal' lag rather than including a full set of lags) sometimes produced slightly better results, but it did not have a major bearing on the models.

Summing up on the basic levels model

Models BL3, BL3s and BL4 produce models with more reliable estimates of the effect of R&D by taking account of dynamics. However, the estimated permanent effect of Australian business R&D is not statistically significant in these models. The economic magnitude of the point estimates is less than in the static models, but the wide confidence intervals do not allow much to be said about the permanent effect on productivity from a permanent increase in Australian BRD.

Allowing for unexplained technology shifts also appears important. The inclusion of a linear time trend and foreign R&D together in a model results in a large negative coefficient on foreign R&D.

From the basic levels model, the best point estimate of the effect of Australian business R&D on MFP is an elasticity of between 0.02 and 0.04, but the coefficients are not precisely estimated.

6.2 Basic productivity growth models

The basic growth models investigate three different long-run relationships (table 6.5):

- the long-run relationship between growth in MFP and the annual growth in knowledge stocks;
  - models J1 and J1 FDL;
- the long-run relationship between growth in MFP and R&D intensity;
  - results are presented for both formulations of the R&D intensity measure: the log of the knowledge stock over output (models Y1 and YI FDL); and the log of the net increase in the knowledge stock over output (models Y2 and Y2 FDL); and
- the long-run relationship between growth in labour productivity and R&D intensity;
  - as for MFP, results are presented for both formulations of the R&D intensity measures (models H1 and H2).

Table 6.5 Estimation of the basic productivity growth model

All variables in logs. Foreign gross R&D (GRD) stock is sum of bilateral import share weighted stocks.

Model	*J1*	*J1 FDL*	*Y1*	*Y1 FDL*	*Y2*	*Y2 FDL*	*H1*[a]	*H2*[a]
R&D variable	*Δln(K)*	*Δln(K)*	*ln(K/Y)*	*ln(K/Y)*	*ln(ΔK/Y)*	*ln(ΔK/Y)*	*ln(K/ (Y*hrs))*	*ln(ΔK/ (Y*hrs))*
Stock rate of decay (%)=	*Aus.=15 For.=15*	*Aus.=15 For.=15*	*Aus.=15 For.=15*	*Aus.=15 For.=15*	*Aus.=5 For.=15*	*Aus.=5 For.=15*	*Aus.=15 For.=15*	*Aus.=5 For.=15*
Δ Aus. BRD stock (t-1)	0.017 (0.041)	0.027[c] (0.036)						
Δ Foreign GRD stock (t)	-0.319 (0.273)	-0.241[c] (0.244)						
Aus. BRD intensity (t-1)			0.017 (0.010)	0.018**[c] (0.008)	0.003 (0.002)	0.010** [c] (0.004)	0.017** (0.008)	0.004** (0.002)
Foreign GRD intensity (t)			-0.040** (0.018)	-0.077*** (0.023)	-0.014** (0.008)	-0.011 [c] (0.009)	-0.014 (0.022)	-0.009 (0.009)
Cycle (ΔΔva)	0.348*** (0.051)	0.398*** (0.049)	0.332*** (0.043)	0.472*** (0.137)	0.353*** (0.044)	0.313*** (0.048)	0.348*** (0.053)	0.394*** (0.058)
Dummy82	-0.018** (0.008)		-0.018** (0.007)		-0.014* (0.007)	-0.017** (0.008)	-0.022*** (0.005)	
Shift1985						-0.013 (0.008)		
Δksrvhr							0.465*** (0.080)	0.430*** (0.109)
Intercept	0.023** (0.010)	0.18* (0.009)	0.109** (0.049)	0.145*** (0.046)	-0.006 (0.016)	0.055 (0.039)	0.113 (0.227)	-0.043 (0.119)
Test statistics								
# of obs.	32	32	34	32	33	33	28	28
R^2	0.705	0.807	0.712	0.850	0.730	0.799	0.778	0.735
DWstatistic	2.147	2.415	2.271	2.364	2.241	2.344	2.291	2.152
Hetero. tests [b]	OK	OK	OK	OK	Fail at 7%	OK	OK	OK
RESET F(3,Z)	1.25 (0.313)	0.87 (0.473)	0.35 (0.787)	0.32 (0.813)	0.28 (0.836)	0.69 (0.568)	0.89 (0.466)	1.32 (0.297)
Errors I(0)? [d]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

*** statistical significance at 1 per cent or greater. ** significance at 5 per cent or greater. * significance at 10 per cent or greater. [a] For models H1 and H2, intensities are per Australian hour worked in the market sector. [b] White's general test and Breusch-Pagan test for heteroskedasticity or non-constant variance in the residuals. [c] Coefficient, standard error and statistical significance is for long-run effect. Joint F-test on lags statistically significant at greater than 5 per cent. [d] See table 6.3 for a description of the unit root tests.

Source: Commission estimates.

The stock of Australian business R&D in models Y2 and H2 was depreciated at 5 per cent.[2] All other R&D stocks were depreciated at 15 per cent. Australian business R&D is lagged one period.

The effect of Australian business R&D

The point estimate for the effect of Australian business R&D on MFP and labour productivity growth is positive in each of the regressions. However, the coefficients are not precisely estimated and the lower bound of their confidence interval takes in zero or is just above zero.

Statistical significance varies across the models. In model J1, the long-run effect is not statistically significant, but transitional effects are significant (J1 FDL). In models Y1 and Y2, Australian business R&D is statistically significant in the distributed lag models, but not the static models. In models H1 and H2, Australian business R&D is statistically significant. Estimating the basic labour productivity growth models as a distributed lag model (not shown) does not greatly affect the magnitude of the coefficients or their statistical significance.

Using model Y2 FDL as an example of how the elasticities are interpreted, a 20 per cent ‘permanent’ increase in net investment in the knowledge stock raises the growth rate of MFP from roughly 1.0 per cent per year (its historical average since 1968) to between 1.04 and 1.36 per cent per year. A 20 per cent increase translates into an increase in the stock from roughly $2.5 billion to $3.0 billion as at 2002-03 (the final year of the data used in the modelling).[3]

While the increase in the MFP growth rate appears large, the models as a whole do not rule out the possibility that R&D has no longer term effect on measured productivity growth. This is seen most clearly in the parameter stability charts in appendix E, where the confidence intervals usually include an estimate of a zero partial effect.

[2] At an assumed decay rate greater than five per cent, net growth in the knowledge declines in real terms in the 1970s. This causes a problem for the log-linear functional form used in these models as the log of a negative number cannot be taken.

[3] Published gross business expenditure for the same year is much larger as it does not include the various adjustments to the data which were made for modelling purposes, including the removal of Property & business services (see appendix A). It also does not include the application of a fifteen per cent assumed rate of decay to accumulated expenditure.

The effect of foreign gross R&D

The coefficient on foreign gross R&D (GRD) is unexpectedly negative in each model, compared with a positive, large and highly statistically significant coefficient in the basic level model (if a time trend is omitted). The plausibility of a negative foreign effect is discussed in the following chapter because it also arises in some market sector models extended to control for other influences on productivity and industry models.

The intercept is not significant in the latter four growth models. In the absence of other explanatory variables, the intercept or constant represents the average rate of growth in MFP resulting from unexplained factors.

Dropping the intercept and holding the other features of the models constant improves the precision of estimates, but the coefficient on foreign GRD is still negative.

Dropping the intercept and retesting down the model, with the inclusion of a trend term in the initial variable set, improves results overall (table 6.6). The effect of foreign GRD on Australian productivity growth becomes positive in models J1, Y1 and Y1 FDL. The effect of foreign GRD remains negative in the labour productivity regressions, and is now statistically significant at 5 per cent or greater. The effect of Australian BRD is also better estimated in models J1, Y1 and Y2.

However, some models now point to a trend decline in productivity growth, holding constant the partial effects of Australian BRD and foreign GRD on productivity. Inclusion of the trend term effectively controls for this negative influence on productivity growth. Linear time trends are often included in levels models to help manage the trending characteristics of the data. Growth models generally do not include time trends as variables specified in growth rates are often stationary.

The negative time trend in the growth models imply a quadratic time trend in the level of MFP which is first positively sloped, then negatively sloped. In these basic models, this seems consistent with expectations based on visually inspecting graphs of the growth rates of productivity and the stock of Australian BRD. The degree of weakness in R&D investment followed by the strength of investment from the mid-1980s does not appear to be mirrored sufficiently in MFP, which suggests there were other factors affecting MFP positively in the first half of the sample, then negatively later in the sample.

Table 6.6 **Improvement, but further puzzles from the basic growth models**

All variables in logs, except for the time trend. Stock of foreign gross R&D (GRD) is the sum of bilateral import share weighted stocks. Heteroskedastic robust standard errors in brackets.

Adjusted Model	*J1*	*Y1*	*Y1FDL*	*Y2*	*H1*[a]	*H2*[a]
R&D variable	*Δln(K)*	*ln(K/Y)*	*ln(K/Y)*	*ln(ΔK/Y)*	*ln(K/ (Y*hrs))*	*ln(ΔK/ (Y*hrs))*
Stock rate of decay (%)=	*Aus.=15 For.=15*	*Aus.=15 For.=15*	*Aus.=15 For.=15*	*Aus.=5 For.=15*	*Aus.=15 For.=15*	*Aus.=5 For.=15*
Linear time trend		-0.002** (0.001)	-0.003*** (0.001)		-0.002* (0.001)	
Δ Aus. BRD stock (t-1)	0.150* (0.075)					
Δ Foreign GRD stock (t)	0.261*** (0.079)					
Aus. BRD intensity (t-1)		0.013** (0.006)	0.029* (0.014)	0.006** (0.003)	0.051*** (0.018)	0.005** (0.002)
Foreign GRD intensity (t)		0.097** (0.035)	0.204** (0.077)	-0.020*** (0.007)	-0.075*** (0.026)	-0.006** (0.003)
Δksrvhr					0.511*** (0.097)	0.434*** (0.113)
Cycle (ΔΔva)	0.296*** (0.065)	0.384*** (0.053)	0.294 (0.190)	0.395*** (0.035)	0.312*** (0.062)	
Dummy81		0.009** (0.004)	0.010** (0.004)	0.008* (0.005)	0.013** (0.006)	
Dummy82	-0.028*** (0.007)				-0.032*** (0.008)	
Shift1982					0.032** (0.014)	
Shift1985	-0.020** (0.008)					
Shift1992	0.013** (0.006)		-0.018** (0.007)	-0.014** (0.005)		
Shift1995			0.028*** (0.005)	0.012** (0.005)		
Test statistics						
# of obs.	32	33	32	33	28	28
R^2	0.770	0.774	0.921	0.814	0.925	0.887
DWstatistic	2.136	1.744	1.679	2.149	2.399	2.134
Hetero. tests[b]	OK	OK	OK	Fail at 7%	OK	OK
Errors I(0)?[c]	Yes	Yes	Yes	Yes	Yes	Yes
AIC*n	-190	-200	-214	-205	-177	-173

*** statistical significance at 1 per cent or greater. ** significance at 5 per cent or greater. * significance at 10 per cent or greater. [a] For models H1 and H2, intensities are per Australian hour worked in the market sector. [b] White's general test and Breusch-Pagan test for heteroskedasticity or non-constant variance in the residuals. [c] See table 6.3 for a description of the unit root tests.

Source: Commission estimates.

The residuals of the productivity growth models do not show evidence of heteroskedasticity or strong serial correlation. Differencing the dependent variable and the use of intensities results in desired statistical properties.

Summing up on basic productivity growth models

Like the basic levels models, the basic productivity growth models favour a positive effect of Australian business R&D on productivity growth. However, the confidence intervals more often include an economically insignificant effect. While the models are more robust in terms of their statistical properties, there are serious concerns with the models based on economic criteria as a permanent negative effect of foreign R&D on Australian productivity is very unlikely.

The relationship between R&D and technological change is inherently dynamic in nature. The unusual coefficients that arise in some of the basic models may be due to their failure to capture important elements of that dynamic process. When models that allow for transitional dynamics are estimated, the long-run impact of an increase in Australian BRD is not always statistically significant. The failure to obtain a statistically significant estimate of the long-run impact of an increase in R&D on MFP in some models may be due to the difficulty of disentangling transitional dynamics from the long-run impact when the number of observations is limited.

7 Extended regressions for the market sector

The basic models in the previous chapter highlighted: a number of issues involved in estimating the relationship between R&D and productivity; strategies to improve regressions; and remaining counterintuitive results. In the basic levels models, making allowance for unexplained shifts in technology and introducing dynamics were important in improving the reliability of inferences. However, when these features were added to the model, the model did not provide a statistically significant estimate of the permanent effect of business R&D.

While the basic productivity growth models pass standard statistical tests, each of the initial models presented suggested that foreign R&D has a negative impact on productivity. Alterations to the models produced a positive foreign effect, but raised other questions.

This chapter investigates these issues while controlling for other sources of growth. Theoretical models and empirical studies point to many influences on productivity in addition to R&D. Brief surveys can be found in Dawkins and Rogers (1998), Rogers (2003) and Parham (2004), which discuss the determinants of productivity growth in an Australian context. While these other sources of growth or controls are not the primary focus, they are of interest in their own right. A general-to-specific test down procedure was used in selecting the eventual set of controls which remained in the model.

The approach in this chapter is similar to chapter 6 in that a 'standard' model is estimated and tests of the model are undertaken. Attempts to improve on the statistical or economic properties of the model are then made.

As in chapter 6, the results of the various tests raise issues in respect of both the effects of foreign R&D and Australian business R&D, each of which is discussed.

- Is there a 'permanent' effect of R&D in the Australian data?
- Is a negative effect of foreign R&D plausible?

7.1 Extensions to the levels model

The first set of extensions is to the basic levels model, in which the log of multifactor productivity (MFP) was regressed on the log of the knowledge stocks and other sources of growth and controls (equation (3) of chapter 4). A description of the control variables is provided in table 7.1. A linear time trend has also been included in the regressions to capture the effect of steady exogenous technological change.

Table 7.1 **Other sources of growth and controls**

Variable	*Description*	*Expected sign*
ci5, ci5iousage	Index of capital services. Communications services industry capital. Excludes IT capital (hardware + software). ci5iousage is ci5 adjusted for usage using input-output tables data. For market sector models, the wage adjustment distinguishes between the market sectors and the non-market sectors share in the use of the infrastructure.	(+)
I3, I3usage2s	Index of capital services. General government capital allocated to industries in the market sector. Excludes IT capital. Road infrastructure forms a very large component. I3usage2s is I3 adjusted for usage based on smoothed value added shares.	(+)
Itcap, nonggitcap	Index of capital services. Computer hardware and software (includes private and allocated general government components). Private IT capital forms roughly 97 to 98 per cent of total. nonggitcap is the private component only.	(+)
education	Index of proportion of the labour force with post-school qualifications.	(+)
QALI	ABS published Quality Adjusted Labour Index. In part, used for constructing productivity measures which attempt to take account of changes in the quality of labour inputs.	(+)
topen	Index of imports plus exports as a proportion of GDP.	(+)
tiopen	Index of imports as a proportion of GDP, where imports include capital, intermediate inputs, consumption and other imports.	(+)
tiopenetm	Imports as a proportion of GDP, where imports cover Elaborately Transformed Manufactures (ETMs).	(+)
era	The Effective Rates of Assistance index is a measure of the degree of industry protection. The index for manufacturing is used in the market sector models.	(-)
centbrg	Centralised wage determination index from TRYM dataset.	(-)

Results

Model L1, the initial and most basic implementation of equation (3) in chapter 4, is the starting point. The coefficient on Australian business R&D (BRD) stocks is positive at 0.077 and statistically significant at greater than 1 per cent (table 7.2). This coefficient is an estimate of the elasticity of MFP with respect to Australian BRD. It suggests a 1 per cent increase in Australian BRD results in a 0.077 per cent increase in the level of MFP.

The implied rate of return is extremely high with the lower bound of the 95 per cent confidence interval roughly 200 per cent and the upper bound roughly 300 per cent. The return is well above those found in the vast majority of studies.[1] The return is well above the rule-of-thumb upper bound discussed in appendix P. In addition to the plausibility of such a high return, another significant concern is that the coefficient on foreign R&D is negative, which is against strong prior expectations.

The model was re-estimated to test the effect of gross R&D (GRD) capital, which includes higher education and Government R&D. While gross R&D capital has also grown strongly for a long period, its rate of growth has been less than for business R&D. Including higher education and Government R&D lessens the disjuncture between pre- and post-1985 growth rates. This might lead it to being better estimated than business R&D if there has been less structural change in the relationship between GRD and MFP. On the other hand, movements in business R&D may be expected to be much more closely associated with productivity trends in the market sector as the factors influencing non-business investment in R&D are more insulated from market forces. If Australian GRD is included in model L1 in place of Australian BRD (not shown), then the coefficient is higher at 0.200 with a standard error of 0.057 and statistical significance greater than 1 per cent. The effect of foreign R&D continues to be negative.

These results suggest that the specification in model L1 can be rejected.

[1] The calculation is based on a ratio of output over the stock of Australian BRD for the market sector of roughly 25, when the knowledge stock is depreciated at 15 per cent and the ratio is taken at the means of the sample.

Table 7.2 Influences on the level of MFP

Knowledge stocks depreciated at 15 per cent. All variables in logs.

Lag structure	*Aus=(t-1) For=(t)*	*Aus=(t) For=(t)*	*Aus=(t-2) For=(t-3)*	*Aus=(t-1)*	*Aus=(t-1) For=(t)*	*FDL*[a]	*Gross exp. FDL*[a]
Model	*L1*	*L1a*	*L2*	*L3*	*L4*	*L5*	*L6*
Linear time trend	0.004 (0.219)	0.035*** (0.008)	0.001 (0.003)	0.003 (0.007)	-0.010 (0.008)	-0.016 (0.009)	-0.009 (0.014)
Cycle (growth in real VA)	0.372*** (0.057)	0.567*** (0.054)	0.401*** (0.051)	0.358*** (0.048)	0.361*** (0.050)	0.565*** (0.035)	0.390*** (0.029)
Australian BRD	0.077*** (0.028)	-0.190*** (0.054)	0.100*** (0.025)	0.042 (0.042)	-0.405 (0.258)	-0.199*** (0.006)	-0.283[b]
Aust. BRD squared					0.071* (0.036)		0.041[b]
Aus. BRD at sample mean[c]					0.111*** (0.029)		0.017 (0.016)
Foreign GRD (ETM weighted)	-0.180*** (0.059)	0.366*** (0.117)	-0.131* (0.064)		0.084 (0.159)	1.082***[b] (0.153)	0.509*[b] (0.279)
ci5iousage						0.051* (0.021)	-0.036 (0.022)
I3usage2s/I3				0.226** (0.102)			0.195 (0.279)
nonggitcap		-0.119*** (0.031)		-0.031* (0.016)		-0.120*** (0.018)	-0.026 (0.023)
education	0.181*** (0.020)	-0.000 (0.051)	0.204*** (0.026)	0.199*** (0.058)	0.231*** (0.034)	0.288***[b] (0.059)	-0.022 (0.076)
tiopen	0.083** (0.036)	0.044 (0.030)	0.078** (0.034)	0.122*** (0.036)	0.101*** (0.036)		
era	-0.042** (0.018)	-0.065*** (0.015)	-0.044** (0.018)	-0.066*** (0.016)	-0.028 (0.021)	-0.167***[b] (0.027)	-0.034[b] (0.032)
centbrg	0.004 (0.003)		0.003 (0.002)		0.007** (0.003)	-0.032***[b] (0.005)	-0.013** (0.005)
Constant	3.852*** (0.355)	3.237*** (0.531)	3.582*** (0.313)	2.212*** (0.470)	3.535*** (0.360)	1.165** (0.417)	2.800 (2.652)
Shift1983		-0.043*** (0.008)				-0.025*** (0.006)	
Shift1985							
Shift1992		-0.027*** (0.007)				-0.010 (0.006)	
Shift1995						0.010* (0.005)	

(continued on next page)

Table 7.2 **(continued)**

Lag structure	Aus=(t-1) For=(t)	Aus=(t) For=(t)	Aus=(t-2) For=(t-3)	Aus=(t-1)	Aus=(t-1) For=(t)	FDL	Gross exp. FDL
Model	*L1*	*L1a*	*L2*	*L3*	*L4*	*L5*	*L6*
Test statistics							
# of obs.	33	28	33	29	33	28	29
R^2	0.995	0.996	0.996	0.994	0.996	0.999	0.999
Durbin-Watson statistic[d]	2.100	2.417	2.405	2.172	2.456	3.386	2.905
White heter.[d]	0.418	0.411	0.418	0.413	0.418	0.411	0.413
RESET, F(3,Z)[d]	0.82 (0.499)	0.31 (0.812)	0.19 (0.904)	0.95 (0.438)	0.58 (0.635)	0.27 (0.847)	0.08 (0.967)
AIC*n (BIC)[d]	-222 -148	-198 -120	-227 -153	-196 -120	-224 -149	-273 -180	-229 -143

*** statistical significance at 1 per cent or greater. ** statistical significance at 5 per cent or greater. * statistical significance at 10 per cent or greater. Heteroskedastic robust standard errors in brackets. [a] Finite distributed lag (FDL). [b] Joint F-test on lags statistically significant at greater than 5 per cent. [c] Coefficient and significance from evaluating Australian BRD at its mean sample value. [d] See table 6.3.

Source: Commission estimates.

Introducing terms that shift the intercept can dramatically alter results (model L1a). The specific shifts were the result of a test down procedure. The intercept shift terms are interpreted as changes in the state of technology after taking account of, in particular, the effects of Australian BRD and foreign GRD. In this model, the coefficient on Australian BRD is negative and highly significant, while the coefficient on foreign GRD becomes positive and highly significant. The results are sensitive to the inclusion of the shift terms and the inclusion of the IT capital variable. This highlights the sensitivity of the signs on the key variables of interest to seemingly modest changes. Including shifts in the basic levels model in chapter 6 improved results, but did not have the effect of altering the sign of either R&D variable.

Australian BRD was not lagged one period, as in model L1, and so the results could suffer from an endogeneity bias. Lagging BRD one period results in the magnitude of the coefficients on both R&D variables being cut by two-thirds and becoming not statistically significant at 10 per cent, but with the same signs.

Model L2 shows that the seemingly high coefficient on Australian BRD and negative coefficient on foreign GRD is not a result of the dating of the knowledge stocks. As discussed in chapter 4, the knowledge stocks were not constructed in a way that takes account of lags between R&D exploration, development of application and commercialisation. Model L1 was re-estimated with Australian

BRD lagged two periods and foreign GRD lagged three periods as per Park (1995). The coefficient on Australian BRD is even larger than in model L1, while the coefficient on foreign GRD is still negative, but less so. The t-statistics for Australian BRD and information criteria on overall model fit suggest this lag structure performs marginally better.

Dropping foreign GRD from the regression and including various infrastructure variables in the test down procedure results in a smaller positive, but statistically insignificant, coefficient on Australian BRD (model L3). Rogers (1995) also found insignificant estimates of the effect of Australian BRD when foreign R&D was excluded from the model. Communications infrastructure is not statistically significant and was dropped. General government infrastructure is highly significant, while non-general government IT capital is negatively signed. The effects should be viewed as 'excess' effects (see appendix D), given that the infrastructure/capital is included in the capital services measure used to derive the MFP index.

Chapter 6 provided some evidence of a partial effect of Australian BRD which varied according to the level of R&D activity. Models L4 and L6 provide supporting evidence. In considering the effect of BRD on productivity both the primary and quadratic terms have to be taken into account. In each model, Australian BRD and its square are jointly significant at greater than 1 per cent, and the coefficient on the squared term is positive. An interpretation is that the partial effect of BRD on MFP depends on the level of BRD, and that the effect increases with the size of BRD. Appendix O explores non-linear partial effects further and discusses possible interpretations related to R&D scale and absorption effects.

Evaluated at the mean of Australian BRD over the sample, the coefficient on Australian BRD is significant in model L4 with a very large elasticity of 0.111 and standard error of 0.029. The economic magnitude of the effect is not plausible, but it does show that changes to how Australian BRD is specified can alter the sign of the foreign effect.

In model L6, the effect of Australian BRD is not significant when evaluated at the mean of the full sample. However, evaluation at the mean of the period up to 1985 and post-1985 indicates a negative and statistically insignificant effect in the first period, followed by a strong positive and statistically significant effect in the second period.

Given the improved results in chapter 6 from introducing dynamics, an extended finite distributed lag (FDL) model was tested (model L5). The longest lag was determined by testing down with an eye on overall model fit. The presented coefficients are the long-run impacts.

According to model L5, Australian MFP is highly driven by growth in the foreign knowledge stock in the long-run. However, there are economic and statistical concerns with the model. The coefficient on Australian BRD is negative, and there is a high degree of negative serial correlation in the residuals. The coefficient signs on the non-R&D variables accord with expectations and are significant.

Model L6 uses gross R&D expenditures rather than stocks. If there are significant problems with the construction of R&D stocks, then the use of gross expenditure might provide better results. A distributed lag model was estimated as expenditures two, three or more years ago would have some effect on current period productivity. This model produced a statistically insignificant estimate of the permanent effect of Australian BERD at the mean of the full sample. The foreign effect is positive and economically large. The transitionary effects are jointly and highly statistically significant, and the permanent effect is significant at 10 per cent.

The signs on other variables accord with expectations and the magnitudes are plausible. The possible exceptions are communications infrastructure and education, which are not statistically significant. Education is included in the model to partially control for changes in the quality of labour arising from slow increases in formal levels of education, since the independent estimation of MFP is not based on a quality-adjusted labour services index (see appendix D for a discussion).

Robustness of the results

The models pass standard tests for heteroskedasticity and functional form. The Durbin-Watson statistic in models L4-L6 is high, which points to negative serial correlation. This sometimes happens when explanatory variables are highly ‘constructed’, for example, variables based on stocks or growth rates.

There was evidence of higher-order serial correlation in the model that includes R&D expenditure (model L6). Serial correlation problems in these models are related to the difficulty in properly specifying the dynamics of the model (a recurring theme) and to possible non-linearities in the relationship between R&D and productivity.

In general, the imprecision of the estimates — the wide confidence intervals — make it difficult to tell whether the partial effect of a parameter is increasing or decreasing over time because the confidence intervals from different sample periods overlap (see results from recursive estimation in appendix E).

The static models were estimated with Australian business R&D lagged at least one period. When the models were estimated with the contemporaneous value of

Australian BRD, there was evidence that BRD is not strictly exogenous. However, exogeneity tests with BRD lagged one period do not reject exogeneity. The test procedure used one or more of higher education R&D, government-performed R&D and/or government financed R&D performed by business as instruments. The instruments were correlated with BRD at a significance level of 5 per cent or more.

While the individual series in the models are non-stationary and appear to be of mixed orders of integration, the residuals from the models do not show signs of a unit root. The residuals were closely checked using the ADF, Philips-Perron, Dickey-Fuller generalised least squares and KPSS tests.[2] The tests suggest that the regressions are co-integrating regressions representing long-run equilibrium relationships unlike the test of co-integration for the basic levels model.

Higher education and government-performed R&D variables are not statistically significant in the regressions. These variables are highly collinear with business R&D impairing the separate identification of their effects.

As discussed in the previous chapter and in appendix L, results can be sensitive to the choice of control for the pro-cyclical nature of productivity. There are alternative methods which can be used, including: the growth rate in market sector value added; unemployment or inflation rates; indicators such as the ACCI-Westpac capacity utilisation measure; and univariate and multi-variate output gap measures.

Summary of the extended levels model

The results demonstrate that a wide range of estimates of the effect of R&D on productivity can be obtained from models that generally pass a common set of standard statistical tests. The magnitude of the coefficient on Australian business R&D varies greatly between models and its statistical significance depends on the particular specification. The sign on some variables can even change — foreign gross R&D, in particular, is sensitive to model specification and estimation.

Overall, the large and negative coefficient on foreign GRD in some models, and the implausibility of the implied very high rates of return to Australian BRD casts serious doubt on the static models. The introduction of dynamics results in an equally unsatisfactory negative effect of Australian BRD.

[2] See table 6.3 for a description of these tests.

7.2 Extensions to the productivity growth models

Results for four different types of productivity growth models are presented:

- models Y3 and Y4 use an R&D intensity measure specified as the knowledge stock over market sector value added (VA);
- in models Y5 and Y6, R&D intensity is specified as the change in the knowledge stock over market sector VA;
- gross expenditure data are used directly in model Y7 rather than a stock measure; and
- model J2 uses the change in the knowledge stock rather than an intensity measure.

The magnitudes of the elasticity coefficients are not directly comparable across the different types of models as they involve different relationships. All four models were estimated in both static and distributed lag forms. The static models of Y7 and J2 produced very poor results, and are not shown. A general-to-specific test down procedure was again adopted utilising the same initial set of controls (expressed in differences).

Results from alternative long-run relationships

Static growth models

Australian business R&D has a positive and statistically significant impact on MFP growth in only two of the six MFP growth models (models Y3 and Y5 in table 7.3). Both of these models are static models with reasonable statistical properties.

The results from model Y3 suggest that a permanent 1 per cent increase in Australian business R&D intensity is associated with a permanent increase in the growth rate of MFP of 0.04 percentage points. It implies that a 1 per cent increase in the intensity leads to an increase in the trend growth rate of MFP from roughly 1.0 per cent per year to 1.04 per cent per year ((0.01 + 0.04/100)*100). A 20 per cent increase would increase the growth rate of MFP to 1.8 per cent per year, which is a very large impact. From 1976-77 to 2002-03, the knowledge stock as a proportion of output increased nearly 70 per cent. The results imply an unrealistically high responsiveness of productivity to changes in intensities.

Table 7.3 **Influences on growth in MFP**[a]

Hetereoskedastic robust standard errors in brackets. All variables in logs

Lag structure	*Static Aus.=(t-1) For.=(t)*	*FDL*	*Static Aus.=(t-1) For.=(t)*	*FDL*	*FDL*	*FDL*
Dep'n rate (%)	*Aus. = 15 For. = 15*	*Aus. = 15 For. = 15*	*Aus. = 05 For. = 15*	*Aus. = 05 For. = 10*	*Gross investment*	*Aus. = 15 For. = 15*
	Y3: ln(K/Y)	Y4: ln(K/Y)	Y5: ln(ΔK/Y)	Y6: ln(ΔK/Y)	Y7: ln(R/Y)	J2: Δln(K)
Cycle (ΔΔ in real VA)	0.439*** (0.043)	0.451*** (0.075)	0.345*** (0.044)	0.357*** (0.031)		0.485*** (0.017)
Australian BRD	0.038** (0.015)	0.000[b] (0.011)	0.018** (0.008)	-0.001 (0.007)	-0.034***[b] (0.008)	-0.121**[b] (0.046)
For. GRD (ETM weighted)	-0.183*** (0.046)	0.079*[b] (0.035)	0.014* (0.007)	0.010[b] (0.007)	0.053[b] (0.048)	2.175***[b] (0.367)
Δci5iousage	-0.067* (0.031)	0.090** [b] (0.028)	-0.038 (0.049)	0.110**[b] (0.041)	0.039[b] (0.040)	0.004[b] (0.066)
Δeducation		0.022 (0.038)	0.093 (0.082)	0.054 (0.048)	-0.037 (0.035)	0.080** (0.031)
Δnonggitcap	-0.257*** (0.063)		-0.082 (0.062)	-0.041 (0.036)	-0.080** (0.026)	-0.157*** (0.020)
Δtiopenetm	0.037 (0.023)	-0.074** (0.029)	0.052 (0.032)	0.042** (0.018)	-0.008 (0.017)	
Δera	-0.052 (0.032)	-0.225*** [b] (0.031)	-0.044 (0.028)	-0.094**[b] (0.034)	-0.168***[b] (0.027)	-0.089**[b] (0.033)
Δcentbrg	-0.020*** (0.006)	-0.032*** (0.006)	-0.011** (0.004)	-0.014*** (0.004)	-0.020*** (0.004)	-0.040*** (0.005)
Dummy82				-0.021*** (0.006)	-0.007 (0.006)	
Shift1982			-0.016* (0.008)			-0.027** (0.008)
Shift1985				-0.016* (0.008)		
Shift1992	-0.022** (0.009)	-0.018*** (0.005)	-0.030* (0.016)		-0.013** (0.005)	0.032*** (0.007)
Constant	0.391*** (0.089)	-0.085 (0.049)	0.201*** (0.068)	0.032 (0.052)	-0.081 (0.194)	-0.031 (0.018)
Test statistics						
# of observations	24	27	27	27	27	25
R^2	0.908	0.992	0.857	0.968	0.984	0.997
1st order s.c.[c]	2.402	1.947	2.224	2.570	2.175	2.779
White heter.[c]	0.404	0.409	0.409	0.409	0.409	0.406
RESET[c] F(3,Z)	1.34 (0.311)	0.25 (0.857)	0.61 (0.620)	0.59 (0.641)	1.64 (0.266)	0.25 (0.856)
AIC*n (BIC)[c]	-159(-29)	-228(-68)	-166(-16)	-198(-47)	-214(-62)	-230(-82)

*** statistical significance at 1 per cent or greater. ** statistical significance at 5 per cent or greater. * statistical significance at 10 per cent or greater. Heteroskedastic robust standard errors in brackets. [a] Coefficients, standard errors and statistical significance is for the long-run effect. [b] Includes one or more lags. Joint F-test on initial value and lags statistically significant at greater than 5 per cent. [c] See table 6.3.

Source: Commission estimates.

Although specified using a different intensity measure, model Y5 lends broad support to the results in model Y3. In this case, a 20 per cent increase in intensity would increase the growth rate of MFP to 1.38 per cent per year. The 95 per cent confidence interval extends from 1.04 to 1.68 per cent per year, which is an extremely wide band considering the very significant welfare consequences of relatively small changes to long-run growth rates.

The two static models produced conflicting results for the effect of foreign R&D. Model Y3, with the larger implied impact of Australian BRD, produced a negative foreign effect, while model Y5 produced a positive effect, which accords better with expectations.

Dynamics in the growth models

The positive, economically large and statistically significant effect of Australian BRD on MFP growth in the static models was not supported by the distributed lag models. When a set of lags was included for each variable and tested down, the result was a negative or insignificant coefficient on Australian BRD and a positive coefficient on foreign GRD.

The permanent or long-run effects for Australian BRD and foreign GRD are only statistically significant at 10 per cent or greater for four of the eight coefficients (four FDL models by two variables). A joint F-test on the lags showed statistical significance at greater than 5 per cent for seven of the eight coefficients indicating that the variables do help explain short-run behaviour.

The partial effect of Australian BRD is insignificant in the FDL models under both R&D intensity specifications (models Y4 and Y6). The effect of foreign GRD is positive, but statistical significance is weak.

Model J2 was used earlier to test the effect of dropping the knowledge stocks in favour of gross investment/expenditure. Model J7 is a test of an intensity measure specified as gross investment over market sector value added. As is the case with all the models, the relationship with MFP growth is specified in log-linear form. The signs of the coefficients in model Y7 accord with the signs in the other distributed lag models. A negative and highly significant effect of Australian BRD is estimated. Foreign GRD is positive, but the permanent effect is not significant at 10 per cent.

In model J2, the magnitude of the coefficients on the R&D variables are much higher than in the other models, but the knowledge stock or change in stock has not been divided by output. The effect of Australian BRD is negative and statistically significant. The effect of foreign BRD is positive, large and statistically significant.

The sign on the coefficients for other variables in the model are consistent with other growth model results, except that education is statistically significant.

Results for the control variables

The coefficient estimates on some of the control variables differ markedly between the static and distributed lag models. The results from the distributed lag models are closer to expectations with the coefficient on communications infrastructure positive, and the coefficient on industry protection highly significant.

Equal percentage reductions in centralised wage bargaining and industry protection were estimated to provide a greater economic impetus to productivity growth than increases in business R&D intensity. In rate of return terms, the policy changes would offer much higher returns as they consume far fewer resources than is required to increase the knowledge stock as a proportion of output (recalling that the marginal product of R&D is the elasticity multiplied by the ratio Y/K, where K is the knowledge stock). However, while the direct resource costs of the policy changes would be small, the broader economic adjustments costs would also have to be taken into account.

Model Y5 appears to provide the best balance as it produced the expected positive signs on both R&D variables, but the non-R&D variables are estimated relatively poorly. Results for the controls can be improved by considering possible lagged impacts.

All variables in the static productivity models, both levels and growth models, use control variables entered contemporaneously. However, changes in some of these variables could be expected to impact on productivity with substantial lags. For example, reductions in industry protection might entail adjustment costs followed by improvements in productivity.

Testing indicated that static model results for the controls can be improved if ‘optimal’ lags are used. For example, industry protection, communications infrastructure and education are all estimated more precisely, and with expected signs, if they enter static models lagged one or two periods. This is consistent with the ‘longest lag’ from the test down procedures employed in the FDL models.

Better results in the controls through the inclusion of ‘optimal’ lags were generally accompanied with an insignificant estimate of the effect of Australian BRD. As there is a degree of arbitrariness in picking lags, the more ‘hands-off’ or conservative approach of including all controls contemporaneously was adopted for the presentation of results. In appendix H, results are presented for the expanded market sector based on ‘fine tuning’ the dating of controls variables.

Other tests and discussion of results

The intercept term was insignificant in all four FDL models. Dropping it changed the estimates for the R&D coefficients as per table 7.4. A significant intercept would be capturing unexplained effects on the average growth rate of productivity.

Table 7.4 **FDL growth models with the intercept removed**

	Model Y4	*Model Y6*	*Model Y7*	*Model J2*
Aus. BRD	0.013*	-0.005**	-0.031***	-0.086
	(0.006)	(0.002)	(0.006)	(0.044)
Frn. GRD	0.041*	0.008	0.033***	1.588***
	(0.022)	(0.006)	(0.006)	(0.182)

Source: Commission estimates.

Whereas the point estimates were zero and insignificant for Australian BRD in Y4 and Y6, they are now significant at greater than 5 per cent. In model Y4, Australian BRD now has a positive and economically significant impact on MFP growth. A 10 per cent increase in the ratio of the knowledge stock over output results in an increase in the permanent rate of MFP growth from around 1.0 per cent per year to between 1.01 to 1.25 per cent per year.

In model Y6, the effect is negative and tightly bound to zero. The effect remains negative in Y7 and J2, but is no longer significant in J2. The main change to the effect of foreign GRD is that its permanent effect becomes highly significant in model Y7.

Model J2 was tested for scale bias by entering the product of the growth rate of capital and labour (see van Pottelsberghe 1997, p. 39). The coefficient was negative, but not statistically significant indicating that the coefficients are not biased by the constant returns to scale assumption used in the construction of MFP.

Overall, the results for the MFP growth models highlight the recurring problem of obtaining positive and plausible coefficients on both domestic and foreign R&D within a single model. None of the regressions was able to separately identify the effect of Australian higher education or government-performed R&D.

That said, the results in models Y4, Y5 and Y6, after dropping the intercept, produce plausible estimates of the effect of Australian BRD and foreign R&D variables. But this still leaves open whether the effect of Australian BRD at the level of the market sector is tightly bound to zero — suggesting that the social and private return to R&D are not that much different — or is positive and economically significant. Chapter 10 tries to narrow the band of results by estimating a two-equation system.

7.3 Static versus dynamic model results

When the ln(MFP) models were extended, the coefficient on foreign GRD turned *negative* and was large and highly statistically significant (with or without the inclusion of a time trend). The implied return to Australian BRD increased and was high even by the standards set in the literature. On the other hand, the FDL models tended to give a large and positive foreign effect: the effect was highly significant in explaining short-run variation in productivity; and the long-run effect was statistically significant in some models, but not others. The effect of Australian BRD varied from a strong positive effect to either an economically and statistically insignificant effect, or a negative and significant effect.

Why the major difference in results? Given unit roots in the data, and if the variables in the static models were to form a strong co-integrating regression, then simple ordinary least squares estimation of the static models and estimation of the long-run effect from the equivalent FDL models (properly dynamically specified, see appendix M) should produce very similar estimates. Crucially, the alternative estimation strategies should not produce oppositely signed estimates.

By introducing lags into the FDL models, more parameters have to be estimated and there can be a loss in efficiency compared with the static models. A significant loss in efficiency could change the sign on coefficients. However, if the nature of the R&D-productivity relationship is such that the presence of lags is important in obtaining an estimate of the effect of R&D, then the static model will generate biased estimates.

Testing indicated that the basic MFP-knowledge stock relationship in levels was not co-integrated (see appendix E). 'White' residuals were only obtained when the relationship was extended to include other sources of growth and controls. Without a co-integrating relationship, the static model may still produce statistically significant results, but they risk being spurious. With the introduction of lags, the FDL model is more likely to detect a 'co-integrating vector'. Even if there is not a long-run or permanent relationship, the FDL model may still explain short-run or transitional variance in productivity, as is evident in some models.

Information criteria indicate that the distributed lag models fit the data better than their static counterparts. Also, the non-R&D variable estimates are usually better estimated in the FDL models.

Four points appear to undermine the results from the static single equation level models: economic criteria concerning the magnitude of the implied returns to Australian BRD and the negatively signed foreign effect; an absence of co-integration in the basic level models without dynamics and which do not include other growth variables and controls; the discrepancy between the static and FDL models on the sign of coefficients in some cases with the results from the FDL models according better with expectations; and the fact that some of the FDL models are unable to detect a permanent or long-run effect (which seems plausible given the amount of change in R&D activity and structural changes in the economy).

Both the static ln(MFP) models and the static productivity growth models may be misspecified from not taking account of the various types of lags associated with R&D investment.

7.4 The effect of foreign R&D on Australian productivity

A large range of tests were carried out to check whether the negative relationship between Australian MFP and foreign GRD in some models was sensitive to choices that had been made in the construction of the foreign R&D expenditure time series, the construction of knowledge stocks, and the estimation of the models. In the static models for the market sector, the negative coefficient held throughout the tests (box 7.1).

Testing indicated that the result was not related to: the aggregation of fourteen countries into a single R&D stock, as a stock based on just US data provided the same result; use of the perpetual inventory method (PIM) stock construction methodology (gross expenditures also produced negative effects); the choice of assumed decay rate; the assumption of a constant rate of decay ('profiles' of a changing rate of decay were tested); or the aggregation or weighting procedure for foreign stocks.

There is a possibility that it is purely a statistical phenomenon associated with the use of non-stationary data in level form. A negative coefficient is found in models where the residuals pass standard statistical tests, but this could be a 'textbook' example of a spurious regression. However, a negative coefficient is also found in some static first differenced regressions (for example, model Y3). The differenced equations may also contain mismatched orders of integration between R&D and productivity growth rates or between productivity growth and R&D intensities.

The distributed lag models produce positive foreign effects, which again suggests that taking account of dynamics is important. However, some of these models produce a negative or insignificant coefficient on Australian business R&D, which is a concern (although possible)

Box 7.1 **A weak or negative effect of foreign R&D on Australia**

A negative foreign effect has been found in other studies. It has arisen in the Australian study of Rogers (1995) and the cross-country panel studies of Engelbrecht (1997) and Madden et al. (2001). Engelbrecht found that R&D spillovers over the period 1971–1990 had a mainly negative impact on domestic total factor productivity in countries with relatively small R&D capital stocks. These countries included Australia, Greece, Ireland, Israel, New Zealand, Portugal and Spain. The elasticity on foreign R&D was -0.06 for Australia. Engelbrecht (1997, p. 318) speculated:

> This interesting finding suggests that, for this group, more domestic R&D might be a prerequisite for increasing the capacity to absorb foreign R&D.

While the lack of 'absorptive capacity' might be an explanation for a weak positive impact of foreign R&D, it is not clear why it should result in a negative impact. A continued inability to absorb foreign knowledge might result in Australia not participating in the uptake of various technologies that provide strong MFP growth elsewhere, but this would be an argument for poor relative productivity performance, and not a negative impact on MFP.

Very sluggish uptake in Australia could be part of a process where overseas changes in the capital stock garner an advantage to overseas firms in competitive markets which suppresses the output of Australian firms. However, this would require that Australian firms did not respond to the deterioration in their competitive positions (and profits), which would be puzzling behaviour. However, high levels of industry protection may have allowed Australian firms to maintain profitability while using higher cost 'out-of-date' production technologies, impacting negatively on productivity. The reduction in industry assistance and other reforms increased competitive intensities providing the incentives for a more rapid up-take of technologies.

Two other possible mechanisms[3] might be:

- International trade and comparative advantage lead Australia to specialise in low-tech industries whilst trading partners specialise in high-tech industries; returns to R&D in high-tech industries are high, so trading partners invest heavily compared to Australia; and productivity growth is inherently lower in low-tech industries. Then a rise in Australian trade openness would lead to a rise in foreign R&D capital (assuming stocks are scaled by the ratio of imports over output as per equation (F2) in appendix F) and a simultaneous drop in Australian productivity growth. But the correlation would be 'accidental' rather than causal.
- Overseas R&D activity and the technological change that it generates affects the capital investment plans of Australian businesses. Overseas technological change increases the value of delaying acquisitions. Lower investment would depress productivity in the short term (resulting in a contemporaneous correlation), but not the long term.

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[3] The first mechanism was suggested by Professor Steve Dowrick and the second by Professor Peter Hall.

Box 7.1 **(continued)**

A mechanism associated with the importing of embodied technology and its measurement in the national accounts might also be part of an explanation. Increases in foreign R&D improves the quality of technologies imported into Australia. The improvements in quality are only partially adjusted for in the national accounts. This results in capital services measures increasing more than otherwise, and a lower MFP growth residual.

Other international studies have generally found a positive but relatively weak foreign effect for Australia, including the Coe and Helpman (1995) study. Kao et al*.* (1999) updated Coe and Helpman's study using advances in panel co-integration techniques and found a similar result for Australia. In relation to Coe and Helpman's findings, Industry Commission (1995, vol. 3, p. QA.48) commented that the magnitude of the foreign effect might increase over time, 'Recent trade liberalisation in Australia over the last decade is likely to increase the importance of foreign R&D to the Australian economy in the future'.

Eaton and Kortum (1996) estimate that foreign technological innovations are much more significant for Australian productivity growth. Only 8 per cent of productivity growth in the 1980s in Australia was due to domestic research activity, while technological innovations from the United States, Japan and Germany contributed 40, 16 and 12 per cent, respectively.

7.5 Summary discussion of market sector results

The modelling of the effect of R&D on market sector productivity has shown a wide range of results. Some results have fewer apparent economic and statistical problems than others. But to rely on the more 'favourable' results would be to underplay the lack of precision and robustness that is shown up by comprehensive testing of models.

The main result from the market sector models at this point in the paper is that there is great uncertainty as to the magnitude of the effect of Australian business R&D and foreign R&D on Australian productivity, as the estimates are very sensitive to model specification. Plausible productivity growth models give a positive foreign effect, but the effect of Australian BRD ranges from implying little difference between social and private returns to an economically important effect of spillovers.

While the effect of both domestic and foreign R&D are expected to be positive — based on theory and the majority of previous empirical studies — the data do not offer strong, unequivocal support for a particular model. However, estimates of the partial effect of some of the control variables appear more robust.

The results raise a number of issues that are investigated further in the following chapters.

- *The aggregation of 'unlike' industries*. Part of the fragility of market sector results may be related to the problem of aggregating industries with very different production technologies. Chapter 8 and appendix J investigate the effect of R&D at a lower level of industry aggregation.
- *A negative foreign effect*. Chapter 9 investigates alternative ways of constructing the potential spillover pool to Australia, whether patent indicators can provide more reliable results than foreign knowledge stocks, and various characteristics of Australia that may condition the magnitude of the foreign effect on Australian productivity.
- *Causes of the increase in business R&D investment*. The contrast between the 'different periods' for the growth in the stock of Australian business R&D is so stark that it naturally motivates an investigation of the causes of the increase in business investment. Chapter 10 investigates various influences on business R&D, with the modelling set-up providing an alternative approach to addressing bias which can result from the 'simultaneity' of R&D and output.
- *Parameter instability*. There are many reasons to suspect that the structural relationship between R&D and productivity may not have been stable over the last thirty years. While various approaches have been tried to precisely identify changes in parameters, there was a lack of consistency in results, hampered by the overall imprecision of many estimates. Appendix O investigates changes in the effect of R&D further. Chapter 11 considers the implications for the measured return to R&D.

8 Industry estimates of the effect of R&D

This chapter discusses estimation issues and results from the regressions that seek to establish the quantitative relationship between R&D effort and productivity performance for individual industries.

A summary of the major data series used in the estimation is provided in chapter 5. As noted in chapter 5, the industries for which data could be obtained were confined to Agriculture, Manufacturing, Mining and Wholesale & retail trade.

8.1 Previous Australian industry studies

The number of empirical works on R&D that focus on broad industry sectors is quite limited. Most other studies tend to use data at a lower level of aggregation, in particular, for the sub-industries within manufacturing. Detailed manufacturing data are relatively easy to obtain, and of relatively better quality, as they have fewer measurement issues compared with data on other sectors.

Industry Commission (1995) and Connolly and Fox (2005) estimate models at the one-digit ANZSIC[1] level. Productivity Commission (2003) used manufacturing data at the 3-digit and 4-digit levels, while Chand et al. (1998) used the Gretton and Fisher (1997) dataset. This dataset, which is also used in appendix J, provides time series of productivity, capital and labour for eight manufacturing subdivisions.[2]

The estimated elasticities and implied rates of return to R&D vary widely across the studies (table 8.1). The rate of return to own-industry R&D in manufacturing (at the one-digit level) is estimated to be only 13 per cent in Industry Commission (1995). Productivity Commission (2003) produces an estimate which is twice as high, although various factors, such as different specifications and data, may explain the difference.

[1] Australian and New Zealand Standard Industrial Classification.

[2] The dataset constructed by Gretton and Fisher (1997) is based on unpublished ABS data.

Table 8.1 The effect of own-industry and foreign R&D on productivity growth in Australian industry-level studies

Study	*Dataset and time period*	*Dependent variable*	*Key findings, Elasticity (γ) rates of return (ρ)*	*Key findings and comments*
Industry Commission (1995)	Various industries, 1976-77 to 1989-90	ln(MFP)	Broadacre agriculture: γ for own R&D not available; γ = 0.066 and ρ = 1.9% for the stock of foreign R&D. Manufacturing: γ = 0.014 and ρ = 13% for own R&D and γ = 0.066 and ρ = 7% for foreign R&D. Mining: both own and foreign R&D stocks are excluded from the regression, as they are not significant. Other services: γ = 0.052 and ρ = 263% for own R&D; γ = 0.030 and 3% for foreign R&D. Wholesale and retail trade: negative γ is estimated, but overall fit and specification of the model are questioned.	R&D has some positive effect on productivity at the industry level. The rates of return to R&D appear to vary among the sectors. Most industries in the study appear to receive spillover benefits from foreign R&D and from R&D undertaken in other sectors. Despite various control variables being used, questions can still be raised about the robustness of the results.
Chand, McCalman and Gretton (1998)	Manufacturing, Gretton and Fisher (1997) dataset	Δln(Y)	γ = 0.06 (not significant at the 10 per cent level) two digit-manufacturing panel (using the economy-wide stock of R&D performed by both domestic private and public sectors), γ = -1.55 (not significant) in Printing etc industry, γ = 2.45 (a significant at 10 per cent level) in Transport equipment.	Trade liberalisation raises output growth, although the estimated elasticities w. r. t. R&D capital, public infrastructure and human capital are negative in several industries. The effect of foreign R&D spillovers is not considered.
Productivity Commission (2003)	Manufacturing, various levels of aggregation, using 3 digit manufacturing data to quantify the effect of R&D intensity on labour productivity growth	Δln(Y/L)	In the regression using 3-digit ANZSIC manufacturing data, the estimated coefficient associated with R&D intensity is 0.26. This implies that an additional 0.26 percentage points of labour productivity growth can be attributed to every percentage point of higher R&D intensity.	The most statistically robust result of the modelling indicates that industries categorised as having high R&D intensities, or characterised as ‘high technology’, had labour productivity growth rates that were significantly higher than other industries.

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Table 8.1 **(continued)**

Study	*Dataset and time period*	*Dependent variable*	*Key findings, Elasticity (γ) rates of return (ρ)*	*Key findings and comments*
Connolly and Fox (2006)	10 one-digit market-sector industries and aggregate market-sector, mainly based on ABS data: 1966-2002	ln(MFP) ln(Y)	The industry's own R&D stock is used as a control variable in the regression for the two market-sector industries, Accommodation, cafes & restaurants and Cultural and recreational services, but the coefficients are both negative and significant in the preferred, ln(MFP) based regressions, γ = -0.772 and -0.485.	The focus of the study is placed on the impact of IT capital on productivity. The issue of the significantly negative estimates of R&D elasticities found in the two industries is not discussed.

Since some of the studies include R&D as a control variable rather than as the variable of primary interest, the estimated R&D effects could be classified as 'incidental', as opposed to thoroughly investigated. The studies of Chand et al. (1998) and Connolly and Fox (2006) focus on industry protection and the role of ICT in productivity growth, respectively. Both studies present elasticity estimates for R&D that are very large and negative in some industries.

Some studies do not include control variables or other sources of growth in their regressions. Other studies include various control variables or other sources of growth that differ greatly across studies, even where the models are based on the same overall framework, and use essentially the same data. Despite the fact that various justifications are given, there is a degree of arbitrariness — which may be unavoidable — in choosing different control variables. The set of control variables also changes across models within this study.

As the estimated R&D elasticities in these studies are wide-ranging, and even negative in some cases, clearly they are highly sensitive to the changes in data, methods, and the focus of the issues under investigation. A lack of robustness in estimates seems to be a common weakness that is shared by many R&D empirical studies (Diewert 2005).

8.2 Regressions

The results in this section are from regressions based on equations (3) and (5) of chapter 4.[3] That is, the two-step approach is used, with both level and intensity specifications.

The main focus is on the estimates of the elasticity of multifactor productivity (MFP) with respect to the industry's own R&D capital stock. Using the estimated elasticities, the gross rate of return to R&D investment can then be derived.

R&D variables

Several measures of R&D capital stock at the one-digit industry-level (as defined in chapter 5) are used in the regressions.

- *Own R&D.* The industry's own R&D stock measure is based on R&D that is performed as well as financed by the industry, with an assumed annual rate of decay of 15 per cent.[4]
- *Inter-industry R&D.* This stock measure is based on the R&D performed by other Australian industries, weighted by either inter-industry trade or technological distance (see appendix C).
- *Foreign.* This stock measure is based on R&D performed in other countries, weighted by either the share in Elaborately Transformed Manufactures imports to Australia or technological distance. It can be aggregate or industry-specific foreign R&D (see appendix F).
- *Public.* This stock measure is based on R&D performed by higher education, government and private non-profit institutions.

As mentioned in chapter 5, appropriate data on R&D expenditure in Agriculture, forestry & fishing, are not available. For this study public expenditure on R&D is used in regressions for this industry. The measure of public R&D is only available for the economy as a whole. Its use in the regressions for Agriculture, forestry &

[3] Regression models based on the specification of equation (2), where value added output is used as the dependent variable, were also estimated. But the results from these models are rather problematic. Thus, the specifications of equations (3) and (5) are preferred.

[4] Regressions with a stock measure based on the R&D performed by the industry, including all sources of finance, were also estimated. The estimated elasticities were not statistically different (see appendix K for sensitivity tests). Also, the implied rates of return did not seem very sensitive to changes in the assumed rate of decay used in the construction of the industry's own R&D stocks.

fishing may be interpreted as capturing the total public R&D effect on the industry's productivity.

Other control variables

Several variables are used to control for productivity enhancing factors other than the R&D capital stock. A time trend is included in the empirical models, except in Agriculture, because many variables in log level form display clear, upward, linear trends (see appendix E for unit root tests). In Agriculture, the intensity specification of equation (5) in chapter 4 is used, in which the time trend is naturally eliminated. The linear time trend in the level specification also captures the causes of measured productivity growth that are not related to growth in the R&D capital stock. These causes may include economies of scale, market power, and factors from other methods of improving the efficiency in production that are not captured by the other control variables included in the regression equations. As there are only 29 years of data, only a small set of control variables could be included in the regression models.

Ruling out panel techniques

It is reasonable to expect that the models for different industries would contain some industry-specific control variables, while any common control variables used in different industries may attract differences in estimated coefficients, reflecting the considerable amount of heterogeneity across industries. The kind of econometric technique applied should allow for these differences.

While panel data techniques are very powerful in dealing with data in both cross-section and time-series dimensions, they may not be the best tool in this instance. They impose a common set of control variables and the same elasticities across different industries, with the differences only being explicitly captured by the intercept terms (in the fixed effects models). Although the elasticities with respect to R&D across industries can be allowed to differ under panel regressions by introducing various interaction terms (see, for example, Cameron 2004), this approach has not been attempted here due to the small sample size available.[5]

[5] The experiments with panel estimation did not yield economic and statistically significant results, indicating that the data may not be 'poolable'.

The 'test down' procedure

As a first step, time series models were estimated for each industry separately. A set of control variables that is most suitable for each industry was determined from theoretical consideration of the variables of economic significance and then testing their statistical significance in regressions. If any coefficient of the control variable did not have the expected sign, and/or its presence adversely affected the overall fit of the model or the significance of the coefficient associated with the main variable of interest, then it was deleted. For example, an index of the level of education for each industry's labour input was included in the industry regressions as a proxy for the measure of human capital and as a control for the quality of labour input. However, the estimated coefficient associated with this variable was either negative or highly insignificant. As a result, this variable was excluded from further regressions. The estimates shown in tables 8.2 to 8.5 are the result of this 'test down' procedure.[6]

The set of control variables

A variable measuring the inter-industry R&D capital stock weighted by either inter-industry trade or technological distance was included initially (see appendix C for more information). The measure was to control for the effects of spillovers and inter-industry technology flows on the industry's productivity growth. It turns out that this variable is highly insignificant (*p*-value >50 per cent) with a negative sign in most of the regressions. This type of spillover among industries is likely to be important, raising the question as to whether this effect has been adequately captured by the constructed variables under the current measurement framework. The industry-level results suggest that the current indicator of this highly aggregated, imprecise measure introduces more 'noise' into the models. Thus, inter-industry R&D stocks were excluded from the regressions. In the manufacturing panel models of appendix J, inter-industry stocks are highly significant, but it was not possible to achieve consistently signed estimates between MFP and LP models.

It is well-known that measured MFP is pro-cyclical. Some empirical studies include a variable to control for this effect in the regression equations in which MFP is used as the dependent variable. However, there is more than one measure that can be used to control for this effect (see appendix L). In some studies, for example

6 This way of selecting the control variables may be said to be 'data mining'. However, since there are no specific theories to draw on to determine which variables should be included and excluded in many empirical studies, it is common practice to choose control variables that are based on some level of judgment as well as on data availability. This may also be one of the reasons that it is often difficult to replicate the estimates from other empirical studies.

Dowrick and Nguyen (1989), a measure of capacity utilisation is used. It is based on the residuals from the regression of a volume measure of value added on a time trend. An increase in this variable approximates the effect of a higher rate of capacity utilisation.[7] Other measures to control for the cyclical effect include the real GDP gap and a variable simply measuring real GDP growth (for example, Engelbrecht 1997).

Clearly, all these cycle variables are proxies. The exact impact of using different proxies to control for the same effect on the econometric estimates is generally unknown.[8] Experiments were conducted using either the capacity utilisation index or the growth rate of real gross value added to control for the cyclical effect in the regressions for each industry. Since the two measures both performed poorly, they were both dropped from the industry-level regressions.

The foreign R&D capital stock is often treated as a variable of main interest in many empirical studies, because it is intended to capture the effect of international R&D knowledge transfer, which is considered to be an important source of domestic productivity growth. As with the measure of domestic R&D capital stocks, foreign R&D stocks can be constructed for the whole economy (or market sector) and for particular industries. For industry level analysis, the construction of foreign R&D stocks can take account of inter-country relationships or both inter-industry and inter-country relationships (see appendix F for details). It is usually more difficult to construct industry-specific foreign R&D stocks because of data constraints. For Manufacturing and Wholesale & retail trade, foreign stocks were constructed from both foreign aggregate or country-level business expenditure on R&D (BERD) data and from industry-level data. For the other two industries, the foreign R&D stock was based only on aggregate BERD. The foreign R&D stocks were weighted by the US Patent and Trademark Office's patent grants data (foreign).

The remaining control variables included in the regression equations were the usage of public infrastructure, change in oil price, an index of trade openness, CPI, a measure of rainfall, IT capital, use of communication infrastructure and farmers'

[7] There is no consensus approach to measuring capacity utilisation. See Hulten (1986 and 1990) and Berndt and Fuss (1986) for a detailed discussion. For a recent discussion of measuring capacity utilisation within the framework of national accounts, see Durand (2002).

[8] Coe and Helpman (1995) do not control for the business cycle effect in their macro-level regression models, while Engelbrecht (1997) uses a variable measuring real GDP growth to control for business cycle effect. Controlling for the business cycle effect could be one of the contributing factors for the negative elasticities on foreign R&D for a number of OECD countries, including Australia, estimated by Engelbrecht (1997). Engelbrecht (1997) uses the same dataset as that of Coe and Helpman (1995), but the latter does not obtain any negative elasticities.

terms of trade. Apart from the variable of usage of public infrastructure, which appears in all the four regression equations, the remainder of the control variables were only included in some industries while excluded from others (as a result of the 'test down' procedure).

The amount of rainfall and farmers' terms of trade were included as being relevant factors affecting productivity in Agriculture, forestry & fishing. The CPI and the change in oil price were included to control for the cyclical effects in Wholesale & retail trade and Mining, respectively. The Wholesale & retail industry largely serves to meet the demands of final consumption, while final consumption demand can be strongly influenced by the changes in CPI. In the absence of an appropriate price index for Mining as a whole, the oil price index is used as a proxy to control for some major cycles which may have a direct impact on the world energy market and the mining industry in particular.

As in other Australian studies, (for example, Chand, McCalman and Gretton 1998, Chand 1999 and Oczkowski and Sharma 2001), an index of trade openness was included in the manufacturing productivity regression. The variables of IT capital and use of communication infrastructure were included for Wholesale & retail trade.

8.3 Results

The results for Manufacturing, Mining and Wholesale & retail trade are based on the log level specification of equation (3) of chapter 4, while the intensity form of equation (5) is used for Agriculture. This choice of specification for Agriculture is an empirical outcome. Because the intensity specification tends to reduce the level of volatility in output and productivity observed in this industry, it yields more plausible results.

The estimated effect of own-industry R&D on MFP is positive for each of the 3 industries for which log levels were used (table 8.2). In Manufacturing, the estimates imply that a 10 per cent increase in the industry's stock of R&D capital results in a 0.38 increase in MFP.

The aggregate foreign R&D stock measure was tested in each of the four industries. The coefficient on foreign R&D is significant (but negative) in Manufacturing only when the aggregate measure was used, whereas it is not significant (also negative) in other industries when either the aggregate or the industry-specific foreign R&D measures were used. As a result, the foreign R&D stock was retained only in Manufacturing, and was in the form of an aggregate measure.

Table 8.2 **Linear regression results for the four market-sector industries**[a]

	Log (MFP) as the dependent variable			Δlog(MFP) as the dependent variable
	Manufacturing	*Mining*	*Wholesale & retail trade*[b]	*Agriculture, forestry & fishing*[c]
R&D capital stocks				
Own	0.038**	0.077**	0.055**	
	(0.0168)	(0.035)	(0.019)	
Public	-2.46**	4.07**		
	(0.455)	(0.814)		
Foreign	-0.2125**			
	(0.0785)			
R&D intensity				
Public				0.317**
				(0.135)
Other control variables				
Time	0.076**	-0.153**	-0.058**	
	(0.015)	(0.021)	(0.009)	
Usage of public infrastructure	0.165*	1.23**	0.844**	0.993**
	(0.0924)	(0.082)	(0.165)	(0.059)
Change in oil price		0.059**		
		(0.020)		
Trade openness	0.077*	0.355**		
	(0.0443)	(0.113)		
CPI			-0.421**	
			(0.094)	
IT capital (hardware and software)			0.179**	
			(0.035)	
Use of communication infrastructure			0.511**	
			(0.102)	
Rain				0.015**
				(0.007)
Farmers' terms of trade				0.159**
				(0.064)
Test statistics				
Sample	1974/75-2002/03	1974/75-2002/03	1974/75-2002/03	1974/75-2002/03
R^2	0.81	0.95	0.96	0.97
DW	2.2	1.7	2.4	2.2
AIC	-183.5	-124.7	-162.6	-124.4
RESET F(2, T-K-3)	0.28	0.84	2.16	0.64
	Pr > F: 0.76	Pr>F: 0.45	Pr > F: 0.14	Pr > F: 0.54
Unit root test (Phillips-Perron) for the residual:	rejected with p-value < 0.0001	rejected with p-value < 0.0001	rejected with p-value < 0.0001	rejected with p-value < 0.0001

** indicates the p-value associated with the estimated coefficient is less than 5 per cent, while * indicates the p-value is between 5 and 10 per cent. **a** Standard errors are in parentheses. **b** For Wholesale & retail trade, the results are based on the Yule-Walker estimates after adjusting for autocorrelation of order 3. **c** The intensity specification of equation (5) in chapter 4 is used for Agriculture. The R&D intensity is defined as the change in R&D capital stock divided by the real output, and the relevant control variables used for this industry are in first difference.

Source: Commission estimates.

A negative foreign spillover effect has also been observed in other empirical studies on R&D, for example Engelbrecht (1997). It was also found in some aggregate market-sector regressions (see chapter 7).

While the estimated models pass major diagnostic tests, including no heteroskedasticity (not shown in the table), there are still some results that are quite 'unsatisfactory'. For example, in Manufacturing the coefficients associated with public and foreign R&D stocks are both negative, and the coefficients associated with public R&D in Manufacturing and in Mining are also quite large in magnitude. Although the negative public R&D coefficient in Manufacturing is somewhat counter-intuitive, the high level of statistical significance of this variable indicates that it may not be appropriate to exclude it from the regression equation.

Only in Wholesale & retail trade are the coefficients on IT capital and usage of communication services by industry significant and of the expected sign. This would support the conclusion that the heavy use of ICT is one of the major determinants of the productivity changes in this industry, a well-known result that has been found in many other studies. For the other industries, this effect does not seem strong enough to warrant the variables being included in their regression equations.

One variable that is significant in each of the four industry-level regressions is the use of public infrastructure. The positive effect of public infrastructure on productivity in Australia has been found in other studies (for example, Otto and Voss 1994; Connolly and Fox 2005). It was also found at the market-sector level in this study.

The regression equations used above do not contain any lagged variables. However, lags do exist between an investment in R&D and its impact on production and productivity.[9] As discussed in chapter 4, it can be argued that the perpetual inventory method (PIM) used to construct the R&D stocks includes current as well as past investment expenditure on R&D, thus there seems no need to use lags of the R&D stock variables. On the other hand, one can also argue that current expenditure on R&D is assigned the largest weight (which is one, because of no depreciation) in PIM, and it has the strongest single impact on the current period R&D stock, thus lagged R&D stock variables may be required in the regression equations to fully reflect the lags between R&D and productivity.

[9] The same is also true for traditional capital. But in general, the lags associated with R&D are likely to be much longer than with traditional capital. See chapter 4 for a brief survey and discussion of the issues of the lag structure related to R&D.

To accommodate the argument about lags between R&D activity and performance effects (chapter 4), the models were re-estimated with lags on all the R&D stock variables. The results show that a one-period lag seemed most appropriate, as it largely maintained the level of significance for the majority of coefficients (table 8.3). Nevertheless, the estimates on the lagged R&D variables (table 8.3) are not significantly different from those without lags in table 8.2.[10]

Table 8.3 **Results from linear regressions using the lagged R&D capital stocks[a]**

	Log (MFP) as the dependent variable			*∆log(MFP) as the dependent variable*
	Manufacturing	*Mining*	*Wholesale & retail trade*[b]	*Agriculture, forestry & fishing*[c]
R&D capital stocks				
Own (t-1)	0.036*	0.081**	0.034	
	(0.0195)	(0.037)	(0.024)	
Public (t-1)	-2.12**	3.81**		
	(0.50)	(0.986)		
Foreign (t-1)	-0.128			
	(0.086)			
R&D intensity				
Public (t-1)				0.332**
				(0.145)
Other control variables				
Time	0.063**	-0.146**	-0.075**	
	(0.017)	(0.025)	(0.012)	
Usage of public infrastructure	0.217*	1.26**	0.556**	0.919**
	(0.102)	(0.084)	(0.224)	(0.052)
Change in oil price		0.055**		
		(0.021)		
Trade openness	0.074	0.38**		
	(0.051)	(0.116)		
CPI			-0.423**	
			(0.114)	
IT capital (hardware and software)			0.219**	
			(0.047)	
Use of communication infrastructure			0.705**	
			(0.118)	
Rain				0.015**
				(0.007)
Farmers' terms of trade				0.149**
				(0.064)

(continued on next page)

[10] With the exception of Wholesale & retail trade where the coefficient on the industry's own R&D became insignificant when the lagged R&D variable was used in the regression.

Table 8.3 **(continued)**

	Log (MFP) as the dependent variable			*∆log(MFP) as the dependent variable*
	Manufacturing	*Mining*	*Wholesale & retail trade*[b]	*Agriculture, forestry & fishing*[c]
Test statistics				
Sample	1974/75-2002/03	1974/75-2002/03	1974/75-2002/03	1974/75-2002/03
R^2	0.77	0.95	0.95	0.97
DW	2.0	1.7	2.2	2.1
AIC	-174	-123	-151	-124
RESET F(2, T-K-3)	0.67	0.56	1.48	0.96
	Pr > F: 0.52	Pr>F: 0.57	Pr > F: 0.25	Pr > F: 0.40

** indicates the p-value associated with the estimated coefficient is less than 5 per cent, while * indicates the p-value is between 5 and 10 per cent. [a] Standard errors are in parentheses. [b] For Wholesale & retail trade, the results are based on the Yule-Walker estimates after adjusting for autocorrelation of order 3. [c] The intensity specification of equation (5) in chapter 4 is used for Agriculture. The R&D intensity is defined as the change in R&D capital stock divided by the real output, and the relevant control variables used for this industry are in first difference.

Source: Commission estimates.

Results from joint estimation

The previous results were obtained from regression equations that were estimated separately for each industry. The models can also be estimated jointly using seeming unrelated regression equations (SURE), which use the contemporaneous correlation in the errors (with error variances able to differ across industries) to possibly improve the quality of the estimates, compared with independent estimation of each of the industries.

The SURE estimator produced similar results to those from the linear regression estimated separately for each industry, but it resulted in the coefficients for industry's own R&D elasticity in Manufacturing and Wholesale & retail becoming insignificant (table 8.4). However, the condition under which SURE improves on the results from equations estimated separately is the existence of contemporaneous correlation. If contemporaneous correlation does not exist, least squares applied separately to each equation is fully efficient and there is no need to employ SURE. Thus, it is useful to test whether the contemporaneous covariances are zero.

In the four-equation system used above, the null hypothesis for the test is that all the contemporaneous cross-model covariances are zero, while the alternative is that at least one of the covariances is nonzero. The test indicated that the evidence for the existence of the contemporaneous correlation in the equation system is somewhat weak.[11] Thus, the results from independently estimated equations are preferred to those based on SURE.

Table 8.4 **SURE results for the four market-sector industries[a]**

	Manufacturing	*Mining*	*Wholesale & retail trade*	*Agriculture, forestry & fishing*[b]
R&D capital stocks				
Own	0.027	0.077**	0.038	
	(0.016)	(0.032)	(0.044)	
Public	-2.53**	3.81**		
	(0.462)	(0.758)		
Foreign	-0.222**			
	(0.085)			
R&D intensity				
Public				0.314**
				(0.132)
Other control variables				
Time	0.094**	-0.134**	-0.042**	
	(0.016)	(0.019)	(0.020)	
Usage of public infrastructure	0.102	1.211**	0.789**	0955**
	(0.090)	(0.075)	(0.382)	(0.056)
Change in oil price		0.072**		
		(0.018)		
Trade openness	0.085*	0.361**		
	(0.045)	(0.105)		
CPI			-0.413**	
			(0.174)	
IT capital (hardware and software)			0.181**	
			(0.071)	
Use of communication infrastructure			0.533**	
			(0.242)	
Rain				0.018**
				(0.006)
Farmers' terms of trade				0.117**
				(0.060)

** indicates the p-value associated with the estimated coefficient is less than 5 per cent, while * indicates the p-value is between 5 and 10 per cent. **a** Standard errors are in parentheses. **b** The intensity specification of equation (5) in chapter 4 is used for Agriculture. The R&D intensity is defined as the change in R&D capital stock divided by the real output, and the relevant control variables used for this industry are in first difference.

Source: Commission estimates.

11 The Lagrange multiplier test statistic suggested by Breusch and Pagan, λ, took a value of 12.39. Under the null, λ has an asymptotic χ^2 distribution with 6 degrees of freedom. At the 5 per cent level of significance, its critical value is 12.59, which is just above the test statistic, while the 10 per cent critical value is 10.64.

Results from the specification adjusted for double-counting

Since R&D activities involve expenditure on labour and capital, the measure of R&D capital stock, which is based on R&D expenditure, naturally includes a portion of the capital and labour inputs that are traditionally included in production function estimates or in deriving MFP estimates that are used in two-step procedures (see chapter 4). This is the issue of double counting discussed in chapter 4 and appendix K. A related issue is that R&D is treated as an intermediate expense rather than as a capital asset in the current framework of national accounts. Thus, the value added generated from this framework may be mismeasured. In econometric estimation, the bias resulting from the mismeasured value added is called expensing bias (Schankerman 1981). This bias can potentially offset the bias arising from the double counting (see appendix K for further details).

The econometric specification set out in appendix K was used to take account of both the double-counting and expensing bias.

$$\ln MFP' = C + \gamma \ln R - A \ln K' - B \ln L' + \theta$$

where C is a constant, $\theta = I_R / Y$ is the R&D intensity measured in flows, and the prime indicates that the variable is derived from the double-counted measures. For econometric estimation, the same set of control variables is included.[12]

While all three additional variables were included in the regressions, some were tested out and their coefficients do not appear in table 8.5. In particular, the coefficient θ was found to be insignificant in all of the regressions.

Inclusion of these new variables impacted on the significance levels of other coefficients previously included in the regressions. For example, the coefficient on the foreign R&D stock in Manufacturing became insignificant, and thus was excluded from the regression (see tables 8.3 and 8.4).

All the coefficients in the regressions are significant with *p*-values below 5 per cent, except for the coefficient on the R&D capital stock in the Wholesale & retail trade regression. Exclusion of the capital stock in this industry regression does not change the estimates and the levels of significance for the other variables in the equation. All the coefficients included in the regression equations are also of the expected signs.

[12] For the estimation of the intensity specification of equation for Agriculture, it should include $\hat{K}'$, $\hat{L}'$ and $\dot{\theta}$ implied by the above equation.

Table 8.5 Results based on the specification adjusted for double-counting

	Log (MFP) as the dependent variable			Δlog(MFP) as the dependent variable
	Manufacturing	*Mining*	*Wholesale & retail trade*[b]	*Agriculture, forestry & fishing*[c]
R&D capital stocks				
Own	**0.055****	**0.061****	**0.055****	
	(0.016)	**(0.026)**	**(0.019)**	
Public	-1.21**	2.55**		
	(0.205)	(0.69)		
R&D intensity				
Public				**0.237****
				(0.110)
Other control variables				
Time	0.030**	-0.082**	-0.059**	
	(0.005)	(0.023)	(0.010)	
Usage of public infrastructure	0.495**	1.066**	0.864**	1.026**
	(0.099)	(0.071)	(0.189)	(0.048)
Change in oil price		0.036**		
		(0.016)		
Trade openness	0.106**	0.187*		
	(0.038)	(0.092)		
CPI			-0.436**	
			(0.115)	
Hours worked	-0.207**			-0.342**
	(0.049)			(0.092)
Capital stock		-0.477**	-0.053*	
		(0.109)	(0.242)	
IT capital (hardware and software)			0.191**	
			(0.065)	
Use of communication infrastructure			0.508**	
			(0.106)	
Rain				0.012**
				(0.006)
Farmers' terms of trade				0.156**
				(0.051)
Test statistics				
R^2	0.86	0.97	0.91	0.98
DW	2.5	1.6	2.4	1.7
AIC	-192.3	-141.3	-142.23	-136.1
RESET F(2, T-K-3)	0.13	2.51	2.22	3.14
	(0.88)	(0.11)	(0.14)	(0.07)

** indicates the p-value associated with the estimated coefficient is less than 5 per cent, while * indicates the p-value is between 5 and 10 per cent. [a] Standard errors are in parentheses. [b] For Wholesale & retail trade, the results are based on the Yule-Walker estimates after adjusting for autocorrelation of order 3. [c] The intensity specification of equation (5) of chapter 4 is used for Agriculture. The R&D intensity is defined as the change in R&D capital stock divided by the real output, while the relevant control variables used for this industry are in first difference.

Source: Commission estimates.

Comparing the above results with those in table 8.2, which were obtained from the specification that does not adjust for the measurement biases, the estimated output elasticity with respect to R&D has increased from 0.038 to 0.055 in Manufacturing, but it has decreased in Mining from 0.077 to 0.06, and the estimated return to public R&D in Agriculture has decreased from 32 to 24 per cent. There is no change for Wholesale & retail trade.

8.4 Concluding remarks

The estimation of the effect of R&D on productivity at the industry level is subject to greater data constraints than at the market sector level. The measurement of industry inputs, outputs and productivity all face difficult issues which affect the quality of the data. The measurement of the R&D capital stocks is also subject to greater uncertainty.

For the four one-digit industries investigated in this chapter, some evidence has been found of a positive relationship between each industry's own R&D capital stock and its productivity growth. But for the R&D capital stocks outside the industry under consideration, the estimated R&D effects on the industry's productivity are somewhat unexpected in some industries. Also, some questions may be raised regarding the magnitude and the robustness of the estimated elasticities.

The estimated elasticities with respect to industry's own R&D are used to derive the corresponding gross rates of return for each of the industries in chapter 11. Some general comments on the results are also provided in that chapter.

9 Further explorations of the effect of foreign R&D

The regression results presented in the paper thus far have sought to measure the importance of both Australian business R&D (BRD) and foreign R&D to Australian productivity growth.

The preferred regressions in chapter 7 found that the knowledge generated from foreign R&D has a strong positive effect on Australian MFP and labour productivity growth. In those models, the foreign knowledge stock is constructed by aggregating the R&D stocks of foreign countries using weights based on each country's share of Elaborately Transformed Manufacturers (ETMs) imports to Australia. The basic models in chapter 6 and the industry models in chapter 8 used a broader measure of trade imports and provide mixed evidence on the importance of foreign R&D, including, in some models, strong negative relationships.

Both weighting methodologies follow Park (1995) and Coe and Helpman (1995) and assume that the effect of foreign R&D is transmitted through new knowledge embodied in traded goods. However, if trade is not the primary mechanism for the transfer of knowledge to Australia, or that the type of knowledge which is transmitted through trade is not the most relevant to Australian productivity growth, then foreign knowledge stocks based on alternative hypotheses may improve estimates of the effect of foreign R&D:

> Park (1995) and Coe and Helpman (1995) examine the impact on a country's productivity growth of the trade-weighted R&D of other countries. Generally, a positive effect is found, which can be interpreted as reduced-form evidence of knowledge spillovers across international boundaries. While the mechanism for such spillovers is not identified, it seems reasonable that many forms of communication and information transfer would be correlated with bilateral trade flows. In these analyses, however, it is difficult to distinguish the effect of "pure" knowledge flows from the effect of technology flows embodied in advanced capital goods sold from one country to another. This distinction is crucial. Knowledge is inherently nonrival in its use [although it may be "sticky" and consume significant resources in its absorption and re-use], and hence its creation and diffusion are likely to lead to spillovers and increasing returns; it is this nonrival property of knowledge that is at the theoretical heart of models that produce endogenous growth from research. But to the extent that the knowledge or technology flows is embodied in a purchased piece of equipment, it may not produce a spillover, or, if it does, the spillover may take the form of a pricing or

pecuniary externality rather than a technological one (Griliches, 1979) … Knowledge spillovers are much harder to measure than technology transfer, precisely because they tend to be disembodied. (Jaffe and Trajtenberg 2002, pp. 199–200)

Therefore, this chapter presents results from the construction and testing of different weighting schemes based on different ideas about how knowledge is transferred to Australia and what types of knowledge are most relevant to Australian productivity growth. It compares alternative measures which favour either embodied knowledge transfer or disembodied transfer. However, as appendix F discusses, the conceptual distinctions between different types of knowledge and spillovers — for example, between rent spillovers versus pure knowledge spillovers — become very messy in interpreting empirical results. This chapter:

- describes the types of alternative foreign knowledge stocks which represent ‘potential’ spillover pools of knowledge to Australia (with supporting detail provided in appendix F), and presents the results of the tests (section 9.1);
- examines the use of patents as an indicator of knowledge outputs rather than the input-based knowledge stocks, and tests alternative weights (section 9.2); and
- examines whether the magnitude of the foreign effect on Australian productivity has changed over time and tests whether various characteristics of the Australian economy influence the magnitude of the foreign effect (section 9.3).

9.1 Testing different hypotheses about the transfer of knowledge

In addition to different weighting schemes emphasising different types of knowledge and transmission mechanisms, the R&D of some countries is likely to be more relevant to Australia than the R&D of other countries.

Empirical studies using foreign knowledge stocks combine the R&D activity of a set of countries or industries into a single explanatory variable. Aggregating stocks naturally raises the issue of how the stocks are to be combined. An unweighted aggregation procedure implicitly assumes that the technological knowledge obtained from a dollar of R&D in country *x* is equally as relevant to Australia as that obtained for a dollar of R&D in country *j*. An unweighted approach takes no position as to the relative importance of different types of knowledge or how they are transmitted.

Various weighting mechanisms can be employed to create a foreign stock which captures the idea that the R&D knowledge from R&D of different countries is not equally relevant to Australia. The task is to construct a foreign knowledge stock so that it is the best possible measure of the 'potential' spillover pool to Australia. Conceptually, the best measure will more fully reflect those changes in foreign knowledge that are most relevant to Australian productivity growth.

The selection of the weighting mechanism is a search for the factors that drive these differences in 'relevance'. They are based on bilateral relationships between Australia and overseas countries and how 'close' Australian cultural and economic characteristics are to those of other countries. Some of the factors include: a common language; bilateral trade patterns; similarities in industry structure; similarities in the concentration of R&D expenditures by research field; similarities in the concentration of patenting activity by technology class; and foreign direct investment (FDI) relationships.

The constructed weights tested in this chapter fall under one of three hypotheses.

- *Embodied knowledge transmitted through trade is what matters*. Bilateral import shares can be used as weights if it is thought that technological knowledge is primarily transmitted to Australia once it becomes embodied in capital and intermediate inputs, or final goods, and imported.
  - Trade shares can also be used if it is thought that the international diffusion of disembodied knowledge is closely aligned with trade patterns (that is, disembodied knowledge follows embodied knowledge). The possible correlation in the pattern of diffusion of embodied and disembodied knowledge across countries is one reason why empirical results are hard to interpret.
  - All imports can be used or some sub-set of imports, such as capital and intermediate goods, or ETMs.
- *Disembodied knowledge is what matters and its transmission is only loosely aligned with trade patterns, or not aligned at all*. An alternative weighting scheme is a 'distance' measure of the similarity of R&D activity or patenting activity between countries. Countries undertaking R&D in the same research field or patenting in the same technology classes might absorb technologies from each other more readily. Transmission would be through many mechanisms not directly related to trade, such as personal communications, collaborations, journal articles, patent disclosures, and international associations and conferences.
- *Investment and ownership shares influence knowledge transfer*. Technology transfer might follow overseas investment activities, particularly those of Multinational Enterprises (MNEs). In this case, knowledge transfers internationally within the firm or same ownership structures and spills over to local industry.

Fourteen countries were included in the construction of the foreign knowledge stocks, including: Canada; Denmark; Finland; France; Germany; Ireland; Italy; Japan; Netherlands; Norway; Spain; Sweden; United Kingdom; and the United States. The perpetual inventory method (PIM) was used for the construction of the stocks with various weighting schemes used in aggregating stocks across countries.

The testing procedure

Ideally, stocks emphasising different types of knowledge transfer could be entered in a regression simultaneously such that the model would produce statistically significant estimates of each stock. This would enable a direct comparison to be made of the relative strengths of the coefficients. However, entering multiple foreign stocks into regressions is severely restricted by both degrees of freedom constraints and the impact of multi-collinearity on the precision of estimates. Multi-collinearity arises because R&D time series across countries and industries tend to have similar upward trends.

Testing of multiple stocks simultaneously did not produce significant estimates. Therefore, the spillover pools were entered in the regressions one-by-one and a comparison of significance and model fit was undertaken.

Strong differences in significance and model fit could be interpreted, at least in principle, as providing evidence for the relative strength of the hypotheses above. Various market sector, industry and manufacturing subdivision models were tested.

Comparisons of the results were made on the basis of coefficient signs corresponding to expected signs, statistical significance and overall model fit. The magnitudes of the coefficients across weighting schemes are not directly comparable because of scaling. For example, the Coe and Helpman weighted stocks "_tch" are scaled by import intensity (M/Y) so the coefficients on these models are not directly comparable to the import share weighted stocks "_td" or the ETM share weighted stocks "_te".

Results from testing market sector models

There is some modest support for the choice of weighting scheme having an impact on the estimated effect of foreign R&D on Australian productivity. The choice of weights can have some important impacts on the statistical significance of estimated effects for both foreign R&D and Australian R&D. For example, the results for model BL4 presented in chapter 6 estimated the effect of Australian BRD very imprecisely. The result was based on "_td" weights. Had "_ti" weighted knowledge stocks been used, the effect of Australian BRD would have been found to be much more significant (table 9.1).

The trade measures which emphasise the transfer of embodied knowledge and rent spillovers do not consistently perform better or worse than the proximity measures which emphasise disembodied spillovers. It depends on the particular model. Tests do not shed light on the relative magnitudes of the alternative types of spillovers to Australia.

In model BL4, the "_tch" measure clearly performs best. Both R&D effects are statistically significant and the Bayesian information criterion (BIC) score is the lowest (indicating best model fit). The weighting scheme is that recommended by Lichtenberg and van Pottelsberghe (1998) as an improvement on the construction methodology used in Coe and Helpman (1995) (see appendix F).

In model Y4, ETM weights clearly provide best overall model fit. However, in most regressions (including the results of tests not shown), there are three to five weighting approaches which provide indistinguishable results. FDI weighted results consistently were weaker. The unweighted stocks do not perform markedly better or worse.

Table 9.1 **Performance of alternative weights in constructing foreign knowledge stocks**

Coefficients are permanent or long-run effects

Weighting scheme	*No weights "_u"*	*Import shares "_td"*[a]	*Import shares (_td * M/Y) "_tch"*[b]	*Import shares adj. for intensity "_ti"*[c]	*ETM import shares "_te"*[d]	*EPO patent apps. "_pe"*[e]	*USPTO patent grants "_pu"*[f]	*USPTO, IP Aus. Hybrid "_pa"*[g]	*FDI shares "_f"*[h]	*IP Aus. Non-PCT apps. "_z"*[i]
BL4 ARDL[j] *ln(K) -*										
Rbus10	0.016	0.019	0.047*	0.071**	0.026	0.005	0.042	0.046	0.008	0.007
	(0.031)	(0.033)	(0.026)	(0.033)	(0.032)	(0.037)	(0.026)	(0.029)	(0.039)	(0.033)
Rfrb10_[x]	0.198***	0.220***	0.101***	0.167***	0.149***	0.178***	0.160***	0.173***	0.202***	0.169***
	(0.049)	(0.042)	(0.027)	(0.033)	(0.046)	(0.045)	(0.035)	(0.045)	(0.068)	(0.049)
BIC	-91.1	-90.2	-96.4	-90.6	-89.2	-91.7	-91.5	-90.4	-89.1	-89.3
L7 FDL[k] *ln(K) -*										
Rbus15 +	0.044**	0.047*	0.028	0.065***	0.017	0.024	0.046*	0.041	0.048	0.070***
Rbus15sq[l]	(0.019)	(0.025)	(0.026)	(0.021)	(0.016)	(0.020)	(0.023)	(0.037)	(0.031)	(0.020)
Rfrg15_[x]	1.016	0.802	-0.081	0.306	0.509*	1.203	1.251	0.485	-1.181	0.898
	(0.724)	(0.242)	(0.074)	(0.286)	(0.279)	(0.721)	(0.872)	(0.611)	(1.012)	(0.725)
BIC	-145.2	-143.6	-126.9	-129.1	-143.0	-137.4	-132.7	-136.8	-127.4	-143.7

(continued on next page)

Table 9.1 **(continued)**

Weighting scheme	No weights "_u"	Import shares "_td"[a]	Import shares "_td"*M/Y "_tch"[b]	Import shares adj. for intensity "_ti"[c]	ETM import shares "_te"[d]	EPO patent apps. "_pe"[e]	USPTO patent grants "_pu"[f]	USPTO, IP Aus. Hybrid "_pa"[g]	FDI shares "_f"[h]	IP Aus. Non-PCT apps. "_z"[i]
Y4 FDL ln(K/Y), without constant -										
Rbus15int	0.008	0.003	0.004	0.007	0.013*	0.006	0.009	0.019	-0.002	-0.002
	(0.008)	(0.007)	(0.004)	(0.012)	(0.006)	(0.006)	(0.010)	(0.012)	(0.008)	(0.006)
Rfrg15int_[x]	0.009	0.005	-0.014	-0.004	0.041*	0.006	0.012	0.029	-0.014	-0.012
	(0.013)	(0.025)	(0.019)	(0.011)	(0.022)	(0.010)	(0.017)	(0.021)	(0.034)	(0.021)
BIC	-213	-209	-213	-203	-226	-213	-210	-214	-203	-206
Y6 FDL ln(ΔK/Y), without constant -										
Rbus15int	-0.003**	-0.004**		-0.005	-0.005**	-0.003**	-0.003*	-0.003*	-0.002	-0.002
	(0.001)	(0.002)		(0.003)	(0.002)	(0.001)	(0.001)	(0.001)	(0.003)	(0.002)
Rfrg15int_[x]	0.006	0.006		0.002	0.008	0.004	0.005	0.004	-0.003	-0.003
	(0.010)	(0.008)		(0.003)	(0.006)	(0.010)	(0.007)	(0.005)	(0.009)	(0.007)
BIC	-199	-197		-195	-199	-200	-201	-199	-195	-197

[a] Refer equation (F1), appendix F: foreign stocks weighted by import shares of capital and intermediate goods from the Australian System of National Accounts. [b] Equation (F2): import share weighted stocks scaled by Australian import intensity. This is the preferred measure in Coe and Helpman (1995). [c] Equation (F3): import share weighted stocks multiplied by foreign country imports to Australia divided by foreign country GDP. [d] Equation (F1) using ETM shares from the DFAT Stars database rather than a broader definition of imports [e] Equation (F5): technological proximity based on a comparison of European Patent Office applications classified by IPC technology classes. [f] Equation (F5), but with technological proximity based on a comparison of United States Patent and Trademark Office patent grants classified by IPC technology classes. [g] Equation (F5), but with technological proximity based on a comparison of foreign country United States Patent and Trademark Office (USPTO) patent grants with Australian patent applications to IP Australia classified by IPC technology classes. [h] Equation (F1), but with shares based on Foreign Direct Investment shares in Australia. [i] Equation (F5), but with technology proximity based on a comparison of foreign country and Australian non-Patent Cooperation Treaty applications to IP Australia. [j] Finite distribution lag (FDL). [k] Autoregressive distributed lag (ARDL). [l] Quadratic evaluated at sample mean.

Source: Commission estimates.

Results from testing industry models

At the one-digit industry level, testing of the foreign R&D stock generally did not produce statistically significant or positively signed coefficients under any of the weighting schemes. The exception was Manufacturing where the coefficient was significant and negatively signed (see chapter 8). Adjusting the weighting scheme had little impact on the regressions.

In manufacturing panel models (model MP9), the use of the same foreign knowledge stocks as used in the market sector regressions resulted in positively signed coefficients on own-industry and foreign R&D, but with relatively weak statistical significance (table 9.2) . For these tests, there is no variance in the foreign stocks by subdivisions. The different country weights for the foreign stock did not change the negative sign on the input-output weighted inter-industry stock. It was negative and statistically significant at greater than 5 per cent in all cases. Various lag structures for the R&D variables were tested, but they did not improve results.

Results from the manufacturing panel are significantly improved when the foreign knowledge stocks are constructed from foreign industry-level data, which permits the construction of industry-specific potential spillover pools. The stocks were constructed using both an inter-industry and country weighting scheme.

Differences in results are driven more by the choice of inter-industry weights than by the choice of country weights. The models with an unweighted stock and stocks which use a SEO inter-industry weight performed best with statistical significance at greater than 10 per cent (td-seo, etm-seo and pu-seo models). The data's apparent preference for relationships between Australian industry i and foreign industry j to be based on the SEO proximity measure contrasts with the results from the analysis of the effects of inter-industry knowledge stocks on Manufacturing productivity in appendix J, which favoured knowledge flows being proxied by trade relationships. If correct, the interpretation would be that the transfer of knowledge across industries at the international level appears to be more of a disembodied story, while the transfer across industries domestically relies more on embodiment in trade.

When model MP9 is estimated with foreign industry-specific weights, the coefficient on own-industry R&D intensity (Ry15) is near zero and not statistically significant at 10 per cent or more under any of the weighting schemes. The construction of the foreign stocks does not affect the sign on the domestic inter-industry stocks (Ryext15) as it is negative and significant in all cases. However, Australian inter-industry R&D is positive and significant in the manufacturing labour productivity growth panel models (see appendix J). .

Table 9.2 **Performance of alternative weights in constructing foreign knowledge stocks, Manufacturing panel**

Coefficients are permanent or long-run effects

Weighting scheme[a]: *[country weight]* *_[inter-industry weight]*	*No weights* *"_u"*	*Import share _SEO* *"td-seo"*	*Import share _IO* *"td-io"*	*ETM share _SEO* *"etm-seo"*	*ETM share _IO* *"etm-io"*	*USPTO _SEO* *"pu-seo"*	*USPTO - _IO* *"pu-io"*	*FDI share _SEO* *"fdi-seo"*	*FDI share _IO* *"fdi-io"*
MP9 ln(K/Y)									
Ry15 (t-1)	-0.009	0.002	0.000	-0.003	-0.000	-0.002	-0.000	-0.002	-0.004
	(0.011)	(0.011)	(0.013)	(0.011)	(0.012)	(0.011)	(0.012)	(0.011)	(0.012)
Rfrybi_[x] (t)	0.080**	0.083**	0.009	0.071**	0.013	0.067*	0.011	0.057	-0.004
	(0.036)	(0.035)	(0.022)	(0.035)	(0.024)	(0.035)	(0.024)	(0.036)	(0.021)
Ryext15 (t)	-0.070***	-0.082***	-0.047*	-0.063***	-0.047**	-0.064***	-0.046**	-0.062***	-0.036*
"_io"[b]	(0.019)	(0.023)	(0.024)	(0.018)	(0.020)	(0.019)	(0.021)	(0.019)	(0.021)
F(12,188)	15.0	15.1	14.3	14.9	14.3	14.8	14.3	14.7	14.2

[a] Country weights as described in notes to table 9.1. Inter-industry weights either based on SEO (socio-economic objective) or IO (input-output) tables (see appendix C).
[b] Trade weighted using ASNA input-output tables.

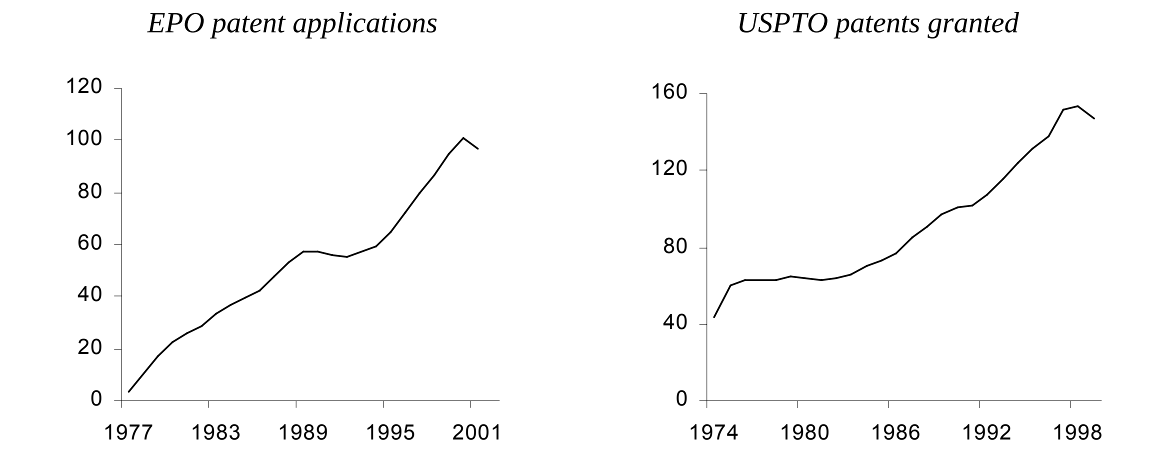
Source: Commission estimates.

9.2 Patent indicators as an alternative foreign knowledge output measure

Patent indicators have both advantages and disadvantages as an indicator of technological change and the potential for R&D spillovers to Australia (see chapter 2). Their main advantage is that they are an indicator of successful advancements in technological knowledge, whereas R&D measures provide an indication of the resources committed to advancing technological and other forms of knowledge. The main disadvantages of patents are: the use of patents as a form of intellectual property protection varies widely by industry, with some industries strongly preferring other forms of protection; and the value of patents is very highly skewed with most patents having very little value. Various institutional changes to the processes governing the registration of patents has also introduced distortions into time series (for example, the increased use of Patent Cooperation Treaty (PCT) processes which are designed to help lower the costs of seeking protection for an invention in multiple countries).

Simple count measures were constructed from the number of patents applied for at the European Patent Office (EPO) and patents granted at the United States Patent and Trade Office (USPTO). The measures include the applications and grants of the set of countries used in the creation of the foreign knowledge stocks for this study. Both unweighted and weighted measures were constructed. Both the EPO and USPTO measures trend strongly upwards (figure 9.1).

Figure 9.1 **EPO applications and USPTO patent grants[a], various periods**
No. of patents ('000).



[a] Based on applications and grants of countries included in the foreign knowledge stocks only. EPO data refer to patent applications to the European Patent Office (Direct EPO filings plus EPO-PCT applications in regional phase). USPTO data refer to patents granted by the US Patent and Trademark Office.

Data source: OECD Patent database.

Testing patent count measures

The patent measures were tested in a selection of chapter 7 and 8 models. The model names (L1 through Y5, table 9.3) refer to the equivalent chapter 7 models, although there may be differences resulting from retesting the models for significance of shift terms and other controls and sources of growth once the foreign knowledge stock is removed from the model and the patent indicator introduced. For example, in model Y3, effective rate of assistance (ERA) tested out of the model with foreign knowledge stocks, but remained significant when the USPTO patent indicator was used.

Market sector models

The estimated coefficient on USPTO patents is positively signed and economically significant in each of the models (although some tests did produce negative coefficients). The USPTO measure consistently produced better model results than the equivalent EPO measure.

In some models, the inclusion of USPTO patents rather than foreign knowledge stocks results in more plausible results in that both Australian BRD and the outputs from foreign R&D investment are important to Australian productivity growth.

For example, in model L1 the coefficient on Australian business R&D is 0.019 (but not statistically significant at 10 per cent), while the coefficient on USPTO grants is 0.042 and significant. This contrasts sharply with the results for this model when foreign knowledge stocks were used. In that case, the coefficient on Australian business R&D is highly significant and the coefficient on foreign R&D is also highly significant, but negatively signed. Based solely on statistical criteria, the model with stocks fits the data better (a BIC of -148 versus -118), but the USPTO results are clearly preferred, based on economic criteria.

When Australian GRD is used with the patent measure (model L1GRD), Australian R&D is highly significant, and the results for USPTO patent grants changes only slightly.

Table 9.3 **Australian productivity and USPTO patents**

Heteroskedastic robust standard errors in brackets. All variables in logs. Australian BRD depreciated at 5 per cent for model Y5, and 15 per cent elsewhere.

Dependent variable : *R&D variable -*	*ln(MFP):* *ln(K)*	*ln(MFP):* *ln(K)*	*ln(MFP):* *ln(K)*	*Δln(MFP):* *ln(K/Y).*	*Δln(MFP):* *ln(ΔK/Y).*
Chapter 7 model -	*L1*	*L1GRD*	*L4*	*Y3*	*Y5*
Linear time trend	-0.006* (0.003)	0.016*** (0.005)			
Cycle (growth of real GDP)	0.392*** (0.059)	0.383*** (0.057)	0.390*** (0.049)	0.397*** (0.027)	0.350*** (0.028)
Australian R&D	0.019 (0.044)	0.224** (0.089)	-0.285*** (0.064)	0.027** (0.011)	-0.007*** (0.002)
Australian R&D squared			0.039*** (0.009)		
USPTO patents (ETM weights)	0.042* (0.023)	0.040 (0.023)	0.051*** (0.017)	0.153*** (0.034)	0.049*** (0.017)
nonggitcap				-0.146*** (0.040)	-0.101*** (0.033)
ci5iousage				0.004 (0.015)	0.020 (0.017)
Education	0.173** (0.066)	0.162*** (0.030)	0.047* (0.027)	0.199*** (0.052)	0.155*** (0.049)
tiopen	0.111** (0.043)	0.102** (0.040)	0.093** (0.036)		0.032* (0.016)
era	-0.082*** (0.016)	-0.060*** (0.015)	-0.051*** (0.014)	-0.079*** (0.024)	-0.100*** (0.019)
centbrg	-0.006** (0.002)	-0.002 (0.003)		-0.026*** (0.005)	-0.018*** (0.004)
Constant	3.376*** (0.503)	2.596*** (0.377)	4.131*** (0.269)	0.140** (0.048)	-0.023* (0.012)
Shift1985				-0.016*** (0.004)	
Shift1989				-0.009** (0.004)	
Shift1992			-0.014* (0.007)	-0.012* (0.006)	
Test statistics					
# of observations	29	29	29	24	26
R^2	0.993	0.994	0.995	0.954	0.922
Durbin-Watson [a]	1.914	2.027	2.218	1.993	2.061
Heteroskedasticity [a]	29 (0.413)	29 (0.413)	29 (0.413)	24 (0.404)	26 0.408
RESET [a]	1.51 (0.248)	1.25 (0.323)	0.64 (0.602)	0.87 (0.490)	1.54 (0.251)
AIC*n (BIC) [a]	-192 (-118)	-196 (-121)	-201 (-125)	-172 (-39)	-177 (-39)

[a] See table 6.3.

Source: Commission estimates.

The use of USPTO patents also improves the results in model L4, where Australian business R&D is specified as a quadratic relationship. The total effect of Australian BRD evaluated at the mean of the sample is still positive, but lower and more plausible. The effect of foreign knowledge is again positive, but is better estimated. As in chapter 7, the coefficient on the quadratic term is positive and significant. Evaluated at the mean of the full sample, the effect of Australian business R&D is not significant with a point estimate of 0.003, a standard error of 0.014, and a p-value of 0.825. However, when evaluated at its mean value for the period up to and including 1985, the coefficient is significant with a point estimate of -0.031, and a standard error and p-value of 0.015 and 0.059, respectively. Evaluated at its mean value from 1986, the coefficient changes from negative to positive and is significant with a point estimate of 0.040, and standard error and p-value of 0.018 and 0.035, respectively.

The increased partial effect of Australian BRD, and the appearance of a stronger relationship between productivity and R&D post-1985 accords with other findings (discussed further in chapters 10 and 11).

For the remaining two models in table 9.3, Australian business R&D is specified in intensities. In model Y3, the foreign knowledge stock was negatively signed, but the USPTO indicator produces a strong positive and highly statistically significant coefficient. In model Y5, the patent and knowledge stock coefficients are similarly signed and significant.

The results were sensitive to the choice of lag structure. In both models, R&D intensity enters lagged two periods and the growth in USPTO patents granted is lagged one period. The strong results for the education and ERA variables in these models were sensitive to both variables being lagged two periods. Testing down of FDL models for chapter 7 resulted in the inclusion of lags for these variables with the second lag often the most significant. Entering contemporaneous values resulted in education and ERA being insignificant, but it did not change the results on the USPTO variable.

Overall, the results suggest that the simple USPTO patent count measure can improve results in some specifications. Therefore, results from the two-equation models, for both foreign knowledge stocks and USPTO patents, are shown in chapter 10.

Industry models

At the one-digit industry level, the coefficients on patent measures are usually negative and insignificant, whether unweighted or weighted.

In the manufacturing MFP growth panel models (appendix J), the USPTO patent measure generates the same pattern of results for the key variables as do the foreign knowledge stocks (that is, an insignificant coefficient for own-industry R&D, a positive and significant coefficient for foreign knowledge, and a negative and significant coefficient for domestic industry-industry effects). In those models, the USPTO measure does not improve the significance of own-industry R&D or change the sign of the inter-industry effect. However, for the manufacturing panel labour productivity growth models, the USPTO measure does have a larger effect on model results (see table J.6, model MLP6), improving the consistency of results between the MFP and labour productivity growth models.

Tests of alternative weights using patent data

The tests of alternative methodologies to constructing potential spillover pools using knowledge stocks did not provide clear support for the relative importance of embodied over disembodied knowledge transfers, or vice versa. However, the significance of results did change markedly according to the chosen weights.

Regression results are less sensitive to the choice of weights when the regressions include USPTO patents in place of foreign knowledge stocks. Models L1, Y3 and Y5 were sensitivity tested using the same set of weighting schemes as used for the foreign knowledge stocks. The choice of weights had very little impact on the sign of the coefficients or their magnitude for either the patent variable or Australian business R&D (table 9.4).

The testing of the weighting schemes for the foreign knowledge stocks showed the importance of creating industry-specific spillover pools in industry-level panel analysis. Patent count data by industry is not directly available as patent offices classify patents applications and grants by various technology classification systems. However, it might be possible to create industry-specific foreign spillover pools based on patent data by taking EPO or USPTO data by technology class and using the OECD technology concordance probability matrixes (discussed in appendix F) to create time series of the number of patents by industry.

Table 9.4 **Test of alternative weights for USPTO patents granted**

Weights	No weights "_u"	Import shares "_td"	Import shares adj. for intensity "_ti"	ETM import shares "_te"	USPTO patent grants "_pu"	USPTO, IP Aus. Hybrid "_pa"	FDI shares "_f"	IP Aus. Non-PCT apps. "_z"
Model L1 -								
Aus. Bus. R&D	0.018 (0.044)	0.012 (0.044)	0.040 (0.043)	0.019 (0.044)	0.017 (0.043)	0.025 (0.043)	0.013 (0.043)	0.010 (0.043)
USPTO	0.053** (0.025)	0.046** (0.019)	0.030 (0.034)	0.042* (0.023)	0.053** (0.023)	0.045 (0.028)	0.042** (0.017)	0.044** (0.016)
BIC	-118	-118	-116	-118	-118	-117	-119	-119
Model Y3 -								
Aus. Bus. R&D	0.026** (0.010)	0.023* (0.011)	0.032** (0.011)	0.027** (0.011)	0.024** (0.010)	0.028** (0.010)	0.022* (0.012)	0.020 (0.012)
USPTO	0.168*** (0.035)	0.151*** (0.040)	0.156*** (0.033)	0.153*** (0.034)	0.172*** (0.037)	0.169*** (0.035)	0.141*** (0.039)	0.142*** (0.041)
BIC	-41	-37	-42	-39	-41	-42	-36	-35
Model Y5 -								
Aus. Bus. R&D	-0.007*** (0.002)	-0.007*** (0.002)	-0.006*** (0.002)	-0.007*** (0.002)	-0.007*** (0.002)	-0.007*** (0.002)	-0.007*** (0.002)	-0.007*** (0.002)
USPTO	0.060*** (0.016)	0.046*** (0.016)	0.062*** (0.020)	0.049*** (0.017)	0.057*** (0.020)	0.057*** (0.020)	0.043*** (0.014)	0.042*** (0.014)
BIC	-38	-36	-39	-37	-37	-38	-35	-35

Source: Commission estimates.

9.3 Has the effect of foreign R&D changed?

As discussed in chapter 7, studies of the effect of foreign R&D on Australian productivity have tended to find a relatively small effect compared with other OECD countries (with some studies even finding a negative effect).

Coe and Helpman (1995) investigate the hypotheses that the degree to which a country is open to international trade will be an important determinant of the extent to which it benefits from international spillovers. This is because they viewed knowledge as being transmitted internationally principally through trade patterns. Other studies have highlighted the role of own R&D and human capital in benefiting from overseas knowledge.

Given changes in Australian R&D intensities, trade openness, and levels of formal education in Australia over the last two to three decades, it might be expected that the importance of foreign R&D as a source of knowledge impacting on productivity may have increased.

As well as complementarities there are also substitution effects between internally sourced knowledge and knowledge sourced from overseas. For example, in some cases, it may be cheaper for a business to identify, access and absorb knowledge generated overseas than it is to generate the knowledge from own-R&D. On the other hand, perhaps higher levels of R&D activity here and higher levels of human capital have made foreign knowledge less important.

While effects can go both ways, recent studies highlight the absorptive capacity contribution of both own-R&D and human capital and find that own-R&D efforts and human capital are net complements to foreign knowledge. There appears to be less agreement on the role of trade openness in influencing the importance of foreign knowledge from overseas investment in R&D.

If the effect of foreign R&D has changed, then adjusting the models provide a more robust estimate of the role of foreign R&D in Australia's productivity growth, since the models assume a constant structural relationship.

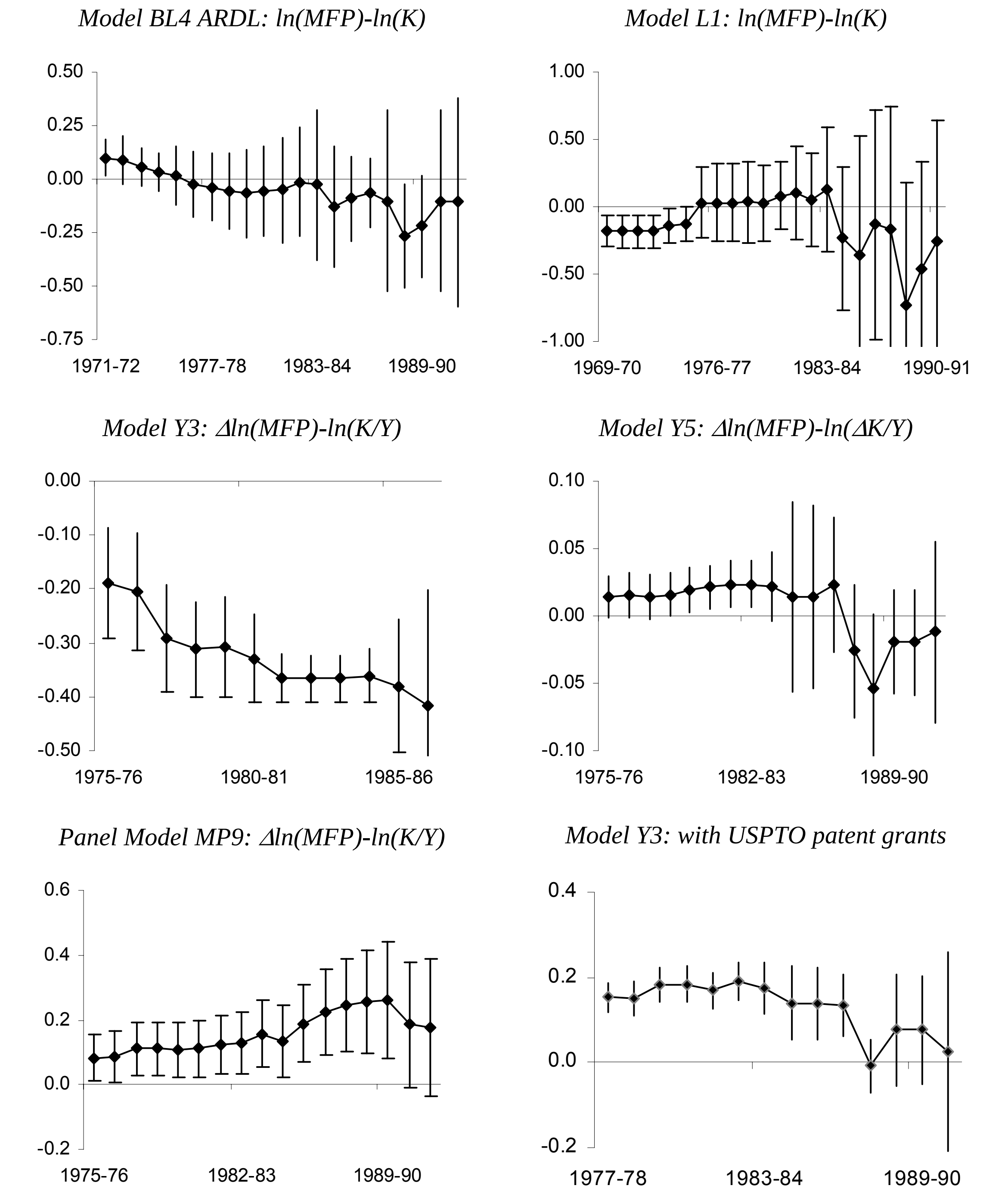
Tests of a changed foreign effect

Tests of the stability of the coefficient on foreign R&D in market sector models did not provide evidence of an increasing partial effect of foreign R&D on Australian productivity (figure 9.2). The parameter stability charts show how the coefficient on foreign R&D changes as the time frame included in the regressions is successively reduced by dropping the earliest observations. The charts are representative of the much larger set of tests which were produced during the testing and re-estimating of models.

Similar recursive regressions cannot be run for the FDL models. The inclusion of more variables in the FDL models severely limits the number of observations that can be dropped before the models cannot be estimated.

The greater number of observations in the panel model produce smoother patterns in the coefficient and a slow increase in standard errors as regressions are based on fewer and fewer observations. The growth in MFP model (model MP9), with R&D intensity specified as the knowledge stock over output, suggests a steadily rising point estimate of the foreign effect but, as with the other tests, the overlapping confidence intervals do not support strong conclusions. Foreign R&D and inter-industry R&D remain highly statistically significant in the recursive regressions. Australian business intensity is statistically significant at 5 per cent if the period is restricted to 1986-87 or 1987-88 to 2000-01. If the sample includes earlier or later observations, the results are not significant at 10 per cent.

Figure 9.2 **Stability of the coefficient on foreign R&D**



Data source: Commission estimates.

Tests of changes in the foreign effect were also undertaken by introducing individual slope shift terms into the market sector models for foreign R&D (allowing for structural breaks in relationships.) Various years and combinations of shifts were tested and were guided, in part, by the unit root and structural break testing in appendix E. However, there was little evidence of significant changes in the estimated elasticity. Foreign R&D was also interacted with a linear time trend, but the interaction term was not significant. Guellec and van Pottelsberghe (2001), in a panel of OECD countries, found that the effect of domestic business R&D had increased over time but, when foreign R&D was interacted with a linear time trend, it was not statistically significant.

Factors that influence the importance of foreign R&D

Various characteristics of the Australian economy may influence the effect of foreign R&D on Australian productivity by altering the costs of absorbing spillovers and the incentives to exploit potential spillovers.

- *Absorptive capacity and the 'two faces' of R&*D. The effect of foreign R&D may be partly dependent on the level of R&D undertaken in Australia. R&D by businesses can contribute to their ability to identify, access, understand and apply foreign generated technological knowledge to Australian production processes (including non-technological forms of innovation). These types of benefits of investing in R&D are often referred to as increasing a firm's 'absorptive capacity'. Cohen and Levinthal (1989) referred to it as the 'two faces' of R&D where R&D provides both own-innovation benefits and absorptive capacity benefits.
  - Similarly, the education or skills level of the workforce may influence the abilities of businesses to absorb foreign spillovers, and hence the net benefits which can be obtained.
- *Openness to imports*. The intensity of imports could condition the effect of foreign spillovers on Australian productivity in a number of different ways. Competition from imports in domestic markets increases the incentives to innovate for Australian businesses also selling products in local markets. This may change their demand for R&D including their demand for overseas knowledge. The importation of 'leading edge' products embodies new knowledge resulting, in part, from foreign R&D. Imitation and adaptation by domestic firms involve a process of learning and secondary innovation, influencing the demand for domestic business R&D.
  - Further, disembodied knowledge, while distinct from, may follow embodied knowledge in international trade. Trade relationships may establish a broader set of relationships and communication channels between people in different

countries, which support the diffusion of disembodied knowledge. Increased trade intensity may be correlated with a process of increased trade within MNEs or groups of firms, and these relationships may support technology transfer.

- *Industry protection*. The level of industry protection can influence the importance of foreign R&D to Australian productivity performance. Decreased levels of assistance expose domestic firms to greater import competition. As noted, this changes the incentives facing firms to innovate. Changes in ERA might provide a clearer linkage to the role of competitive intensities in affecting incentives, since many factors can influence import intensities.
  - Reductions in protection may have increased the incentives to exploit the potential of international spillovers as a source of *relatively* lower cost technology.

To test whether the characteristics affect the magnitude of the foreign effect, including changes over time, each of the characteristics was interacted with the foreign knowledge stock. When an interaction term between two variables x and y are entered in a regression, the partial effect of variable x depends on the value of y and vice versa.

Absorptive capacity

Testing produced some models which accorded with prior expectations of a positive and significant coefficient on the interaction term with Australian BRD (table 9.5). In market sector model L1, it is positive and statistically significant at 13 per cent. Its inclusion results in the coefficient on foreign R&D changing from large, negative and highly statistically significant to a coefficient which is insignificant. The economic magnitude of the effect of Australian BRD is not significantly affected.

Interaction terms were also tested in various market sector productivity growth models, but the interaction terms were not significant. In these models, the hypotheses tested was that the effect of the foreign knowledge stock as a proportion of the scale of the Australian economy is partly dependent on the intensity of Australian business R&D investment.

Replacing the foreign R&D knowledge stock in model L1 with an index of USPTO patents granted resulted in a positive and significant interaction term. The coefficient on Australian BRD is positive, but not statistically significant, while the coefficient on USPTO patents granted is 0.054 and significant at greater than five per cent. The significance of the foreign effect increases over time: when evaluated at the mean of the period 1974 to 1985, the coefficient is 0.027 with a standard error of 0.028; but, when evaluated at the mean of the period 1986-87 to 2002-03, the coefficient is 0.072 and statistically significant at greater than 1 per cent.

Testing of the interaction between Australian business R&D and foreign R&D in models based on the expanded market sector (appendix H) also produced mixed results. In model EM3, the interaction term is positive and significant. Its inclusion has a large impact on the coefficient for foreign BRD, with foreign BRD becoming economically highly significant and statistically significant at greater than 10 per cent. In model EM6, the coefficient on the interaction term is similarly positive and significant. With its inclusion, the coefficients on Australian BRD and USPTO patents granted increase, but do not become statistically significant.

Table 9.5 **Interaction between foreign R&D and Australian business R&D[a]**

Models specified as Ln(MFP) is a function of Ln(K). Foreign spillover pool represented by foreign BRD, foreign GRD or USPTO patents granted.

	Results without interaction		*Results with interaction*		
	Australian BRD	*Foreign R&D*	*Interaction term*	*Australian BRD*	*Foreign R&D*
Market sector -					
Model L1 with foreign GRD	0.077*** (0.028)	-0.180*** (0.059)	0.089 (0.057)	0.070** (0.029)	0.016 (0.133)
Model L1 with USPTO patents granted	0.019 (0.044)	0.042* (0.023)	0.050* (0.029)	0.032 (0.041)	0.054** (0.021)
Expanded Mkt. Sector -					
Model EM3 with foreign BRD	0.063 (0.041)	0.023 (0.230)	0.114** (0.042)	0.048 (0.032)	0.279* (0.135)
Model EM6 with USPTO patents granted	0.043 (0.052)	0.021 (0.020)	0.095* (0.049)	0.052 (0.035)	0.037 (0.028)
Mining with foreign BRD (USPTO weights)	0.077** (0.035)	—	0.313** (0.076)	0.046 (0.037)	0.512 (0.342)

a The elasticities with the interaction term can be interpreted as the partial elasticity when the other R&D variable is evaluated at its mean value. Heteroskedastic robust standard errors in brackets.

Source: Commission estimates.

The inclusion of an interaction term in the productivity growth models for the expanded market sector did not result in significant interaction terms or better overall model fit.

For manufacturing subdivisions, testing of the models in appendix J produced widely varying results. In some manufacturing subdivisions, the interaction term was economically large and positive, while in others it was negative. The results point to both complementarity and net substitution effects between own-industry R&D and foreign BRD, depending on the industry.

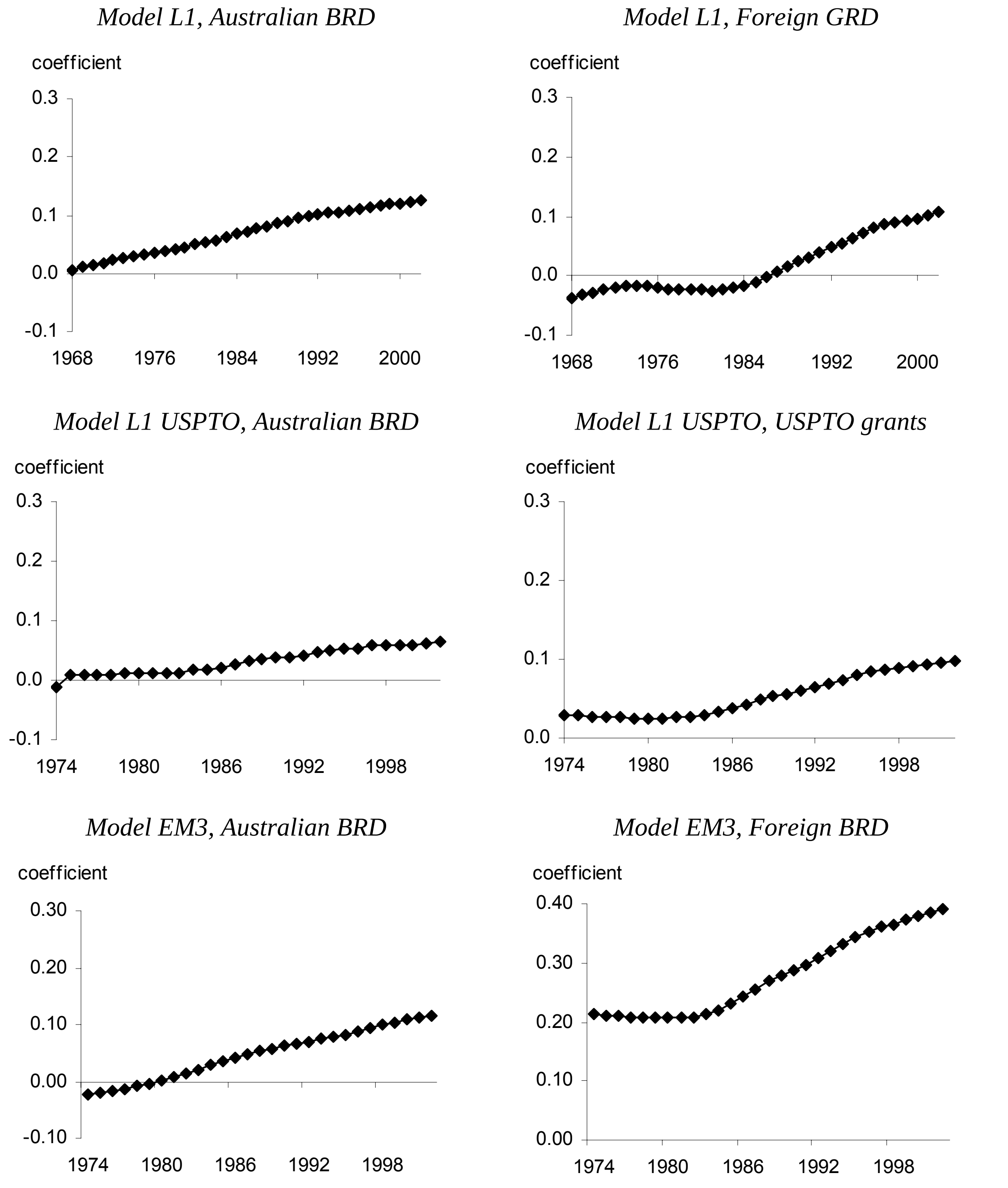
For mining, the individual coefficients are not statistically significant, but a joint test rejects the hypotheses that the R&D coefficients and the interaction term are all zero. The above results indicate that if there is a 1 per cent increase in the mining industry's own R&D capital stock, while the foreign R&D stock is at its average value and holding other effects constant, it will raise the industry's productivity by 0.05 per cent. The magnitude of the effect on Australian productivity from foreign R&D spillovers is large. If the industry's own R&D stock is at its average value and other effects are being held constant, a 1 per cent increase in the foreign R&D capital stock could result in a 0.5 per cent increase in mining's productivity.

While the results regarding the effect of foreign R&D spillover seem plausible in mining, the same cannot be said about the other industries. Based on the current one-digit industry level data, there is no clear indication as to whether the effect of foreign R&D spillover does or does not exist for these industries, and which measure of foreign R&D is the most appropriate one to be used to capture this effect.

The interaction between domestic and foreign R&D can be evaluated at each time period and the resulting coefficients plotted (figure 9.3). With a positive interaction term, the partial effect of Australian business R&D and foreign R&D is increasing in each of the models L1, model L1 with USPTO patents granted, and model EM3. The point estimate of the foreign effect was slightly negative in model L1 until the mid-1980s (although confidence intervals would make it not statistically different from zero), then it increased steadily driven by the underlying increase in the stock of business R&D. In the expanded market sector, the coefficient on foreign BRD was around 0.2 up until the mid-1980s, before increasing.

The presented test results are for models which produced a positive and significant interaction between Australian BRD and an indicator of the potential foreign spillover pool. However, some models did produce negative interaction terms. Therefore, the testing of interaction terms has not provided robust evidence of an absorptive benefit of Australian business R&D.

Figure 9.3 **Profiles of the total effect of Australian business R&D and foreign knowledge[a]**



Data source: Commission estimates.

A different way to investigate the absorptive capacity role of domestic R&D is to estimate productivity gap models as set out in Griffith et al. (2003) (box 9.1). In these models, productivity growth is determined by R&D-induced innovation, technology transfer and R&D-based absorptive capacity. An interaction term between R&D intensity and a productivity gap term is meant to capture the role of domestic R&D in absorbing disembodied knowledge. R&D raises the rate at which technology is transferred from frontier to non-frontier countries. The authors find that all three sources of growth are significant.

The relative magnitudes of the coefficients can be expected to vary by country. For example, R&D-induced innovation would be more important for a country on the technological frontier, while technology transfer might be more important for countries lagging the frontier.

The Griffith et al. papers did not include Australia in the sample of countries used in the panel. Initial testing of a simplified version of the model was undertaken for this project, where the productivity gap was based solely on a comparison of Australian and US manufacturing MFP. The initial results, in part, motivated the establishment of separate 'spin-off' projects on productivity gaps and technology transfer.

Box 9.1 **Convergence in MFP growth rates**

Griffith et al. (2000, 2003) develop a theoretical model for cross-country convergence in MFP growth rates. Empirical implementation of the model for Australia using time series data, can be specified as:

$$\Delta \ln A_t = \rho(\frac{R}{Y})_{t-1} + \mu(\frac{A_F}{A_A})_{t-1} + \phi(\frac{R}{Y})_{t-1} * \ln(\frac{A_F}{A_A})_{t-1} + \beta X_{t-1} + e_t$$

where *A* is MFP, the subscript *F* represents MFP for the frontier country, the subscript *A* represents MFP for Australia, *R* is R&D, *Y* is output, *X* is a vector of control variables (including the growth rate of productivity in the frontier country), and *e* is the error term.

The first term on the right-hand-side is the ratio of prior-period Australian R&D to output, or R&D intensity. Rho (ρ) is the return to R&D from R&D's role in domestic innovation.

The second term is the prior-period productivity gap represented as the ratio of the level of foreign productivity over Australian productivity. The larger the gap the greater the potential for disembodied knowledge transfer and faster growth in MFP. (μ) corresponds to the rate of productivity convergence.

The third term is the interaction between the first two terms, and (ϕ) represents the return to R&D resulting from R&D's role in absorbing overseas knowledge. The total return to R&D takes into account both the role of R&D in own-innovation and the role of R&D in absorbing knowledge generated overseas. The latter role is often referred to as R&D's 'absorptive capacity' role.

Source: Griffith, Redding and Van Reenen (2003).

The interaction of the foreign knowledge stock with human capital controls (the proportion of the labour force with post-secondary school qualifications and the QALI index) did not produce statistically significant interaction terms.

Intensity of imports

To test whether import intensity has an impact on the partial effect of foreign R&D, interaction terms between trade openness and foreign knowledge stocks were included in the models.

The testing of the alternative weighting schemes for the construction of foreign knowledge stocks earlier in this appendix included a stock which was scaled by import intensity (denoted _tch). The import intensity weighted stock did not provide overall better model results or greater statistical significance.

Coe and Helpman (1995) found that countries with a higher ratio of trade to GDP benefited more from spillovers. Dowrick (1994a) questioned whether this result was really a trade effect or if it had more to do with relative population levels, since population and 'openness' are correlated (that is, larger populations rely relatively less on trade). Various studies since have also questioned Coe and Helpman's findings on the closeness of the relationship between the effects of foreign R&D and trade intensity (see Kao et al. 1999).

The interaction of the foreign R&D stocks with measures of trade openness (imports of capital and intermediate inputs or ETMs) provided mixed evidence as to whether the effect of foreign R&D on Australian productivity is partly dependent on the level of openness of Australia to imports. The interactions were rarely significant.

Industry protection

Tests of the interaction between industry protection and the potential foreign spillover pool resulted in a significant interaction term and overall better model fit in some models. The lowering of industry protection has been associated with an increase in the partial effect of the potential spillover pool on Australian productivity in the three models with a negatively signed interaction term (table 9.6). Model EM3 is based on the expanded market sector (appendix H). Models L1 (with knowledge stocks) and Y3 (with USPTO patents granted) are based on the market sector.

However, the other two models give a conflicting story. Model L4 uses USPTO patents granted and includes a quadratic term for Australian BRD. Model Y3 is a productivity growth model and uses growth in USPTO patents granted to represent the spillover pool. Both models suggest that the decline in ERA has been associated with a decline in the partial effect of the spillover pool to Australia. They suggest that Australian productivity growth was more reliant on R&D spillovers from abroad under higher levels of protection.

Testing in the majority of models resulted in an insignificant relationship between the foreign effect and industry assistance.

Table 9.6 **Tests of the interaction between industry protection and the potential spillover pool to Australia[a]**

	Without interaction			*With interaction*			
	ERA	*Foreign spillover pool*	*BIC*	*Interaction term*	*ERA*	*Foreign spillover pool*	*BIC*
Market sector -							
Model L1 with USPTO ln(MFP) = ln(patents)	-0.082*** (0.016)	0.042* (0.023)	-118	-0.034 (0.021)	-0.054*** (0.017)	0.057** (0.021)	-116
Model L4 with USPTO ln(MFP) = ln(patents)	-0.051*** (0.014)	0.051*** (0.017)	-125	0.050* (0.027)	-0.054** (0.013)	0.017 (0.028)	-124
Model Y3 Δln(MFP) = ln(K/Y)	0.033* (0.017)	-0.130** (0.056)	-21	-0.494** (0.192)	0.037** (0.016)	-0.214*** (0.069)	-24
Model Y3 with USPTO Δln(MFP) = Δln(patents)	-0.079*** (0.024)	0.153*** (0.034)	-39	1.040** (0.354)	-0.134*** (0.029)	0.224*** (0.031)	-49
Expanded mkt. sector -							
Model EM3 ln(MFPdl) = ln(K)	-0.093*** (0.026)	0.023 (0.100)	-140	-0.125** (0.043)	-0.092*** (0.020)	0.208* (0.113)	-149

a Model re-parameterised as per Wooldridge (2003, p. 194). With the inclusion of the interaction term, the presented elasticities can be interpreted as the partial effect when either ERA or the spillover pool is evaluated at its mean value. Heteroskedastic robust standard errors in brackets.

Source: Commission estimates.

Tests of the interaction between industry protection and the stock of foreign BRD for manufacturing subdivisions indicate that the reduction in ERA has been part of a process which has increased the partial effect of the R&D spillover pool in some industries, and lowered it in others (table 9.7). In three of the eight subdivisions included in the panel, the interaction was insignificant (Printing, publishing & recorded media, Structural & sheet metal products, and Transport equipment).

Table 9.7 **Interaction between industry protection and the potential spillover pool to Australia, manufacturing subdivisions[a]**

Foreign BRD stock constructed from foreign industry-level R&D expenditure

Ln(MFP) = ln(K)	*Interaction term*	*ERA*	*Foreign spillover pool*
Food, beverages & tobacco	-0.190***	-0.097***	0.545***
	(0.065)	(0.021)	(0.138)
Textiles, clothing, footwear & leather	-0.163**	-0.051**	0.604***
	(0.067)	(0.025)	(0.207)
Petroleum, coal, chemicals etc.	0.683***	-0.012	-1.477***
	(0.080)	(0.033)	(0.213)
Basic metal products	0.111***	0.034**	1.534***
	(0.037)	(0.015)	(0.139)
Other manufacturing	-0.463***	0.208***	0.400**
	(0.057)	(0.028)	(0.167)

[a] See table 9.6. For details of industry classification, see table A.2. Estimates from SURE estimation. Foreign BRD stock constructed from foreign industry-level R&D expenditure with country weights based on ETM import shares and inter-industry relationships based on ASNA input-output tables.

Source: Commission estimates.

9.4 Overall assessment

Testing of the alternatively weighted foreign knowledge stocks did not provide clear support for the importance of embodied over disembodied knowledge transfers to Australia, or vice versa. The performance of the various weights varied by empirical specification. However, the testing showed that the findings from regressions in terms of the magnitude and statistical significance of the effect of foreign R&D could be quite different if one weighting approach had been selected to the exclusion of all others (as is almost always done in the empirical literature on R&D and productivity).

Some promising results were obtained from the use of a simple patent measured based on the counts of USPTO patents granted for the fourteen countries used in the construction of the foreign knowledge stocks.

It is difficult to tell whether the effect of foreign R&D on Australian productivity has changed over time. There is an expectation that it would have, given significant changes in the Australian economy which are believed to ‘condition’ the importance of foreign knowledge. However, testing of the interaction between foreign R&D and Australian BRD, Australian formal education levels, openness to imports, and the level of industry assistance provided inconclusive results.

10 Rising business investment in R&D

The single equation regression results in chapters 6 through 9 were based on one of two approaches:

- the 'standard' framework outlined in chapter 4, where the postulated long-run relationship is between the level of output or MFP and the level of R&D capital; or
- simplified versions of three alternative long-run relationships drawn from the R&D-based endogenous growth literature.

Testing of the exogeneity of Australian business R&D in these equations indicated that the contemporaneous value of business R&D was probably endogenous. Therefore, the initial observation on business R&D was lagged at least one period. However, greater certainty that the estimated elasticities are reflecting the effect of R&D on productivity and not a demand for R&D is desirable.

This chapter models the determinants of productivity within a simple two-equation system consisting of an R&D equation and a productivity equation. The set-up of the equations provides an alternative way of addressing bias from the potential endogeneity of R&D.

The system provides two other potential benefits:

- Estimating an R&D equation can provide information on some of the broad factors associated with increased demand for R&D. A better understanding of why business R&D investment has risen strongly might help with understanding the relationship between R&D and productivity.
- Estimation of the system using seemingly unrelated regression estimation (SURE) can provide more precise estimates of the effects of R&D (under certain conditions). More precise elasticity estimates:
  - translate into more precise estimates of the rate of return to R&D (chapter 11);
  - could help with identifying breaks in parameters; and
  - might assist with a number of ancillary questions that are of interest, which currently 'fall within the errors' of the regressions, for example:

- is the return to own-financed business R&D higher than to business R&D financed from all sources?; and
- is the statistical and economic significance of the coefficient estimates for R&D sensitive to the assumed rate of decay?

These latter questions form part of the sensitivity testing undertaken in appendix K.

10.1 The investment environment

The level of resources directed towards R&D activity in Australia, and various characteristics of that R&D activity, have been discussed in earlier chapters. The dominant pattern is that business R&D investment was weak in the 1970s to early 1980s, then there was a rapid acceleration in investment and sustained high rate of investment until the mid-1990s, a brief dip, then further strong growth (figure 10.1). This has led to business's share of gross expenditure on R&D (GERD) increasing markedly.

The pattern of investment is the outcome of changes in the incentives to undertake R&D — the relative costs and benefits of R&D investment compared with alternative investments. Major changes in the operating environment of businesses in the market sector, which could be expected to have affected the demand for R&D, include the following.

- *Program of policy reforms*: many of the macro and micro-economic policy reforms undertaken over the last twenty-five years were explicitly motivated by arguments expected to alter the environment in which businesses operated, including the incentives to innovate. In particular, businesses were exposed to greater competitive pressures, and a raft of changes in institutional arrangements put greater reliance on the market provision of goods and services (for example, many infrastructure services) over direct Government provision (box 10.1).
- *Changes in production technologies*: over the time period under study, there has been significant change in the capital stock of businesses, including the broad diffusion of technologies primarily adopted from overseas (for example, ICTs).

Box 10.1 **Immediate and gradual structural breaks**

From 1968-69 to 2002-03, the economy experienced a number of ‘immediate’ shocks:

- sharp increases in oil prices in and around 1973-74 which, at least coupled with other factors and policy responses, led to higher inflation, lower output growth and significantly higher unemployment;
- a sharp fall in agricultural output of 22 per cent in 1982-83 due to the drought, taking around 1 percentage point off GDP growth and causing a decline in MFP; and
- the recessions of the early 1980s and 1990s.

Two policy related R&D shocks occurred.

- Introduction of the 150 per cent tax concession for R&D in 1985-86. It has been suggested that the growth in business expenditure on R&D (BERD) in the two years prior to this reflected a ‘gearing up’ effect on companies in anticipation of the introduction of the tax concession. However, it is only one of a number of factors that influenced the increase in BERD in the 1980s.
- The reduction in the rate of the tax concession from 150 per cent to 125 per cent in 1996-97, ending of the registration of new syndicates from July 1996, and a suite of changes to eligible costs.

More gradual and fundamental structural breaks can be linked to the *Prices and Incomes Accords* and the programs of macroeconomic and microeconomic policy reforms.

The *Prices and Incomes Accords* operated from 1983 to 1996, affecting wages growth, employment demand and the capital-labour ratio. Labour productivity growth in the 1980s was probably slower than it would otherwise have been because of the Accords, which held down real wage growth, and thereby generated faster growth in employment and substitution into labour or ‘capital dilution’.

Wide-ranging macroeconomic and microeconomic policy reforms occurred through the 1980s and 1990s. The abolition of exchange controls, reduction in tariffs and deregulation of selected industries in the early to mid-1980s opened the Australian economy to international competitive pressures, which in turn played a catalytic role in encouraging R&D. The National Competition Policy reforms commenced in 1995, involving broad-ranging reforms to essential service industries, government businesses and anti-competitive regulation.

The diffusion of ICTs increased rapidly, particularly from the mid-1990s. The total volume of IT investment accelerated in the second half of the 1990s, partly due to some cyclical and one-off factors (for example, Y2K) but also due to structural developments including more rapid technological advances. The diffusion of ICTs across firms was also rapid in the 1990s.

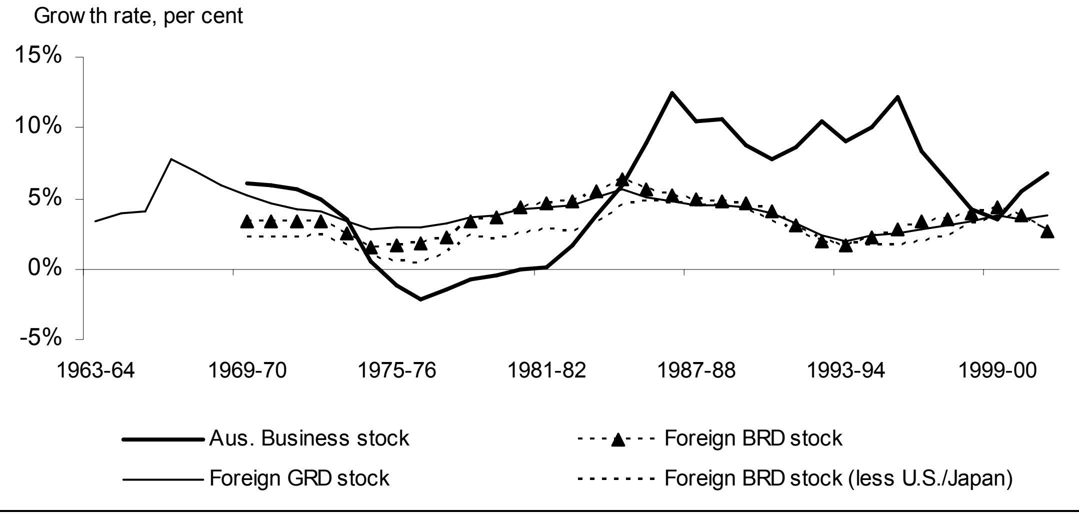
Sources: Gruen and Stevens (2000); Chapman (1990); PC (2004); Banks (2005).

The international environment

International investment in R&D should have a large impact on the incentives facing Australian businesses to invest in R&D through a combination of the provision of new areas of technological opportunities, knowledge spillovers, and competition effects. However, testing in appendix E did not find evidence of a long-run relationship between Australian business R&D (BRD) and foreign business R&D or foreign gross R&D (GRD). The testing included tests of the four different long-run relationships outlined in chapter 2. The available time series may be too short to detect permanent effects, particularly given some of the important structural changes contained in the data.

The Australian business knowledge stock has grown faster than the foreign BRD or GRD knowledge stock since 1985-86 (figure 10.1). The different periods in rates of investment may be part of a broader convergence story. A sustained period of catch-up in investment appears to have occurred following a period of low rates of investment.[1] The period of high investment rates coincides with the period where the bulk of policy reforms occurred and with the introduction of the R&D tax concession.

Figure 10.1 **Two starkly different periods of relative R&D investment rates**
Assumed rate of decay of 15 per cent



[a] Comparisons are based on the fourteen countries used to construct the foreign R&D knowledge stocks (discussed in appendix F). These countries are the larger and higher R&D intensive countries of the OECD. The aggregation of the foreign stocks is unweighted.

Data sources: OECD (ANBERD database); ABS (*Research and Experimental Development, Businesses, Australia,* Cat. no. 8104.0); ABS unpublished data; Commission estimates.

[1] The Commission is undertaking a separate study on Australia's level of productivity compared with other countries and whether the gap has changed over time. If it has, it is possible that the period of high business R&D investment in Australia may have played a role.

The different periods in the growth rate of the knowledge stocks drives comparisons in intensities, measured as the net accumulation in the knowledge stock as a proportion of output (top panel of figure 10.2). Expansion of the knowledge stock as a proportion of output was very weak or non-existent in the 1970s and into the 1980s in Australia. By the 1990s, the rate of accumulation of knowledge from business investment in R&D was roughly the same as for foreign businesses (with or without the inclusion of United States and Japan). It was higher in the first half of the 1990s, and lower in the second half, with rates equal at 2001-02.

In 2001-02, the stock of Australian BRD as a proportion of output was less in Australian than overseas (6 per cent versus 10 per cent, including the United States and Japan) (bottom panel). The difference is driven by the low rate of investment prior to the mid-1980s. For these comparisons, a rate of decay of fifteen per cent has been assumed (see chapter 4 for a survey of empirical estimates of the rate of decay). Australia's intensities would be increased relative to foreign intensities if a higher rate of decay was assumed, since more of Australia's accumulated investment is relatively 'new'.

Explanatory variables

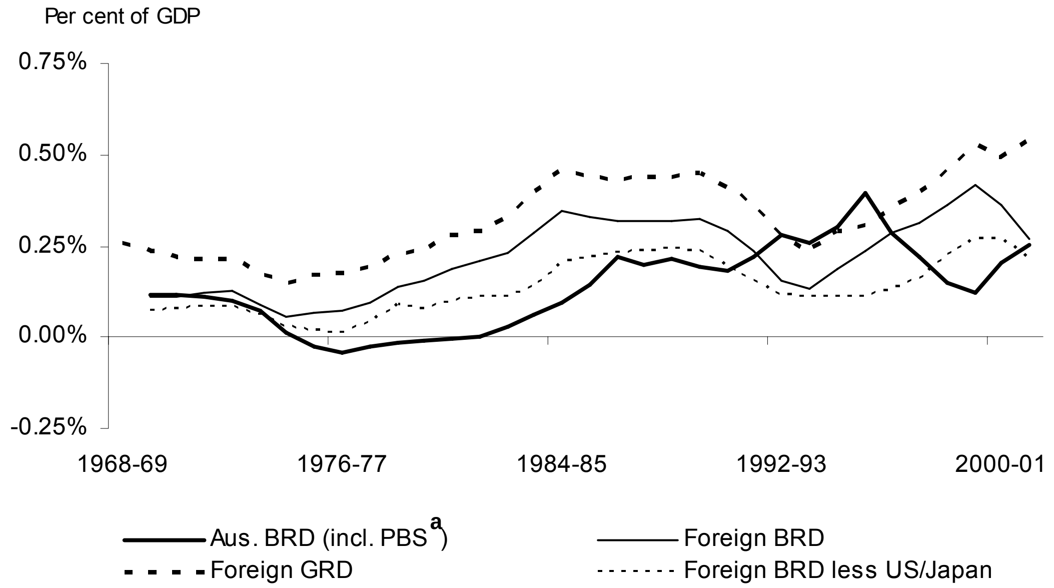
The choice of explanatory variables for the R&D equations draws on various theoretical models and empirical studies of the factors that determine the costs and benefits of R&D investment.

There is potentially a large range of factors that have important influences on the costs of undertaking R&D and the benefits that a business may appropriate, including: the responsiveness of prices to quality change in final outputs and intermediate inputs; the price of R&D personnel; the intensity of competition and the penalty to non-innovation that it imposes; business cycle effects; technological opportunities created by overseas advances in technological knowledge and other forms of knowledge, as well as advances made by non-business R&D investment in Australia; policy interventions that seek to lower the costs of undertaking R&D; and policy interventions that seek to support the ability of inventors to appropriate the benefits of their R&D. An even broader set of influences relate to the effects that product market and labour market regulatory environments can have on the incentive to invest in R&D, including the 'organisation' of the production of R&D and the potential for spillovers.

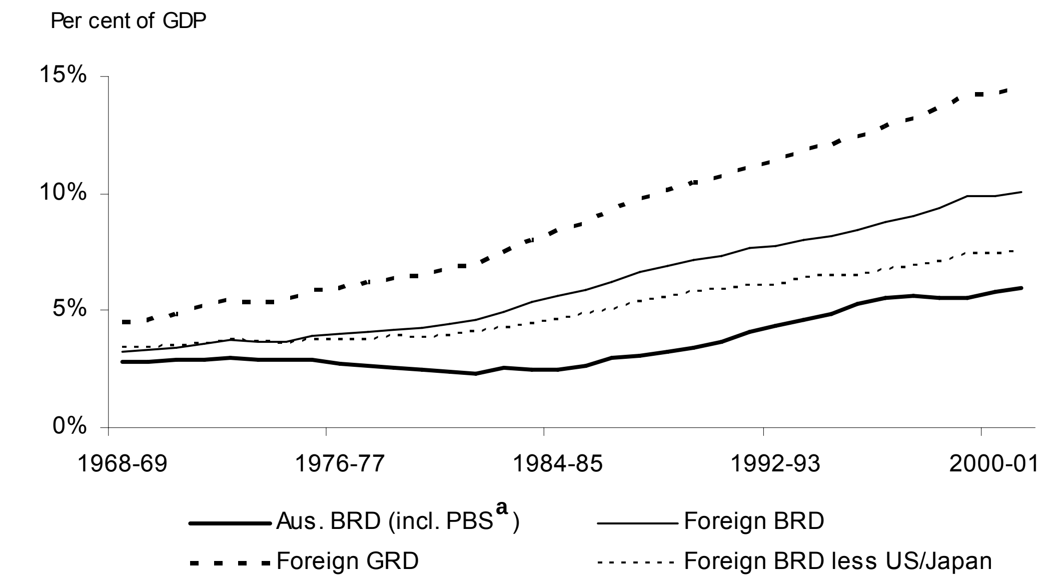
Data limitations severely limit investigation of many factors that may influence R&D investment. Such factors include direct measures of competitive intensities, and demand and appropriability conditions. Measures that could be constructed are listed in table 10.1.

Figure 10.2 **Comparative knowledge intensities, 1968-69 to 2001-02**

Change in the knowledge stock as a proportion of output (ΔK/Y)



Knowledge stock as a proportion of output (K/Y)



[a] Property & business services.

Data sources: OECD (ANBERD database); ABS (*Research and Experimental Development, Businesses, Australia,* Cat. no. 8104.0); ABS unpublished data; Commission estimates.

Table 10.1 **Factors influencing R&D investment**

Variable	*Description*	*Expected sign*	*Rationale*
Lagged dependent	Lagged dependent variable	(+)	High adjustment costs contributing to persistence in R&D investment behaviour
Δvams	Change in real market sector value added	(+)	R&D expenditure may be pro-cyclical if it is cash constrained or if recent economic conditions affect investment expectations
yrshortbond	Spliced 2 and 3 year Government bond rate	(-)	Alters cost of capital. A higher cost of capital discounts benefits more heavily than costs as benefits are spread farther into the future
bondvol	Average percentage change in yield over previous three years	(-)	Volatility in the cost of capital can increase investment uncertainty, reducing the level of investment
rbusgf	R&D performed by Australian businesses but financed by governments	(?)	Contemporaneous: businesses may substitute government finance for own-finance with no net additionality. Dynamic: even if no additionality contemporaneously, government financed R&D might support future higher levels of investment if it builds capabilities which increases net profits of future investment
rfrg_te	Foreign GRD weighted by Elaborately Transformed Manufactures (ETM) import shares	(+)	Knowledge spillovers to Australia can substitute for Australian R&D, but they also provide technological opportunities and raise the net profits from innovation by lowering costs of R&D production and likely increasing the penalty to non-innovation in competitive markets. Trends in foreign R&D may alter the incentives to invest in own-R&D through the 'absorptive' benefit of R&D
rhe rgp	R&D performed in higher education institutions and performed by Governments	(+/-)	Source of technological opportunity and spillovers to business R&D. May play role in absorbing overseas knowledge and transferring to Australian businesses. However, may also directly displace business investment or increase inputs costs which crowd-out business R&D. Displacement impacts will be less if the R&D undertaken is subject to fixed cost/appropriability conditions which impede private investment
concpost	R&D Tax Concession Scheme: nominal subsidy equivalent (post-tax basis)	(+)	Induces additional R&D expenditure by lowering costs of marginal R&D investment. Calculated as ((Concessional rate of deduction – 100) * Company tax rate)/100.
era/nrao	Effective or nominal rates of industry assistance to total manufacturing	(-)	Lower industry protection increases competitive pressures and raises the net return from innovating versus not innovating
manushare	Share of manufacturing in market sector value added	(+)	Manufacturing has historically had much higher R&D expenditure and R&D intensities than services industries. The decline in the share of manufacturing would have suppressed aggregate R&D intensities

Modelling strategy

The stock of R&D and R&D expenditure are modelled using a simple, descriptive approach following Jaffe (1988) and Guellec and van Pottelsberghe (2000).[2] R&D is regressed in 'informal' fashion[3] on a range of explanatory variables thought to affect the costs and benefits of investment in R&D.

The specification of the R&D variables was taken from the long-run relationships investigated in earlier chapters and outlined in chapter 2. Equation (1) below investigates the partial effects of the explanatory variables on the level of the business own-financed knowledge stock (used for models S1 and S2). Equations (2) (models S3 and S3LP) and (3) (models S4 and S4LP) are motivated by the endogenous growth models, which consider the impact of R&D on productivity in terms of the proportion of resources devoted to R&D rather than the level of the knowledge stock. These equations investigate correlations with the fraction of the economy's resources devoted to R&D.

All variables are in logs (except for the variable representing volatility in the cost of capital), and so the coefficients are to be interpreted as elasticities. All R&D explanatory variables were entered lagged one period. The coefficients (βs) are dropped here for ease of presentation. The government-financed, foreign, higher education and government-performed R&D variables, all take an equivalent form to own-financed R&D:

$$\ln(rbusof_t) = \ln(rbusof_{t-1}) + rbusgf_{t-1} + rfrg\_te_{t-1} + rhe_{t-1} + rgp_{t-1} + x_{it} + \varepsilon_t \qquad (1)$$

$$\ln(\frac{rbusof_t}{Y_t}) = \ln(\frac{rbusof_{t-1}}{Y_{t-1}}) + rbusgf_{t-1} + rfrg\_te_{t-1} + rhe_{t-1} + rgp_{t-1} + x_{it} + \varepsilon_t \qquad (2)$$

$$\ln(\frac{\Delta rbusrof_t}{Y_t}) = \ln(\frac{\Delta rbusrof_{t-1}}{Y_{t-1}}) + rbusgf_{t-1} + rfrg\_te_{t-1} + rhe_{t-1} + rgp_{t-1} + x_{it} + \varepsilon_t \qquad (3)$$

where *rbusof* is either the business own-financed knowledge stock, or own-financed business real R&D expenditure, *rbusgf* is R&D performed by businesses but financed by governments, *rfrg_te* is the stock of foreign GRD, *rhe* is the stock of R&D performed by Australian higher education institutions, *rgp* is the stock of

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[2] More formal approaches are adopted in Jaumotte and Pain (2005) using country-level data, and Cincera (2002) and Harhoff (2000) using micro-level data.

[3] Jaffe (1988, p. 433) noted in relation to his own regression: 'This equation is not an R&D demand equation derived from optimal firm behaviour; it is simply a device to examine patterns of R&D intensity descriptively. It is motivated by heuristic arguments about things that affect the cost and benefits of R&D.'

R&D performed by Australian government institutions, *x* is other explanatory variables (including the bond rate, volatility in the bond rate, a cycle control variable, R&D tax concession, and industry protection), and ε is a stochastic error term.

The R&D equations S1 through S3LP are specified as autoregressive models (that is, they capture dynamics of adjustment over time). Guellec and van Pottelsberghe (2000) justified their use of an autoregressive distributed lag model, in modelling R&D expenditure, on the basis that R&D expenditure is subject to high adjustment costs. High adjustment costs mean that 'equilibrium' is only established over time and, consequently, that current investment is related to past investment behaviour.

> … a dynamic specification for an R&D investment equation is not a common procedure in the existing literature on the effectiveness of government support to R&D. On *a priori* grounds, however, the inclusion of lagged private R&D may be seen as an important determinant of present R&D investment. Mansfield (1964, p.320) notes that: "First it takes time to hire people and build laboratories. Second, there are often substantial costs in expanding too rapidly because it is difficult to assimilate large percentage increases in R&D staff. (…) Third, the firm may be uncertain as to how long expenditures of (desired) R&D levels can be maintained. It does not want to begin projects that will soon have to be interrupted." Therefore, the behaviour of private investors can be best described in terms of a dynamic mechanism that allows for a long-term adjustment path. (p. 12)

The R&D equations in models S4 and S4LP were specified as finite distributed lag (FDL) models, rather than autoregressive distributed lag (ARDL) models. Testing of an ARDL specification produced coefficients on the lagged dependent variable very close to one. Specifying the equation as a simple static model produced very highly serially correlated errors.

Each R&D equation was estimated in tandem with a productivity equation using SURE. Models S1, S3LP and S4LP were set-up as a sequential system where R&D in period (t) is determined by a range of explanatory variables, which then determines future output (that is, own-financed R&D enters the productivity equation as a lagged variable). Own-financed R&D is a pre-determined variable in the productivity equation and identifies the system. For models S2, S3 and S4, the productivity equations are specified as FDL models.

The R&D equations provide estimates of the sign and magnitude of the net effect of various factors influencing business R&D investment. Modelling at a high level of aggregation implicitly captures these effects between firms and industries:

> As compared to the firm level approach that is more common in the field, the macroeconomic approach allows the indirect effects of policies to be captured – negative as well as positive spillovers. A firm benefiting from subsidies is likely to boost its own R&D activity but the R&D activity of competing firms might decline, for

> instance because they see their chances of having a competitive edge waning due to the financial advantage given to the recipient. Negative externalities can also take place between industries as shown by Mamuneas and Nadiri (1996) with US manufacturing industries. On the other hand, the recipient firm's research may generate knowledge spillovers that will flow to its competitors as well. The potential presence of these effects makes the case for empirical studies at an aggregate level, which implicitly take them into account (be they positive or negative). (Guellec and van Pottelsberghe 2000, p. 12)

The components of the 'net' effects are discussed below in the interpretation of the results.

10.2 Results from the productivity equation

The static productivity models give an estimate of the permanent or long-run relationship once all change has ceased. Different lag structures for the R&D variables in the productivity equation were tested to see which lags provided the most robust estimate of the permanent effect. Picking an optimal single lag tries to recognise that lags in R&D are important. The distributed lag models attempt to provide a better estimate of the permanent effect by separating out the transitionary from permanent effects of R&D (see chapter 6 for a discussion).

Results using foreign knowledge stocks

The extended models of chapter 7 produced estimates of the effect of Australian BRD on multifactor productivity (MFP), which were both positively and negatively signed. Estimating a two-equation system with SURE was not expected to, and does not, remove this uncertainty.

Australian own-financed business R&D has a positive and economically significant impact on productivity in models S1, S2, and S3LP (table 10.2). It has a negative or economically insignificant effect in the other models.

Table 10.2 **Influences on MFP and labour productivity[a], and R&D[b]**

Model -	*S1*	*S2*	*S3*	*S3LP*	*S4*	*S4LP*
Dep. var.-	*ln(MFP)*	*ln(MFP)*	*Δln(MFP)*	*Δln(LP)*	*Δln(MFP)*	*Δln(LP)*
	Static	*FDL*	*FDL*	*Static*	*FDL*	*Static*
R&D spec. -	*ln(K)*	*ln(K)*	*ln(K/Y)*	*ln(K/(Y*hrs))*	*ln(ΔK/Y)*	*ln(ΔK/(Y*hrs))*
R&D lags[b] -	*Aus. = 2 For. = 3*	*Aus. = 3 For. = 4*	*Aus. = 2 For. = 2*	*Aus. = 1 For. = 2*	*Aus. = 2 For. = 4*	*Aus. = 2 For. = 4*
Influences on MFP and labour productivity						
Time trend	0.010	0.006***				
	(0.006)	(0.002)				
Cycle	0.391***	0.465***	0.366***	0.391***	0.448***	0.352***
	(0.043)	(0.009)	(0.061)	(0.030)	(0.029)	(0.024)
rbusof	0.052**	0.079***	-0.012*	0.025	-0.001	-0.005
	(0.025)	(0.023)	(0.006)	(0.016)	(0.004)	(0.003)
Rfrg_te	-0.205***	0.457***	0.054***	0.065**	0.018***	0.028***
	(0.045)	(0.025)	(0.019)	(0.028)	(0.004)	(0.010)
ksrv				0.376***		0.243***
				(0.075)		(0.074)
ci5iousage	-0.034	-0.122***	0.080***	0.010	0.202***	0.014
	(0.025)	(0.014)	(0.018)	(0.016)	(0.036)	(0.017)
I3usage2s	0.256**					
	(0.113)					
nonggitcap	-0.005	-0.077***		-0.069***	-0.038	-0.032***
	(0.018)	(0.004)		(0.013)	(0.015)	(0.010)
education	0.063	0.031*	0.071***	0.085**	0.071**	0.109***
	(0.048)	(0.017)	(0.018)	(0.036)	(0.028)	(0.039)
tiopenetm	0.060***			0.044***	0.015	0.051***
	(0.021)			(0.014)	(0.011)	(0.015)
era	-0.063***	-0.023***	-0.153***	-0.061***	-0.111***	-0.096***
	(0.015)	(0.003)	(0.018)	(0.016)	(0.018)	(0.014)
centbrg		-0.044***	-0.019***	-0.005	-0.016***	-0.012***
		(0.001)	(0.002)	(0.004)	(0.003)	(0.003)
Intercept	3.617***	3.006***	-0.098***	1.171**	0.047	0.320***
	(0.482)	(0.070)	(0.025)	(0.508)	(0.030)	(0.109)
Dummy, Shift1982		0.012***		-0.015**	-0.030***	
		(0.002)		(0.007)	(0.006)	
Shift1983				-0.024***		
				(0.006)		
Shift1985		0.017***			-0.026***	
		(0.001)			(0.007)	
Shift1989		-0.003**	0.005*			
		(0.001)	(0.003)			
Shift8589				-0.006*		-0.009**
				(0.004)		(0.004)
Shift1992		-0.007***	-0.012***	-0.034***		-0.016***
		(0.001)	(0.003)	(0.009)		(0.005)
Shift1995				0.016***		0.022***
				(0.004)		(0.006)

(continued on next page)

Table 10.2 **(continued)**

Model -	*S1*	*S2*	*S3*	*S3LP*	*S4 FDL*	*S4LP FDL*
	ARDL	*ARDL*	*ARDL*	*ARDL*	*FDL*	*FDL*
Dep. Var.	*ln(K)*	*ln(K)*	*ln(K/Y)*	*ln(K/(Y*hrs))*	*ln(ΔK/Y)*	*ln(ΔK/(Y*hrs))*
Decay rate -	*Aus=15 For=15 HE/GP=10*	*Aus=15 For=15 HE/GP=10*	*Aus=15 For=15 HE/GP=10*	*Aus=15 For=15 HE/GP=10*	*Aus=05 HE=05 For/GP=10*	*Aus=05 HE=05 For/GP=10*
Influences on R&D						
Lag dependent	0.945*** (0.023)	0.951*** (0.041)	0.969*** (0.060)	0.846*** (0.098)		
Trend					0.059*** (0.008)	0.076*** (0.005)
cycle	0.157*** (0.058)	0.169*** (0.060)	-0.504*** (0.131)	-0.475*** (0.173)	2.401*** (0.622)	0.848** (0.354)
yrshortbond	-0.022** (0.011)	-0.024* (0.013)	-0.075*** (0.018)	-0.176*** (0.028)	-0.898*** (0.203)	-0.972*** (0.147)
bondvol	-0.088*** (0.019)	-0.107*** (0.032)	0.094*** (0.030)	0.108** (0.050)	0.431*** (0.165)	0.392** (0.159)
Rbusgf	0.234*** (0.036)	0.296*** (0.091)	0.082 (0.063)	-0.064 (0.095)	0.139*** (0.030)	0.213*** (0.036)
Rfrg_te	0.376*** (0.073)	0.411*** (0.085)	0.381*** (0.049)	0.323*** (0.081)	1.767*** (0.090)	1.986*** (0.085)
Rhe	-0.743*** (0.133)	-0.768*** (0.176)	-0.131 (0.099)	-0.044 (0.166)	0.983*** (0.173)	1.138*** (0.143)
Rgp	0.421 (0.393)	0.214 (0.429)	-0.128 (0.131)	-0.234*** (0.081)	0.636*** (0.126)	0.373*** (0.094)
concpost	0.003** (0.001)	0.002 (0.002)	-0.001 (0.002)	0.000 (0.003)	0.029*** (0.008)	0.002 (0.007)
era	-0.117*** (0.032)	-0.148*** (0.041)	-0.043 (0.053)	-0.120 (0.081)	-0.453** (0.213)	-0.645*** (0.161)
Intercept	-0.395 (1.220)	0.369 (1.383)	-0.736 (0.808)	-4.173* (2.419)	7.706*** (1.715)	40.460*** (3.462)
Test statistics						
# of obs.	29	26	27	27	26	25
ADF Equation 1[c]	-4.564 (0.000)	-4.921 (0.000)		-3.318 (0.014)		-4.081 (0.001)
ADF Equation 2	-4.826*** (0.000)	-5.719 (0.000)		-5.163 (0.000)		-3.921 (0.002)

[a] Seemingly Unrelated Regression Equations (SURE) were used for estimation. Knowledge stocks used in both equations. All variables specified in logarithms. For the productivity equation, the initial observation for Australian BRD in the FDL models is lagged one period (t-1). Therefore, in the case of model S3, the inclusion of two lags means that observations at (t-1), (t-2) and (t-3) are included in the regression. In the case of the static model S1, a single observation of Australian BRD at period (t-2) and foreign GRD at (t-3) is included in the regression. For models S3-S4LP, non-R&D explanatory variables are in first differences. [b] All variables specified in logarithms (except bondvol). [c] Augmented Dickey Fuller Test with MacKinnon approximate p-value in brackets. Test of I(1) against a level stationary process.

Source: Commission estimates.

Models S1 and S2 are the two-equation counterparts to the extended levels models of chapter 7. Model S1 is a static levels model and provides a large negative coefficient on foreign R&D. Model S2 is an FDL model which produces a very large coefficient on Australian BRD. The implied rate of return is well above the rule-of-thumb upper bound. In model S2, the large positive coefficient on Australian BRD is only obtained with the inclusion of shift terms. Without the shifts, the coefficient becomes large and negative. Dropping it from the model and retesting down results in the coefficients and standard errors for foreign R&D, communications infrastructure, IT capital, education, era and centbrg becoming 0.491 (0.044), -0.086 (0.022), -0.146 (0.018), -0.068 (0.010), and -0.033 (0.004), respectively. The trend is 0.017 (0.006) and the intercept is 1.699 (0.315). The main change was the increase in the economic significance of education.

This result shows that it is possible to specify a model, resulting from a general-to-specific test down procedure, which explains MFP without including Australian BRD. The model produces coefficient signs that are expected (except for communications infrastructure) and economic magnitudes that are plausible.

Dropping communications infrastructure and IT capital results in foreign R&D, education, era and centbrg becoming 0.335 (0.067), 0.088 (0.033), -0.101 (0.012) and -0.008 (0.003), respectively. The intercept is 3.785 (0.0186). However, the trend term becomes -0.015 (0.004). If only communications infrastructure is dropped, IT capital remains negative and significant, while the trend term becomes economically and statistically insignificant. The other variables are largely unaffected.

In model S3LP, a 10 per cent increase in R&D intensity, measured as the knowledge stock over the product of market sector value added and hours worked, implies an increase in the labour productivity growth rate of 0.25 percentage points. The average labour productivity growth rate over the sample is 2.2 per cent.

Both the MFP and labour productivity (LP) models, which specify R&D as the net accumulation in the knowledge stock, produce economically insignificant estimates of the effect of own-financed R&D. The results for foreign R&D, and controls are generally significant, well estimated, and of the expected sign.

Dropping the constant in model S4 FDL results in the effect of BRD becoming significant but negative at -0.007 with a standard error of 0.001. The other variables are not affected. The coefficient on BRD is well estimated and indicates that net changes in the stock of Australian BRD as a proportion of output has had a small negative impact on MFP growth.

The signs of effects are consistent between the MFP and labour productivity models (S3 vs S3LP and S4 vs S4LP). The exception is the sign on own-financed business R&D between models S3 and S3LP. Signs are also equivalent across the four growth models for each variable, other than own-financed R&D. This provides some confidence in the direction of the estimated effects. In the case of the manufacturing panel models in appendix J, the MFP and labour productivity growth models did not always produce consistently signed estimates of the effect of foreign R&D.

The models imply that overseas investment in R&D has important positive implications for Australian productivity. The system models, other than S1, produce an estimate of the effect of foreign R&D which is economically significant, positive, and highly statistically significant. This is a major improvement on the single equation productivity growth regressions of chapter 7, which tended to produce positively signed coefficients that explained transitionary behaviour, but had trouble estimating the permanent effect with precision.

The regressions in this chapter all support a strong, positive effect of education on productivity growth.[4] In chapter 7 growth regressions, education was positively signed, but estimated imprecisely.

The coefficients on communications infrastructure is negative in the system ln(MFP) models, but positive in the MFP and labour productivity growth models. The signs on the other explanatory variables are more consistent across specifications. Once communications infrastructure is held constant, the partial effect of IT capital on productivity is negative in all specifications. Openness to Elaborately Transformed Manufactures (ETM) imports is positive and significant, while greater industry protection and centralised determination of wages are negative and significant.

These models all assume that the partial effect of Australian BRD on productivity has been reasonably constant over time. Basic models later in this chapter and re-estimation of these models in appendix O, relax this assumption. The models give an estimate of the average effect over the sample.

Results using USPTO patents

The use of a simple count measure of patents granted by the US Patent and Trademark Office (USPTO) as a measure of the output from foreign R&D, rather

[4] In the two labour productivity regressions, which are both static productivity equations, education and ERA enter the regression lagged two periods.

than the use of foreign knowledge stocks based on the perpetual inventory method (PIM), improved the regressions of some empirical specifications in chapter 9.

The system models were re-estimated with the USPTO measure substituted for the foreign knowledge stocks to test to see if overall results could be improved (table 10.3). The estimated effect of foreign R&D is positive and highly significant, consistent with the results just presented.

Australian BRD is poorly estimated in the levels specifications (model S1). However, the productivity growth models again point to a negative partial effect of Australian own-financed BRD. The negative effect is estimated with lower standard errors than when the models included foreign knowledge stocks. In the case of the two labour productivity growth models, the negative effect is tightly bound to zero. The statistical significance of the results is sensitive to the 'optimal' lag chosen for both variables, but not to the direction of the effects.

Table 10.3 **Re-estimated system with USPTO patents granted**[a]

In MFP growth models, USPTO patents is differenced. In labour productivity growth models, USPTO patents is divided by Australian market sector hours worked and differenced.

Model -	*S1*	*S3*	*S3LP*	*S4*	*S4LP*
Dep. var.-	*ln(MFP)*	*Δln(MFP)*	*Δln(LP)*	*Δln(MFP)*	*Δln(LP)*
Rbusof spec. -	*ln(K)*	*ln(K/Y)*	*ln(K/(Y*hrs))*	*ln(ΔK/Y)*	*ln(ΔK/(Y*hrs))*
Rbusof lag -	*1*	*1*	*2*	*2*	*2*
USPTO lag -	*1*	*1*	*3*	*1*	*4*
Rbusof	-0.025	-0.020***	-0.007***	-0.007***	-0.001***
	(0.017)	(0.006)	(0.001)	(0.002)	(0.000)
USPTO_te	0.043***	0.043***	0.030**	0.119***	0.013
	(0.009)	(0.013)	(0.013)	(0.038)	(0.015)

[a] See table 10.2.

Source: Commission estimates.

Improvement of the basic models

The basic productivity models of chapter 6 were re-estimated using the two-equation system. The measure of USPTO patents granted was used where it improved upon the results of the knowledge stocks. The R&D equations were as specified in models S1 through S4LP. The productivity equation included only Australian BRD and foreign GRD or USPTO patents. A range of time dummies, intercept shifts and slope shifts for Australian BRD were also included and tested down.

In chapter 6, estimation of basic productivity growth models produced negative coefficients for foreign R&D. In the levels specifications, dynamic models were required to obtain desired statistical properties. However, these models generally had difficulty estimating a permanent effect (i.e., there was very wide standard errors).

The effect of foreign R&D — either the foreign knowledge stock or USPTO patents granted — has a positive and highly significant effect in five of the six models (table 10.4). If a linear time trend is entered into the ln(MFP) model S1 Basic, the foreign effect remains significant with a coefficient of 0.138, a standard error of 0.084, and a p-value of 0.102. The trend is 0.003 and significant at only 27 per cent.

The effect of own-financed Australian BRD is also positive and significant in five of six models. In model S4 LP it is significant at 10 per cent or greater, but the coefficient is economically insignificant at zero.

In the systems models, adding other controls raises the coefficient on Australian BRD in the levels specifications, and reduces it in the growth specifications.

The system results produce slope changes in the effect of Australian BRD that accord better with expectations. The results presented in earlier chapters, and the testing of parameter stability and structural breaks in appendix E, suggested changes, but they were not dramatic. The graphs of the growth rate of Australian BRD compared with productivity support an expectation of very different economic periods pre- and post-1985 (at least in terms of R&D investment).

The acceleration and sustained high rates of R&D investment from the mid-1980s, according to models S1 and S2, reduced the partial effect of R&D on MFP by at least one-third. In the case of model S2, the estimated effect of Australian BRD up to 1985 suggests that a 1 per cent increase in the knowledge stock would result in a 0.033 per cent increase in the level of MFP. After 1985, the estimate is reduced to 0.020 and then increases marginally up to 0.024 from 1995.

Model S3 also highlights the different periods prior to and after the mid-1980s. The intercept term is highly significant for the first period and the coefficient on Australian BRD is positive and highly significant at 0.132. However, for the second period, the intercept is reduced to a small negative value and the partial effect of the intensity of Australian BRD on the growth rate of MFP is reduced to zero.

The labour productivity models estimate better with the foreign knowledge stock replaced with USPTO patents granted. However, neither model shows any significant reductions in the effect of Australian BRD.

Table 10.4 **Basic productivity models within the two-equation system**

'Basic' productivity equations estimated jointly with the previous R&D equations using SURE. Productivity equations are static models using 'optimal' lags.

Model -	*S1 Basic*	*S2 Basic*	*S3 Basic*	*S3LP Basic*	*S4 Basic*	*S4LP Basic*
Dep. var.-	*ln(MFP)*	*ln(MFP)*	*Δln(MFP)*	*Δln(LP)*	*Δln(MFP)*	*Δln(LP)*
R&D spec. -	*ln(K)*	*ln(K)*	*ln(K/Y)*	*ln(K/(Y*hrs))*	*ln(ΔK/Y)*	*ln(ΔK/(Y*hrs))*
R&D lags -	*Aus. = 2 For. = 4*	*Aus. = 1 For. = 0*	*Aus. = 2 For. = 2*	*Aus. = 2 For. = 1*	*Aus. = 2 For. = 4*	*Aus. = 2 For. = 1*
Cycle	0.594*** (0.050)	0.435*** (0.067)	0.409*** (0.040)	0.382*** (0.045)	0.330*** (0.053)	0.331*** (0.050)
Rbusof	0.029* (0.015)	0.033* (0.018)	0.132*** (0.035)	0.019*** (0.006)	0.011** (0.004)	0.000* (0.000)
Rbusof slope shift 1982/3	0.004** (0.002)		-0.132*** (0.000)			
Rbusof slope shift 1985	-0.011*** (0.002)	-0.013*** (0.002)				
Rbusof slope shift 1995	0.005*** (0.001)	0.004** (0.002)				
Rfrg_te	0.230*** (0.017)	0.281*** (0.023)	0.089** (0.036)		0.007 (0.570)	
ΔUSPTO patents				0.060*** (0.019)		0.126*** (0.047)
ksrv				0.476*** (0.080)		0.236** (0.106)
Intercept	3.475*** (0.071)	3.245*** (0.085)	0.446*** (0.123)	0.302*** (0.101)	0.103*** (0.036)	
Dummy81		-0.015** (0.007)				
Dummy82		-0.030*** (0.010)			-0.022* (0.011)	
Shift1983	-0.041*** (0.007)	-0.053*** (0.008)				
Shift1985			-0.527*** (0.147)		-0.022** (0.010)	
Dummy8589						-0.008* (0.005)
Shift1989		-0.018** (0.007)				
Shift1992	-0.025*** (0.007)	-0.011* (0.007)				
Shift1995	0.016*** (0.006)	0.018*** (0.007)				0.010*** (0.004)

[a] For each model, a full set of dummies and intercept shifts were included in the initial variable set prior to testing down. A full set of slope shift terms for Australian BRD was also included with shifts at the years 1982, 1983, 1985, 1989, 1992 and 1995. The assumed rates of decay for the knowledge stocks are 15 per cent, except in models S4 and S4LP that use 5 per cent.

Source: Commission estimates.

Why does system estimation produce better results?

SURE estimation improves the precision of the estimates compared with results in chapter 7. It does this by exploiting the contemporaneous correlation in the error terms of the two equations. The two sets of error terms will be correlated when R&D investment and productivity have been subjected to common shocks that are not captured in each equation's set of explanatory variables.

It is possible that important shocks such as economic reforms are not well captured. In the case of the R&D equation, the inclusion of the other knowledge stocks probably does a reasonable job of representing changes in technological opportunity. The inclusion of the cycle variable only partly controls for demand conditions. Appropriability conditions are largely absent from the model. Effective rate of assistance (ERA) may partly capture changes in both demand and appropriability conditions to the extent that reductions in assistance altered competitive environments which in turn affected the responsiveness of demand to quality change, and the ability of firms to appropriate a sufficient proportion of the benefits to justify investment.

However, the processes at work here are far more complex than can be explicitly captured in the model, yet are likely to be important in understanding R&D investment behaviour.

One possible reason why SURE produces better estimates is that the process of economic reforms and consequential changes in investment incentives is not captured well in either equation, but is relevant to understanding both R&D investment patterns and productivity performance.

Comin (2004) notes that productivity-R&D studies typically omit factors from regressions that simultaneously affect MFP growth and the incentives facing firms to invest in R&D. Anything that enhances disembodied productivity falls into this category, such as changes in organisational practices and learning-by-doing.

Aghion and Howitt (1998, chapter 6) set out a learning-by-doing model that also includes R&D. Any parameter that increases the productivity of the innovation process will shift resources out of learning-by-doing (which is tied to conventional production activity) and into research, even where the parameter change increases the productivity of learning-by-doing.

Repeated changes in the efficiency with which businesses are able to obtain product, process and non-technological innovations would impact on MFP, but may not be captured in the productivity equations. These changes could be expected to induce additional R&D investment, but they are also absent from the R&D equations. However, while it is difficult to say with certainty that Australian businesses are more efficient innovators, and what are the sources of increased efficiency, there are many indicators that point in this direction.

10.3 Under what conditions are the social and private return close?

Some models find an economically insignificant or small negative effect of Australian business R&D on market sector productivity.

An economically insignificant effect implies that the level of social and private returns are similar. A negative excess effect implies that the social rate of return to R&D is less than a 'conventional' private return on R&D capital. The social return is the sum of the conventional return, any private supranormal returns, and external effects. The latter two components form the excess return which is what the coefficients from the market sector models are interpreted as measuring.[5]

It is conceivable that the net external effects or the private supranormal return could have been very small in Australia, or even that the social return could be less than the total private return. However, with more highly aggregated industry data, an increasing proportion of the spillovers between firms and industries should be captured in the estimates (assuming that the economic importance of the spillovers between firms and industries is indeed large). Therefore, an insignificant or negative excess effect seems less likely.

Few studies find a negative effect of business R&D on productivity, but some have (box 10.2). Apart from the market sector results in this chapter, estimates for manufacturing sub-industries also produce negative or economically insignificant effects for some industries (appendix J). In addition, other Australian manufacturing studies produce negative estimates for some industries (see, for example, Chand et al. 1998).

Factors that may have contributed to the positive external effects of R&D being dampened or offset (if indeed they were) are discussed below. It is not known if the magnitude of the factors is economically significant in the Australian context.

[5] The issue of double counting blurs interpretations somewhat, but it is not material to the overall findings.

Box 10.2 Studies that find a low or negative return to domestic R&D

There are many studies that find that the impact of R&D on productivity is large and positive, but this is by no means universally true. There are some studies that find a much smaller rate of return to own R&D. A small number of studies even find a negative rate of return. Surveys of existing studies of the impact of own R&D on MFP can be found in Cameron (1998), Mairesse and Sassenou (1991) and Dowrick (2003).

Small but positive returns to R&D

The estimated returns surveyed in Cameron (1998) and Mairesse and Sassenou (1991) range from negative to large and positive. Most of the estimates are positive and with some reasonably large and others quite small. Most of the studies that yield small but positive returns are at the firm level.

Klette and Johansen (1998), using a knowledge accumulation equation that allows for inter-temporal effects between knowledge investment and accumulated knowledge, estimated a return close to those for conventional capital, and many of the models produce returns not significantly different from zero or small negatives. However, their preferred specification shows a positive effect of R&D on firm performance.

Rouvinen (2002), based on a panel of OECD manufacturing industries, found an elasticity of R&D of almost zero for the period 1985-97. Industry level studies, surveyed in Cameron (1998) and Mairesse and Sassenou (1991), that estimate small returns include O'Mahony and Wagner (1996), O'Mahony (1992), Mohnen, Nadiri and Prucha (1986), Griliches and Lichtenberg (1984), Hartwick and Ewen (1983), Postner and Wesa (1983), Griliches (1980), Link (1978), and Globerman (1972).

Negative returns to R&D

Only a small number of studies have found that own R&D can have a negative impact on the growth rate of MFP. These include Mairesse and Hall (1996), Hall and Mairesse (1995), Rogers (1995), Sassenou (1988), Odagiri (1985) and Odagiri (1983). The Sassenou (1988) and Odagiri (1983) results are reported in Mairesse and Sassenou (1991), while the Odagiri (1985) results are reported in Cameron (1998). Mairesse and Hall (1996) obtained both positive and negative estimates of the impact of own R&D on the productivity of French and US firms. Overall, they concluded that the excess return to R&D for the set of firms was essentially zero, although it may have been slightly negative for the French firms. Hall and Mairesse (1995) obtained similar results for a panel consisting only of French firms.

Based on Australian time series data for the market sector, Rogers (1995) obtained estimates of the elasticity of MFP with respect to own knowledge stocks that ranged anywhere from -0.604 to +0.420. The models differed along three dimensions. First, some of the models included measures of the foreign knowledge stock as well as measures of the domestic knowledge stock. Second, some of the models included a time trend, while others did not. Third, some of the models used a PIM-based knowledge stock from R&D expenditures, while others approximated the knowledge stocks with patent counts. The negative estimates of the elasticity of MFP with respect to own R&D only occurred when a time trend was included.

Characteristics of R&D which could produce negative effects on MFP

Empirical studies of the return to R&D report the net effect of R&D on productivity growth, which includes the following negative influences.

- *Duplication and creative destruction:* if a large proportion of business R&D investment was directed towards alternative solutions to the same problem, or, similarly, the same types of quality improvements, or the introduction of very similar new products, then a large amount of R&D effort would result in a negative 'duplication' externality and the transfer of rents between past innovators and current innovators ('creative destruction').
  - These effects are part-and-parcel of how markets work and why firms within markets are so successful in innovating compared with other systems of economic production. In this sense, they are not 'negative'.
- *Long term technology cycles and a prolonged transitionary period*: the share of BERD expended on ICT-related research fields has increased very sharply over the last two decades. From an extremely small base, the share of IT technologies in Australia's capital stock has also risen rapidly. Historically, there have been periods where the wide diffusion of a new set of technologies has had both disruptive and complementary effects on the existing capital stock over a number of decades, even if the longer term effect was to replace existing technologies.
  - The coefficients on IT capital are consistently negative when estimated for the entire sample. This is consistent with a 'General Purpose Technology' story. As an increasing share of BERD is expended on these technologies, ICT-related adjustment costs might suppress the positive effect of R&D on productivity.

Factors which mute the positive impacts of R&D

While the stepping-on-toes and creative destruction characteristics of R&D have negative impacts on MFP, it is generally believed that these are offset by the positive effects of R&D which stem from the 'special' characteristics of knowledge (see chapter 2). Most empirical studies support a substantial net positive impact on productivity. However, the characteristics of knowledge as a source of increasing returns is subject to constraints.

- *Product proliferation:* the horizontal proliferation of products is a mechanism which dilutes the effect of R&D in some theoretical growth models and constrains the scale effect of R&D in those models (see chapter 2). An increasing amount of R&D must be undertaken to improve the range of products a given amount, which is equivalent to holding a given growth rate.

- *Diminished exogenous technological opportunities*: Australia generates a small fraction of the world's technological knowledge, even if it does well in per capita terms (as bibliometric indicators suggest). Neoclassical models and the semi-endogenous R&D-based growth model of Jones (1995a) emphasise the constraint that exogenously determined diminishing returns can impose on growth. For Jones, diminishing returns to R&D sets in as R&D investment rises. For Australia and other small countries, technological opportunities are largely set externally.

  – However, it is far from clear whether technological opportunities in the larger frontier countries have declined, particularly the United States, Japan, United Kingdom and Germany. There does seem to be some evidence of declines over certain periods (box 10.3).

- *Complexity and the amount of resources required to advance knowledge a given 'distance':* technological improvements may become increasingly difficult to obtain as the threshold for new discoveries rises (Evenson and Kislev 1976). Kortum (1997) states that this is the reason why patenting has been roughly constant as research employment has risen sharply over the last forty years in the United States. He develops a search model of invention which he uses to explain why research inputs have grown rapidly in the face of falling patents per researcher, and why there is not any equivalent increase in total factor productivity growth.

- *Reduction in spillover parameter:* the rapid increase and sustained high levels of R&D investment since the mid-1980s may have reduced the average spillover parameter of knowledge.

  – *Increase in share of 'D' versus 'R'*: the share of applied research and experimental development has risen dramatically for GERD as a result of the equally dramatic increase in the BERD share. Within BERD, the share of applied research and experimental development has also risen, but not nearly as significantly. If firms can more easily protect the outcomes from this type of R&D, or if the proportion of this type of R&D has less value to other users, then real increments to the general knowledge stock could have declined for a given amount of measured R&D expenditure.

Box 10.3 **US evidence on the question of diminishing returns to R&D**

The United States is at or near the technological frontier in most research fields. US evidence does not appear to support diminishing technological opportunities over the long run.

> It is not clear whether the "productivity" of R&D has been growing or diminishing over time. From a social point of view it could be growing. From a private point of view it has probably been declining, in the sense that to keep the same competitive edge, to stay in the same position in the commercial or academic market, R&D laboratories today need more expensive equipment, computers and materials. (Griliches 1984a, p. 148)

> … although the contribution of R&D investment to productivity growth was low during the 1970s and the first half of the 1980s, it revived in the second half in all sectors except electrical and large-scale computing, machinery, metals and autos (the well-publicized corporate behemoths). (Hall 1993, p. 290)

> It seems that the observed decline in the R&D coefficients did not begin seriously until the latter half of the 1970s, with the second oil-price shock and the rise in the dollar exchange rate. The abruptness of the decline argues against a 'supply-side' exhaustion of inventive opportunities explanation. It is more likely that the peculiar aggregate shocks of that time went against R&D-intensive industries … The subsequent rise in the coefficients, if it did in fact occur, the rise in corporate R&D investments through most of the 1980s, and also the rise in patenting in the late 1980s, all argue against interpreting these coefficient movements as reflecting 'real' declines in the once and future 'potency' of R&D. What did happen, though, was a sharp widening of the differential between social and private returns to R&D. The internationalization of R&D, the rise in the technical and entrepreneurial skills of competitors, and the sharp rise in the dollar exchange rate in the mid-1980s, all combined to erode, rather rapidly, the rents accruing to the earlier accumulated R&D capital and to the technical expertise positions of many US enterprises. This rise in the rate of private obsolescence and the fall in the 'appropriability' of R&D, led to sharp declines in both profitability and real product prices. The latter, if they had actually been reflected in the appropriate price indexes, would show up as an increase in productivity, rather than a decline. (Griliches 1995, pp. 62–3)

The Federal Reserve Board of San Francisco (FRBSF) (Wilson 2003) investigated the long-run decline in patents granted to US residents per capita relative to real industrial R&D per capita, and whether the decline could be interpreted as evidence of diminishing returns. Three reasons were given why the decline may be misleading:

- the relationship between R&D effort and granted patents may be influenced by non-technology factors, such as staffing at patent offices;
- economic incentives may have reduced the relative importance of patents as a means of appropriating the benefits of R&D effort; and
- the value of patents may have increased over time pulling-up research costs. The total value, or quality, of patents per R&D dollar could have remained constant or actually increased. Alternatively, the 'size' of the technological change codified in the average patent may have increased.

Surveys of laboratory managers indicated a relative decline in the use of patents as a strategy for protecting IP. Using patent citations data, the FRBSF found that the value of patents had increased, counter-acting the decline in numbers for a given R&D effort.

– *A substantial over-emphasis of the public good aspects of knowledge*: the properties of non-rivalry and non-excludability of knowledge underpin the growth mechanisms in R&D-based endogenous growth models (see chapter 2). However, the extent to which knowledge can be characterised by these properties depends on economic incentives. How much spills over and how fast is influenced by the state of technology, institutional arrangements, government policies, and the nature of competition within markets.

… Knowledge is more or less 'codifiable'[6] at different points on the diffusion path of major technologies, which affects its transfer cost. Therefore, the proportion of the stock that is private or excludable versus public and 'accessible by all', and the rate at which knowledge moves from one to the other, can change. This could have impacts on the size of the potential spillover pool, particularly transitional effects.

… The diffusion or transfer of knowledge is not costless. The search for, acquisition of, and understanding of knowledge consumes significant resources, which contrasts with the often made assumption that the cost structure of knowledge can be described as high fixed costs with marginal costs tending to zero. If more or less of society's resources are being consumed in the transfer and utilisation of knowledge, then this will affect the returns to R&D.

– *Policy distortions*: the introduction of government assistance programs geared towards R&D, particularly the R&D Tax Concession Scheme, may have resulted in the re-labelling of existing types of economic activities as R&D. These activities may have a lower spillover parameter compared with the previous average spillover parameter, and be less closely aligned with the concept of R&D in the theoretical models.

… However, if the true increase in R&D activity is less than measured, then the adjustment costs associated with the increases will be less.

– *Inelastic supply of scientists and engineers*: increased resources to R&D is partly absorbed by increases in the wages of scientists and engineers. Data for

[6] Fundamental innovation generates knowledge characterised by a high degree of uncertainty. Secondary innovation, in part, explores the opportunities created by fundamental innovation and involves a process of learning how to make best use of the new knowledge. Use of the knowledge is refined over time as outcomes become more predictable and a common understanding of the knowledge increases amongst suppliers and users. The knowledge is increasingly embodied in physical objects or codified, such as, in patents, journal articles and manuals. As technologies mature, an increasing proportion of the knowledge required for use of the technology evolves from being highly tacit to being explicit. While knowledge is technically non-rival, the acquisition and use of knowledge can be costly (see Machlup 1980, Nelson and Winter 1982 and Cowan et al. 2000).

Australia show that the growth rate in average labour costs per person year is much higher than growth in the number of person years devoted to R&D (although there are measurement concerns stemming from the growth in outsourcing (see appendix B)).

… Goolsbee (1998) found that a significant fraction of the increased R&D spending resulting from US Government assistance to businesses went directly into higher wages. Further, he highlighted that by altering the wages of scientists and engineers, even for firms not receiving federal support, government funding directly crowds out private inventive activity. For a given level of R&D expenditure, if the amount of new knowledge that scientists and engineers produce has not kept pace with the wage increases, then the aggregate knowledge stock will be less than otherwise and the quantum of spillovers reduced (public-private R&D interactions are discussed briefly in chapter 10).

… In Australia, the rapid acceleration in business investment, in the presence of inelastic supply of R&D labour, would likely have had a negative shock on the amount of knowledge which is generated for a given level of R&D inputs. Given the size of the potential shock, the negative influence on the efficiency of R&D may have applied for much of the period from 1985.

- *High real interest rates*: Jones and Williams (2000) set out a framework to investigate whether there is over or under-investment in R&D in the United States. High real interest rates reduce the magnitude of the negative effect that inter-temporal knowledge spillovers can have on a firm's ability to appropriate the returns of its R&D investment, and reduce the expected value of the capital loss associated with creative destruction. Both the appropriability and capital loss effects support under-investment in R&D by businesses meaning that the social return is above the private return to R&D. A dampening of the effects reduces the degree of under-investment and reduces the size of the difference between social and private returns. The authors state:

  Our central finding, robust to reasonable changes in parameter values, is that in the absence of taxes and subsidies, the decentralized economy underinvests in R&D, with the primary impetus coming from the surplus appropriability problem. The only exceptions to this conclusion occur when there is both a powerful duplication externality and a relatively high equilibrium real interest rate. Overall, there appears to be too little private R&D in our calibrated model. (p. 66)

  – There was a very substantial increase in US and Australian real interest rates in the 1970s, which was sustained through the 1980s (see chapter 10). The yield on Australian Government ten year bond rates averaged was significantly above equivalent US bond rates, so the effect of real interest rates may have been stronger in Australia. In this situation, and holding other parameters constant, the model would predict a reduction in the degree of under-investment (a decrease in the net positive external effects of R&D), or an increase in the degree of over-investment (an increase in the net negative external effects of R&D).

Changes in industry structure and the 'organisation' of R&D activity

The increase in the service sector's share of output and BERD over the last twenty to thirty years has been dramatic. The service sector's share (broadly defined as industries other than manufacturing and mining) has risen to be equal to manufacturing's share (chapter 3). It would be surprising if such significant changes did not have implications for the effect of R&D on productivity.

- *The 'organisation' of R&D activity in the production of knowledge*: the high rate of business investment in BERD since the early to mid-1980s has been accompanied by periods of rapid firm entry, shifts in shares of BERD by firm size, and increasing average expenditure per firm, but minimal growth in average person years per firm (see appendix I). Anecdotal evidence suggests there has been a rapid rise in contracting out and in joint or collaborative arrangements in R&D, including internationally. Services R&D has played a large role in these trends, which conceivably could have affected, in particular, the relationship between R&D inputs and outputs.
  - For example, the increase in business R&D expenditure since the mid-1980s is explained more by the entry of new firms performing R&D than it is by increases in the average expenditure of existing R&D performers. This may have pulled down the average efficiency of R&D activity in Australia if R&D or knowledge 'production' is subject to significant learning costs or scale effects (as net entry was driven primarily by smaller firms).
  - In the United States, R&D performed in the service sector is more likely to be conducted by firms with fewer employees and smaller R&D budgets than is the R&D conducted by manufacturers (Janokowski 2001, p. 333). In 2001-02, 63 per cent of Australian R&D performing businesses with fewer than twenty employees were classified in industries other than manufacturing and mining. In 2002-03, average expenditure per R&D performing enterprise for manufacturing, mining and services was $1.5 million, $3.9 million and $1.2 million, respectively. Appendix I contains a range of other information that shows how these and other characteristics of R&D activity differ across industries.
- *Differences in the 'external effect' characteristics of the R&D undertaken*: With the rise in service industries there may have been a parallel rise in the proportion of society's resources being consumed in the spillover process, raising measured inputs and, all else being equal, lowering measured productivity.

– Uncodified, tacit, or unarticulated knowledge may play a larger role in the innovation process in services than other industries, in which case transfer, absorption and imitation costs may be higher. Knowledge which is more codified, articulated or embodied tends to require fewer resources in its re-use. Therefore, the amount of 'free' information which spills over per dollar of R&D expenditure may be less in services on average.

… The use of patents as a means of protecting new information and knowledge varies greatly by industries. On average, it is lower in services than in either of mining or manufacturing. While there is a number of determinants of patenting activity, one of the reasons relates to the degree to which information is codified and the cost of imitation.

– There are differences across industries in the extent to which markets within those industries are characterised by competition between domestic firms versus competition between firms across national boundaries. This might extend to differences across industries in the extent to which any negative congestion externalities and creative destruction effects are 'internalised' to Australia and implicitly measured within the national accounts.

Measurement and attribution issues

R&D is directed towards introducing new products, improving production processes, and improving the quality of existing products. These activities impact on both measured inputs and outputs. To the extent that the measures of inputs and outputs used in the model estimates do not account for changes in quality, biases will be introduced into the estimates. For example, if the price deflator used to net out price changes in output does not take account of quality changes, then this may lead to an understatement of the effect of R&D (see Mairesse and Hall 1996).

- *Output and input quality adjustment in the national accounts*: output measurement has historically been significantly harder in service industries, although some of the industries with particular difficulties are outside the definition of the market sector on which the models are based, for example, health services. Part of the positive impact of business R&D will be linked to the process of the uptake of new technologies. The embodiment of new knowledge in capital and how it is measured can affect measured inputs to production, trends in productivity and the attribution of productivity gains to alternative sources.

  The ABS method for calculating capital stocks takes (some) account of embodied technological change by altering the price indexes of capital. This has the effect of increasing the capital stock and increasing measured capital intensity, so that MFP may not rise. On the other hand, the adjustments to capital that take account of quality improvements may also sometimes apply to outputs. For example, this would be true for a manufacturer of the relevant capital inputs. In that case, the net effect may still be a gain in MFP. However, the high technology outputs where such quality adjustments are most relevant (such as computers, numerical controllers and robots) are a small component of total production in Australian manufacturing. (PC 2003, pp. 158–9)

- *Missing benefits:* the estimated elasticities will only capture the effects on output that are within the scope of the Australian System of National Accounts (ASNA). For business R&D, the vast majority of the costs and benefits of R&D should be captured. A type of missing benefit is that the choice associated with an increase in the number of similar products may be valued by consumers. If so, this would work against the dilution effects of product proliferation.
  - Any limitations of the national accounts in evaluating the social return to R&D are more of an issue when evaluating the contribution of higher education and Government R&D.

10.4 Results from the R&D equation

The large coefficient on the lagged dependent variable in models S1 to S3LP is a result of the use of variables which are highly integrated. R&D expenditure is not stationary and the process of constructing stocks further increases the degree to which the knowledge stocks are integrated. The large coefficient implies that shocks which alter the growth path of the knowledge stock take a long time to return to ‘equilibrium’.

The impact of foreign and Australian non-business R&D

The R&D equations suggest that business R&D investment in Australia is strongly and positively associated with foreign R&D. For model S1, a 1 per cent increase in the stock of foreign R&D is associated with a long-run increase in the stock of Australian business R&D of 6.8 per cent (0.376/(1-0.945)). The estimated effect is positive and very large in all of the models. It is more consistently estimated than the other R&D stocks and it is the least sensitive to alterations to lag structure.

R&D performed by business, but financed by government, has a positive contemporaneous impact on business own-financed R&D investment. A negative or zero coefficient would arise if the effect of government financing was mainly to substitute government monies for private financing that would have been spent on R&D activity in any case. However, the positive coefficients indicate that the overall level of R&D performed by businesses is increased.

The estimated negative effect for higher education R&D in some models implies that the crowding-out, substitution and displacement effects of higher education R&D outweigh the technological opportunity and spillover effects that stimulate additional business investment (see box 10.4). However, it may reflect the inability of the models to capture the complementary, but longer term, effects of R&D performed in universities and TAFEs.

The positive sign on government-financed R&D and negative sign on higher education R&D are consistent with the Guellec and van Pottelsberghe (2000) results. However, the Guellec and van Pottelsberghe (2000) found a negative effect of government performed R&D:

> Government and university research both have a negative and significant impact on business-funded R&D. Moreover, this negative impact is spread over several years (although there is no contemporaneous impact), especially in the case of government research. The crowding-out effect (due either to an induced increase in the cost of R&D or to direct displacement …) dominates the stimulating effect … The negative impact of university research shows the difficulty of transferring basic knowledge to firms. (p. 13)

Overseas studies tend to estimate higher social returns from basic research than from other forms of research. Therefore, even if the estimated negative net effect of higher education R&D did crowd out business R&D, the higher education R&D might provide higher social returns at the margin than the forgone business R&D.

David et al. (1999) specify a formal model containing the types of effects in box 10.4. They set out conditions under which the complementary or stimulatory effects of public investment in R&D are likely to dominate the substitution and displacement effects. A net stimulatory effect on business R&D investment will be more likely where the following hold.

- The relative size of the public sector in total R&D activity is small.
  - A relatively small public sector would tend not to push up demand for, and prices of, R&D inputs.
- The supply of qualified scientists and engineers is elastic.
  - The more responsive is the supply of scientists and engineers to changes in demand, the less upward wage adjustment will be required in response to increases in demand for R&D personnel.

Box 10.4 **Positive, negative and net effects**

Public policies aimed at stimulating additional business R&D investment might be successful where they result in *knowledge and training spillovers* that stimulate private R&D by raising the returns to business R&D projects. R&D undertaken in higher education and Government institutions can provide technological opportunities for business investment by advancing the science and engineering knowledge base. Where this knowledge is formally transferred or spills over to businesses it can raise the private return to additional investment by businesses. Other benefits associated with public R&D contracts can include:

- increases in the efficiency of the firm's R&D by lowering common costs or increasing absorptive capacity;
- signalling future demand;
- improving the chances for success on the firm's other R&D projects; and
- reducing the barrier from high fixed R&D startup costs.

However, the policies' intended effects can be constrained by unintended effects.

- *Crowding-out*: Government spending can crowd out private investment by increasing the demand for R&D. Increased demand will result in R&D costs rising. The degree to which they rise will depend on the various input supply elasticities. The increase in costs will also affect the investment decisions of firms that are not a direct target of the policy measures.
  – Goolsbee (1998) and David and Hall (1999) argue that the major effect of government funding is to raise the wage of researchers. This raises the costs of undertaking R&D and, therefore, firms will invest less in R&D at the margin. Even if the total nominal amount of R&D is higher due to government funding, the amount of knowledge from R&D investment will be less as average efficiency is lower.
- *Displacement/substitution*: Public money can directly displace private funding where contracts are targeted in areas of technological development that firms otherwise would still find it worthwhile undertaking. In this case, public funding substitutes for private funding, with the overall level of research changing little.
  – For other firms, displacement relates to lower expected rates of return to R&D in the same area as the policy interventions are directed, because of the expectation that the contracted firms will succeed in producing commercially exploitable innovations and that the government may disseminate knowledge to increase competition in the end-product market.
- *Allocative distortions*: Government allocation of R&D resources may be less efficient than market allocations (that is, directed towards projects which improve welfare less). Government allocation can also distort competition amongst firms.

Sources: David et al. (1999); David and Hall (1999); Goolsbee (1998).

- The rate at which the private marginal yield of R&D decreases more gradually with increased R&D expenditures.

– If businesses select the highest return projects first, then as expenditure increases, increasingly less attractive projects are available for funding (see the description of the marginal rate of return curve in box 10.5). A net stimulatory effect is more likely where the rate of decline in the returns ‘on offer’ is less.

The share of GERD performed by higher education and Government institutions has historically been high in Australia compared with other OECD countries (see appendix G). Australian parameter estimates for the elasticity of supply of scientists and engineers and the slope of the marginal rate of return curve have not been produced.

The impact of the tax concession and cost of capital

The timing of the acceleration in business R&D investment preceded the introduction of the R&D Tax Concession Scheme by about two years.

The acceleration has been linked to a number of factors. BIE (1993) commented:

> There is no simple explanation for the dramatic increase in BERD between 1981-82 and 1984-85 (from 0.25 to 0.34 per cent of GDP). Partial explanations include: extension in the definition of R&D in 1984-85 to include computer software development; ‘gearing up’ in anticipation of the tax concession; a receptive climate in industry towards R&D and innovation as a result of Government initiatives to develop a venture capital market; and increased awareness of science and technology (DITAC 1987).

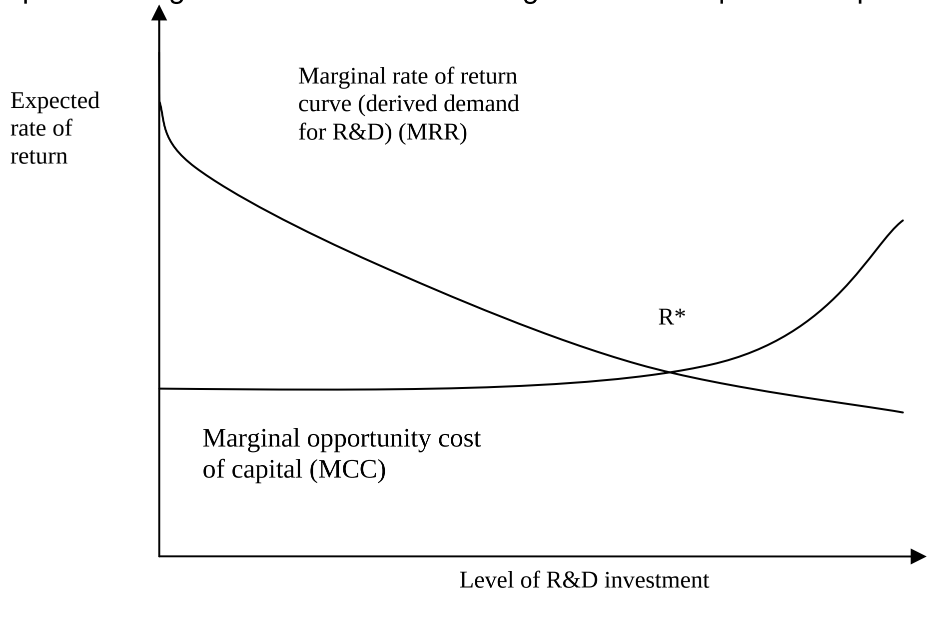
Given the strength of the acceleration and that it began at about the same time as the introduction of the scheme, it might be expected that the coefficient on the tax concession variable would be highly economically significant in the regressions.

Box 10.5 **Equating expected marginal returns and the cost of capital**

The firm's marginal rate of return (MRR) curve is formed by rationally considering the expected costs and benefits for the firm's feasible set of projects (its "technological innovation possibility set") within the planning period, and ranking these projects by descending order of anticipated yield. The marginal expected yield and cost of capital are plotted on the vertical axis. The horizontal axis represents the cumulated amount of investment required as the firm proceeds down the schedule of projects. As the firm moves along the MRR curve, there is no change in any variables that would influence the rate of return for the schedule of projects. The net impact of changes in those variables results in shifts in the MRR schedule.

The marginal cost of capital (MCC) curve reflects the opportunity cost of investment funds at difference levels of R&D investment. The relatively flat then upward slope of the curve reflects that, as the volume of financing increases due to higher levels of R&D investment, retained earnings/cash flow become insufficient to finance investment, and there is greater reliance on external financing which might increase the firm's marginal cost of capital more expensive external finance must be used to finance investment.

The firm's optimal or profit maximising level of R&D investment is at *R**, where the expected marginal rate of return and marginal cost of capital are equalised.



(continued on next page)

Box 10.5 **(continued)**

Publicly funded R&D may put upward pressure on the prices of R&D inputs resulting in increased costs for potential private R&D projects and a lowering of the MRR schedule. Performance of R&D in public institutions, which provides technological opportunities to businesses, will shift the firm's MRR schedule to the right (assuming these opportunities take the form of higher project returns).

Other factors which will shift the MRR schedule to the right include the following.

- Better information on the state of demand in its potential market area or line-of-business.
– For example, government contract R&D, by signalling future public sector product demand, and private sector demand in markets for dual-use goods and services, may raise the expected marginal rates of return on product or process innovation targeted to those markets. This would move the MRR schedule to the right.
- Increased ability to appropriate the benefits of innovation, which is affected by institutional factors and other conditions.

Factors which can shift the firm's MCC schedule include the following.

- Technology policy measures that affect the private cost of R&D projects, such as the tax treatment of R&D, R&D subsidies and cost-sharing programs of government procurement agencies.
– For example, direct R&D subsidies and cost-sharing arrangements by public agencies, by relieving the firm of some of the joints costs of R&D, would be equivalent to shifting the MCC schedule to the right.
- Macroeconomic conditions and expectations that affect the internal cost of funds, via the general state of price-earnings ratios in equity markets.
- Bond market conditions that affect the external cost of funds.
- The availability and terms of venture-capital finance, as influenced by institutional conditions (such as the development of initial public offering markets) and the tax treatment of capital gains.

Source: David et al. (1999).

Results indicate that the concession has a small positive association with business R&D investment.[7] The relatively modest economic magnitude of the effect is robust to model specification and sensitivity testing of the models.

The measure used in the regressions above is based on the nominal subsidy equivalent (post-tax basis), which only incorporates information on the headline corporate tax rate less the headline rate of assistance. While the gap between these two rates drives the overall incentive provided by the scheme, other aspects of the tax concession affect the generosity of the scheme, some of which have changed significantly over time (for example, the treatment of capital allowances and the introduction of the 175 per cent premium rate).

The estimated impact of OECD tax incentives was economically and statistically much more significant (see table 10.6). The measure used in those regressions is the OECD B-index and is a more comprehensive measure (box 10.6). The B-index is useful for cross-country comparisons of the level of tax incentives, but the available time series does not currently reflect the changing nature of Australian incentives over time. In addition to tax incentives, many other Commonwealth and State government expenditure programs also affect business R&D activity, but have not been controlled for in the models.

A higher cost of capital discourages R&D investment.[8] The benefits of an R&D project are spread out over time, while costs are much more immediate. A higher cost of capital means that the required rate of return for investment is higher. Increases in the cost of capital will affect the present value of benefits more heavily than costs.

The volatility in the average annual yield on 2-3 year bonds issued by the Commonwealth Government has a separate and negative effect on investment. The measure of volatility is the average percentage change in the yield over the previous three periods. This means that periods of high and low yields are treated symmetrically in the sense that percentage changes can be large at both high and low yields. However, R&D investment might be more sensitive to volatility and associated uncertainty in the cost of capital at higher yields than it is at lower yields.

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[7] BIE (1993) undertook a detailed evaluation of the R&D tax concession. The tax concession appeared to have induced an additional 10 to 17 per cent of BERD. On balance, the BIE stated it was inclined to the view that the concession offered net social benefits, but estimated impacts relied on a number of critical assumptions concerning the share of the subsidy paid in respect of R&D that would have been undertaken anyway, the size of the spillovers benefits from the induced R&D, the economic costs of funding the program and the losses due to leakage of transfer payments overseas.

[8] See Jaumotte and Pain (2005) who construct a measure of the user cost of capital.

Box 10.6 **The OECD B-index**

The amount of tax subsidy to R&D is calculated as 1 minus the B index. The B index is defined as the present value of before-tax income necessary to cover the initial cost of R&D investment and to pay corporate income tax, so that it becomes profitable to perform research activities. This means that the calculation includes the consideration of depreciation allowances, tax credits and other allowances on R&D assets.

Algebraically, the B index is equal to the after-tax cost of an expenditure of $1 on R&D divided by one minus the corporate income tax rate. The after-tax cost is the net cost of investing in R&D, taking into account all the available tax incentives.

$$\text{B Index} = \frac{(1-A)}{(1-\tau)}$$

where A = the net present discounted value of depreciation allowances, tax credits and special allowances on R&D assets; and τ = the statutory corporate income tax rate (CITR). In a country with full write-off of current R&D expenditure and no R&D tax incentive scheme, A = τ, and consequently B = 1. The more favourable a country's tax treatment of R&D, the lower its B index.

B indexes are calculated under the assumption that the "representative firm" is taxable, so that it may enjoy the full benefit of the tax allowance or credit. For incremental tax credits, calculation of the B index implicitly assumes that R&D investment is fully eligible for the credit and does not exceed the ceiling if there is one. Some detailed features of R&D tax schemes (for example, refunding, carryback and carryforward of unused tax credit, or flowthrough mechanisms) are therefore not taken into account.

The effective impact of the R&D tax allowance or credit on the after-tax cost of R&D is influenced by the level of the CITR. An increase in the CITR reduces the B index only in those countries with the most generous R&D tax treatment. If tax credits are taxable (as in Canada and the United States), the effect of the CITR on the B index depends only on the level of the depreciation allowance. If the latter is over 100 per cent for the total R&D expenditure, an increase in the CITR will reduce the B index. For countries with less generous R&D tax treatment, the B index is positively related to the CITR.

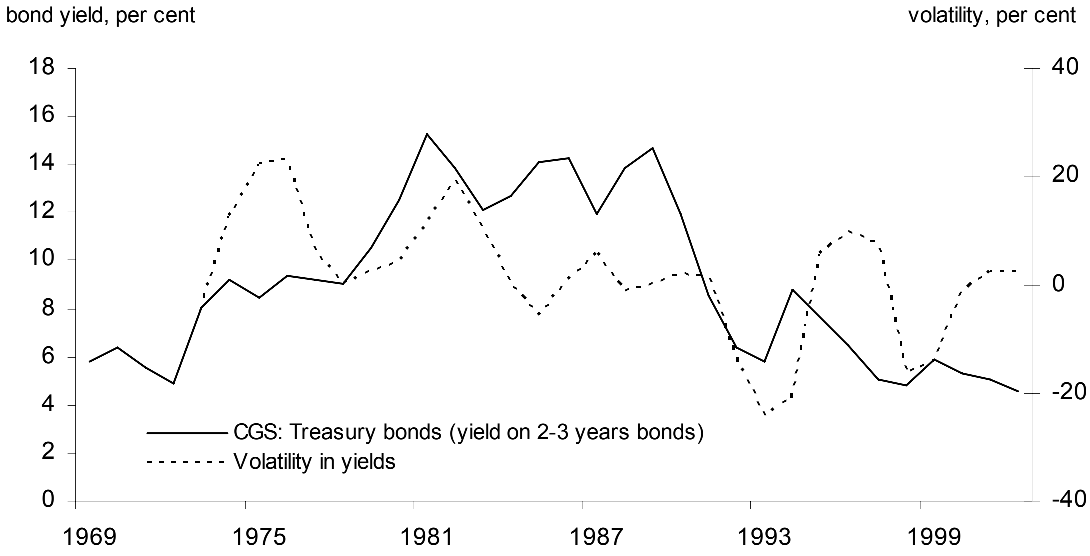
Source: OECD (2004).

Yields increased very sharply through the 1970s and remained high throughout the 1980s before falling sharply back to the levels that existed prior to the 1970s. Volatility increased in the 1970s and then declined through the 1980s and 1990s (figure 10.3).

The benefits from R&D performed in higher education and Government institutions accrues further in the future, since the share of basic R&D is high compared to business. The high discount rates may have had a disproportionate effect on non-business R&D, suppressing the positive technological opportunity and spillover impacts of public R&D.

Figure 10.3 **Cost of capital and its volatility, 1969 to 2002**

Commonwealth Government Securities, Treasury bonds (2-3 year spliced series).



Data sources: Reserve Bank of Australia (RBA) Bulletin Statistical tables — Financial Markets (F Tables), accessed 11 July 2004; Commission estimates.

Industry protection and exposure to competition

Protection of manufacturing has a net negative impact on market sector R&D expenditure. The point estimate results imply that a 1 per cent increase in the ERA index would result in at least a 0.12 per cent reduction in the level of own-financed R&D expenditure as a whole. They also imply reductions in R&D intensities. Rogers (2001, p. 16) also found a negative impact of ERA based on firm-level analysis:

> The results in regression (1) to (3) show that the level of protection has a negative association with R&D intensity. One explanation for this association would be that ERP [effective rate of protection] is 'picking-up' the effect of old, technologically stagnant industries. These industries would have low technological opportunity and hence firms would have low R&D intensities … Perhaps the strongest hint that the relationship may be in part due to a 'competitive' effect, and not just technological opportunity effect, is from the fixed effect estimates in regression (5) (since the coefficients are estimated on the basis of within movements of R&D intensity and ERP). The negative coefficient in this regression implies that rising (falling) ERPs are associated with falling (rising) R&D intensities.

The share of manufacturing in market sector or economy-wide output has been declining over a long period. Changes in industry composition can affect aggregate R&D expenditure levels and intensities because expenditures and intensities vary greatly across industries. Manufacturing has historically invested proportionally much more in R&D than other industries, but investment in recent decades has grown faster in services and mining (see chapter 3).

> High-tech industries in OECD countries grew faster than the rest of the economy in 1975-85, but slower thereafter … More specifically, the growth of technology intensive sectors was little affected by the recession of the early 1980s, but was strongly influenced by the recession of the 1990s, a period during which their share in the economy declined. Moreover, the share of services (which on average are much less R&D intensive than manufacturing) in GDP surged in the 1990s. Thus, overall, changes in industry structure contributed substantially to the acceleration of R&D expenditures in the early 1980s and to the slowdown of the 1990s. (Guellec and Ioannidis 1997, p. 134)

The R&D equations were re-estimated with a variable representing the share of manufacturing in market sector value added ('manushare') in order to test whether coefficients were biased by ignoring structural change. The coefficient was positive and significant in the growth models indicating that the compositional shift in output towards services has suppressed growth in R&D expenditure and its intensity, consistent with what a shift-share analysis would show. Holding constant the relative decline in manufacturing did not alter the sign on any coefficient. There was some change in magnitudes and minor changes in statistical significance. In particular, the coefficient on industry protection remained negative and significant, strengthening the 'competitive effect' interpretation whereby reduced protection results in increased competitive pressures, spurring innovation related investments.

Apart from the incentives facing manufacturing firms to innovate, reduced protection of manufacturing may have stimulated the demand for R&D in other sectors of the economy as manufacturers demanded improved inputs and services from supplying sectors. Reductions in protection may also have reduced broader distortions to the allocation of investment across industries, affecting the growth potential of non-manufacturing industries in concert with a shift in technological opportunities towards ICTs and other technologies.

Liquidity constraints and the elasticity of R&D expenditure

Growth in market sector value added was used to control for the effects of the cycle in the R&D equations. In models S1, S2, S4 FDL and S4LP FDL, the sign on the cycle variable is positive and significant. In models S3 and S3LP, where R&D intensity is specified as the level of the knowledge stock over output or the product of output and hours worked, the sign on the cycle variable is negative and significant, signifying that the stock of knowledge changes less rapidly to business cycle fluctuations than does output.

Guellec and van Pottelsberghe (2000) found a large and statistically significant effect of growth in value added on R&D expenditure. The effect could be related to either liquidity constraints or output expectations where future expectations are closely tied to recent past experience.

Guellec and Ioannidis (1997) undertook a study of OECD countries over the period 1972 to 1996 to assess the role of macroeconomic and policy factors in the levelling off of OECD R&D expenditure growth in the early 1990s. They modelled the variation in own-financed business R&D expenditure. The key explanatory factors were found to be cyclical factors associated with the economic downturn of the early to mid-1990s, reductions in government funding of research, high real interest rates and a shift in the industrial composition of GDP with an expansion in the share of services, and a reduction in the share of high-tech manufacturing.

One of the issues Guellec and Ioannidis (1997) considered was whether R&D investment is elastic or inelastic. Drawing on a wide body of literature, the authors noted a number of reasons why R&D expenditure might be elastic.

- *Liquidity constraints*: evidence suggests that R&D expenditures are financed primarily through internal cash flow, which suggests expenditure should be pro-cyclical. When cash flow is tight, say during an economic downturn, R&D expenditure programs would be cut or new programs delayed.
- *Short-term orientation*: a significant proportion of BERD is directed towards short-term adaptations of existing products. Expansions and contractions in product demand due to, for example, economic fluctuations, may translate readily into investments in short-term oriented R&D activity.
- *Fixed costs and scale in exploitation*: if the commercial exploitation of the knowledge generated from R&D exhibits economies of scale, then suppression/expansion of demand may reduce/increase the returns to R&D activity, altering investments.

On the other hand, high adjustment costs may make R&D investment unresponsive.

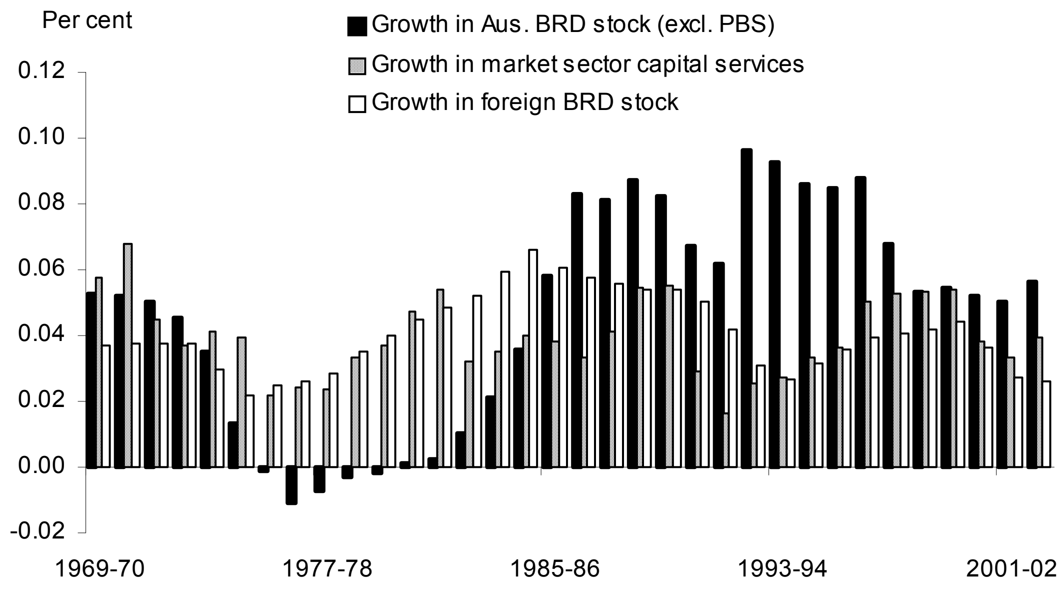
- R&D is a sunk investment and, at least prior to finalisation of a project, outputs are ill-defined, specific to the firm or personnel, and non-tradeable. This affects the cost of stopping a project as investment costs are difficult to recoup.
- R&D activity involves learning which is embodied in R&D teams and forms a type of organisational or human capital. Chopping and changing projects can reduce the value of this capital.
- Labour costs form a large proportion of R&D expenditure. Adjustment costs for labour are generally higher than other inputs.

They compared the standard deviations of annual growth rates from their means for own-financed BERD, GDP, gross fixed capital formation, and the number of researchers (as an indicator of the labour component of BERD). The volatility of BERD financed by business had a lower standard deviation than gross fixed capital formation, with the labour component of BERD lower again. GDP was the least volatile measure.

Net growth in the Australian BRD R&D capital stock has been more volatile than either the foreign BRD stock or growth in capital services for the market sector (figure 10.4). During the mid-1970s, investment in all three measures declined, but net contributions to the Australian R&D capital stock may have even been negative. The late 1980s to early 1990s saw a similar weakness in capital services growth associated with the recession. However, net growth in the Australian R&D stock was maintained at over 6 per cent. From the mid-1980s, net real growth in R&D capital has been much higher than capital services.

Figure 10.4 **Growth in Australian and foreign BRD stocks compared with capital services for the Australian market sector, 1969-70 to 2002-03**

Assumed rate of decay of 10 per cent.



Data sources: ABS (*Australian System of National Accounts*, Cat. no. 5204.00); ABS *(Research and Experimental Development, Businesses, Australia* 8104.0); OECD (ANBERD database); Commission estimates.

Robustness of the results

The static system models were not set-up as a simultaneous equation system where R&D and productivity are jointly contemporaneously determined. This was partly because valid instruments for R&D would be needed to identify the system. Also, a recursive system may more accurately reflect the relationship between R&D and productivity. Past R&D expenditures impact on current output and current output can have effects on contemporaneous R&D expenditure decisions (for example, cash flow effects), which will impact on future output, and so on.

While this sequencing may adequately describe the relationship between business R&D expenditure and productivity, R&D expenditure does have contemporaneous effects as well. Investment in R&D takes time to produce benefits, while the costs are more immediate and impact on output/productivity negatively (at least in the short term). Another complicating factor is that R&D investment may be influenced by expectations about future output, so the simultaneity problem is difficult to escape.

All of the models were estimated with both SURE and three stage least squares (3SLS). If the R&D variables can legitimately be treated as predetermined variables in the two equation set-up, then the different estimation procedures should produce equivalent results. If the simultaneity problem is present and strong, the estimates will differ. The signs, coefficient magnitudes and significance levels were all very similar under both estimation strategies. This provides some confidence that estimates are not strongly biased due to the simultaneity of R&D and productivity.

Static models give an estimate of the permanent or long-run relationship once all change has ceased. Given the measurement error in the stocks associated with the various lags in R&D, different lag structures for the R&D variables in the productivity equation were tested to see which lags provided the most robust estimate of the permanent effect.

For model S1, the significance of the coefficients on the R&D variables is sensitive to lagging Australian business R&D two periods and lagging the stock of foreign GRD three periods. This lag structure abstracts from the contemporaneous or short term effects of R&D which are likely to be negative while resources are consumed in finding new knowledge, whereas the benefits of that knowledge accrue to future periods. If business R&D is lagged one period and foreign GRD is not lagged, then the coefficient on BRD decreases to 0.011 and is statistically insignificant. If the contemporaneous values of both variables are used, then the coefficient on Australian business R&D is -0.023 and statistically insignificant. This highlights just how sensitive results from static models are to the treatment of lags.

The models that specify the productivity equation as a finite distributed lag (FDL) model (models S2, S3 and S4) were estimated with the initial observation on Australian business R&D lagged one period and then re-estimated with it included contemporaneously. It made very little difference to the coefficient estimates.

In terms of the R&D equations various strategies were employed to test the sensitivity of the results to the choice of method for dealing with lags. Independent R&D equations were estimated as FDL models with the lag structure determined by a test down procedure. The broad pattern of results were similar to those shown.

In addition, the longest lag for each variable from the FDL exercise was included in a re-estimation of the R&D equations of the two-equation system. This generally meant that government-financed R&D entered contemporaneously or lagged one period. Foreign R&D and government performed R&D entered lagged between one and three periods. Higher education entered lagged between three and six periods. The results for higher education and government-performed R&D were the most sensitive to the choice of lag structure. Adjusting the lag structure affected the magnitude and significance of the explanatory variables, but the sign on the coefficients, relative magnitudes and overall stories across models were consistent.

While there are different approaches to dealing with the problem of lags in the R&D equation, the results presented provide a fair reflection of successive iterations of the models, especially for the positive coefficient on foreign R&D and the mixed results on the coefficients on higher education and government-performed R&D.

Dropping the constant term from the R&D equations had no impact on the signs of variables, while the statistical significance of the explanatory variables tended to increase somewhat. In model S5, where the constant term is statistically significant, the magnitudes of the slopes coefficients did change, but the signs and statistical significance of variables held. The coefficients on higher education R&D and government-performed R&D roughly halved, and the negative coefficient on industry protection doubled.

Unit root tests indicated that the residuals from both equations were stationary in all models.

10.5 Modelling R&D expenditure rather than stocks

The R&D equations above used PIM-based knowledge stocks in the models, consistent with the productivity equations. The models below are specified in terms of R&D expenditure (table 10.5). Model R1 is a simple static model estimated by OLS. The residuals of the model are subject to strong serial correlation. However, by adding shifts in the intercept (model R2), more reliable results are obtained. As discussed earlier, high adjustment costs associated with R&D provide a rationale for introducing dynamics into the models. Model R3 is estimated as an ARDL model, while model R4 was estimated as an FDL model with the lag structure determined by testing down. In addition to the initial observation at (t-1), the test down procedure resulted in the inclusion of three additional lags for foreign GRD and higher education R&D, and two additional lags for government-performed R&D.

The sign on the coefficients for each variable are consistent across models. The cost of capital and its volatility are negative and economically significant, but statistical significance at 10 per cent or greater is not held in all cases. The inclusion of the variable manushare to control for industry compositional shifts is important to the overall results of the models. Nominal rates of assistance (nrao) have a negative relationship with business own-financed R&D expenditure, even after attempting to control for the relative decline in manufacturing's share of market sector value added.

The long-run elasticities from model R3 are presented in table 10.6. The results are contrasted against results obtained from Guellec and van Pottelsberghe (2000), who also modelled growth in R&D expenditure for a panel of OECD countries. The direction of the effects for Australia and the OECD are the same, except for government-performed R&D.

The Australian estimates of the responsiveness of own-financed business R&D expenditure to changes in government-financed, higher education and government-performed R&D expenditure are much larger than the equivalent OECD estimates. However, it is difficult to determine how much of the difference is 'real' versus an outcome of the problems that arise in comparing and reconciling results from empirical studies based on different countries, data structures and modelling approaches. For example, various biases can result in comparing panel and time series estimates from the same dataset let alone estimates based on different countries (see Mairesse 1990). In addition, biases resulting from measurement errors and model specification can distort comparisons.

Table 10.5 **Influences on own-financed business R&D expenditure[a]**
Dependent variable equals growth in own-financed R&D expenditure (Δln(R))

Model -	*R1*	*R2*	*R3*	*R4*
Specification -	*OLS*	*OLS with shifts*	*ARDL*	*FDL*
Lag dependent			0.435** (0.174)	
Cycle (Δ market sector GVA)	1.112 (0.924)	0.944*** (0.288)		
Δyrshortbond	-0.187** (0.076)	-0.135** (0.057)	-0.072 (0.070)	-0.139 (0.093)
Δbondvol		-0.135 (0.117)	-0.163 (0.156)	-0.695** (0.245)
ΔBus. R&D exp. financed by Gov't	0.269** (0.096)	0.343*** (0.087)	0.236** (0.090)	0.576** (0.190)
ΔForeign GERD expenditure	4.749** (1.933)	8.481*** (1.623)	3.358 (2.055)	5.972** (1.773)
ΔHigher education R&D expenditure	-1.715*** (0.384)	-2.028*** (0.358)	-1.669*** (0.460)	-2.041*** (0.529)
ΔGov't performed R&D expenditure	1.366*** (0.418)	1.524*** (0.370)	1.072** (0.445)	4.419*** (0.462)
Δconcpost	0.027*** (0.003)	0.022*** (0.004)	0.020*** (0.005)	0.015*** (0.003)
Δnrao	-0.337* (0.193)	-0.220* (0.116)	-0.387** (0.179)	-0.625* (0.298)
Δmanushare	2.368** (0.968)	3.331*** (0.552)	1.937** (0.869)	2.593*** (0.745)
Intercept	-0.119 (0.089)	-0.307*** (0.068)	-0.055 (0.088)	-0.141* (0.068)
Shift1982		0.198*** (0.027)		
Shift1985		-0.095** (0.035)		-0.162** (0.050)
Shift1989		-0.089* (0.047)		-0.094 (0.062)
Shift1992		0.083* (0.041)		0.339*** (0.069)
# of obs.	28	28	28	28
R squared	0.568	0.930	0.680	0.979
DWstat[b]	1.131	2.203	0.007[c] (0.935)	2.631
Functional form[b]	0.07 (0.975)	2.42 (0.127)	0.71 (0.560)	0.22 (0.880)
Heteroskedasticity[b]	28 (0.411)	28 (0.411)	28 (0.411)	28 (0.411)

*** statistical significance at 1 per cent or greater. ** significance at 5 per cent or greater. * significance at 10 per cent or greater. [a] All R&D variables based on R&D expenditure and specified in logs. R&D explanatory variables are lagged one period. Heteroskedasticity-consistent t-statistic in brackets. [b] See table 6.3. [c] Durbin-Watson 't' statistic.

Source: Commission estimates.

Table 10.6 **Long-run elasticities for Australia and the OECD**

Australian estimates from model R3

	Output	*Government-financed R&D*	*Higher education R&D*	*Government -performed R&D*	*Tax incentives*
OECD average	1.54	0.08	-0.05	-0.08	0.33
Australia	Not significant	0.42	-2.95	1.90	0.04
Ratio of mean expenditures[a]					
OECD average		8.7	3.6	5.5	
Australia		20.8	1.0	17.8	

[a] Ratio of own-financed business expenditure to government-financed, higher education and government-performed expenditure. Evaluated at the mean for the period 1975-76 to 2002-03.

Sources: Guellec and van Pottelsberghe (2000); Commission estimates.

The coefficient on the lagged dependent variable in Guellec and van Pottelsberghe (2000) ranged between 0.102 and 0.154 (see table 2, p. 14), which is much lower than the coefficient in model R3 at 0.435. For a given estimated short-run elasticity, a smaller coefficient on the lagged dependent variable results in a smaller estimated long-run effect. A direct reading of the larger Australian coefficient means that R&D expenditure at period (t-1) is more important for understanding current expenditure than in the OECD case. The ARDL specification was adopted to recognise relatively high adjustment costs associated with R&D expenditure. The results appear to suggest that these types of costs play a larger role in understanding R&D expenditure behaviour in Australia. The 'averaging' of a panel of OECD countries may also be a factor.

The estimated long-run effects for Australia may be biased upwards if the coefficients are picking-up a transitional slope rather than a permanent effect. There is significantly greater variation in Australia's R&D expenditure performance over the last thirty years than there is for the average of the OECD. As shown in figure 10.1, the period up to the mid-1980s appears much less conducive to R&D investment in Australia than the environment from the mid-1980s. Something changed in the potential relative rewards to R&D investment which led to a strong increase in the demand for R&D (discussed in chapter 11).

The significance of the lagged dependent variable depends on the inclusion of both periods, but the magnitude of the effects relative to the OECD average does not. Adjustment costs play a much larger role in understanding expenditure behaviour when both periods are included in the regressions. If model R3 is re-estimated with the sample restricted to the period 1985-86 to 2002-03, then the coefficient on the lagged dependent variable and the cost of capital variables are insignificant.

Dropping the dynamics and estimating for the shorter time period, robust estimates of the long-run effects can be obtained without the need to allow for adjustment costs. The long-run effects for government-financed, foreign, higher education, and government-performed R&D remain large at 0.102, 4.673, -1.252, and 0.500, respectively. The coefficient on the tax concession increases slightly to 0.027. The model passes standard statistical tests.

The results in this chapter include foreign R&D and the cost of capital and its volatility, whereas Guellec and van Pottelsberghe (2000) does not. However, dropping these variables did not make a great deal of difference to the estimated Australian long-run effects.

The responsiveness of Australian expenditure to changes in incentives, including environmental conditions, matters for policy purposes. If the estimated effects are indeed significantly larger for Australian businesses, then why? Further research is required, possibly into some of the issues listed below.

- Differences in the balance between innovation strategies (quality improvements related to input cost reduction, incremental quality improvements to outputs, radical innovations) and the role played by R&D in these strategies.
- Whether and how differences in competitive intensities or regulatory environments make Australian businesses more sensitive to opportunities to exploit spillovers or be more responsive to changes in the cost of R&D.
- Differences in the organisation of R&D production. Appendix B highlights the increase in Australia of outsourcing of R&D which may give firms greater flexibility to adjust R&D expenditures if there are high adjustment costs in altering their internal R&D workforce.
- Differences in firm dynamics and contributions to productivity growth and the role played by R&D. The Australian Business Longitudinal Survey covered the period 1994-95 to 1997-98, a period of strong economic expansion. This survey data and aggregated Australian Taxation Office data suggest that firm turnover rates in Australia in the 1990s may be towards the low end compared with other OECD countries (see Wong 2005). Australia is characterised by higher entry rates alongside relatively low exit rates, which is expected given the time period covered. Entrants are much smaller compared with the average incumbent. The entrant-incumbent size differential is more akin to that in the United States and Canada, and unlike European countries where entrants tend to be larger.[9]

[9] OECD (2003e, chapter 4) and Bartelsman (2004) provide analysis of cross-country differences in firm dynamics, but the data do not include Australia.

- The share of small and medium sized enterprises (SMEs) in business R&D expenditure is high in Australia compared to the OECD average. The share of government-financed business R&D directed toward these firms is higher than in any other OECD country (see OECD 2003d, p. 29). Aggregate SME R&D expenditure might be more elastic due to higher entry/exit rates, a tendency to grow faster, more binding financing constraints, a higher propensity to undertake R&D with a shorter term focus where adjustment costs play less of a role, and/or a greater likelihood that SMEs are more likely to be non-manufacturing.

- Differences in industry structure and changes in output shares, particularly the greater relative importance of non-manufacturing industries in Australia. For example, business demand for R&D in service industries would be more elastic than manufacturing if the technology of innovation in services allows, on average, for greater substitutability between alternative inputs to innovation. Non-manufacturing businesses might have greater flexibility in how they obtain quality improvements, cost reductions and/or the introduction of new products.

- Differences in technology take-up rates where R&D is undertaken to support adoption and secondary innovation processes.

11 The return to R&D

The modelling of the effects of Australian business and foreign R&D on productivity was undertaken to better understand Australian productivity growth.

The strategy for the empirical component of the study was to begin by using accepted methodologies from the extensive literature on the R&D-productivity relationship. Those techniques were used in a number of Australian studies completed in the early to mid-1990s. The framework is set out in chapter 4.

Advances in theoretical models over the last decade have provided different perspectives on the relationship between R&D and productivity. This study adopted three such theoretical models. Each model views the relevant long-run relationship between R&D and productivity quite differently. However, while the theoretical models are used for motivating the empirical relationships, simplifying assumptions are required for empirical work. A full empirical implementation of the models would require quite a different type of empirical exercise, and would be severely hampered by data constraints.

The study also estimated R&D equations for Australia to investigate various influences on business R&D investment given the dramatic changes in investment rates over time. Understanding business investment might provide valuable clues to the R&D-productivity relationship. The R&D equation is estimated jointly with a productivity equation to partly address the potential problem of the 'simultaneity' of R&D, but also to improve the precision of estimates in the productivity equation.

The development of models through the preceding chapters and appendixes have produced estimates of the elasticity of productivity with respect to R&D. This chapter:

- uses those elasticities to derive estimates of the rate of return to R&D (section 11.1);
- further considers the effects of R&D on productivity growth (section 11.2);
- investigates whether the return to R&D has declined (section 11.3);
- considers R&D investment in the context of Australia's recent economic history (section 11.4)

- considers whether R&D investment contributed to the improved productivity performance of the 1990s (section 11.5); and
- discusses policy implications (section 11.6).

11.1 Estimates of the return to R&D

The regressions of the previous chapters, and appendixes H and J, provide an estimate of the elasticity of productivity with respect to R&D. While the level of the estimated elasticity is informative, it is often of more interest to derive the rate of return to R&D. For the regressions based on the 'standard' framework, the rate of return was derived in chapter 4. It is the product of the elasticity and the ratio of output over the knowledge stock.

The concept of the return is based on the additional output that is obtained from a change in the knowledge stock. The interpretation of the marginal product depends on the particular models estimated. The market sector models, expanded market sector models and manufacturing panel models use data that are not adjusted for double counting and expensing bias (although results are sensitivity tested using a direct adjustment to the data). The one-digit industry level models use an estimation technique to undertake an adjustment for both the double counting and expensing bias (see appendix K).

Dowrick (2003) undertook a survey of the rates of return to R&D commonly found in the literature. While estimated returns do vary widely, he suggested that the following returns are representative:

- firm-level returns: net required rate of return pre-tax in range of 20 per cent;
- industry-level returns: gross returns up to 40 per cent or more; and
- economy-wide returns: gross returns of 80 per cent or more.

There are three main points: the estimates increase as the level of aggregation increases; the implied returns are very large relative to returns to conventional capital; and the returns mainly reflect results from overseas studies. Other surveys also find high returns to R&D indicating social returns significantly greater than private returns.

Point estimates of the return to R&D

The basic autoregressive distributed lag (ARDL) model from chapter 6 (model BL4) provides a point estimate of the gross return to Australian business R&D

(BRD) of 50 per cent at the level of the market sector (table 11.1). The 50 per cent return is over and above a normal return to conventional capital, and it includes the 'supranormal' private returns to R&D. If a 15 per cent decay rate is assumed then the estimated net return is 35 per cent. If the supranormal return was, say, 10 per cent, then there is a return related to the external effects of R&D of roughly 25 per cent. The 25 per cent would be composed of the effects of spillovers (assumed to be positive) and negative effects, such as duplication externalities.

Table 11.1 **The rate of return to business R&D[a,b]**

For Agriculture, the rate of return applies to public R&D. R&D intensity is the average for the sample.

					Market sector	
	Manufacturing	*Mining*	*Wholesale & retail trade*	*Agriculture*	*BL4*[c]	*S2 Basic*[c]
Business R&D intensity (K/Y)	0.11	0.038	0.013		0.045	0.030
Elasticity of R&D	0.055*	0.061*	0.055*		0.021	0.020
Rate of return (%)	50	159	438	24*	50	75

[a] All models are based on a regression of the log of the level of MFP on the log of the level of the knowledge stocks. Results are presented in chapter 6 for model BL4 and in chapter 10 for model S2 Basic. Model S2 Basic includes slope shift terms. The elasticity is for Australian BRD from 1985. [b] The figures marked by * are based on results from table 8.5. Industry estimates are double counting and expensing bias adjusted. The return to public sector Agriculture R&D was estimated directly. [c] The business intensities differ for the market sector models due to the different assumptions about the rate of decay of knowledge.

Source: Commission estimates.

A gross return of 50 per cent at the level of the market sector is well within the range of plausible estimates, as surveyed above. However, the estimate is not precisely estimated. The precision of estimates is discussed further below. Extended levels models produce higher returns for both the market sector and extended market sector, but the results are not reliable.

The two-equation model of chapter 10 was used to estimate a basic productivity equation containing only Australian BRD and foreign R&D as explanatory variables, plus a suite of intercept terms and slope shift terms for Australian BRD. The intercept shifts represent unexplained changes in technology, while the slope shift terms represent a changed partial effect of Australian BRD on productivity (model S2 Basic in table 10.4). An estimated gross return of 75 per cent applies to the period from 1985.

While many of the difficulties of getting robust estimates of the return to R&D at the level of the market sector also apply at the industry level, the R&D and other national accounts data at the industry-level are much less certain in quality than those at the market-sector level.

The industry results provide some support for a positive effect of R&D on productivity growth at the one-digit industry level. The confidence intervals do not contain zero and the hypothesis of a zero estimated rate of return in each industry is rejected at the 5 per cent level of significance.

The estimated return in Manufacturing falls within reasonable bounds at 50 per cent. The return is higher than the 13 per cent found in Industry Commission (1995).

The return to the industry's own R&D stock in Mining and Wholesale & retail trade is unexpectedly high, although it is not uncommon to obtain high rates of return for empirical studies below the one-digit level.[1]

The estimate of the return to public R&D in Agriculture also falls within reasonable bounds. The return in Agriculture is a return to the public R&D stock. Given the that the returns to research in broadacre agriculture in Australia have been estimated to be in the range of 15 to 40 per cent (Mullen and Cox 1995), the estimated rate of 24 per cent for Agriculture seems reasonable.

Significant questions remain regarding the magnitudes and robustness of the industry level estimates of the return to R&D. Although there are justifications for high rates of return, it may be difficult to accept rates as high as those estimated in Mining and Wholesale & retail trade. As such, the results from the current exercise should be considered only indicative. They point to returns which may have been higher in these industries than for Manufacturing, but by how much is uncertain.

Imprecision in the estimated returns

The rate of return to R&D is estimated imprecisely in most models. This means that the confidence interval encompasses a wide range of likely values of the parameter. The size of the confidence interval increases with the level of the point estimates (figure 11.1).

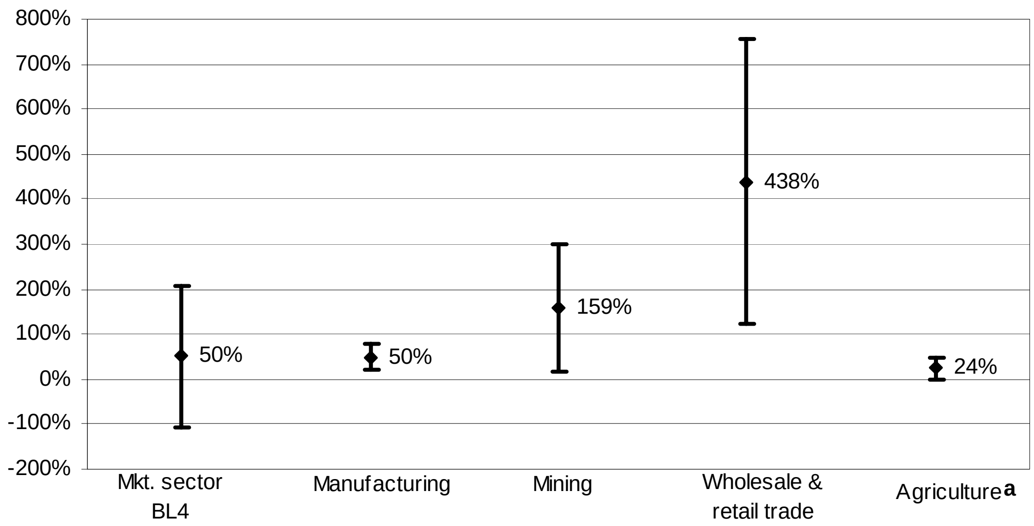
With the confidence interval based on plus or minus two standard deviations from the point estimate, the ARDL specification of the basic market sector model (model BL4) results in a confidence interval ranging from negative 100 per cent to 200 per cent.

[1] Nadiri (1993) surveys mainly US studies at the firm level and one-digit industry level and finds estimated returns to R&D varying widely from 3 to 143 per cent.

Manufacturing and Agriculture are estimated reasonably well with lower and upper bounds of 20 to 80 and 1 to 46 per cent, respectively. The lower bounds of the confidence intervals for Mining and Wholesale & retail trade are 123 per cent and 18 per cent, respectively.

Figure 11.1 **Implied rates of return to R&D**

Point estimate and confidence interval based on plus or minus two standard errors



a The return for Agriculture is the return to public R&D.

Data source: Commission estimates.

Aggregation and spillovers — not a neatly cascading story

One of the rationales for modelling at different levels of aggregation was that the breadth of spillovers captured in estimates varies by aggregation level. Each higher level of aggregation should capture an 'average' of the component industries which make it up, but there should be an additional return to spillovers. Estimates at higher levels of aggregation could be expected to produce larger returns as more of the intra and inter-industry spillovers are measured.

By comparing estimates of the returns from regressions based on different aggregation levels, some sense of the magnitude of spillovers could be obtained.

However, the estimated returns do not neatly increase as the aggregation level increases. Some of the manufacturing subdivision estimates are far larger than for total manufacturing or the market sector, and some of the industry estimates are higher than for the market sector as a whole, while others are not.

The results suggest significant heterogeneity in returns across industries. As the measured returns are driven by the external effects of R&D, including spillovers, this means that the external effects of R&D vary significantly, even if risk-adjusted private returns are similar.

Data quality

Problems with the data

Estimating the effect of R&D on productivity is heavily dependent on the quality of data used in the analysis. Some of the generic data issues include the following.

- *Missing observations*: various methods of approximation have been used to fill the data gaps for the series to be useful for econometric estimation, and many proxies have also been used where there is no properly measured variable available. The impacts of such approximations are generally unknown.
- *Small sample size*: the number of observations is limited (small sample), and many econometric tests under small samples have very low power.
- *Core issues in the measurement of inputs, outputs and productivity*: the use of industry-level data, in particular, is subject to significant quality concerns for the purposes of productivity analysis (Diewert 2000; OECD 2001).
  - The input-output tables from which the industry-level data are sourced still suffer from many problems. The current input-output framework deals reasonably well with the flows of materials, but not so with inter-sector flows of services from contracted labour and rented capital. There are additional problems associated with the constant price input-output tables. They are largely due to the lack of detailed price deflators that are required to derive the volume indexes for a large number of goods and services produced and used in different industries. But these tables are the basis for the volume measures of outputs and inputs at the industry-level.
  - Service industries' outputs are notoriously difficult to measure conceptually and more so in practice. There are various long-standing issues in the measurement of capital, including inventories, land and environmental resources, which are major classes of inputs for an industry.
  - For the purposes of productivity analysis, labour input requires quality-adjustment to take account of skill differences in an hour's work. The information required to measure skill-level, even very crudely, are rarely available at the industry-level. Thus the industry-level labour input is often not quality-adjusted.

There are also some concerns with the R&D expenditures series used to construct the knowledge stocks which could affect the apparent degree of change in investment rates (appendix A). Changes in organisations' accounting practices can introduce non-systematic errors into R&D expenditure estimates. The introduction of government financial assistance to R&D activities, and changes in accounting standards, may have altered how businesses structure their financial accounts, which activities they recognise as R&D, and how they record R&D. Grants and tax concessions give a financial incentive to minimise 'unreported' R&D and, where feasible, to classify borderline activities as R&D. The announcement and introduction of tax concessions may have increased reported R&D more than they affected true innovation-directed R&D activity.

Econometric methods, no matter how sophisticated they are, do not solve measurement problems. There is simply no substitute for properly measured variables.

Some improvements in data used in this study

More and better quality data were assembled for the study. The earlier Australian studies were severely restricted by small sample sizes. With the addition of at least twelve more years of annual data — nearly doubling the sample size of some studies — it was hoped that more precise estimates of the effect of R&D on productivity could be obtained.

Significant improvements were made to the quality of the set of control variables. Capital services measures were constructed for communication infrastructure, private IT capital, general government infrastructure, and many variations thereof. Services measures are used by the ABS in its construction of multifactor productivity (MFP) estimates for the market sector and offer improvements over net capital stock measures for productivity analysis.

Better controls for changes in human capital were constructed. Separate series of unpublished ABS data on post-secondary school qualifications were spliced together to create time series from 1968. In addition, the ABS's Quality Adjusted Labour Index (QALI) was tested in regressions. This recent index attempts to take account of changes in human capital both from formal education and work experience.

Alternative ways of aggregating foreign knowledge stocks to create a better measure of the potential spillover pool to Australia were thoroughly investigated, with alternative measures being tested under many different empirical specifications. The effort in this area was in acknowledgement of the findings from previous Australian and most overseas studies which have suggested that foreign R&D and the knowledge it generates is not very important for Australian productivity. Needless to say, a puzzling result.

The heavy reliance put on the construction of knowledge stocks

The analysis of the effects of R&D is heavily reliant on the assumptions underlying the construction of knowledge stocks. Many types of potential problems are present.

- The construction of an aggregate knowledge stock assumes that the R&D of all businesses can be summed and that the resulting 'volume' of knowledge is available to all. Chapter 4 referred to problems with this assumption as the 'fallacy of aggregation'.
- The assumption of a constant rate of decay of knowledge may be wrong. The rate of decay of appropriable revenues from the accumulated knowledge stock may have changed over time or be subject to shocks.
  – The assumption rather than estimation of a decay rate can also be criticised as sensitivity testing of decay rates using a best fit strategy may result in a decay rate that resembles the true rate only by chance. The true rate is not necessarily the rate that produces statistically significant estimates of the effect of R&D on productivity.
- The true knowledge stocks are unobserved and are based on the output of R&D activities. There may have been shifts in the relationship between the level of resources devoted to R&D and the amount of knowledge that is generated (in a technical sense) and the initial value of that knowledge.
- The linear knowledge accumulation process of the perpetual inventory method (PIM) may provide a poor model of how knowledge actually accumulates. Chapter 4 presented a more general specification of knowledge accumulation, which attempted to take into account of certain relationships between contemporaneous R&D expenditure and the existing stock of accumulated knowledge. However, empirical implementation is difficult and was not pursued in this study.

As an alternative to knowledge stocks, a simple measure of the count of patent applications granted by the US Patent and Trademark Office (USPTO), for the same set of countries as used in the knowledge stocks, improved results under some empirical specifications.

The fragility of the estimated elasticities

The estimated elasticities were generally robust to the following variations to the regressions.

- *The choice of assumed decay rate*: sensitivity testing of the assumed decay rate (appendix K) showed some variation in the estimated elasticities under alternative assumptions, but it was not economically very significant. However, the lack of overall precision in estimates means that important differences may fall within the 'errors' of the models.
- *Own-financed R&D versus total performed R&D*: some overseas studies have found that the return to business R&D that is financed by the business is higher than the return to R&D performed by the business, but financed from other sources (for example, under contractual arrangements with Government). Testing in appendix K was inconclusive, possibly again because of the width of the standard errors.
- *Double counting and expensing bias*: at the level of the market sector, sensitivity testing of regressions results was undertaken by directly adjusting the capital and labour input indexes used to construct MFP (see appendix K). The adjustments had very little impact on elasticities. However, at the industry level, adjustments to the estimation methodology, which takes account of the biases, did have some impact on estimated elasticities, with the direction of the bias varying by industry.
- *Gross foreign R&D versus foreign business R&D*: models results did not turn on whether gross foreign R&D or foreign business R&D was included in the regressions. The use of foreign business R&D possibly introduces an omitted variable problem in that it excludes all overseas R&D-related knowledge generation not undertaken by businesses. On the other hand, the linkages between foreign business R&D and Australian productivity might be easier to detect if, for example, foreign business R&D was more readily embodied in trade and trade-weighted stocks were used in the regressions, or if businesses patent a much higher proportion of their R&D 'output' compared with public sector institutions and technological proximity measures were used to aggregate the stocks based on patenting activity.

The following factors generally were important in influencing the estimated coefficients for the R&D variables.

- *Controlling for the business cycle*: as productivity is pro-cyclical, it is desirable to control for the business cycle in order to remove this 'noise' from the regressions. All the results in the chapters used a simple measure of the business cycle: levels models used the first derivative of value added; and growth rate models used the second derivative. Sensitivity testing of estimated elasticities to alternative cycle control measures revealed that the choice of control can have important effects on the estimated returns to R&D (appendix L).

- *Breaks in technology parameters*: allowing for 'unexplained' shifts in technology and various shocks made a significant difference to results in the market sector and expanded market sector regressions. The coefficient on Australian BRD was the most sensitive to the inclusion or exclusion of dummies and shifts in the intercept.
- *Changes in time period*: tests of the stability of the estimated coefficients show that the magnitude of the coefficient estimate for many variables and models is sensitive to the choice of time period included in the regression sample.
- *Static versus dynamic models*: the economy can be characterised as having experienced a number of important shocks with long adjustment periods. Allowing for dynamics improved results in many models. The length of the implied adjustment period to a single shock and the fact that some dynamic models have difficulty estimating a permanent effect puts uncertainty on the results of other models which appear to estimate, in some cases quite robustly, a 'permanent' effect.
- *Inclusion of certain variables*: estimates of the effect of Australian BRD from the market sector and expanded market sector regressions were sensitive to the inclusion of either the foreign knowledge stock or a foreign patents measure. Without them, the estimate on Australian BRD was usually insignificant.
  - At the industry level, a careful search for an appropriate empirical model resulted in different levels of success in different industry regressions. To a certain degree the estimates are still liable to changes in model specifications and changes in the control variables used for regressions. For instance, a significantly negative public R&D elasticity is found in the manufacturing regressions. While it is somewhat difficult to justify this result, if this variable is excluded from the model, the industry's own R&D elasticity decreases in magnitude by nearly 40 per cent and becomes insignificant.
- *Alternative measures of the potential spillover pool to Australia*: different construction methodologies for foreign knowledge stocks are based on different ideas about what type of knowledge matters for Australian growth and how knowledge is transferred to Australia. Testing provided inconclusive support for the alternative hypothesis of whether disembodied or embodied knowledge is more important. However, the choice of weighting scheme can make a difference to whether a 'significant' result is found or not.
- *Higher education and government R&D*: the inclusion of higher education and government knowledge stocks in market sector, expanded market sector,

Mining, Wholesale & retail trade, and manufacturing subdivision regressions did not produce significant results and generally impacted very negatively on the estimate for Australian BRD. The level and intensities of the Australian BRD and higher education stocks are highly collinear. The problem in including a higher education stock points to the absence of a strong long-run relationship between Australian R&D and higher education R&D, or at least a relationship that could be detected in this study.

Bias in the returns

Some of the estimated returns to R&D appear high. Are they strongly biased upward?

For the market sector and expanded market sector returns, the estimates are interpreted as excess returns meaning that both the supranormal private returns to R&D and external effects are included. The inclusion of the supranormal returns is one reason why measured social returns are expected to be higher than conventional private returns. However, supranormal returns might be in the order of 5 to 15 per cent, so they do not account for much of the measured high returns. In addition, testing of the importance of the bias from double counting for the market sector was undertaken by directly adjusting the MFP and input indexes. The estimated returns were not significantly different.

At the industry level, the estimates are adjusted for double counting and expensing bias so that the supranormal private return is not included.

Other sources of bias might relate to human capital, organisational capital, absorptive capacity, and misspecification of the knowledge accumulation equation.

- One criticism often directed at studies that produce high returns is that the measured return is reflecting both a return to R&D plus a return to increasing human capital. Growth in R&D capital may be highly correlated with growth in human capital, or other sources of growth in the knowledge stock, such as, learning-by-doing. If changes in human capital are omitted from the models, or controls are inadequate, then measured rates of return to R&D may be biased upward.
  - Extended market sector regressions do include a variable based on the proportion of the workforce with post-secondary school qualifications. Tests were also undertaken using the quality adjusted labour input ‘QALI’ index produced by the ABS. This index takes some account of workforce experience. The introduction of these variables did not reduce the high estimated returns to R&D in the extended models.

- Another potential source of bias relates to the intangible assets of the firm. Changes in the demand for R&D may have been a common response to changes in the incentives facing businesses to innovate, which also resulted in increases in organisational capital (as distinct from knowledge within organisations embodied in human capital). If so, changes in R&D capital and organisational capital may be highly correlated.
  - Increased competitive pressures and changes in regulatory arrangements gathered momentum in the 1980s, and would have significantly affected the net benefits from innovating versus not innovating. The measured partial effect of R&D may be biased upwards if it is picking up this broader process of businesses improving their organisational structures, processes, strategies and other abilities.
  - The indexes of nominal or effective rates of assistance to industry compiled by the Commission are used as summary indicators of the broad policy reform process. However, they are only partial indicators as there are many aspects of the reform process not reflected in the indexes (for example, changes in labour market regulatory arrangements and workplace flexibility, product market regulation, and reforms which support the development of markets in various infrastructure services).
- Griffith et al. (2003) find that ignoring the absorptive capacity role of R&D introduces an upward bias on the primary or 'own-innovation' coefficient for R&D. However, while taking account of the absorptive capacity benefit of R&D reduces the direct return to R&D through its 'own-innovation' benefit, the total return is actually increased.

  > The implied social rate of return to R&D-based innovation ρ is over 60 per cent, which is high relative to many existing US studies … The higher estimated social rate of return on the innovation variable … may therefore reflect the fact that in non-frontier countries R&D also has the potential to generate productivity growth through technology transfer. That is, the theoretical model implies an omitted variable for R&D-based absorptive capacity … [following re-estimation and including a variable to capture the absorptive capacity role of R&D] Having controlled for R&D-based absorptive capacity, the implied social rate of return on the linear R&D innovation variable ρ falls to around 40 per cent, which is more in line with existing US studies. (Griffith et al. 2003, p. 113)

  - The Griffith et al. approach was to estimate a cross-country model including productivity gaps and to investigate the role of R&D in absorbing disembodied knowledge. Testing in chapter 9 of the interaction between Australian business BRD and foreign R&D did not produce strong results.
- Jones and Williams (1998) use an R&D-based growth model to investigate the question of whether there is too much or too little business R&D. The production function for new ideas allows various interactions between current R&D

expenditure and the existing stock of accumulated knowledge which the traditional PIM does not (see chapter 4 for a general specification of the knowledge accumulation equation). They found that the seemingly high returns to R&D reported in the productivity-R&D literature, based on the PIM methodology, are not significantly biased by ignoring the 'standing on shoulders' and 'stepping on toes' effects of R&D. They viewed the estimated returns as representing a lower bound on the true social rate of return.

– Stokey (1995) and Jones and Williams (1998) find that US businesses tend to undertake too little R&D from a social perspective. In contrast, Comin (2004) and Strulik (2005) suggest that business R&D investment may be close to the socially optimal level.

11.2 The effect of R&D on productivity growth

In the Young (1998) and Howitt (1999) models, the impact of a permanent increase in R&D intensity on the growth rate of output is ambiguous. There are multiple types of R&D in these models. In particular, R&D can be devoted to either attempts to improve product quality or attempts to increase product variety. Increases in R&D devoted to quality improvements can have a permanent impact on growth rates, but increases in R&D devoted to increasing product variety cannot do so by assumption (Segerstrom (2000) generalises Howitt's model and analyses the impact of R&D subsidies on growth when growth can be generated by either horizontal or vertically oriented R&D). Even in those cases where an increase in R&D intensity does not alter the long-run growth rate, it can still result in level effects.

In Australia's case, it is possible that the series of increases in R&D intensity could have resulted in a series of increases in the level of output/productivity, even if there was no long-lasting impact on the rate of productivity growth.

Percentage point impacts

The alternative long-run relationships between productivity growth and R&D intensity generally do not provide support for a strong positive effect of business R&D on productivity growth.[2] With confidence intervals of plus or minus two standard deviations, many of the growth regressions encompass an estimate of a zero partial effect. Some estimates are positive and significant, but others are

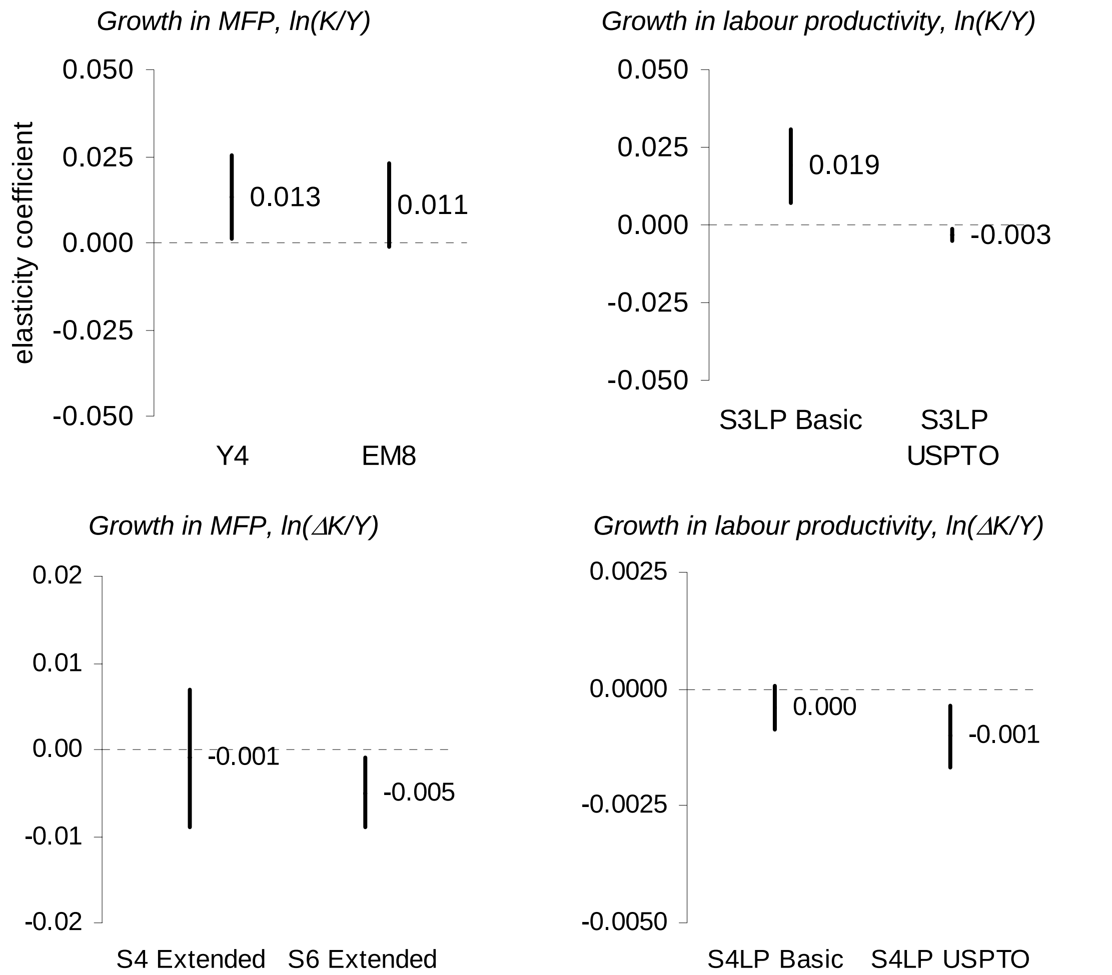
[2] The results from these models are presented as percentage point impacts on MFP and labour productivity growth. A rate of return cannot be recovered from the regressions in the same way as results from the standard framework.

negative or tightly bound to zero. The more precisely estimated coefficients tend to suggest a small negative effect.

The coefficient estimates have an elasticity interpretation. Model Y4 (top left-hand panel of figure 11.2) estimates a strong positive effect for Australian BRD over the period 1974-75 to 2002-03. A 10 per cent permanent increase in the knowledge stock as a proportion of output adds 0.13 percentage points to the growth rate of MFP. This would have large welfare consequences over time. If MFP was growing at roughly 1.0 per cent per year, then the rate of growth increases to 1.13 per cent per year, with a confidence interval ranging from 1.01 to 1.25 per cent per year. All the results in the upper panels have the same interpretation, either impacting on the rate of growth of MFP or labour productivity.

Figure 11.2 **The effect of business R&D on the rate of productivity growth**[a]

Confidence interval based on plus or minus two standard deviations. Note that the vertical scale differs across graphs.



[a] The full results for all models beginning with 'S' can be found in chapter 10. The results for model EM8 can be found in appendix H. Results for model Y4 are presented in chapter 7.

Data source: Commission estimates.

Real value added per person in the labour force was roughly $47 500 at 2002-03. Model Y4 suggests that, holding the capital-to-labour ratio constant, a 10 per cent increase in the intensity permanently raises real value added per person by $6 182, with the confidence interval, based on two standard deviations, ranging from $476 to $11 888.

For model S3LP, which includes USPTO patents granted rather than a measure of the foreign knowledge stock (top right-hand panel), a 10 per cent increase in intensity reduces the growth rate of labour productivity (output per hour worked) by 0.03 percentage points. If labour productivity was growing at roughly 2.2 per cent per year, the rate of growth would decline slightly to 2.17 per cent per year, with a confidence interval between 2.15 and 2.19 per cent per year.

In model S4LP, which includes USPTO patents granted (bottom right-hand panel), a 10 per cent increase in the rate of net accumulation of the stock as a proportion of output results in a decline in the rate of labour productivity growth of 0.01 percentage points, with a confidence interval ranging from -0.02 to 0.00 percentage points. All the results for the bottom two panels have an interpretation based on the rate of accumulation of the knowledge stock. Note that the vertical scale of the two bottom panels differ with the coefficient estimates for the labour productivity growth models more precisely estimated.

The two-equation models are much more likely to produce a statistically significant estimate of the impact of R&D intensity on productivity growth which is either zero or negative and tightly bound to zero. This occurs in both MFP and labour productivity models and with both intensity measures. Compared with their single equation counterparts, the system results are more precisely estimated.

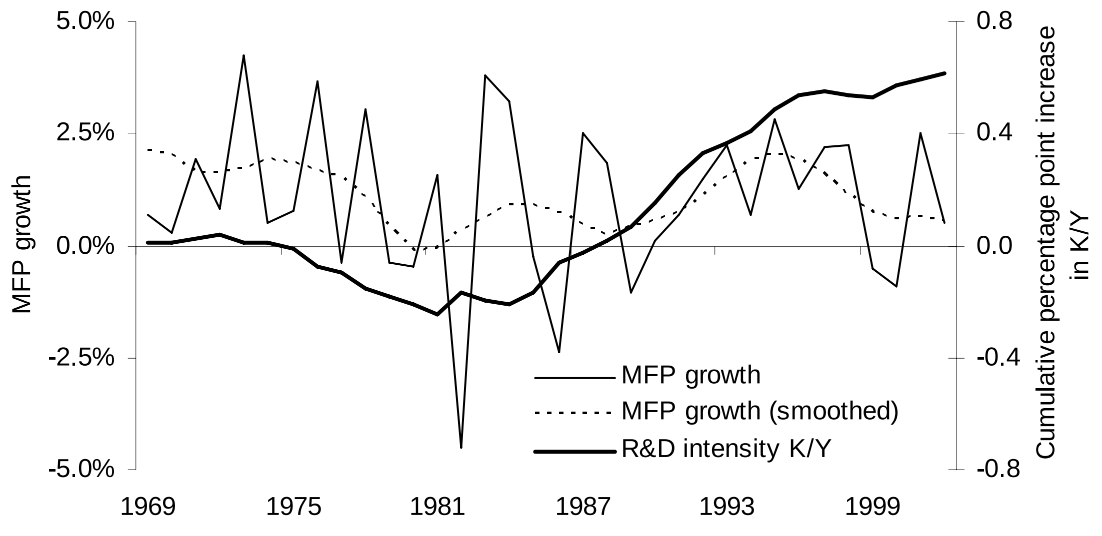
However, it is difficult to test these models against one another with the objective of eliminating one set of results in favour of another. For example, do foreign knowledge stocks or the USPTO patent measure provide a truer indicator of the potential for spillovers to Australia? Which intensity specification is the most relevant for understanding the long-run relationship between R&D and productivity? Does MFP or labour productivity better capture the contribution of R&D? There are arguments in favour of each specification.

Possible impacts from the cumulative increase in R&D intensity

Figure 11.3 shows the cumulative percentage point increase in the ratio of the knowledge stock over output. The ratio of the knowledge stock to output (K/Y) increased by 77 per cent from 1974-75 to 2002-03. Using the coefficient of 0.013 and standard error of 0.006 from model Y4, this translates into an implied increase in the growth rate of MFP of between 8 and 190 percentage points (based on plus or minus two standard errors). From 1974-75 to 2002-03, MFP grew at an average of roughly 0.93 per cent per year in the market sector. Therefore, model Y4 suggests that the accumulated increases in R&D intensity should increase the growth rate of MFP from 2002-03 to between 1.01 and 2.83 per cent per year. This is a very wide confidence interval.

The ratio of the knowledge stock to output (K/Y) increased by 40 per cent between 1974-75 and 1993-94. Again using model Y4, this translates into an implied increase in the growth rate of MFP of between 0.04 and 0.98 percentage points. From 1974-75 to 1993-94, MFP grew at an average of roughly 0.8 per cent per year in the market sector. Therefore, the increased intensity suggests that MFP growth post 1993-94 would increase to between 0.84 and 1.76 per cent (ignoring further increases in intensity after 1993-94). MFP grew at an average rate of 2.0 per cent from 1993-94 to 1998-99 and 1.0 per cent from 1998-99 to 2003-04 (see figure 3.9).

Figure 11.3 **MFP growth and the cumulative increase in R&D intensity**



Data sources: ABS (*Research and Experimental Development, Businesses, Australia*, Cat. no. 8104.0); ABS (*Australian System of National Accounts*, Cat. no. 5204.0); Commission estimates.

11.3 A declining return to business R&D?

A first look at whether the return to business R&D has changed

The estimated elasticity represents the *average* estimated elasticity across the sample period. At a given estimated elasticity, the rate of return to R&D is inversely related to the level of R&D intensity (defined as K_t/Y_t). As R&D intensity rises, the annual rate of return to R&D will decrease.

The procedure of applying the estimated elasticities to sub-samples of the data to detect changes in the return to R&D over time is reliant on the assumption that the structural relationship — as summarised in the elasticity — is reasonably stable across time. With good data and a properly specified model, and with reasonably stable structural relationships, the procedure can detect changes in the marginal product of R&D.

The implied rates of return to Australian BRD do appear to have decreased over time (table 11.2). The level of the return post-1985 is still economically significant.

The estimated elasticities for Australian business R&D from model BL4 and the industry models were applied to the mean of the ratio (Y/K) for the period up to and including 1985 and after 1985. The estimated return for the full sample is also shown for comparison.

The reduction in the return to R&D pre- and post-1985 in model S2 was obtained differently. In that model, a term was entered directly into the regression which allowed the elasticity to be different between the two periods. The two elasticities were applied to the mean of the inverse of the intensity for their respective time periods.

Table 11.2 **Change in the implied rates of return to business R&D**

Return evaluated at the mean for the full regression sample and the first and second halves of the sample.

	BL4	*S2 Basic*	*Total manufacturing*	*Mining*	*WRT*
Implied return -					
1st half of sample (%)	58	123	78	278	1523
Full sample (%)	50		50	159	438
2nd half of sample (%)	42	75	44	114	297

Source: Commission estimates.

There are two major qualifications to the apparent diminished return to Australian BRD. The first is that the movement of the point estimate in some models is well within the confidence interval of the full-sample estimate. The second is that that assumption of a constant elasticity is not supported by some tests and models that point to changes in the relationship between R&D and productivity.

Evidence of a change in the elasticity of business R&D

Most regressions in this study produce an average estimate of the effect of R&D holding other factors constant. A log-linear functional form is adopted where the partial effect of R&D on productivity is treated as constant. With a constant elasticity, the levels models suggest diminishing returns to R&D (table 11.2). However, there are both *a priori* reasons and evidence to support changes in the effect of R&D.

Estimating the rate of return directly from within the standard rate of return framework produced very fragile and poorly estimated returns at all levels of industry aggregation (except Agriculture). This is consistent with the rate of return being subject to greater change than the related elasticities. However, formal tests for breaks in the relationship between productivity and R&D generally did not provide strong support for a break, but the failure of the tests to detect clear breaks is believed to be related to the imprecision of the estimates (see appendixes E and O).

If productivity is specified as a quadratic or higher polynomial function of Australian BRD, then the levels models of the standard framework produce an increasing partial effect of Australian BRD on productivity (appendix O). The increasing effect could be interpreted as resulting from various types of traditional or learning related scale effects. However, these models have a number of problems including that the increasing effect is not 'bounded'. In addition, the effect is at odds with the declining partial effect found in levels models with slope shift terms (see, for example, the two-equation basic models in table 10.4).

The alternative productivity growth and intensity models with a quadratic relationship also support a declining impact on growth rates as intensities have continued to increase. These models produce a pattern for the partial effect which appears more consistent with changes in the economy over the last thirty years.

11.4 Business R&D investment and Australia's recent economic history

Weak business R&D investment and declining economic performance prior to the 1980s change in economic policies

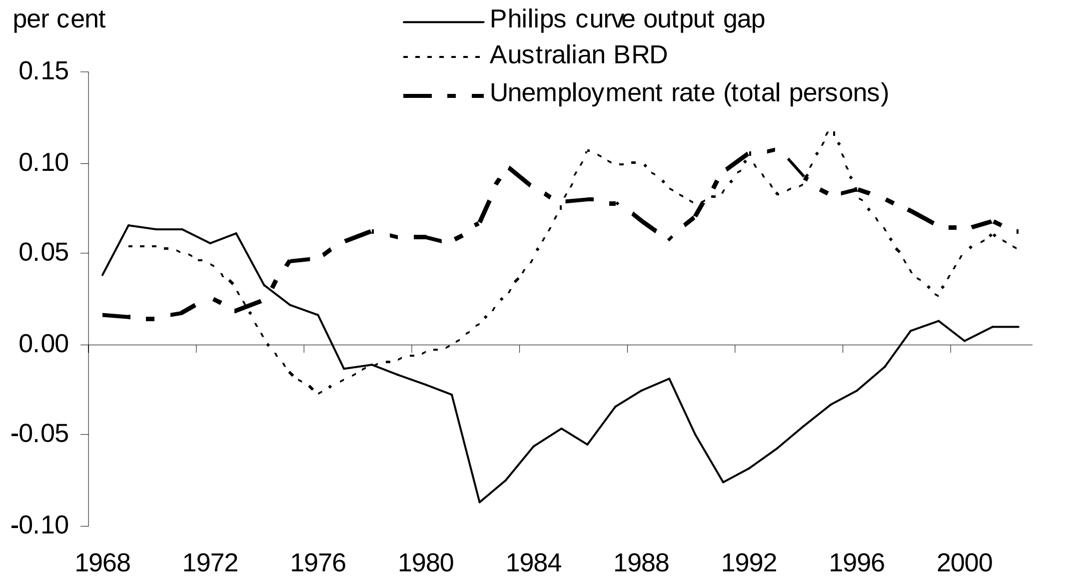
The private marginal product of R&D almost surely declined sharply during the 1970s, which would be consistent with the very weak demand for R&D during this period. The weakness in R&D investment resulted in a rate of investment that was insufficient to ensure positive net growth in the knowledge stock (assuming a decay rate of roughly 10 per cent or greater and the validity of the PIM methodology in constructing knowledge stocks).

Economic performance also severely deteriorated as reflected in the Philips curve output gap measure. The output gap is the difference between actual and 'potential' output. The output gap deteriorated from 1973 and weakened continually until the early 1980s (figure 11.4). The unemployment rate increased sharply in the early 1970s and again in the early 1980s.

The reasons for the decline in economic performance are widely regarded as being an economic and incentives structure poorly equipped to adapt to the shocks of the 1970s, underpinned by inappropriate economic and social policy settings.

Figure 11.4 **Australia's declining fortune**

Decay rate of 15 per cent assumed for stock of Australian BRD. The Philips curve output gap measure is described in appendix L.



Data source: Commission estimates.

While weak R&D investment may have contributed to the decline, R&D and productivity responded to common shocks (as suggested by the modelling in chapter 10). One mechanism for the shocks to have affected R&D is through the very large increase in the cost of capital and the increase in its volatility. These reduced the rate of R&D investment.

In the 1970s, manufacturing's share of business expenditure on R&D was much higher than it is today. Various shocks to the competitive positions of Australian manufacturing firms may have both reduced productivity and the demand for R&D.

Policy responses delayed adjustment while propping up the profitability of protected industries. Updating of the capital stock was possibly much less rapid than it otherwise would have been, which had negative impacts on productivity.

With parallels to Griliches interpretation of the US evidence in box 10.3 (but possibly differences in timing), weak private investment as a response to a decline in the private return to R&D does not necessarily signal a decline in the social marginal product. The gap between the social return and private return to R&D likely widened in Australia during this period.

The perceived high social returns to private R&D investment prior to the mid-1980s — or the perceived under-investment by businesses in R&D from a social perspective — provided the rationale for the introduction of the R&D Tax Concession scheme which took effect in 1985-86. The primary objective of the scheme was to increase business investment in R&D. In chapter 10, the scheme appears to have had a small positive impact on investment. Previous evaluations of the scheme found that its impact was more likely to be positive than negative.

The platform of policy reforms of the 1980s was largely motivated by concerns about the declining competitive positions of Australian businesses and how policy settings of the time were creating investment incentives that were not conducive to improving performance, including investment in the capabilities required for innovation. It was anticipated that the exposure of businesses to greater competition would result in businesses responding by improving their abilities to compete, including their abilities to innovate.

Strong business R&D investment as reforms took hold

Business investment in R&D was sufficiently strong and sustained that the knowledge stock grew at an average of 7.5 per cent per year from 1984 to 2002 (except for a brief dip around 1998 and 1999). From 1985 to 1996, the stock grew at 9.1 per cent per year.

With various reforms and the ‘opening-up’ of the Australian economy through the 1980s, the private marginal product of R&D likely increased as the net profits from innovating versus not innovating increased, or, equivalently, the penalty to non-innovation increased. The connection between R&D, innovation and earning a sufficient risk-adjusted rate of return to satisfy shareholders strengthened. Case study evidence shows that businesses invest in R&D because they believe that, if they did not, they would no longer be in business.

It is difficult to measure major changes to the business operating environment that conditions investment incentives towards more productive investments. In terms of how Government affects the incentives to innovate, this is because many different economic (and social) policies affect the level, timing and direction of investments. Industry policies, labour market regulatory policies, product market regulatory policies, tax policies and associated distortions all have effects on the cost of technology adoption and innovation.

The timing of accelerated reductions in industry assistance and the take-off of R&D investment are not purely coincidental. The R&D equations in chapter 10 included the effective rate of assistance (ERA) index as a summary indicator of these 'framework' changes. Declines in industry protection were strongly associated with increased levels and intensities of business R&D investment. As discussed in chapter 10, however, the ERA measure is only a partial indicator of the pervasiveness of changes in the incentives facing businesses to innovate. A broader measure or set of measures would likely also be significant in explaining R&D investment.

What were businesses investing in? Decompositions of R&D expenditure by socio-economic objective or research field shows that businesses were investing heavily across the board. ICT-related investments were particularly strong, which is a story essentially about technology adoption, adaptation of technologies, and investments in developing complementary assets.

Technology is not a driving force in explaining the very different periods depicted in figure 11.4. Deteriorating performance was not a technology shock story, and improving performance was principally not a story about increasing technological opportunity. Firms chose various paths to improve their performance, but it was the significant change in the need to improve performance which mattered.

Implications for the social return to business R&D

The strong growth rates from the early to mid-1980s are a response to an economic environment that entails dramatically different incentives to improve business performance. However, increased private incentives — increases in the private marginal product to R&D investment — do not mean an increase in the social return to R&D.

The very rapid and sustained high rates of investment could be expected to have significantly eroded the 'problem' of business under-investment in R&D that likely existed in the 1970s and early 1980s. Increases in congestion externalities, the transfer of rents between firms, transitional drops in the average productivity of

R&D, and increasing complexity may all have played a role. Other factors discussed in chapter 10 may also have been important in diluting the effects on productivity of the rapidly accumulating knowledge stock.

The productivity growth models are more consistent with this story as they show a declining effect of R&D on productivity growth from continued increases in intensity (appendix O). The levels models incorporating ‘unexplained’ slope shift terms support the results from the productivity growth models in indicating a significant decline in the social return to R&D post-reforms (for example, model S2 Basic in table 11.1). These models still point to a positive and large social return to R&D.

The productivity growth models support a high social return to R&D which was eroded as business investment responded strongly to changed incentives. Such a strong response provides the conditions for a significant decline in the social return to business R&D.

Counter arguments relate to the scale and absorptive capacity arguments outlined in appendix O, and a rapid expansion in technological opportunities that was sufficiently strong to offset the tendency to diminishing returns.

11.5 Did business R&D contribute to the better productivity performance of the 1990s?

This study finds significant uncertainty about the level of the rate of return to R&D that is consistent with the summation in Diewert (2005).

> Bartelsman (2004a) asked what do we really know about the effects of R&D investments on productivity performance? As can be seen from the above discussion, the existing econometric evidence on this question seems, at least to this reader of the evidence, to be unreliable and inconclusive. Hence, at this stage, I do not think that there is much reliable advice that we can give to policy makers on this topic. (p. 11)

An average return at the level of the market sector of 75 per cent post-1985 could be right (model S2 Basic). This is a high return suggesting that the observed increases in business R&D investment would have had an important impact on the improved productivity performance of the 1990s.

The two-equation productivity growth models provide some evidence that the social and private returns to R&D have converged. Some models produce a positive effect, but some produce an economically insignificant effect that is well estimated. These models have good statistical properties, and contain control variables that are signed as expected and generally well estimated. However, like the levels models, the estimates for Australian BRD are sensitive to relatively minor alterations.

Although the permanent impact on productivity growth might be economically insignificant from continued increases in R&D intensity, past increases in intensity may have resulted in a sequence of productivity improvements.

The two-equation models also consistently find a very large, positive and robust effect for foreign R&D on Australian productivity. Single equation models with dynamics also support this finding. This is important because previous Australian studies and some cross-country studies have found that the effect of foreign R&D on Australia was very weak (or even negative). Initial regressions in this study produced similarly troubling results. The results from some of these regressions were presented in earlier chapters as 'straw men'.

Model improvements in a number of directions were important in finding a foreign effect on Australia which is much more consistent with the view that virtually all countries benefit substantially from international spillovers (with a large share of the spillovers emanating from the United States). Australia is a very small economy whose R&D activities are dwarfed by the largest R&D performing countries, and even some individual firms. Trends in the foreign stock of knowledge have a very large bearing on Australian productivity growth.

11.6 Summary and policy implications

Over the last ten or fifteen years there has been a shift in perspective, in empirical work, policy discussion and, in part, data collection, which emphasises the role of innovation in growth. Innovation is often a complex process involving many different inputs, where incentives are affected by a myriad of institutional arrangements.

This perspective downplays the overriding importance of any one particular input to the process, including R&D. R&D does not 'drive' growth any more than many other factors. This is true for almost all countries. However, it may make a valuable contribution, and the contribution of overseas R&D to Australian productivity growth is undoubtedly large (if hard to measure).

Transparency

Contrary to what most studies show, measuring the effect of R&D on productivity is very messy. It involves a lot of assumptions that matter to the results — conceptual, estimation and practical data construction. It involves a lot of regression results that go unreported. The economic priors of the analyst can make a large difference.

This study has been transparent about these problems.[3] The modelling of the effect of R&D on market sector productivity has shown a wide range of results. Some results have fewer apparent economic and statistical problems than others. But to present only the more ‘favourable’ results would be to underplay the lack of precision and robustness that is shown up by comprehensive testing of models.

The different modelling approaches point in the same direction: the importance of Australian BRD to productivity is very difficult to pin down. Significant uncertainty surrounds the elasticity estimates for Australian BRD, and, hence, the return to R&D.

The importance of business R&D to productivity growth

The lack of genuinely robust estimates of the effect of R&D in Australia reflects the sheer difficulty of the conceptual and empirical challenges facing empirical economic research in this area. The difficulties range from the degree of complexity of the issues under investigation to severe data constraints. The ‘data problem’ may not be merely a shortage of data or the need for longer time series, but may also reflect some fundamental problems of the existing measurement framework under which the R&D and other national accounts data are generated. Some of these problems are having to be faced now with current moves to capitalise R&D within the national accounts.

The number of studies that quantify the link between productivity and R&D in Australia at the aggregate and industry levels is relatively small. Given the difficulties involved, it is likely to be some time before generally accepted estimates of the effect of Australian business R&D emerge. Hopefully, this study has contributed to that goal if for no other reason than it has shown the fragility of estimates of the effect of R&D on productivity.

In the absence of consensus Australian results, it is tempting to rely on overseas studies. However, the majority of studies are based on US data where the historical pattern of R&D investment differs substantially to that in Australia. In addition, the United States sits at or near the technological frontier in so many research fields and product markets and, therefore, the role that R&D plays in US productivity may be quite different to Australia.

Many other studies are based on OECD cross-country panels and great care has to be exercised in comparing the effects of R&D in Australia with the average effects derived from these studies. When the United States is removed from the results, the

3 Rogers (1995) also showed the fragility of estimated returns to R&D.

remaining ‘average’ effect represents predominantly European structural relationships, which may be very different to those prevailing in Australia.

Odds on to win

Which model gives the return to R&D and does it indicate under-investment in R&D by businesses?

A single preferred estimate of the return to R&D at the level of the market sector has deliberately not been selected, in part, because of the difficulty in testing models against one another. The data do not allow strong conclusions to be drawn on the effect of Australian business R&D on productivity. However, the results do point to a number of tentative conclusions.

- Evidence supports changes in the relationship between business R&D and productivity at the level of the market sector.
  - The changes favour a reduction in the degree to which businesses ‘under-invest’ in R&D from a social perspective. How much of a reduction is unclear.
- The effect of foreign R&D is positive and very economically significant. Both foreign knowledge stock and patent measures are shown to have a large impact on Australian productivity.
- There is even greater uncertainty about the effect of R&D at the industry level, both in terms of the effect of an industry’s R&D on its own productivity, and the productivity of other industries. There appears to be significant heterogeneity in returns, so that little can be said about the magnitude of spillovers from comparing results from different levels of aggregation.
- Foreign R&D, a lower and more stable cost of capital, and reductions in industry protection are highly positively associated with increased business expenditure on R&D.

Importance of public sector R&D

The focus of the study was on business R&D. In general, the problem of multi-collinearity between knowledge stocks did not allow the inclusion in regressions of stocks for higher education and government-performed R&D, along side those of Australian BRD.

The R&D equations which sought to explain influences on rising own-financed business investment in R&D did include stocks (or expenditures) for government financed R&D performed by businesses, higher education R&D, and government-performed R&D.

Most results indicated that higher education R&D had a net negative effect on business investment. The model is relatively simple, so concerns can be raised about how adequately it captures longer term relationships between public and private R&D. That said, there are plausible explanations of the negative effect.

The rapid rise, the magnitude of the rise and the sustained high level of business investment would have put significant pressures on the market for scientists and engineers, as their supply is very inelastic. The public sector share of total R&D activity is also very high on average compared with other OECD countries (although that is changing with continued strong business investment). These are conditions which support crowding-out of private investment by public investment.

The benefits of public R&D to businesses may also have been discounted more heavily than in periods prior to that covered by this study given the significant increase in the real rate of interest that occurred in the 1970s and the fact that lags in public R&D can be long.

While the results only provide a net effect, an interpretation is that business investment would have been even higher if not for the upward pressure on wages resulting from the competition with public sector institutions for R&D personnel. Various other displacement, substitution and allocative distortion effects may also be involved. Whether this is undesirable from a social perspective depends on the relative marginal social returns of higher education and business investment.

A structural modelling approach might allow the separate and competing effects of public-private interactions to be identified. This would provide greater confidence that important interactions between private and public R&D are being adequately captured, such as the role of public sector institutions in training future scientists and engineers.

Importance of productivity of R&D and not just the amount of R&D

Many factors may have impacted on the amount of knowledge obtained for a given level of R&D investment, for example: strong growth in the price of inputs, such as the wages paid to scientists and engineers; increased outsourcing of R&D; rapid entry into performing R&D by small firms (at least temporarily reducing the average efficiency of knowledge production); increasing complexity (requiring more R&D effort to obtain a given advancement or 'distance' in knowledge); and advances in the technologies used in research, such as ICTs. Some factors may have improved R&D productivity, while others may have impaired it.

The technical efficiency of the production of knowledge is one dimension to the ‘productivity of R&D’. Another dimension is the potential economic value of the knowledge obtained. This dimension highlights that the direction of the allocation of R&D resources can have an important impact on the eventual social return to R&D in Australia.

Changes in the relationship between the inputs to R&D and the knowledge obtained from R&D has implications for the measurement of the knowledge stocks used to estimate the return to R&D. The knowledge stocks assume a constant relationship given that the true relationship is unobserved. If this assumption is systematically wrong, the estimates of the returns will be biased.

Improvements in the productivity of R&D decrease the required costs to obtain a given advancement in knowledge. If the price of R&D effectively falls, then businesses will undertake more R&D (that is the rationale behind subsidies) or spend fewer resources generating the same amount of knowledge. Both outcomes are desirable from a social perspective.

Evidence of stronger private and market drivers of R&D

The R&D investment of Australian businesses has become much more important in determining the aggregate level of resources devoted to R&D in Australia, and the composition of those investments. Business investment now represents roughly half of GERD. The share of business increased rapidly from the mid-1980s.

Business investment is responsive to market incentives. The private return or marginal product of R&D is determined within the broader context of the rewards to innovation. Policy settings can have impacts that suppress these rewards by weakening the link between innovation and profitability. Policy settings can also influence the costs of technology adoption, and associated secondary innovation, where they impede the flexibility of businesses to adjust their capital stocks and workforces in response to market opportunities and shocks.

Policy settings since the mid-1980s have been far more favourable to R&D investment because they allow the disciplines of the market to reward better firm performance. Most believe that innovation is a critical ingredient in relative firm performance.

The share of businesses performing R&D is quite small and most businesses do not classify themselves as innovators in surveys. They play a role in the diffusion process as adopters of improved technologies. It is through the diffusion of new ideas and technologies that R&D impacts on productivity growth.

Evidence of benefits from local R&D to adapt foreign-developed technologies to domestic opportunities

Similar to Australia, ICT-related R&D has been the fastest growing category of foreign R&D expenditures. Overseas R&D investment related to ICTs is relatively more geared towards technological advances in hardware and systems, which requires very large investments. The importation of these technologies and their subsequent use contributed to the improved productivity performance of the 1990s.

Australian investment is directed more at supporting the adoption of technologies developed overseas, their adaptation, and finding niche markets to develop complementary assets that do not require large scale investments.

Private IT capital is negative in almost all market sector models, but this may be a function of the rapid uptake of the technologies and associated adjustment costs. Based on results in other studies, IT likely began to have a positive, but modest, effect on productivity at some point in the 1990s. This study did not specifically investigate whether the effect of IT capital had changed over time, although recursive estimations did show the coefficient increasing as the sample was successively shortened by dropping the earliest observations.

The coefficient on IT capital is interpreted as the partial effect on productivity holding all other variables constant, including the partial effect of communications technologies, which is positive and statistically significant in many models. It is possible that the contribution to productivity of communications infrastructure is more economically significant than that of IT capital, although there are many relationships between the technologies. Changes in communications technologies might have less disruptive impacts on non-ICT capital, or be more complementary to non-ICT capital. Another complicating factor is that some studies find that it is not IT equipment per se that has a positive impact on productivity. Rather, it is the increase in human capital associated with the use of the equipment that is important.

Results for the expanded market sector and some industries, particularly Wholesale & retail trade, support a positive effect for both IT capital and communications infrastructure.

Evidence to support a change in the level and allocation of government support for R&D?

Government programs aimed at raising the level of business investment in R&D are predicated on the belief that businesses would otherwise under-invest in R&D, in other words, social returns are believed to be much higher than private returns. Many empirical studies provide support for these beliefs.

There is some evidence that social returns at the level of the market sector were high in the 1970s, but were rapidly diminished by the dramatic increase in business investment. Depending on the model, this still leaves room for social returns in Australia above private returns by a good margin. However, there is a lot of uncertainty about the average gap from the 1970s onwards, let alone what the gap is now.

The degree of under-investment can sometimes change dramatically and persist for decades, as has likely been experienced over the last thirty years. So, even if the gap between social and private returns was measured with greater confidence, there still would be significant uncertainty about the stability of the gap in future years.

At the industry level, the apparent very significant heterogeneity in social returns is subject to many qualifications. Not a great deal is known about the relative gap between social and private returns by industry or how it has changed over time. As such, there is no evidence base for seeking to channel resources more towards some industries than others in order to selectively address perceived business under-investment. The risks of using an average return as an indicator of future marginal returns is even more acute at the industry level.

Much of knowledge is not a public good

Policy interventions related to R&D are often predicated on assumptions about the public good characteristics of knowledge that can lead to market failures and business under-investment in R&D from a social perspective.

However, much of the knowledge obtained from business R&D may not have the properties of a public good. There may be a gulf between the characteristics of R&D that businesses actually do, what is measured, and the assumed characteristics of R&D in growth models.

A large share of business expenditure is ‘D’ and not ‘R’. However, basic or fundamental knowledge more closely aligns with the non-excludability and non-rivalry properties of knowledge — its ‘public good’ characteristics — which potentially enable knowledge to be a source of increasing returns.

While the transmission of knowledge can be relatively inexpensive, there are significant resource costs in understanding and utilising knowledge. The need for each user of a ‘piece’ of knowledge to consume resources in absorbing it lowers the social return relative to the private return as knowledge spillovers can no longer be used over and over without cost.

11.7 Directions for further work

The study was unable to estimate either a rate of decay of knowledge or adopt a more flexible specification of the knowledge accumulation process, given relatively few observations. While the assumption of a rate of decay is not that serious, since it can be sensitivity tested, the assumption of a constant decay rate and a constant relationship between R&D inputs and knowledge outputs is more troublesome. A more flexible knowledge accumulation equation could incorporate within the modelling the ‘standing on shoulders’ and ‘stepping on toes’ effects of R&D, as has been done in some overseas studies using simulation methods.

As with other countries, the benefits that Australian businesses receive from undertaking R&D are likely to be weighted more towards absorptive capacity benefits and the contribution that own-R&D makes to the process of technology adoption and adaptation, compared with the own-innovation benefits. Frameworks that separately identify the different ways R&D contributes to better firm performance may produce more robust estimates of the effect of R&D. Linkages between R&D investment and technical inefficiency is one example.

There would appear to be benefits in setting the investigation of the role of R&D in productivity growth in an international context, particularly a model that takes into account relative productivity levels. Changes in business investment might be better understood in the context of the broader pattern of convergence in income levels and/or productivity across countries. This may also provide a better perspective on the issue of the simultaneity of R&D, as well as allowing a better investigation of overseas knowledge transfer to Australia.

Going in the opposite direction, analysis on micro-longitudinal datasets being developed by the ABS will prove beneficial because they allow R&D to be placed in the more detailed context of the innovation processes and strategies of businesses.

Future work on the relationship between R&D and productivity at the industry level may need to address some of the difficult measurement issues that affect the quality of industry level data. Extending time series to increase the number of observations would also be helpful. More specific industry-level theoretical models may also be needed.

Improvements in the efficiency of the innovation process from sources other than R&D affects the net returns on offer from R&D investment. Stronger evidence that firms have become more efficient innovators may help explain the dramatic increase in Australian business R&D investment. The innovation surveys conducted by the ABS provide four cross-sections from the early 1990s that could be used for this purpose.

A Construction of Australian R&D databases

A.1 The sources of Australian R&D data

The Australian Bureau of Statistics (ABS) provides the principal source of data on R&D activity in Australia. The data focus on expenditure (inputs used) and sources of funds. The Bureau compiles estimates from its dedicated surveys of organisations that undertake R&D.

The definition of R&D

The ABS observes international conventions in relation to the collection of R&D data. The OECD has set out internationally-accepted definitions of R&D and classifications of R&D activities in the *Frascati Manual*. The manual also provides a guide to the measurement of human and financial resources devoted to R&D.

The *Frascati* definition of R&D, used by the ABS in its surveys, is:

> Research and experimental development (R&D) comprise creative work undertaken on a systematic basis in order to increase the stock of knowledge, including knowledge of man, culture and society, and the use of this stock of knowledge to devise new applications. (OECD 2003c, p. 30)

R&D has ‘investigation as a primary objective’ (ABS Cat. no. 8104.0, 1998, p. 4). The outcomes that characterise R&D are ‘new knowledge, with or without a specific application’ and ‘new or improved materials, products, devices, processes or services’. The criteria for delineating the boundaries of activities included in the definition are as follows.

- *Presence of novelty*. Does the activity increase the stock of scientific and technological knowledge?
- *Resolution of technological uncertainty*. Does the activity provide a solution to a problem which was not readily apparent to someone familiar with the relevant stock of knowledge and techniques?

Because the ABS observes the *Frascati Manual* conventions, comparability of Australian estimates with those from other OECD countries is enhanced.

Coverage of the surveys

Institutional sectors

The ABS conducts surveys of four institutional sectors engaged in R&D activity.

- *Businesses*. Including public businesses mainly engaged in trading or financial activities. Data are collected every year.
- *Higher education organisations*. From 1994, data have been collected on a biennial basis.[1]
- *Government agencies*. Since 1988-89, surveys have been conducted every two years.
- *Private non-profit organisations*. Surveys have also been conducted every two years since 1988-89.

The relevant ABS publications are listed in box A.1.

Box A.1 **ABS R&D publications**

The ABS issues R&D estimates in four regular publications:

- *Research and Experimental Development, Businesses, Australia* (Cat. no. 8104.0).
- *Research and Experimental Development, Higher Education Organisations, Australia* (Cat. no. 8111.0).
- *Research and Experimental Development, General Government & Private Non-Profit Organisations, Australia* (Cat. no. 8109.0).
- *Research and Experimental Development, All Sector Summary, Australia* (Cat. no. 8112.0), which presents summary data for business, higher education institutions, government and private on-profit organisations.

[1] In the 1970s and 1980s, data were compiled from ABS R&D surveys in conjunction with general expenditure estimates obtained from the Department of Employment, Education, Training and Youth Affairs (DEETYA). Data for 1990 and 1992 were collected by DEETYA.

Survey sample

The surveys are intended to be a complete enumeration of organisations performing R&D in Australia, including all businesses undertaking R&D.[2] The ABS maintains a register of organisations identified as likely R&D performers. As noted below, however, farms are not surveyed.

Statistical unit

The statistical unit for collection of R&D data is generally the management unit. In business, the management unit is the highest-level entity within an enterprise for which accounts are maintained, having regard to industry homogeneity. In nearly all cases, the management unit coincides with the legal entity owning the business. For large diversified businesses, a division or line of business is recognised in cases where separate and comprehensive accounts are compiled.

Industry coverage and allocation

The industry scope of the business surveys covers all industries in the market sector of the economy[3], with the exception of Agriculture, forestry & fishing (ANZSIC division A). In addition, certain non-market sector industries are included — Property & business services, Education, Health services, Personal services and Other services.

Although the ABS does not directly survey farms and other businesses classified to division A, R&D related to these industries is performed in government, higher education and private non-profit institutions, as well as by businesses classified to other industries. In part, this is the result of the financing arrangements involving Research Development Corporations (RDCs) which impose levies on division A businesses to jointly fund R&D by entities not classified to division A, such as the CSIRO, the universities, or specialised research units. However, data collected as part of the administration of the R&D Tax Concession scheme indicate that some R&D is performed directly by division A businesses. This suggests that excluding division A businesses introduces a downward bias in the measurement of the level of resources utilised in R&D.

[2] Four business surveys undertaken during the 1980s were a stratified random sample of likely R&D performers. For these years, a reduced range of data is available.

[3] Australian and New Zealand Standard Industrial Classification (ANZSIC) divisions A to K, plus P. The market sector excludes industries with outputs that are not marketed or are measured wholly or primarily on the basis of input use.

Each management unit surveyed is classified to the industry in which it mainly operates (even though it may have business activity in other industries). The R&D expenditure is similarly allocated to the industry of principal activity of the management unit.[4]

Table A.1 shows the institutional assignment and industry classification of various entities performing R&D in Australia.

Table A.1 **Examples of the classification of R&D performers**

Entity	*Assignment*
Defence Science and Technology Organisation (DSTO)	Government sector
Commonwealth Scientific and Industrial Research Organisation (CSIRO)	Government sector
Australian Nuclear Science and Technology Organisation (ANSTO)	Government sector
Research and Development Corporations	Principally a source of funds for R&D performed in the government, higher education and/or business sector oriented towards agriculture, forestry and fishery industries.
Incorporated Cooperative Research Centres	ANZSIC 7810 Scientific research
Unincorporated Cooperative Research Centres	R&D activity recorded in the accounts of the participating entities.
Specialised scientific research units providing services solely to a company group	Predominant industry of company group
Start-up firms undertaking R&D in the pre-commercialisation phase	ANZSIC 7810 Scientific research
R&D performed overseas by Australian owned businesses	The scope of business R&D statistics is R&D carried out in Australia. However, some overseas expenditure does get reported and classified to the predominant industry of the business ($98.3 million in 2002-03).

Measures of R&D activity

The ABS requests information on a number of aspects of an organisation's total R&D activity.

[4] Where a management unit establishes a dedicated research unit, that unit is classified (in accordance with the *Frascati Manual*) to the predominant industry of the unit. An alternative would be to allocate the expenditure to ANZSIC 7810 Scientific research. Dedicated research units in the Scientific research industry generally undertake R&D for more than one industry, for example, on a contract basis.

Expenditure and labour-years data

Two main types of data are collected from respondents:

- expenditure on and funding of R&D; and
- labour inputs measured in person years.

Since labour forms a large proportion of total expenditure, person years data can also act as a check on trends in R&D expenditure.

Intramural versus extramural R&D, and sources of funds

The majority of R&D data is collected on the basis of ‘intramural’ R&D expenditure — that is, as identified by the organisation that undertakes (as opposed to funds) R&D. The *Frascati Manual* (OECD 2003c) defines intramural expenditure as:

> … all expenditures for R&D performed within a statistical unit or sector of the economy during a specific period, whatever the source of funds. (p. 108)

Intramural R&D expenditure data focus on where the R&D is performed and ignore the significant flow of funds between businesses, governments and other institutions. To provide information on these flows, data are separately collected on the sources of funds for R&D expenditure on the basis of:

> … performer-based reporting of the sums which one unit, organisation or sector has received or will receive from another unit, organisation or sector for the performance of intramural R&D during a specific period. (OECD 2003c, p. 114)

Classifications for sources of funds include own funds, other businesses, the Australian Government, State and Territory governments, other Australian sources, and overseas sources.

Data are also compiled on the basis of ‘extramural’ R&D expenditure, defined as:

> Extramural expenditures are the sums a unit, organisation or sector reports having paid or committed themselves to pay to another unit, organisation or sector for the performance of R&D during a specific period. This includes acquisition of R&D performed by other units and grants given to others for performing R&D. (OECD 2003c, p. 118)

Measures of the structure of R&D activity

The ABS records a number of dimensions of R&D activity that enable assessment of trends in the structure of R&D activity. The main classifications used in this paper are now outlined.

Institutional sector

As noted above, the surveys cover four institutional sectors: business, government, higher education and private non-profit.

Type of activity or orientation of R&D

The ABS classifies the orientation of R&D activity according to the following types.

- *Pure basic research.* Experimental and theoretical work undertaken to acquire new knowledge without looking for long term benefits other than the advancement of knowledge.
- *Strategic basic research.* Experimental and theoretical work undertaken to acquire new knowledge directed into specific broad areas in the expectation of useful discoveries. It provides the broad base of knowledge necessary for the solution of recognised practical problems.
- *Applied research*. Original work undertaken primarily to acquire new knowledge with a specific application in view. It is undertaken either to determine possible uses for the findings of basic research or to determine new ways of achieving some specific and predetermined objectives.
- *Experimental development*. Systematic work, using existing knowledge gained from research or practical experience, that is directed to producing new materials, products or devices, to installing new processes, system and services, or to improving substantially those already produced or installed.

Cost structure — forms of intramural expenditure

The following forms of intramural expenditure data are collected.

- Expenditure on land and buildings.
- Expenditure on other capital.
  - Capital expenditures are not amortised, but are fully allocated to the year in which the expenditure occurs.

- Labour costs.
  - Labour costs cover wages, salaries and on-costs.[5]
- Other current expenditure (OCE).
  - OCE covers purchases of intermediate goods and purchased services.[6]

Industry

Some industry breakdown of R&D activity within the business sector is possible. In general, reliability and confidentiality considerations permit only a broad sectoral breakdown, although more reliable industry detail in the manufacturing sector, for example, is possible.

A.2 Constructed R&D databases

The description of R&D trends in this paper is undertaken at three levels of aggregation.

- *Economy-wide:* consisting of R&D data obtained from ABS publications at the whole-of-economy level. Depending on the specific series, the first observation is either for 1973-74 or 1976-77. The data are obtained from published ABS documents and are 'most recently revised and published'.
- *'Long' panel:* consisting of industry R&D data obtained from ABS publications and departmental surveys at a level of industry aggregation close to that used by the ABS in presenting business R&D survey information (Cat. no. 8104.0). The first observation is one of 1968-69, 1973-74 or 1976-77. Manufacturing data are generally at the 2 digit level, while data for other industries are at the divisional level, with some divisions needing to be combined.
- *'Short' panel:* consisting of unpublished data obtained from the ABS for 65 industries covering the period 1988-89 to 2001-02. 1988-99 is the first year of the panel because it is the earliest year for which business survey data are held in

[5] They include overtime allowances, penalty rates, leave loadings, bonuses, commission payments all paid leave, employer contributions to superannuation and pension schemes, payroll tax, fringe benefits tax, payments to contract staff on the payroll, severance, termination and redundancy payments, and workers compensation insurance.

[6] It includes the costs of materials, supplies and equipment purchased to support R&D; prototypes or models made outside the R&D unit; administrative and other overhead costs; and all costs for indirect services, such as security, building use and maintenance, computer services and report printing and publishing. These acquired services may be carried out within the organisation or hired or purchased from outside suppliers.

electronic format by the ABS (that is, extending the short panel back further would have required accessing historical survey information held in paper format/microfiche).

Adjustments to the data are undertaken for modelling the effect of R&D at the level of the market sector and at the one-digit industry level for Agriculture, forestry & fishing, Mining, Manufacturing, Wholesale trade and Retail trade combined.

Modelling at the highest level of aggregation was based on an industry coverage corresponding to the ABS's definition of the market sector. This allowed use of the official multifactor productivity (MFP) index produced by the ABS and it excluded the non-market sector from the analysis. The exclusion of non-market sector industries should have reduced the 'noise' in the relationship between R&D and output, since output in the non-market sector is subject to more substantial measurement problems.

On the other hand, it was not possible to obtain an R&D expenditure series based solely on the market sector. From the 1970s, ABS business survey publications have included the R&D expenditure of some non-market sector industries. For publications since the introduction of ANZSIC in 1992-93, Property & business services, Education, Health services, Personal services and Other services have all been included. Prior to this time, only the expenditure and funding of Property & business services and Research and scientific institutions were separately identified. Other non-market sector industries were bundled together with various market sector includes under the heading 'Other not elsewhere classified'. Although unpublished data could be obtained from 1988-89 which would allow a split out of the industries, equivalent data were not available for any of the earlier years. Therefore, all analysis based on the market sector includes the R&D expenditure of some non-market sector industries. This overstates the level of R&D activity in the market sector and would have some impact on its growth rate.

The Scientific research industry (ANZSIC 781) is classified as part of Property & business services. It undertakes R&D principally for other industries. The R&D of this industry was distributed to other industries using a breakdown of the industry's R&D expenditure by socio-economic objective, and is, therefore, included in market sector and industry models. The distribution method is imperfect, but it was thought that this was a better option than leaving Scientific research out of the analysis altogether.

Published data for 2002-03 indicates that Property & business services, Scientific research, and Other n.e.c. accounted for 17.5, 5.8 and 9.4 per cent of total expenditure on R&D. Along with non-market sector industries, some of the market sector industries in Other n.e.c. include Electricity, gas & water supply, Construction, Transport & storage, and Communication services.

Two other types of adjustments were made to the data.

- Unpublished business R&D data for 65 industries was obtained from the ABS for the period 1988-89 to 2001-02. This data was used to update the published estimates at a higher level of aggregation as it incorporates revisions to the data which have not been published.
- The former Department of Industry, Technology and Commerce (DITAC) maintained historical series of R&D expenditure. This series included various unpublished ABS revisions, and adjustments to the data, such as estimates for industries not included in the 1968-69 to 1973-74 surveys and adjustments for the inclusion of computer software in the definition of R&D in 1984-85. The adjusted BERD series was used in Industry Commission (1995) for its analysis of the relationship between R&D and growth.
  - The DITAC adjustments were done on the basis of product field and not industry classification. The adjustments have been distributed to each industry according to each industry's share in business expenditure on R&D (BERD). This raises the estimates of the level of R&D expenditure in the early years of the time series, and reduces growth rates. However, the 'true' industry distribution of the adjustments may be different.

Gretton and Fisher (1997) established a dataset of eight manufacturing industries containing time series information on MFP, capital and labour inputs (table A.2). An update of the dataset was used to investigate the effect of R&D on productivity in manufacturing. There are some differences in industry classifications compared with the current two-digit ANZSIC classifications for manufacturing.

Table A.2 **Gretton and Fisher manufacturing industries**

Gretton and Fisher industry	*Abbreviation*	*ANZSIC code*
Food, beverages & tobacco	FBT	21
Textiles, clothing, footwear & leather	TCF	22
Printing, publishing & recorded media	PPRM	24
Petroleum, coal, chemicals & associated products	PCCAP	25
Basic metal products	BMP	271, 272, 273
Structural & sheet metal products	SSMP	274, 275, 276
Transport equipment	TE	281, 282
Other manufacturing	OM	23 Wood & Paper Products, 26 Non-metallic mineral products, 283 to 286 Other machinery & equipment, 29 Other manufacturing

Source: Gretton and Fisher (1997).

A.3 Issues affecting the quality and interpretation of the datasets

A range of issues may affect identified trends and model results. For the purposes of this project, there is greater concern about the reliability of measured trends over time than there is about the accuracy of point estimates. For example, a systematic error that has a proportional effect on estimates at all survey points would have little or no consequence for the determination of growth trends.

Several issues are most likely to have only a marginal effect on the trends identified:

- a potential for under-enumeration due to omission of organisations performing R&D from the surveys;[7]

[7] Whilst the ABS puts considerable effort in to ensuring that any organisations performing R&D are included in the R&D surveys, some proportion may be missed. R&D performed within service industries is generally regarded as being more difficult to measure, which may lead to under-representation in these industries.

- a potential for respondent error due to respondents' inability to identify R&D activity separately;[8]
- the possibility of respondent error due to differences in accounting standards and different R&D definitions used in different contexts;[9] and
- difficulties in distinguishing with precision between R&D and pre-production expenditure.

These potential errors would tend to be systematic ones over reasonably short periods and would therefore tend to have little effect on the detection of trends over periods of say 5 to 10 years. However, the accuracy of data has likely improved since the early to mid 1970s, injecting a non-systematic error in the long-term trends. It is not clear, however, that the net effect of different factors would necessarily be an upward or downward bias.

Errors in the assessment of longer-term trends could also be more prevalent in structural dimensions. In particular, changes in industry classification systems required the use of industry concordances to construct long-term databases of R&D activity by industry. Imprecision in these concordances introduces the potential for error in industry data.

Finally, it should be noted that, because of likely changes in R&D productivity, the implicit assumption that R&D output trends can be approximated by R&D input trends becomes more tenuous over longer periods of time.

'Long' panel concordance and the construction of consistent time series

Since the early 1970s, the system of industrial classification used by the ABS has changed a number of times, with the most important change being the transition from the *Australian Standard Industrial Classification* (ASIC) system to the *Australian and New Zealand Standard Industrial Classification* (ANZSIC) system introduced for 1992-93 collections. Problems in concordance between ASIC and ANZSIC can introduce breaks in the R&D time series at the industry level. The lower the level of industry aggregation, the greater the potential for distortions to be

[8] Some businesses only provide estimates because their accounts do not separately record data on R&D activity. In some organisations — in particular, universities — it may be difficult for administrators to distinguish R&D activity accurately from other activity such as teaching, except in a generalised fashion.

[9] The statistical definition of R&D used in the surveys differs in some respects from definitions used for industry R&D grant schemes and the R&D Tax Concession scheme. However, as part of its quality control procedures, the ABS has found that businesses report accurately.

introduced to the data in splicing industry series under different classification systems.

The first column of table A.3 shows the level of aggregation used in the 'long' panel. Compared with the level of industry aggregation currently used in ABS Cat. no. 8104.0, Wood & paper products and Printing, publishing & recorded media are combined, and Finance & insurance is combined with Other n.e.c. instead of being separately identified. All of the industries listed under Other n.e.c. are combined to form a single time series.

Concordance at the level of aggregation in the long panel is not a significant problem. The largest potential problem was for Wholesale trade and Retail trade divisions as there was significant changes in the assignment of industries between them. However, combining the divisions 'internalised' the changes. As the long panel is based on published industry-level data, no other adjustments for concordance have been made.

The following industries were not separately identified in the 1973-74 business survey: Wood, wood products & furniture; Non-metallic mineral products; Fabricated metal products; Photographic, professional & scientific equipment; and Appliances & electrical equipment. Therefore, most manufacturing data are presented from 1976-77 to 2001-02 to provide full coverage of the division.

Table A.3 **Industry aggregation and concordance in the long panel**

ANZSIC description	*ANZSIC Code*	*Abbrev. used*	*ASIC Code*	*Concordance issues unable to be addressed*
Mining	B	Mining	B	
Manufacturing				
Food, beverages & tobacco	21	FBT	21	Part of ASIC 2115 Meat (except smallgoods or poultry) transferred to ANZSIC 2531 Fertiliser manufacturing. Part of ASIC 2161 transferred to ANZSIC 5124 Bread and cake retailing
Textiles, clothing, footwear & leather	22	TCF	23, 24	ASIC 2341 Cotton Ginning transferred to ANZSIC Division A: Agriculture, forestry & fishing
Wood and paper products; Printing, publishing & recorded media	23, 24	WPP	25, 26	ASIC 2538 Wood products n.e.c., 2541 Furniture (Except Sheet Metal), 2542 Mattresses (Except Rubber), and 2632 Paper bags did not map in whole or in part to ANZSIC 23 or 24
Petroleum, coal, chemical & associated products	25	PCCAP	27	Part of ASIC 2761 (Ammunition, explosives and fireworks) mapped to ANZSIC 27
Non-metallic mineral products	26	NMP	28	No concordance issues
Metal products	27	MP	29, 31	Part of ASIC 2957 Secondary recovery and alloying of non-ferrous metals n.e.c. mapped to ANZSIC 25. Part of ASIC 3141 Fabricated structural steel, 3152 Sheet metal furniture, 3153 Sheet metal products, and 3168 Fabricated metal products n.e.c. mapped to ANZSIC 29
Motor vehicle & parts; Other transport equipment	281, 282	TE	323, 324	Part of ASIC 3245 Transport equipment n.e.c. mapped to ANZSIC 29
Photographic & scientific equipment	283	PSE	334	Part of ASIC 3341 Photographic and optical goods mapped to ANZSIC 284. ASIC 3342 Photographic film processing mapped to ANZSIC 95
Electronic equipment; Electrical equipment & appliances	284, 285	AE	335	Parts of ASIC 3351 Radio and TV receivers & audio equipment, 3352 Electronic equipment n.e.c., 3353 Refrigerators & household appliances, and 3357 Electrical machinery & equipment n.e.c. mapped to ANZSIC 283 or 286

(continued on next page)

Table A.3 **(continued)**

ANZSIC description	*Code*	*Abbrev. used*	*ASIC Code*	*Concordance issues unable to be addressed*
Industrial machinery & equipment	286	IME	336	Parts of ASIC 3367 Dies, saw blades & machine tool accessories and 3369 Industry machinery & equipment n.e.c. mapped to ANZSIC 283 or 284
Other manufacturing	29	Other manu.	34	ASIC 345 (Leather and leather products), 346 (Rubber products), and 347 (Plastic and related products) largely mapped to ANZSIC 22 and 25. ASIC 348 (Other manufacturing) partly mapped to ANZSIC 28, 78 and 25
Wholesale & retail trade	F, G	WRT	F	Part of ASIC 4728 Builders hardware dealers n.e.c., 4731 Farm and construction Machinery wholesalers, 4734 Business machines wholesalers, 4736 Machinery and equipment wholesalers 4751 Wool selling brokers; Stock and station agents, and 4763 Fish wholesalers mapped to ANZSIC 21, 26, and Division L
Property & business services	L	PBS	63	Part of ASIC 6322 mapped to ANZSIC Division P
Scientific research	7810	SR	8461	No concordance issues
Other n.e.c. (single series)		Other n.e.c.		Concordance issues not significant as industry classifications are combined within a single series (that is, any movements between industries are 'internalised')
Electricity, gas & water	D		D	
Construction	E		E	
Accommodation, cafes & res.	H			
Transport & storage	I			
Communication services	J		G	
Finance & insurance	K		H	
Government admin. & defence	M		61, 62	
Education	N		J	
Health & community services	O		K	
Cultural & recreational services	P			
Personal & other services	Q		L	

Source: Based on ABS (*Australian and New Zealand Standard Industrial Classification 1993,* Cat. no. 1292.0).

'Short' panel concordance

The short panel was constructed at as detailed a level of industry classification as possible subject to the impact of ABS confidentialisation procedures on the quality of individual time series, including various expenditure decompositions.

The panel was constructed by undertaking a concordance exercise at the three or four digit level, and the resulting time series combined to form the sixty-five industries in table A.4. The panel includes: four Mining industries; thirty-six Manufacturing industries; five Wholesale & retail trade industries; three Finance & insurance industries; two Property & business services industries; Scientific research; three industries predominantly IT related; and eleven other industries.

Industries not included in the short panel are: 81 Government administration; 82 Defence; 87 Community services; and 97 Private households employing staff. These industries are either not part of the 'business sector' or have no R&D expenditure.

The construction of the time series for the short panel involved splicing together data held by the ABS for 1988-89, 1990-91 and 1991-92, based on the ASIC classification system, with data collected annually from 1992-93 based on ANZSIC. The majority of the ASIC classifications mapped one-to-one with ANZSIC classifications. Many ASIC classifications mapped to more than one ANZSIC classification, but the classifications aggregated within a single industry in the above table. The remaining ASIC classifications mapped to more than one of the sixty-five industries. In these cases, each ASIC classification was assigned to a 'primary' ANZSIC classification (see table A.5). The primary classifications were determined in consultation with the ABS and other sources. There do not appear to be any clear breaks in the series introduced by the concordance procedure at the cut-over year of 1992-93.

Table A.4 **The 65 industries of the short panel**

Code	*ANZSIC description*	*Code*	*ANZSIC description*
	Manufacturing		*Mining*
211	Meat & meat products	11	Coal mining
212	Dairy products	13	Metal ore mining
213	Fruit & vegetable processing	12, 14	Oil & gas extraction; Other mining
215	Flour mill & cereal food	15	Services to mining
216	Bakery products		
214, 217, 219	Oil & fat; Other food; Tobacco products		*IT sectors*
218	Beverages & malt	2841	Computer & business machine mfg
221	Textile fibre, yarn & woven fabric	461	Machinery & equipment wholesaling
222, 223, 224	Textile products; Knitting mills; Clothing	783	Computer services
225, 226	Footwear; Leather & leather products	7810	*Scientific research*
231	Log sawmilling & timber dressing		
232	Other wood products		
233	Paper & paper products		*Wholesale & retail trade*
241	Printing & services to printing	45	Basic material wholesaling
242	Publishing	462	Motor vehicle wholesaling
243	Recorded media & publishing	47	Personal & household good wholesaling
251, 252	Petroleum refining; Petroleum & coal products	51, 52, 57	Food retailing; Personal & household good retailing; Accommodation, cafes & restaurants
253	Basic chemical manufacturing	53	Motor vehicle retailing & services
254, 255	Other chemical product; Rubber products		
256	Plastic products		*Finance & insurance*
262	Ceramic products	73	Finance
263	Cement, lime, plaster & concrete products	74	Insurance
261, 264	Glass & glass product, & non-metallic mineral products	75	Services to finance & insurance
271	Iron & steel		
272, 273	Basic non-ferrous metal; Non-ferrous basic metal products		*Property & business services (less 783 and 7810) -*
274	Structural metal products	77	Property services
275	Sheet metal products	78 less 783 less 7810	Business services (less 7810 Scientific research and 783 Computer services)

(Continued on next page)

Table A.4 **(continued)**

Code	*ANZSIC description*	*Code*	*ANZSIC description*
	Manufacturing (cont'd)		*Other not elsewhere classified (n.e.c.)*
276	Fabricated metal products	36	Electricity & gas supply
281	Motor vehicle & parts	37	Water supply, sewerage & drainage services
282	Other transport equipment	41	General construction
283	Photographic & scientific equipment	42	Construction trade services
284 less 2841	Electronic equipment (less computer & business machine)	61, 63	Road transport; Water transport
285	Electrical equipment & appliances	62, 64, 65, 67	Rail transport; Air & space transport; Other transport plus Storage
286	Industrial machinery & equipment	66	Services to transport
291, 292	Prefabricated building; Furniture	71	Communication services
294	Miscellaneous manufacturing	84, 86	Education; Health services
		93	Sport & recreation
		91, 92, 95, 96	Motion picture, radio & television; Libraries, museums & arts; Personal services; Other services

Source: Based on ABS (*Australian and New Zealand Standard Industrial Classification 1993*, Cat. no. 1292.0).

Table A.5 **ASIC classifications assigned to ANZSIC by a primary mapping**

Code	*ASIC classification*	*Code*	*ANZSIC correspondence*
2645	Printing trade services n.e.c.	2413	Services to printing
3341	Photographic & optical goods	2831	Photographic & optical good manufacturing
3351	Radio and TV receivers; audio equipment	2849	Electronic equipment manufacturing n.e.c.
3352	Electronic equipment n.e.c.	2842	Telecommunication, broadcasting & transceiving equipment
3353	Refrigerators & household appliances	2851	Household appliance manufacturing
3357	Electrical machinery & equipment n.e.c.	2859	Electrical equipment manufacturing n.e.c.
3367	Dies, saw blades & machine tool accessories	2864	Machine tool & part manufacturing
3369	Industrial machinery & equipment n.e.c.	2869	Industrial machinery & equipment manufacturing n.e.c.
3484	Signs & advertising displays	2949	Manufacturing n.e.c.
3487	Manufacturing n.e.c.	2949	Manufacturing n.e.c.
4728	Builders hardware dealers n.e.c.	4539	Building supplies wholesaling n.e.c.
4731	Farm & construction machinery wholesalers	4611	Farm & construction machinery wholesaling
4734	Business machines wholesalers	4613	Computer wholesaling
4736	Machinery & equipment wholesalers n.e.c.	4619	Machinery & equipment wholesaling n.e.c.
5113	Short distance road freight transport	6110	Road freight transport
573	Services to air transport	663	Services to air transport
8493	Prisons & reformatories	9632	Corrective centres

Source: Based on ABS (*Australian and New Zealand Standard Industrial Classification 1993,* Cat. no. 1292.0).

Decompositions of expenditure into capital, labour and other current expenditure, and by type of R&D activity (pure basic, strategic basic, applied, and experimental development) could not be obtained. For the data that were obtained, generally only one to two observations in each industry's time series required interpolation, although some industries had up to five missing observations. A combination of simple averaging and regression methods were used for interpolation. All data for 1989-90 were interpolated as the ABS did not undertake a survey of businesses in that year.

The boundaries between R&D and production

It can be difficult to determine where experimental development ends and pre-production begins. The *Frascati Manual* highlights the following areas where problems tend to arise in considering whether an activity is to be reported as R&D:

- R&D versus education and training;
- R&D versus related scientific and technological activities, such as the provision of scientific and technical information, testing, quality control and analysis;
- R&D versus other industrial activities, such as patent filing and licensing, market research, manufacturing start-up, tooling-up and redesign of manufacturing processes; and
- R&D administration and indirect supporting activities, such as the provision of library and computer services, and management, administration and clerical overheads.

Unless these borderline issues become more or less prominent, they would tend to be systematic problems that would have little effect on the determination of trends.

Intramural and extramural: R&D performance versus financing

The border between intramural and extramural expenditure is not always clear. The *Frascati Manual* advises that the acquisition of services which are closely related to intramural R&D activities should be considered intramural expenditure. On the other hand, if the services are separate R&D projects, the expenditures should be classified as extramural expenditure. In the case of consultancies, on-site consultancies are classified as intramural expenditure. They are recorded as OCE and not labour costs. Off-site consultancies constituting a separate R&D project would not be included in intramural R&D data. Other off-site consultancies would be considered acquired services and recorded as OCE. Some tasks are not strictly R&D, but they closely support R&D activities. These expenditures are also classified as OCE.

This issue, especially in the absence of any change in the degree of outsourcing (see below), would tend to affect estimates of the structure of expenditure (rather than the level of expenditure) in a systematic way.

Potential for under-enumeration of businesses with R&D activity

The ABS puts considerable effort in to ensuring that any enterprise performing R&D is included in the R&D surveys. However, some proportion of performing businesses may be missed. Any changes in this proportion over time could alter apparent trends in the level of resources devoted to R&D. Empirical analysis could be biased if certain firm characteristics, for example, firm size, are highly correlated with the likelihood of being excluded from the survey. R&D performed within service industries is also generally regarded as being more difficult to measure, which may lead to under-representation in these industries.

Potential for respondent error

In the explanatory notes to recent editions of its business R&D publication (Cat. no. 8104.0), the ABS highlights the following issues, which may affect the reliability of business R&D data.

- Many data providers make estimates because their accounts do not separately record data on R&D activity.
- The OECD standard definition of R&D used in the surveys differs in some respects from what data providers may regard as R&D activity. This is because the definitions used for industry R&D grant schemes and the R&D Tax Concession scheme are slightly different from the definitions used by statistical agencies in R&D surveys.

At the front of the business survey questionnaire, the ABS highlights that the definition of R&D used for the survey is different from that used in government programs. As part of its quality control procedures, the ABS has investigated whether businesses are aware of the differences in definitions and whether the information provided to the ABS is based on the proper definition. The investigation indicated that businesses reported accurately.

In any case, to the extent that there is any error, it would tend to be a systematic one (individual businesses continue to use the same definition), which would have little effect on the detection of trends.

Changes in expenditure accounting

Changes in organisations' accounting practices can introduce non-systematic errors into R&D expenditure estimates. The introduction of government financial assistance to R&D activities, and changes in accounting standards, may have altered how businesses structure their financial accounts, which activities they recognise as

R&D, and how they record R&D. Grants and tax concessions give a financial incentive to minimise 'unreported' R&D and, where feasible, to classify borderline activities as R&D.

With the introduction of tax concessions for R&D expenditure in the mid-1980s and a major modification in the 1990s, there is potential for a significant bias in determining long-term trends. The announcement and introduction of tax concessions may have increased reported R&D more than they affected true innovation-directed R&D activity. The tightening of concession criteria and other changes to R&D policies in the 1990s would have reduced the incentive.

Outsourcing of business R&D activities

To complete an R&D project, an enterprise may choose to internalise or perform all relevant tasks within the individual enterprise. This might include the provision of supporting R&D services. However, businesses may choose to enter into arrangements with other enterprises or institutions for the provision of discrete tasks, supporting services or even the contracting of the entire R&D project. Where the coordination of the R&D project involves external entities, the measurement of the resources committed to R&D is more difficult.

The strong growth in the externalisation or contracting out of R&D activities over many years is likely to result in an underestimate of both labour expenditure and human resources devoted to R&D. If purchased and acquired R&D services were undertaken internally by the firm, recorded labour expenditure would be increased and the human resources related to that expenditure would be recorded. Externalisation of the service results in labour expenditure being recorded as other current expenditure and human resources being underestimated. The rapid increase in the share of other current expenditure in total expenditure (discussed in appendix B) suggests that this is a significant measurement issue.

The choice method to deflate R&D expenditure

The ABS constructs chain volume measures of R&D expenditure by applying generic price deflators to the individual cost components collected in the R&D surveys:

> Deflators are calculated for three institutional sectors: private business, government and non-profit institutions. In each case the current price R&D expenditure is broken down into four components: wages and salaries; other current expenditure; land and buildings; and other capital expenditure … The price indexes used are broad based

> input price indexes and do not relate specifically to R&D expenditure. This remains an area of relative weakness.[10] (ABS 2004, p. 2)

The weights used by the ABS in constructing the volume measures correspond to the shares of each cost component in total R&D expenditure.

Labour costs are deflated using a generic wages deflator not a deflator representing price changes in the wages of scientists and engineers. For OCE, the deflator is a composite price index used to deflate non-wage expenditure. It is based on component price indexes from various sources, such as the consumer price index (CPI) and Price Indexes of Articles Produced by Manufacturing Industry indexes. The composite index reflects price movements in such things as: motor vehicles; electricity; domestic airfares; telephone fees and charges; postal services; printing costs; taxi fares; rent; and building maintenance costs.

The growth rate in real Australian business R&D expenditure is slightly higher when deflated by the GDP implicit price deflator (GDP(IPD)) compared with deflating the cost components separately and aggregating (figure A.1, panel 1). Each cost component was separately deflated using the same price indexes as the ABS uses in the creation of the chain volume measures (the price indexes were provided by the ABS on special request). However, real total expenditure was not chained in order to focus more clearly on the alternative price deflating assumptions.

Diewert (2005) recommends use of the CPI rather than the GDP(IPD) to deflate R&D expenditures as the latter is affected by changes in import prices. However, the two indexes track very closely over time (figure A.1, panel 2).

Modelling at the market sector level is undertaken on data deflated using the GDP(IPD). Apart from the fact that use of the GDP(IPD) does not appear to understate growth in R&D prices, at least compared with the approach of separately deflating individual cost components using available price indexes, there are a number of other benefits in using the GDP(IPD).

- *Coverage period*: the official chain volume measures and many of the underlying component price indexes are available from 1984-85, while the first observation for most models is between 1968-69 and 1974-75.

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10 The ABS compiles a specific producer price index for services provided by the Scientific research services industry (ANZSIC 781). The index is output based with most of the price information relating to rates charged by organisations in the industry. It is available quarterly from September 1998. As a longer time series of data becomes available, the ABS intends to investigate whether it can be used as a proxy price index for the whole of R&D activity.

- *Adjusted data*: the historical current price R&D expenditure data have been adjusted in various studies in a way which has broken the link between total expenditure and its various decompositions, including by type of input. It could be assumed that the component input shares which applied to the official published estimates also apply to the adjusted series, but there are many complications of this sort.
- *Uncertainty about OCE*: deflating each input separately should have the advantage of capturing changes in input shares where the pure price trends of the inputs differ. However, deflating component inputs highlights the problem of identifying the drivers of OCE expenditure and the appropriate choice of deflator. Should OCE be deflated as if it was mainly wage costs or intermediate inputs (as is done in the ABS chain volume measures)? Given the share of OCE has risen from around 24 per cent of BERD in 1976-77 to 51 per cent of BERD in 2002-03, the treatment of OCE could distort the estimates of real expenditure.

Mansfield (1984) found that R&D prices varied by industry and Jankowski (1993, p. 195) cautioned against using the GDP(IPD) at the industry level:

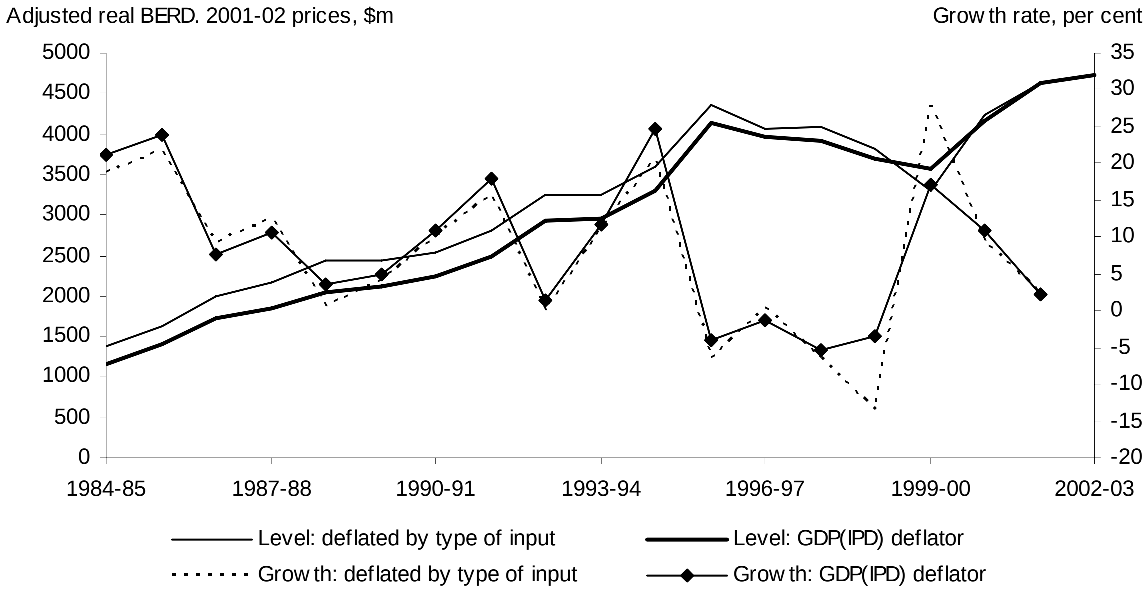
> Although broad-based deflators — such as the GNP deflator used in reporting most official R&D statistics — provide reasonable approximations of changes in aggregate industry R&D costs, they are much less appropriate for calculating real R&D expenditures of individual industries.

The ABS does not publish chain volume measures of R&D expenditure at the industry level, as industry-specific price deflators for the various components of R&D expenditure generally do not exist. Industry-specific indexes could be constructed, but the indexes would have to be a combination of national or broad-based deflators weighted by industry-specific cost shares.

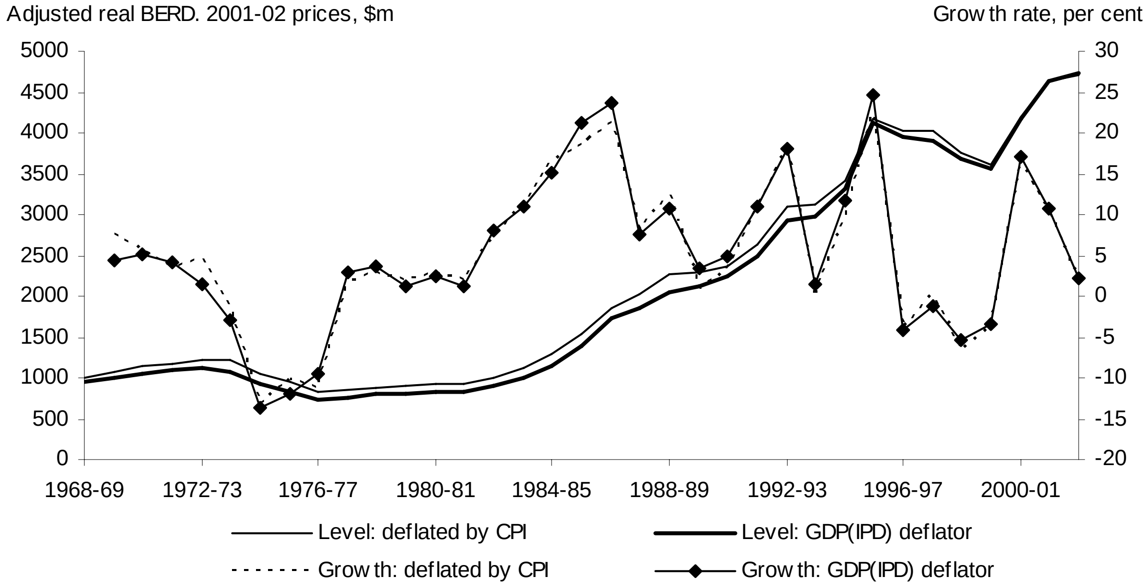
Figure A.1 **Alternative methods for deflating business R&D expenditure[a], various periods**

Measures are not chain linked

Aggregate versus component deflation



GDP(IPD) versus CPI deflation



a Labour, OCE and capital were separately deflated using the non-R&D specific deflators used by the ABS in its production of chain volume measures. The ABS separately deflates land and buildings and other capital expenditure. This split was not available for the adjusted BERD series, so it was assumed that each type of capital formed one half of total capital expenditure. OCE was deflated using composite price index used to deflate non-wage expenditure (based on CPI and Prices Indexes of Articles Produced by Manufacturing Industry). The deflated individual series were then summed to provide an estimate of adjusted BERD, but they were not chained.

Data sources: Component price deflators provided by the ABS; ABS (*Research and Experimental Development, Businesses, Australia*, Cat. no. 8104.0); ABS unpublished data; Commission estimates.

The only industry-level price deflator available in Australia is the output IPDs. In Mining, deflation using the industry IPDs tends to give a higher growth rate in the stock of BERD in the mid-1970s to early 1980s compared with the GDP deflator. Overall, Mining and Manufacturing IPDs result in lower growth rates, but a similar pattern of growth (figure A.2). However, as R&D is recognised as an input in the modelling of productivity, it is not correct conceptually to use the industry-specific output deflator to obtain an input volume measure. Thus, in the absence of the appropriate industry-specific input and R&D deflators, modelling at the industry level in this study is based on current R&D expenditures deflated using the GDP(IPD).

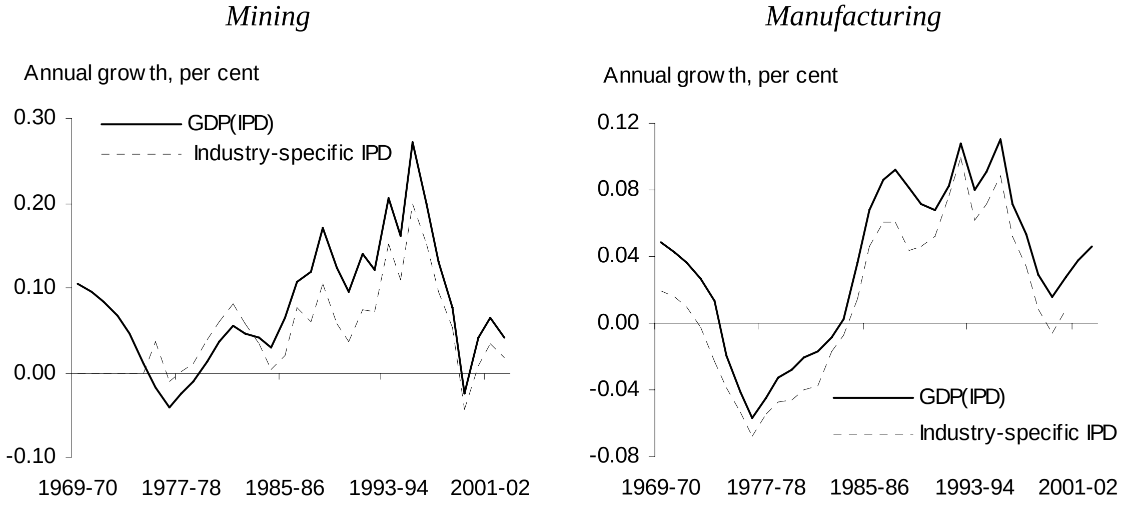
Cameron (1996) found that R&D input costs varied significantly across industries:

> Second, we have shown that the cost of R&D in individual industries can rise at very different rates from that in manufacturing as a whole. (p. 12)

Given that the cost share of wages in R&D expenditure is roughly fifty per cent, and it is suspected that a large proportion of OCE expenditure is also wage costs, wage pressures in the labour markets for R&D personnel could suppress any sustained divergence in R&D price inflation across industries. The real wages for scientists and engineers may be more highly correlated across industries than would their wages be correlated with broad-based output IPDs within each industry. If so, the distortion from using the GDP(IPD) might be less than that introduced from assuming that the wages of scientists and engineers follow the industry-specific time paths in the industry IPDs.

Figure A.2 **Growth in industry knowledge stocks with alternative deflators, 1969-70 to 2002-03**

Stocks depreciated at 15 per cent



Data sources: ABS (*Research and Experimental Development, Businesses, Australia*, Cat. no. 8104.0); ABS (*Australian System of National Accounts*, Cat. no. 52040); Commission estimates.

B Trends in costs and outsourcing

This chapter examines trends in the cost structure of R&D spending. It reviews:

- capital, labour and other current inputs to R&D activity (section B.1);
- trends in increased non-labour current costs in more detail (section B.2); and
- trends in increased labour costs in more detail (section B.3).

The structure of costs has changed with large increases in non-labour current costs. These have also shown more variation over time in reflection of changes in the degree of outsourcing of R&D activity.

B.1 Changes in the structure of R&D costs

R&D activity is very intensive in current expenditures, rather than capital costs. Labour costs and other current expenditure (OCE)[1] each accounted for 46 per cent of gross expenditure on R&D (GERD) in 2002-03 (table B.1). Capital expenditure — expenditure on land and buildings and on other capital[2] — accounted for 8 per cent. The cost structure is broadly similar in the different institutional sectors (table B.2).

Table B.1 **Cost structure of GERD[a], 1976-77, 1984-85, 1996-97 and 2002-03**

	1976-77		*1984-85*		*1996-97*		*2002-03*	
	$b	%	$b	%	$b	%	$b	%
Land and buildings	0.12	3.9	0.16	3.7	0.29	2.8	0.34	2.8
Other capital expenditure	0.17	5.6	0.37	8.5	0.92	9.1	0.68	5.6
Labour costs	2.19	69.8	2.79	63.5	4.29	42.6	5.53	45.1
Other current expenditure	0.65	20.7	1.07	24.3	4.58	45.5	5.70	46.5
Total	**3.13**	**100.0**	**4.39**	**100.0**	**10.07**	**100.0**	**12.25**	**100.0**

a Expenditures are in real terms, based on the GDP price deflator.

Sources: ABS (*Research and Experimental Development, All Sector Summary, Australia*, Cat. no. 8112.0); ABS (*Australian System of National Accounts*, Cat. no. 5204.0); Commission estimates.

1 The coverage of OCE is explained in appendix A.

2 As noted in appendix A, capital purchases are fully expensed in the year of purchase and are not amortised over the effective life of an asset life.

Table B.2 **Cost structure[a], by institutional sector, 1984-85, 1996-97 and 2002-03**

Percentage share within sector

	1984-85	*1996-97*	*2002-03*
Business			
Capital	13.6	13.6	7.7
Labour	54.9	37.6	43.9
Other current expenditure	31.5	48.8	48.4
Government			
Capital	13.4	13.2	8.8
Labour	63.7	48.8	51.9
Other current expenditure	22.8	38.1	39.4
Higher education			
Capital	7.5	7.7	9.0
Labour	73.4	45.5	41.9
Other current expenditure	19.0	46.8	49.1
Private non-profit			
Capital	33.1	12.1	11.5
Labour	46.7	51.9	49.7
Other current expenditure	20.3	35.9	38.8

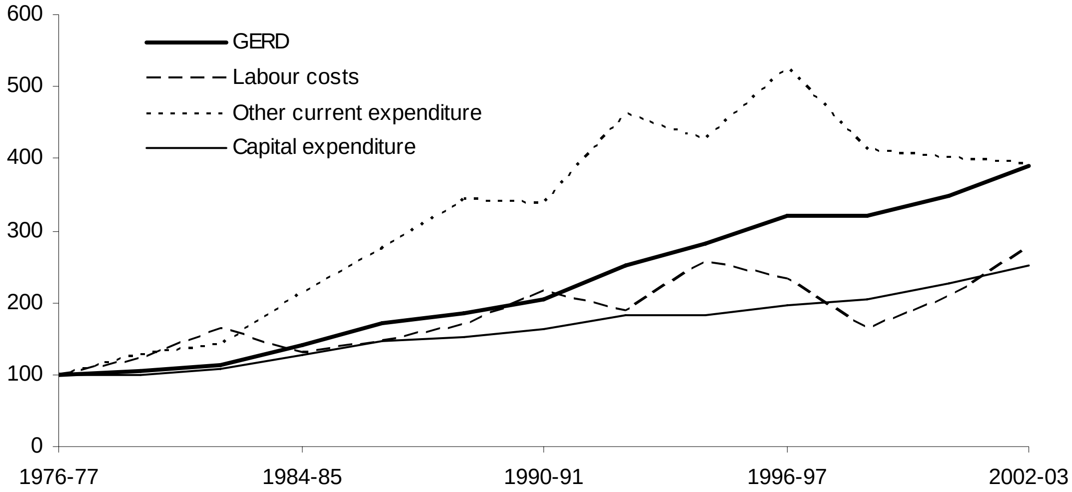
a Expenditures are in real terms, based on the GDP price deflator.

Sources: ABS (*Research and Experimental Development, All Sector Summary, Australia*, Cat. no. 8112.0); ABS (*Australian System of National Accounts*, Cat. no. 5204.0); Commission estimates.

Whilst costs have grown in all categories, the pattern of growth has been uneven. OCE has been the strongest growth area (figure B.1) — increasing at an average annual rate of 8.4 per cent in real terms since the 1970s, compared with 5.2 per cent for GERD (table B.3). OCE accounted for over a half of the growth in GERD since the mid-1970s (table B.3). Labour costs grew at 3.6 per cent a year and accounted for 37 per cent of the growth in GERD.

Figure B.1 **Indexes of GERD, labour, capital and other current costs[a], 1976-77 to 2002-03**

Indexes 1976-77 = 100



[a] Expenditures are in real terms, based on the GDP price deflator.

Data sources: ABS (*Research and Experimental Development, All Sector Summary, Australia*, Cat. no. 8112.0); ABS (*Australian System of National Accounts*, Cat. no. 5204.0).

Table B.3 **Growth in cost categories and contribution to growth in GERD[a], various periods**

	1976-77 to 1984-85		*1984-85 to 1996-97*		*1996-97 to 2002-03*		*1976-77 to 2002-03*	
Growth in expenditure (per cent per year):								
Land and buildings		3.4		4.8		2.9		3.9
Other capital expenditure		9.5		7.5		-4.9		5.3
Labour costs		3.0		3.6		4.2		3.6
Other current expenditure		6.2		12.2		3.6		8.4
Growth in GERD		**4.2**		**6.9**		**3.3**		**5.2**
Contributions to growth in GERD (percentage points[b]):								
Land and buildings	0.1	(3)	0.2	(2)	0.1	(2)	0.1	(2)
Other capital expenditure	0.7	(16)	0.7	(10)	-0.3	-(11)	0.3	(6)
Labour costs	2.0	(48)	1.8	(26)	1.9	(57)	1.9	(37)
Other current expenditure	1.4	(33)	4.3	(62)	1.7	(51)	2.9	(55)

[a] Expenditures are in real terms, based on the GDP price deflator. [b] Numbers in brackets refer to the percentage contribution to growth in GERD over the relevant period. May not add due to rounding.

Sources: ABS (*Research and Experimental Development, All Sector Summary, Australia*, Cat. no. 8112.0); ABS (*Australian System of National Accounts*, Cat. no. 5204.0); Commission estimates.

The disparities in rates of growth have led to a seemingly substantial change in the structure of costs. On paper, the growth in OCE has reduced the importance of expenditure on labour. Whilst the share of current costs in GERD has remained between 88 and 92 per cent since 1976-77, labour's share has fallen by 25 percentage points (table B.1).

However, the strength of the shift to OCE expenditure and away from labour costs is probably significantly overstated. While data on the components of OCE are not available, it is likely that purchased or acquired services, including consultancies and contracting out of some supporting services, were a strong contributor to the growth in OCE expenditure.[3] To the extent that this is the case, the increase in OCE expenditure could be considered as expenditure on labour costs organised under different administrative relationships.

OCE has shown more variation over time than has labour costs. OCE growth was particularly strong, at over 12 per cent a year, between the mid-1980s and mid-1990s, but slipped behind growth in labour costs in the second half of the 1990s and beyond. Indeed, OCE has not regained its 1996-97 peak, whereas labour costs surpassed their 1995-96 peak in 2002-03.

The variations in OCE have been driven largely by movements in business R&D activity. Institutional sectors have shown less divergence in their cost structures over time than they have in their activity levels (table B.2).

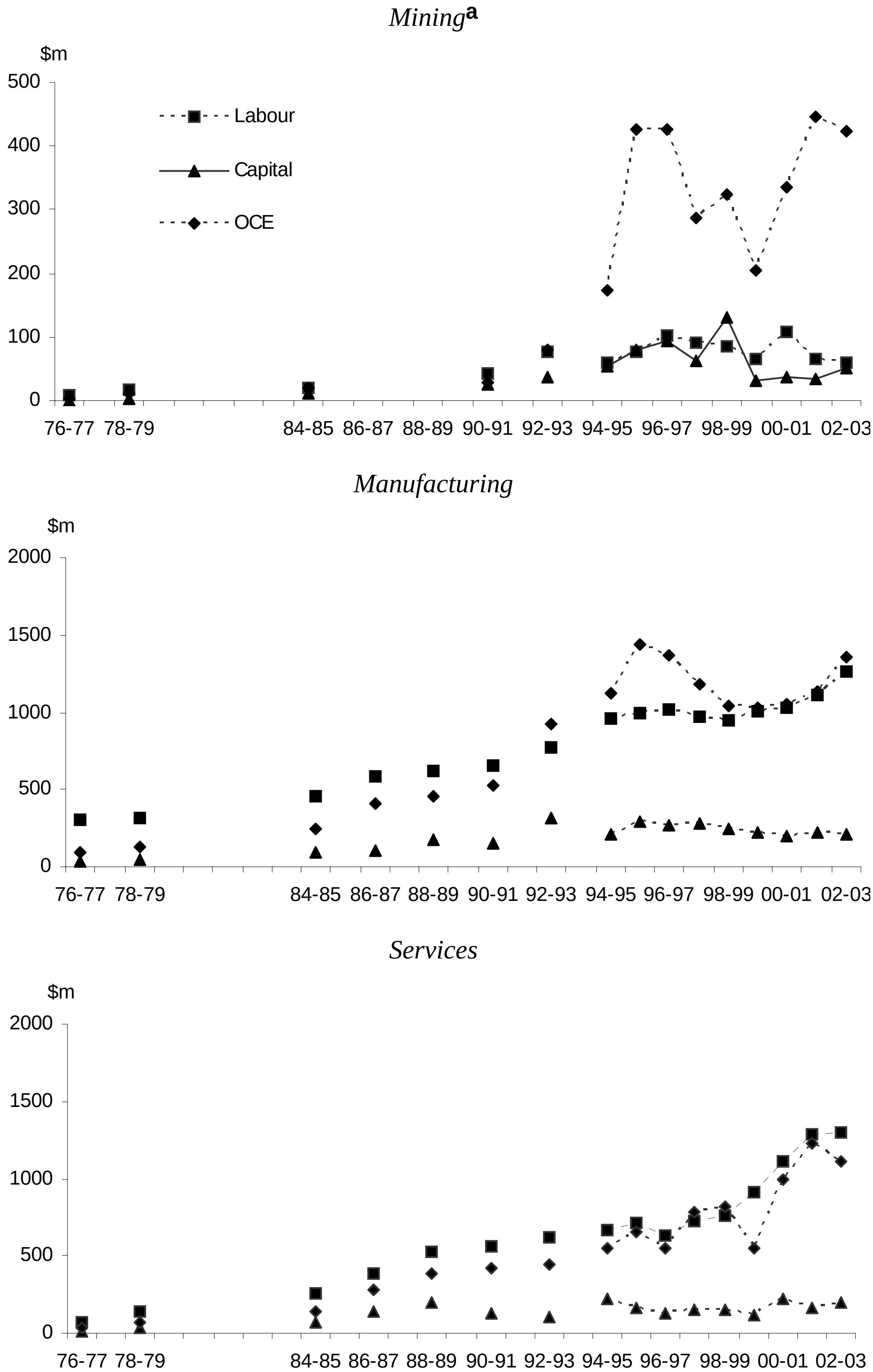
OCE has therefore tended to mirror the business expenditure on R&D (BERD) pattern of strong growth up to the mid-1990s, followed by decline. OCE also featured in this same pattern in Manufacturing R&D and, in stand-out fashion, in Mining (figure B.2). OCE did not become more prominent in Services R&D.

It appears that not only has OCE featured prominently in the major deviations in BERD from trend in the 1990s (chapter 3), but OCE has also become the 'variable cost' in business R&D activity.

[3] Other drivers of OCE may be growth in the leasing of ICT equipment and related services.

Figure B.2 **BERD by type of input and aggregated industry, 1976-77 to 2002-03**

Constant 2002-03 prices



[a] Mining data by type of input were not published for 1986-87 and 1988-89.

Data sources: ABS (*Research and Experimental Development, Businesses, Australia*, Cat. no. 8104.0); ABS (*Australian System of National Accounts*, Cat. no. 5204.0).

B.2 A closer look at growth in other current expenditure

As noted above, there are no data on the components of other current expenditure. The secular increase in OCE could most likely be explained by either or both of:

- an increase in the purchase of knowledge; and
- an increase in outsourcing of R&D activity.

Purchase of knowledge

Data on the purchase and receipt of technical know-how (TKH) suggest that there has been a growing market for knowledge among R&D performers (figure B.3).[4] Receipts and payments for the exchange of TKH have both increased.[5] However, the increase in receipts has been greater and more sustained than the increase in payments.

There was a transient increase in both receipts and (especially) payments in the mid-1990s. The importance of both in relation to total expenditure on R&D activity also dropped in the second half of the 1990s.

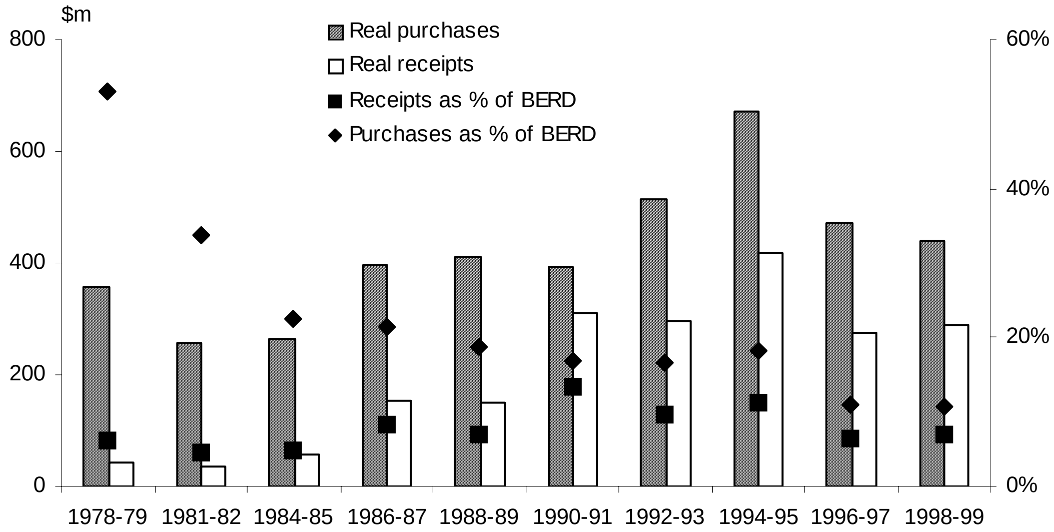
Although the accuracy of these data is somewhat uncertain, they are consistent with at least some of the transient increase in OCE in the 1990s being associated with payments for knowledge. However, the deviations in payments for knowledge are not as marked as they are for OCE.

[4] The data series is subject to some uncertainty about accuracy. The ABS discontinued the series after 1998-99. The ABS defines TKH as: Specialised technical knowledge required to successfully produce a product or implement a process, etc. (for example, patent licences, technical data and information; scientific, technical or engineering assistance) that increases technical knowledge and understanding in a business. Payments are those made directly to the holders of TKH which is new to a business. They exclude non-monetary transfers, and costs incurred by a business in obtaining TKH, such as overseas travel costs. (ABS Cat. no. 8104.0, 1998-99, p. 24).

[5] These include non-R&D performing firms. In these cases, the sale of TKH would be related to technological knowledge obtained by processes other than formal R&D (for example, through production experience and learning). If non-R&D performers are a net purchaser of TKH, then the receipts series is likely a better indicator of trends in receipts for all businesses than the purchase series is of trends in purchases of TKH for all businesses.

Figure B.3 **Receipts and purchases of Technical Know-How by business[a], 1978-79 to 1998-99**

Constant 1998-99 prices[b]



[a] Payments for technical know-how do not include non-monetary expenses or incidental costs incurred in procurement — such as travel costs, or overheads. The data includes information on market based, renumerated trades of TKH and not other forms of exchange (for example, in-kind exchanges). Therefore, the data are likely to underestimate total resources expended in obtaining technical know-how. [b] Deflated using the GDP implicit price deflator.

Data sources: ABS (*Research and Experimental Development, Businesses, Australia*, Cat. no. 8104.0); ABS (*Australian System of National Accounts*, Cat. no. 5204.0); Commission estimates.

Outsourcing and collaboration

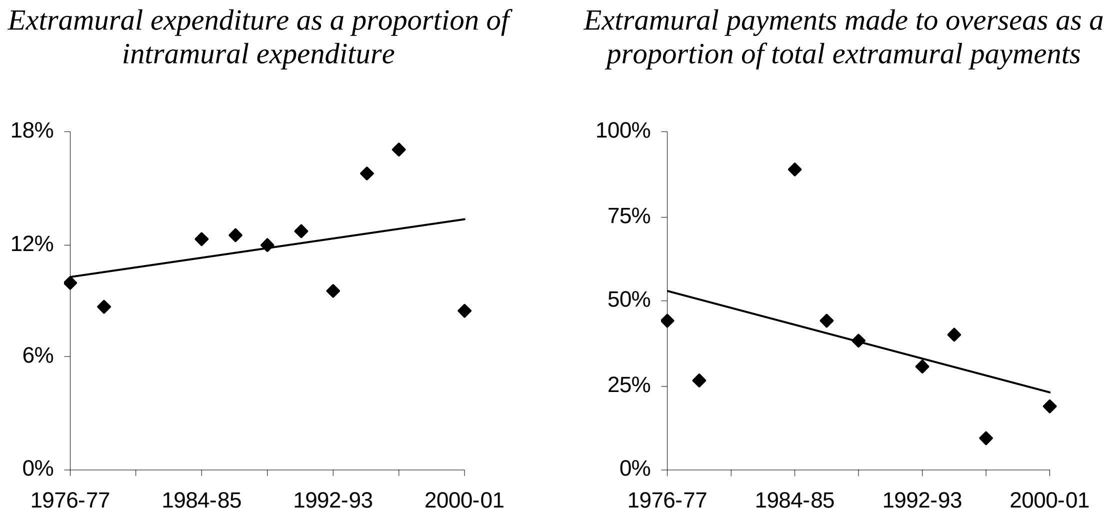
There is clearer evidence of businesses outsourcing more of their R&D effort. The left-hand panel of figure B.4 shows a trend increase in extramural expenditures as a proportion of intramural expenditures. A decreasing proportion of these payments has been made to overseas entities (right-hand panel).

Case study evidence also points to an increase in R&D related linkages:

> With the increasing trends towards outsourcing, especially R&D, there has been an increase in the number of alliances struck for R&D purposes … Non-joint venture strategic alliances appear to have become a particularly important feature in Australia as the larger firms have sought to outsource their R&D to other firms and to the research institutions. (DITR 2003, pp. 4 and 7)

The evidence on extramural expenditures shows that the reliance on external activity increased substantially in the mid-1990s and then dropped off markedly. Extramural expenditure data were collected in 1996-97, but not again until 2000-01.

Figure B.4 **Trends in extramural R&D expenditure, 1976-77 to 2000-01**



Data source: ABS (*Research and Experimental Development, Businesses, Australia*, Cat. no. 8104.0).

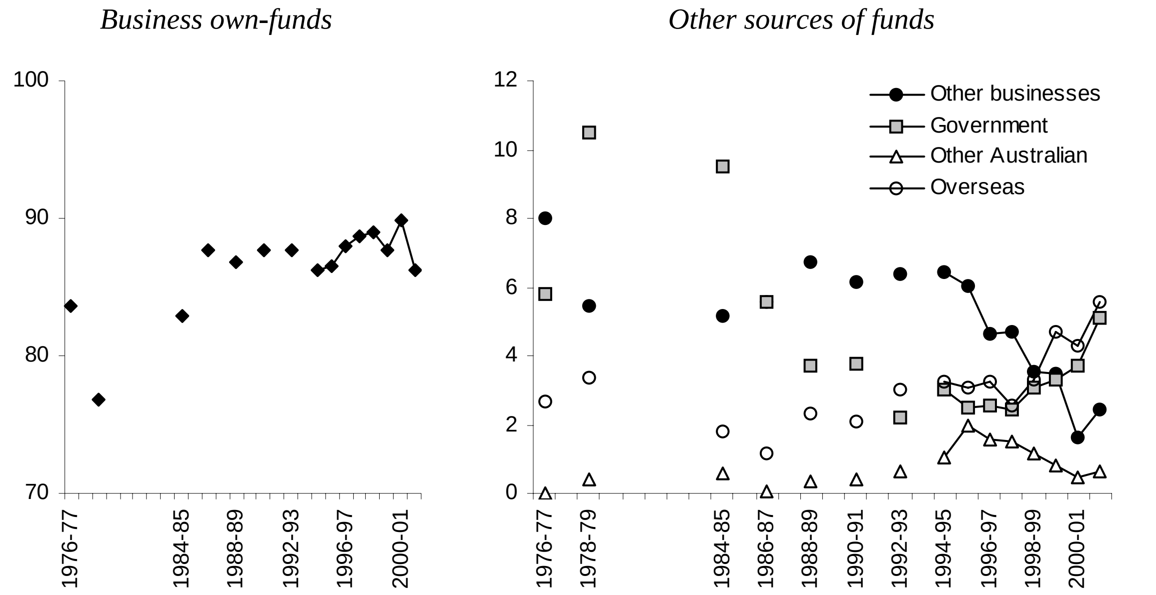
There was a large drop in extramural expenditure and in the extramural/intramural ratio between these two years.

There have been marked differences across industries in the shift toward external funding. Extramural expenditure increased in Manufacturing, but declined in Mining and Services.[6]

The evidence of a decline in outsourcing to other firms in the late 1990s is supported by sources of funds data. Businesses have provided a reasonably steady proportion, around 85 per cent, of the funds for their R&D expenditure since the mid-1980s (figure B.5). The proportion of funds coming from other businesses was also reasonably steady, at around 6 per cent, until it fell away after 1995-96. (As noted in chapter 3, the proportion of government and overseas funding has increased in recent years.)

[6] Mining extramural expenditure decreased from $83.7 million (15.3 per cent) in 1996-97 to $65.1 million (14.3 per cent) in 2000-01; Manufacturing increased from $121.6 million (5.0 per cent) to $152.8 million (7.0 per cent); and services fell from $497.7 million (43.5 per cent) to $190.2 million (8.6 per cent). Wholesale & retail trade decreased from $43.3 million to $24.5 million. Scientific Research increased from $38.9 million to $48.7 million. Other n.e.c. fell from $161.1 million to $51.3 million. The remainder of the fall is shared between Finance & insurance and Property & business services.

Figure B.5 **Sources of funds for business R&D, 1976-77 to 2001-02**
Percentage shares of total BERD



Data sources: ABS (*Research and Experimental Development, Businesses, Australia*, Cat. no. 8104.0); ABS (*Australian System of National Accounts*, Cat. no. 5204.0); Commission estimates.

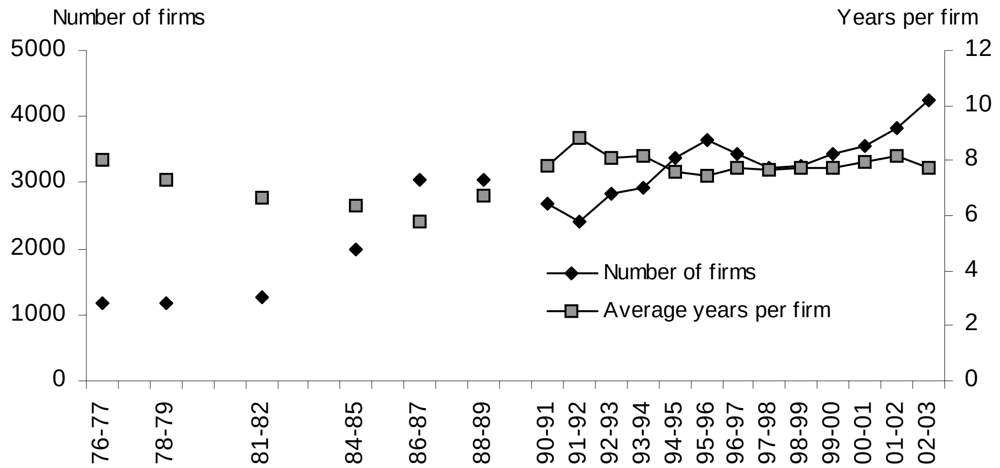
Two industries that capture a high degree of outsourced R&D activity have also exhibited the same trends. Computer services and Scientific research have increased their R&D activity substantially (chapter 3). They showed some hesitation in growth — but not decline — after 1995-96.

The absence of a scale increase in the number of R&D personnel per firm

The average size of firm (in terms of labour use) has remained remarkably stable, while variations in R&D activity have mostly been through entry and exit of firms into R&D activity. The variation in the 1990s could reflect increased reliance on outsourcing.

Across the business sector, the average use of labour per firm has shown only minor variation over time. Around 8 person years have been used per firm over the past 10 years — about the same average use as in the 1970s (figure B.6). The average declined in the mid-1980s, associated with a large step up in the number of firms undertaking R&D, to a low of 5.8 in 1986-87. The average returned to around 8 person years in the first half 1990s, with some additional variation due to the drop in numbers of firms around the recession and a build-up in numbers of firms to 1995-96.

Figure B.6 **Average use of labour per firm, 1976-77 to 2002-03**



Data source: ABS (*Research and Experimental Development, Businesses, Australia*, Cat. no. 8104.0).

The average use of labour has settled over the 1990s to within a narrow band around 8 employees per firm in most industries (figure B.7). The major exception is Transport equipment, where the average number of R&D employees has nearly doubled since the early 1990s, to reach 30.9 in 2002-03.

The stability in the average use of labour could reflect a trend toward outsourcing R&D. The data here include both contractor and contracted firms, but a plausible link is that the intramural use of labour became stable in the 1990s and variation in R&D expenditure was reflected in outsourcing (as evident in OCE) and this, in turn, was reflected in variation in the number of firms undertaking R&D.

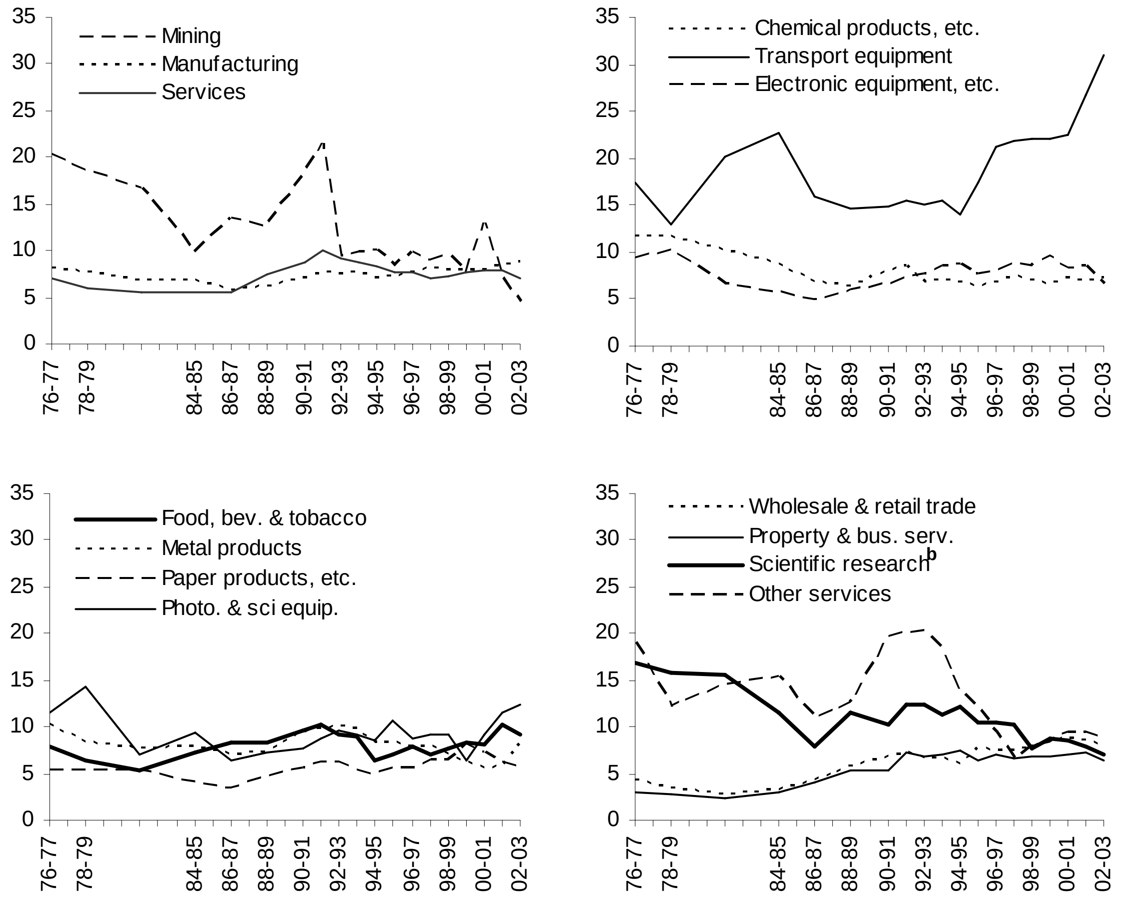
Business cycle or policy?

Overall, the available evidence supports the view that secular growth and variations in the degree of outsourcing of R&D contributed in a major way to the trend increase and to the transient build-up and decline in OCE in the 1990s.

Many factors influence the strategic decisions of organisations to perform R&D internally, to enter into cooperative arrangements, to finance the performance of R&D undertaken by others, or to purchase technological knowledge in secondary markets, such as through licensing patents. The factors include the inherent complexity of the R&D tasks, specificity in fixed costs associated with R&D activity and associated risks, costs associated with specifying and administering contractual agreements relative to the costs of internal coordination, the comparative advantages of a business in the production of R&D, and the relationship between the expected benefits of the R&D and the sources of competitive advantage for a business.

Figure B.7 **Human resources and average R&D employment per enterprise[a], by industry, 1976-77 to 2002-03**

R&D employees per enterprise



[a] See table A.3 for details of manufacturing industry groups. [b] Scientific research is also included in Property & business services.

Data sources: ABS (*Research and Experimental Development, Businesses, Australia*, Cat. no. 8104.0); Commission estimates.

As noted in chapter 3, the business cycle can affect the degree of reliance on outsourcing and collaboration (on top of any structural trends). This type of expenditure appears to be more easily adjusted to output fluctuations than is intramural expenditure.

However, the variation in extramural activity in Australia appears to have been governed by much more than the business cycle. Indeed, reliance on outsourcing and collaboration grew and peaked in a strong growth phase of the 1990s. Whilst it is true that the reliance then declined as the strong growth phase continued, the sharpness and degree of decline suggest that some other factor was at work.

It is more plausible that the abolition of the Syndicated R&D program and changes to the R&D tax concession scheme in 1996-97 had a major effect on the degree of extramural spending. The modifications ended the registration of new R&D syndicates from 23 July 1996, and the underlying partnership arrangements, and reduced the headline rate of tax concession from 150 per cent to 125 per cent.

B.3 A closer look at growth in labour costs

Real labour costs have increased by about 2½ times in all-sector R&D and nearly 7-fold in business R&D.

Real labour costs can increase through any combination of:

- growth in the total employment of labour;
- growth in wage rates paid to labour (beyond a general inflationary component) due to:
  - increased demand for workforce skills; or
  - reduced supply of researchers and other employees with skills in demand; and
- changes in the composition of employment toward the more highly-paid.

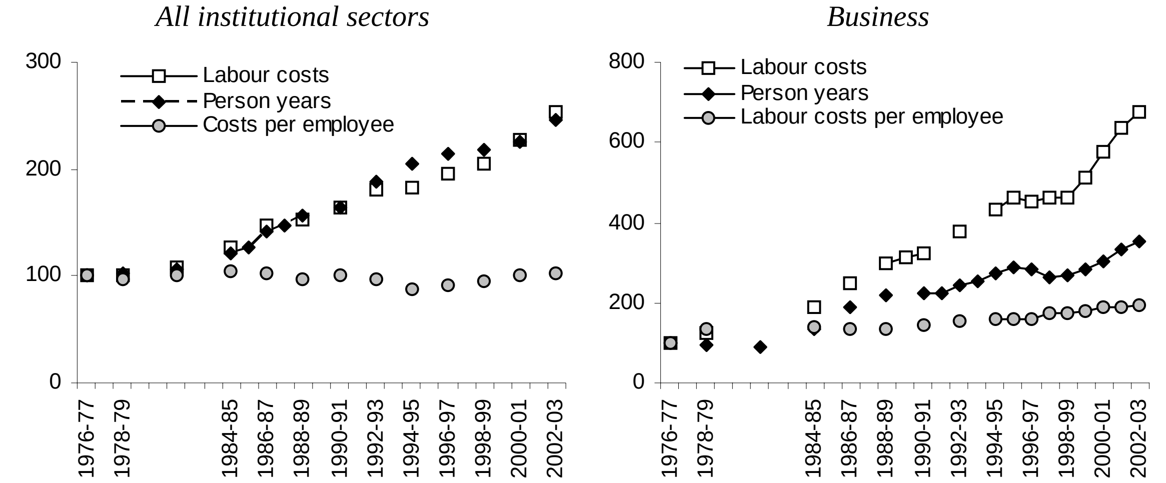
The use of labour has increased in all-sector R&D and in business R&D (figure B.8). The number of person-years has increased by 2½ times and 3½ times respectively. As was pointed out in chapter 3, increases in outsourcing have probably led to understatement of the growth in use of labour in R&D.

Labour expenditure per person-year increased at an average rate of 2.5 per cent per annum. Labour costs per person-year have also increased for businesses, from a low of about $41 000 per person-year in 1976-77 to $79 600 in 2002-03. Labour expenditure per person-year ranged from $49 600 in Other manufacturing to $100 000 in mining in 2002-03.

At the aggregate level, growth in labour costs exceeded growth in use of labour by 1.7 percentage points annually (table B.4). The divergence was more marked in Mining and in Services and less marked in Manufacturing. There were also large differences in Food, beverages & tobacco, Metal products, Scientific research and Other services (table B.5).

Figure B.8 **Indexes of labour costs, use of labour and average labour costs per employee[a], 1976-77 to 2002-03**

Indexes 1976-77 = 100



[a] Expenditures are in real terms, based on the GDP price deflator.

Data sources: ABS (*Research and Experimental Development, All Sector Summary, Australia*, Cat. no. 8112.0); ABS (*Research and Experimental Development, Businesses, Australia*, Cat. no. 8104.0); ABS (*Australian System of National Accounts*, Cat. no. 5204.0); Commission estimates.

Table B.4 **Growth in labour use and labour costs[a], by institutional sector, various periods**

Per cent per year

	1976-77 to 1984-85	*1984-85 to 1996-97*	*1996-97 to 2002-03*	*1976-77 to 2002-03*
All sectors				
Labour costs	3.0	3.6	4.2	3.6
Use of labour	2.4	4.8	2.3	3.5
Average labour costs	0.6	-1.2	1.9	0.1
Business				
Labour costs	5.1	7.7	6.1	6.5
Use of labour	3.7	6.2	3.7	4.9
Average labour costs	1.4	1.5	2.4	1.7
Government				
Labour costs	1.1	0.4	1.8	0.9
Use of labour	0.1	0.9	-0.6	0.3
Average labour costs	1.0	-0.6	2.3	0.6
Higher education				
Labour costs	4.1	2.2	3.0	3.0
Use of labour	3.9	6.0	2.5	4.5
Average labour costs	0.2	-3.7	0.5	-1.5

[a] Expenditures are in real terms, based on the GDP price deflator.

Sources: ABS (*Research and Experimental Development, All Sector Summary, Australia*, Cat. no. 8112.0); ABS (*Australian System of National Accounts*, Cat. no. 5204.0); Commission estimates.

Table B.5 **Measures of the demand for R&D labour, by industry, 1976-77 to 2002-03**

		Labour inputs in person years			*Real labour expenditure*		
Industry		*Level in 2002-03*	*Change from 1976-77*	*Annual growth*	*Level in 2002-03*	*Change from 1976-77*	*Annual growth*
		years	years	%	$m	$m	%
Mining		608	162	4.3	61	51	8.1
Manufacturing[a]		16 858	10 555	4.1	1 269	961	5.4
Food, beverages & tobacco	FBT	1427	876	4.2	122	96	6.1
Textiles, clothing, footwear & leather	TCF	195	89	6.3	13	8	6.0
Wood & paper products; and Printing, publishing & recorded media	WPP	509	310	4.3	34	24	5.9
Petroleum, coal, chemical & associated products	PCCAP	2 751	1 416	2.8	192	130	4.3
Non-metallic mineral products	NMP	375	206	3.9	32	24	5.2
Metal products	MP	1 395	264	1.1	113	57	2.9
Transport equipment (includes Motor vehicle & parts, and Other transport equipment)	TE	4 537	3 776	6.4	333	292	7.4
Photographic & scientific equipment	PSE	1 733	1 502	8.6	162	151	10.1
Electronic equipment; and Electrical equipment & appliances	AE	2 520	1 311	3.8	181	123	5.0
Industrial machinery & equipment	IME	1 192	767	4.4	75	55	5.9
Other manufacturing	Other manu.	224	40	-0.2	11	0.9	0.3
Services		15 516	12 922	7.3	1 297	1 227	9.5
Wholesale & retail trade	WRT	2 898	2 517	8.9	226	208	10.2
Property & business services	PBS	7 954	7 422	11.4	637	613	12.9
Scientific research	SR	1 673	1 169	5.0	148	125	6.9
Other n.e.c.	Other n.e.c.	2 991	1 814	2.6	287	281	7.8
Total		**32 982**	**23 639**	**5.3**	**2 626**	**2 239**	**7.0**

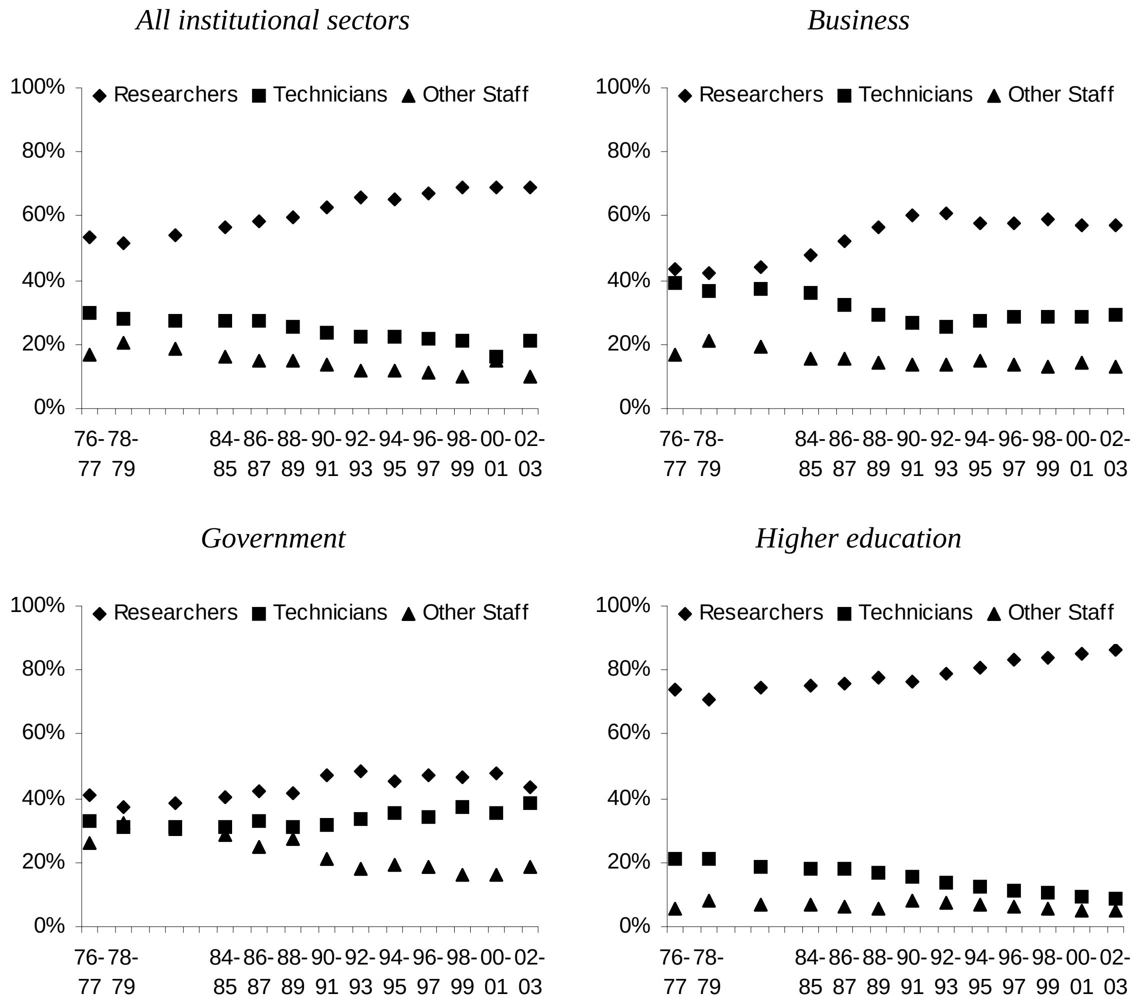
[a] See table A.3 for industry classification details.

Sources: ABS (*Research and Experimental Development, All Sector Summary, Australia*, Cat. no. 8112.0); Commission estimates.

A compositional shift toward more highly-skilled employment provides at least part of the explanation for the increase in average cost of labour (figure B.9). In 1976-77, the share of researchers in the business sector was 44 per cent. By 2002-03, the share had increased to 57 per cent, while the share of technicians had fallen from 39 per cent to 29 per cent. To the extent that the average wage of researchers is higher than that of technicians and other supporting staff, this compositional change would explain at least some of the stronger increase in real labour expenditure.

Figure B.9 **Composition of the R&D labour force, by institutional sector, 1976-77 to 2002-03**

Shares of total person years



Data source: ABS (*Research and Experimental Development, All Sector Summary, Australia*, Cat. no. 8112.0).

In terms of the volume of person years devoted to R&D the universities made the major contribution (table B.6). The growth in use of labour was highly skewed toward researchers (compared with technicians and other support staff), who accounted for four out of five additional person-years devoted to R&D. This skew toward skill could be associated with greater contracting out of more routine tasks. Half of the total increase in R&D labour has been in university researchers.

Table B.6 **Growth of human resources[a] in GERD, by institutional sector[b], 1976-77 to 2002-03**

labour is measured in person years

		… is the result of the increase in …							
		Total		*Researchers*		*Technicians[c]*		*Other support staff[c]*	
		%		%		%		%	
The increase in…	**Total**	**100.0**	**3.5**	**79.1**	**2.7**	**15.3**	**0.5**	**5.6**	**0.3**
	Business	**38.1**	**1.3**	23.9	0.8	9.8	0.3	4.5	0.2
	Government	**2.4**	**0.1**	1.8	0.1	2.4	0.1	-1.7	-0.1
	Higher education	**55.3**	**1.9**	50.8	1.8	2.0	0.1	2.6	0.1
	Private	**4.1**	**0.1**	2.7	0.1	1.2	0.0	0.3	0.0

a Labour is measured in person years. **b** The first column of numbers for each type of labour gives the percentage contribution of an institutional sector to the total increase in human resources person years. The second column in each case gives the percentage-point contribution of each labour type, by each institutional sector, to the total increase in person years. **c** Estimates of aggregate person years for Technicians and Other support staff were used as the higher education sector did not separate these categories in reporting after 1992-93.

Sources: ABS (*Research and Experimental Development, All Sector Summary, Australia*, Cat. no. 8112.0); Commission estimates.

B.4 Key point summary

- There has been substantial change in the structure of costs of R&D activity.
  - Strong growth in other (non-labour) current expenditure since the 1970s has reduced the prominence of labour costs. Each now account for around 46 per cent of total costs.
  - However, some of this apparent switch away from labour is most likely overstated as some use of labour has been included in OCE through payments for outsourced activities.
  - There has also been some increase in the purchase of knowledge.
- Variation in OCE was the principal driver of variation in R&D expenditure in the 1990s, resulting in the rise in BERD to its peak in 1995-96 and its decline to a trough in 1999-00.

- It is most likely that the variation in OCE reflects variation in the degree of outsourcing. Intramural effort was stable through the 1990s and extramural activity was variable.
- Variation in business R&D expenditure has been through firm entry and exit into R&D activity, more so than variation in average firm expenditure levels. R&D-performing firms across industries (with the exception of Transport equipment) have used around 8 person-years of labour each year for a long time.
- At least some of the variation in outsourcing appears to have coincided with variation in the start-up and closure of R&D firms.

* Government policy in the form of the R&D tax concession appears, at least at first glance, to have had an influence on the behaviour of R&D firms.
  - There was a large step-up in firm entry in the mid-1980s, around the time of the introduction of the scheme. A decline in average use of labour suggests that smaller firms were more numerous in entry.
  - The number of firms undertaking R&D built up fairly rapidly around the mid-1990s and declined fairly rapidly around the time that scheme modifications were introduced.
* Growth in labour costs exceeded growth in labour use.
  - A compositional shift toward more highly skilled labour provides at least part of the explanation. Universities featured strongly in both the increased employment of labour and the switch to the more highly skilled.
  - If the more skilled remained on the payroll, the use of relatively unskilled labour in more routine tasks may have been part of the trend growth in outsourced activity.

C Construction of the Australian R&D stocks

C.1 The aggregate Australian time series

Table C.1 presents the official published estimates of business expenditure on R&D (BERD), adjusted BERD data (used for the construction of knowledge stocks or directly in models which use expenditure for modelling purposes) and gross expenditure on R&D (GERD). Table C.2 provides the BERD data at the industry level.

C.2 Aggregate and industry Australian R&D stocks

R&D stock indexes for the market sector were constructed using the perpetual inventory method (PIM). Indexes of the stocks are provided in table C.3 for various institutional sectors.

The industry stocks were constructed using the same methodologies as for the aggregate business expenditure on R&D, gross expenditure on R&D and international stocks. Industry nominal R&D expenditure was deflated using the GDP implicit price deflator (GDP(IPD)) (table C.4). Indexes are also provided for industry stocks constructed from deflating industry expenditure with an industry-specific output IPD (table C.5).

Table C.1 **BERD and GERD time series[a] underpinning R&D stocks, 1968-69 to 2002-03**

All data are intramural expenditure

Year	*BERD as published*[b]	*BERD IC(1995)*[c]	*BERD adjusted*[d]	*BERD adjusted*[d]	*GERD*[e]	*GERD*[e]
	$m	$m	$m	Real $m (2001-02)	$m	Real $m (2001-02)
1968-69	85	124	123	959	370	2887
1969-70			136	1000	415	3052
1970-71			150	1051	466	3261
1971-72		166	166	1094	524	3447
1972-73			184	1111	589	3546
1973-74	190	210	205	1078	661	3480
1974-75			208	931	732	3281
1975-76			210	821	810	3162
1976-77	203	225	213	743	896	3132
1977-78			237	766	987	3195
1978-79	246	280	263	794	1088	3277
1979-80			296	803	1233	3342
1980-81			333	823	1398	3452
1981-82	374	397	375	833	1585	3522
1982-83			449	901	1824	3662
1983-84	402		533	1000	2099	3938
1984-85	731	731	648	1150	2416	4291
1985-86	922	948	831	1395	2776	4658
1986-87	1280	1289	1102	1727	3374	5289
1987-88	1327	1456	1282	1858	3685	5341
1988-89	1795	1798	1546	2056	4263	5669
1989-90	1939	1990	1688	2128	4863	6133
1990-91	2082	2082	1832	2234	5109	6231
1991-92	2320	2320	2070	2476	5175	6190
1992-93	2855	2788	2470	2923	6483	7672
1993-94	3120		2528	2964	6957	8156
1994-95	3498		2858	3312	7467	8652
1995-96	4341		3647	4126	8102	9166
1996-97	4247		3551	3959	8792	9802
1997-98	4219		3555	3907	8864	9741
1998-99	4090		3366	3695	8936	9809
1999-00	4112		3312	3565	9648	10386
2000-01	4983		4071	4171	10417	10673
2001-02	5770		4623	4623	11296	11296
2002-03	5979		4844	4722	12250	11939

a Data available for selected years with intervening years interpolated. See table 5.1 for details. **b** BERD as originally published by the ABS. Includes published revisions. **c** BERD as used in IC (1995) and includes DITAC historical adjustments. **d** Adjusted BERD excluding Property & business services (PBS), except for Scientific research. Also includes unpublished revisions from 1988-89. **e** Nominal GERD series deflated with the GDP implicit price deflator. Will differ from published GERD series as it includes adjustments made to BERD (including PBS).

Sources: ABS (Research and Experimental Development, Businesses, Australia, Cat. no. 8104.0); ABS (Research and Experimental Development, All Sector Summary, Australia, Cat. no. 8112.0), IC (1995); Commission estimates.

Table C.2 **Industry BERD, deflated using GDP implicit price deflator, 1968-69 to 2002-03[a]**

All data are intramural expenditure, $ million, constant 2000-01 prices

Year	*Total manufacturing*	*Mining*	*Wholesale & retail trade*	*Agriculture, forestry & fishing*[b]	*Remainder of market sector industries*[c]	*Property & business services*[d]
1968-69	880	47	4	1	4	7
1969-70	901	52	8	3	13	10
1970-71	918	55	15	5	32	18
1971-72	926	57	20	7	57	24
1972-73	912	58	23	8	84	27
1973-74	858	55	23	8	108	28
1974-75	698	47	27	9	128	33
1975-76	572	39	31	11	148	38
1976-77	477	32	36	12	168	43
1977-78	505	35	37	12	158	46
1978-79	538	38	39	12	148	48
1980-81	541	44	36	13	149	48
1981-82	553	52	33	14	152	48
1982-83	560	59	29	15	151	47
1983-84	583	60	40	16	180	74
1984-85	625	60	56	17	217	116
1985-86	769	59	64	14	216	145
1986-87	938	73	98	15	237	191
1987-88	1092	95	156	19	323	286
1988-89	1226	111	155	20	301	246
1989-90	1276	152	210	28	340	298
1990-91	1325	151	215	24	363	289
1991-92	1398	151	222	21	387	285
1992-93	1599	201	242	21	355	346
1993-94	1945	215	260	27	407	420
1994-95	1917	328	262	20	366	515
1995-96	2186	345	218	21	462	678
1996-97	2602	578	363	12	471	690
1997-98	2439	605	388	10	421	656
1998-99	2399	579	362	14	459	635
1999-00	2213	522	390	16	465	659
2000-01	2107	307	403	13	649	788
2001-02	2293	463	370	14	931	867
2002-03	2497	542	436	20	1016	1042

[a] Data available for selected years with intervening years interpolated. See table 5.1 for details. [b] Includes portion of Scientific research distributed to Agriculture, forestry & fishing by socio-economic objective only. [c] Includes R&D for Education and Health services as well as Personal and other services as these could not be separately identified in the historical series. [d] Includes Scientific research.

Sources: ABS (*Research and Experimental Development, Businesses, Australia*, Cat. no. 8104.0); Commission estimates.

Table C.3 **Australian R&D stock indexes, 1968-69 to 2002-03**

Indexes 2001-02 = 100. Assumed decay rates of 15 per cent for business and 10 per cent for non-business stocks.

Year	*BERD*[a]	*Own-finance BERD*[b]	*GERD*[c]	*Higher education*	*Government performed*[d]	*Non-business*[e]
1968-69	21.0	19.4	25.4	21.3	49.0	33.8
1969-70	22.2	20.5	26.7	22.5	50.4	35.1
1970-71	23.4	21.7	28.1	23.9	52.0	36.5
1971-72	24.6	22.8	29.6	25.3	53.9	38.2
1972-73	25.7	23.9	31.1	26.8	55.8	39.8
1973-74	26.5	24.7	32.3	28.0	57.3	41.2
1974-75	26.6	24.7	33.2	29.1	58.5	42.3
1975-76	26.1	24.3	33.8	30.1	59.5	43.3
1976-77	25.4	23.7	34.3	31.0	60.5	44.3
1977-78	24.9	23.2	34.9	32.2	61.3	45.2
1978-79	24.6	22.8	35.5	33.5	62.0	46.2
1979-80	24.4	22.6	36.1	34.8	62.8	47.3
1980-81	24.3	22.5	36.8	36.0	63.8	48.4
1981-82	24.2	22.4	37.5	37.1	65.1	49.5
1982-83	24.5	22.7	38.4	38.2	66.1	50.7
1983-84	25.1	23.4	39.4	39.6	67.3	52.0
1984-85	26.3	24.6	40.9	41.3	68.7	53.6
1985-86	28.4	26.7	42.6	43.0	70.2	55.2
1986-87	31.6	30.0	44.9	45.1	71.8	57.1
1987-88	34.9	33.4	47.1	47.3	72.9	58.7
1988-89	38.5	37.0	49.5	49.2	74.2	60.3
1989-90	41.9	40.6	52.2	51.7	76.1	62.4
1990-91	45.3	44.2	54.8	54.2	78.2	64.7
1991-92	49.2	48.2	57.0	56.4	79.2	66.3
1992-93	54.4	53.5	60.9	60.1	81.6	69.4
1993-94	59.1	58.2	65.0	63.7	84.1	72.5
1994-95	64.5	63.5	69.3	67.2	86.7	75.7
1995-96	72.7	71.5	73.8	71.3	88.9	79.0
1996-97	78.9	77.8	78.7	76.2	91.0	82.6
1997-98	83.9	83.1	83.0	81.0	92.8	86.1
1998-99	87.3	86.8	86.9	86.0	94.4	89.5
1999-00	89.6	89.2	91.2	90.8	96.3	93.1
2000-01	94.2	94.2	95.4	95.1	98.3	96.4
2001-02	100.0	100.0	100.0	100.0	100.0	100.0
2002-03	105.4	105.4	104.9	105.6	101.6	103.9

a Includes adjustments as set out in appendix A. Based on intramural expenditure. **b** Includes R&D expenditure performed and financed by businesses. **c** Includes adjustments made to business expenditure. **d** Includes R&D performed by the Australian and state governments. **e** Includes R&D performed by higher education, government and private non-profit institutions.

Source: Commission estimates based on ABS data.

Table C.4 **Industry R&D stocks indexes[a], deflated by GDP(IPD), 1968-69 to 2002-03**

Indexes 2000-01 = 100. Assumed decay rate of 15 per cent.

Year	Total Manu.	FBT	TCF	PPRM	PCCAP	BMP	SSMP	TE	OM	AFF	Mining	WRT
1968-69	34.1	24.9	45.5	157.9	41.0	39.1	127.9	33.6	23.4	na	7.9	0.4
1969-70	35.8	26.4	48.5	155.9	42.6	40.6	126.6	35.5	25.3	na	8.8	0.7
1970-71	37.3	27.7	52.3	152.3	43.8	41.6	119.8	37.2	27.8	na	9.7	1.6
1971-72	38.7	28.8	57.0	147.4	44.4	41.9	109.1	38.4	30.8	na	10.5	3.1
1972-73	39.8	29.5	62.0	140.8	44.4	41.6	95.9	39.0	34.0	na	11.3	5.1
1973-74	40.3	29.6	66.6	132.5	43.5	40.4	83.7	38.9	37.0	na	11.8	7.5
1974-75	39.6	29.5	66.8	125.5	42.5	39.4	73.0	37.4	37.3	na	11.9	10.2
1975-76	37.9	29.1	64.0	119.1	41.5	38.2	65.7	35.0	35.8	na	11.7	13.1
1976-77	35.8	28.5	59.5	113.3	40.2	37.0	61.1	32.1	33.4	na	11.2	16.1
1977-78	34.3	28.3	54.5	108.9	39.4	35.9	57.3	29.5	31.8	na	10.9	18.4
1978-79	33.2	28.6	49.3	105.7	39.1	34.9	53.9	27.3	30.9	na	10.8	20.0
1979-80	32.3	28.2	44.1	102.6	39.1	33.9	51.3	26.0	29.9	na	11.0	21.4
1980-81	31.6	27.3	39.1	99.5	39.3	32.9	49.2	25.7	29.1	na	11.4	22.7
1981-82	31.1	26.1	34.4	96.3	39.7	31.9	47.6	26.4	28.1	na	12.0	23.8
1982-83	30.8	26.1	31.9	95.5	39.5	31.1	46.9	26.5	27.8	na	12.6	25.6
1983-84	30.9	27.6	33.1	97.2	38.9	30.7	47.2	26.1	28.2	na	13.1	28.2
1984-85	32.1	28.0	34.3	93.2	40.5	31.1	49.5	28.6	29.0	na	13.5	30.4
1985-86	34.3	30.3	39.6	93.1	42.1	32.0	53.1	32.8	30.9	na	14.4	32.9
1986-87	37.4	33.3	46.3	93.8	44.5	33.2	57.5	35.8	34.8	na	16.1	37.6
1987-88	41.1	37.0	53.8	103.1	47.6	36.1	57.0	39.4	38.9	na	18.1	40.9
1988-89	44.5	40.8	62.1	94.2	51.2	37.9	59.8	42.0	43.4	na	21.5	44.8
1989-90	47.8	43.5	66.6	87.3	54.9	42.4	61.8	44.0	47.2	na	24.3	48.9
1990-91	51.2	45.5	68.4	82.9	59.0	48.8	63.4	45.6	50.8	na	26.7	53.1
1991-92	55.6	49.1	71.4	81.2	63.3	54.5	65.1	49.1	55.8	na	30.7	55.6
1992-93	61.9	54.5	72.5	80.9	69.3	67.0	73.6	55.9	60.4	na	34.7	59.4
1993-94	67.1	59.4	74.6	80.4	73.4	75.0	80.2	60.2	65.8	na	42.6	61.4
1994-95	73.5	63.1	83.6	84.3	79.2	82.8	87.6	66.7	72.6	na	50.0	65.9
1995-96	82.1	79.3	89.1	93.5	84.3	92.9	93.7	75.2	80.7	na	65.6	70.0
1996-97	88.2	87.8	90.5	94.7	86.8	103.0	96.1	81.6	86.7	na	80.0	72.0
1997-98	93.0	90.9	92.4	97.6	89.4	109.2	96.6	88.4	92.1	na	91.1	74.8
1998-99	95.8	96.0	95.0	98.4	92.2	109.7	96.4	91.5	94.9	na	98.3	77.4
1999-00	97.3	97.9	95.0	98.8	95.9	104.9	99.2	95.2	96.3	na	95.9	85.1
2000-01	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	na	100.0	100.0
2001-02	103.8	103.5	100.8	99.7	105.5	97.9	99.2	106.9	104.0	na	106.7	115.2
2002-03	108.8	106.3	104.8	98.2	112.5	99.5	105.9	118.8	106.1	na	111.2	126.0

a Includes adjustments to industry data as described in appendix A. For industry abbreviations see table A.2.

Sources: ABS (*Research and Experimental Development, Businesses, Australia,* Cat. no. 8104.0); ABS unpublished data; DITAC (1994); Commission estimates.

Table C.5 **Industry R&D stocks indexes[a], deflated by industry-specific output IPD, 1968-69 to 2002-03**

Indexes 2000-01 = 100. Assumed decay rate of 15 per cent.

Year	Total Manu.	FBT	TCF	PPRM	PCCAP	BMP	SSMP	TE	OM	AFF	Mining	WRT
1968-69	6.9	5.4	4.4	43.7	11.1	9.8	17.8	5.7	4.1	na	na	na
1969-70	7.6	6.0	5.1	44.5	11.9	10.6	18.4	6.3	4.7	na	na	na
1970-71	8.2	6.6	5.9	44.9	12.6	11.2	18.0	6.8	5.4	na	na	na
1971-72	8.9	7.2	6.9	44.9	13.1	11.8	16.7	7.3	6.3	na	na	na
1972-73	9.5	7.6	8.0	44.1	13.3	12.1	14.9	7.8	7.4	na	na	na
1973-74	9.9	8.0	9.2	42.6	13.3	12.1	13.2	8.2	8.4	na	na	na
1974-75	10.3	8.5	10.3	42.4	13.6	12.4	11.8	8.4	9.1	na	4.4	1.9
1975-76	10.6	9.1	10.6	43.1	14.1	13.1	11.3	8.4	9.3	na	4.9	2.4
1976-77	10.7	9.5	10.6	43.8	14.5	13.6	11.7	8.1	9.1	na	5.1	2.9
1977-78	11.0	10.2	10.3	45.1	15.1	14.3	12.3	7.9	9.3	na	5.5	3.6
1978-79	11.5	11.1	9.8	46.7	15.9	14.8	12.7	7.9	9.7	na	6.0	4.2
1979-80	12.0	11.7	9.1	48.0	16.9	15.2	13.3	8.2	10.2	na	6.9	4.7
1980-81	12.7	12.1	8.4	49.3	18.3	15.6	14.1	9.1	10.6	na	8.1	5.1
1981-82	13.5	12.4	7.7	50.7	19.9	16.1	14.9	10.6	11.0	na	9.8	5.4
1982-83	14.9	13.6	7.9	55.0	21.5	17.4	17.0	12.0	12.3	na	11.4	6.3
1983-84	16.5	16.2	9.9	60.9	22.7	18.5	19.9	13.1	14.1	na	12.8	7.8
1984-85	18.7	17.8	11.7	60.8	25.6	19.9	24.1	16.4	15.7	na	13.8	9.4
1985-86	21.9	21.4	15.4	64.2	28.6	21.9	29.4	21.4	18.1	na	15.1	12.4
1986-87	25.9	25.4	20.3	68.2	32.4	24.1	35.3	25.5	22.3	na	17.7	18.3
1987-88	30.3	30.2	25.9	79.3	36.6	27.9	36.5	30.2	26.9	na	20.4	23.5
1988-89	34.6	35.5	32.5	73.7	41.6	30.8	40.1	33.9	31.5	na	24.9	30.9
1989-90	39.3	39.8	38.1	69.8	47.5	35.8	44.1	36.9	36.7	na	28.3	37.7
1990-91	44.4	43.2	41.8	68.4	53.6	43.1	48.4	40.5	42.3	na	31.0	45.0
1991-92	51.1	48.5	46.9	70.3	60.4	49.3	53.2	47.2	49.8	na	35.3	52.4
1992-93	59.6	55.6	50.6	72.5	68.8	62.6	64.1	57.6	56.2	na	39.6	59.8
1993-94	65.8	61.6	54.8	74.1	74.2	70.5	72.2	63.6	62.6	na	48.3	65.6
1994-95	73.0	66.2	65.5	79.4	81.0	79.1	81.1	71.3	69.8	na	55.6	67.3
1995-96	82.5	84.0	73.9	90.2	86.3	88.9	89.2	80.9	78.7	na	70.4	75.9
1996-97	89.1	93.6	78.1	91.8	89.0	99.4	92.4	87.5	85.4	na	84.1	83.7
1997-98	94.0	96.1	82.3	95.5	91.4	106.7	93.3	93.6	91.2	na	94.2	88.5
1998-99	96.2	99.7	86.7	96.7	93.2	107.3	93.4	95.6	93.8	na	100.7	93.2
1999-00	97.0	99.7	89.6	96.8	96.3	103.5	97.5	96.5	95.0	na	97.3	97.3
2000-01	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	na	100.0	100.0
2001-02	na	na	na	na	na	na	na	na	na	na	105.8	105.1
2002-03	na	na	na	na	na	na	na	na	na	na	110.0	107.8

[a] Includes adjustments to industry data as described in appendix A. For industry abbreviations see table A.2.

Sources: ABS (*Research and Experimental Development, Businesses, Australia,* Cat. no. 8104.0); ABS unpublished data; DITAC (1994); Commission estimates.

C.3 Construction of Australian inter-industry stocks

Australian inter-industry R&D stocks were constructed as unweighted stocks, stocks weighted by inter-industry trade relationships, and stocks weighted by a measure of technological distance.

The unweighted stocks are based on the assumption that, for a given industry, the R&D expenditures of every other industry are equally as relevant as a source of potential spillovers. While this is unlikely to be true, it may be that available weighting schemes do not perform better in regressions than simple unweighted measures.

The *Australian System of National Accounts* (ASNA) supply-use tables were used to obtain a matrix of the trade relationships between industries. The underlying assumption is that the trade structure provides a reasonable representation of the pattern of knowledge flows between industries. If it is assumed that embodied knowledge in goods and services is recompensed, then it is also being assumed that the structure of flows of embodied knowledge provides a reasonable indication of the structure of flows of disembodied knowledge. As discussed in chapter 9, weighting measures based on trade relationships emphasise rent spillovers over knowledge spillovers.

Supply-use tables are available for many different years so that weights change over time reflecting changes in trade relationships. A different set of weights was constructed for each one-digit industry and each of the eight manufacturing subdivisions covering the period 1968-69 to 2002-03. The weights were then smoothed over time using the Hodrick-Prescott filter.

Each industry's R&D expenditure can be decomposed by socio-economic objective (SEO) or field of research. An SEO decomposition was used to form a technological proximity or 'distance' measure for each pairing of industries (table C.6). The comparison was based on data for the year 1994-95 only, with weights held constant through the time series. The measures were calculated by the ABS according to Commission specifications. The measures represent a comparison of each industry's expenditure decomposed into ninety-five SEO classifications.

The underlying idea is that the R&D stock of industry i forms a greater share of the potential spillover pool to industry j the more similar are the R&D activities between industry i and j. The increased similarity facilitates knowledge transfer which may or may not be closely related to the trade relationships between the industries. Each pair's distance measure provides a weight for the aggregation of R&D stocks.

Table C.6 **SEO technological proximity of industry, government and higher education R&D activity, 1994-95**

Year	Mining	Total Manu.	FBT	TCF	PPRM	PCCAP	BMP	SSMP	TE	OM	WRT	Other	Gov't	Higher edu.
Mining	-	.172	.009	.058	.004	.036	.416	.086	.002	.031	.054	.098	.119	.029
Total Manu.[a]	-	-	-	-	-	-	-	-	-	-	-	-	-	-
FBT	.009	-	-	.004	.005	.042	.003	.017	.001	.023	.042	.036	.161	.045
TCF	.058	-	.004	-	.007	.066	.011	.015	.004	.015	.068	.009	.093	.011
PPRM	.004	-	.005	.007	-	.024	.006	.104	.005	.527	.807	.883	.103	.096
PCCAP	.036	-	.042	.066	.024	-	.047	.101	.010	.067	.136	.058	.119	.039
BMP	.416	-	.003	.011	.006	.047	-	.375	.017	.058	.048	.198	.065	.012
SSMP	.086	-	.017	.015	.104	.101	.375	-	.033	.235	.071	.070	.062	.036
TE	.002	-	.001	.004	.005	.010	.017	.033	-	.106	.051	.152	.144	.014
OM	.031	-	.023	.015	.527	.067	.058	.235	.106	-	.629	.354	.257	.083
WRT	.054	.449	.042	.068	.807	.136	.048	.071	.051	.629	-	.795	.241	.184
Other	.098	.378	.036	.009	.883	.058	.198	.070	.152	.354	.795	-	.194	.147
Government	.119	.315	.161	.093	.103	.119	.065	.062	.144	.257	.241	.194	-	.329
Higher edu.	.029	.081	.045	.011	.096	.039	.012	.036	.014	.083	.184	.147	.329	-

[a] For industry abbreviations see table A.2.

Sources: ABS unpublished data; Commission estimates.

Goto and Suzuki (1989) constructed a technological proximity measure for a dataset of 50 Japanese industries. They used a decomposition of each industry's R&D expenditure by product type to determine the 'distance' between firms. They found that:

> These results suggest that the impact of electronics technology on other industries' productivity growth is mainly achieved through the diffusion of technological knowledge, rather than through the transaction of intermediate and investment goods embodying the electronics technology. (p. 563)

As R&D performed by higher education and government institutions can also be decomposed by SEO, a hybrid measure was calculated for each industry which incorporates both industry and non-business R&D. The measure represents the total domestic 'external' potential spillover pool to an industry. Weights were calculated based on the single year 1994-95.

As the inter-industry trade weights vary over time reflecting any changes in trade relationships between industries, but the SEO proximity measures do not, there may be a bias favouring the trade weighted stocks over the SEO proximity stocks in terms of their performance in econometric regressions.

Other methods for constructing inter-industry spillover pools

Patent offices record patent applications and grants by various technology classification systems, such as the International Patent Classification (IPC) system. The patent offices do not classify patent activity by industry. An exception is the Canadian Intellectual Property Office (CIPO) which uses both technology and industry classifications.

The Yale Technology Concordance was established to map patent information by technology class to the economic sectors generating and using the patents. The concordance is based on the historical information collected by CIPO. The concordance maps Canadian industry classified data to the US industrial classification system.

The OECD Technology Concordance (OTC) was developed to provide a mapping between IPC patent product and process categories and the economic sectors responsible for their creation and subsequent use, classified by the International Standard Industrial Classification (ISIC) system. The OTC matrix transforms a vector of patent data classified by technology class into a matrix of Industry of Manufacture and Sector of Use (IOM-SOU) pairings. It is based on a re-working of the Yale Technology Concordance. For each industry, the pairings provide information on which industries are using the patents generated by the industry.

The OTC data was aggregated to match the level of industry detail in the 'long' industry panel (see appendix A). However, there were data problems with the Wholesale & retail trade and Printing, publishing & recorded media industries, which did not allow a full set of inter-industry weights to be constructed. At this high level of aggregation, there is a very high probability that the industry which generated the patent is also the industry which uses the patents (table C.7). Inter-industry usage is much greater at lower levels of aggregation.

Table C.7 **Industry-of-manufacture (IOM) and sector-of-use (SOU) patent shares[a,b]**

IOM below/SOU to the right	*AFF*	*Mining*	*Total manu.*	*FBT*	*TCF*	*PCCAP*	*BMP*	*SSMP*	*TE*	*OM*	*Other n.e.c.*
Agriculture, forestry & fisheries(AFF)	0.97	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mining	0.17	0.83	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total Manu.[c]	0.02	0.02	0.69	0.01	0.02	0.01	0.02	0.01	0.01	0.62	0.27
FBT	0.02	0.06	0.34	0.05	0.01	0.01	0.01	0.00	0.01	0.26	0.58
TCF	0.02	0.00	0.81	0.00	0.55	0.04	0.02	0.00	0.01	0.19	0.16
PCCAP	0.03	0.01	0.29	0.00	0.00	0.25	0.00	0.00	0.00	0.03	0.68
BMP	0.01	0.21	0.45	0.00	0.01	0.00	0.35	0.03	0.00	0.05	0.32
SSMP	0.00	0.01	0.75	0.00	0.01	0.00	0.03	0.59	0.00	0.12	0.24
TE	0.01	0.00	0.64	0.00	0.00	0.00	0.00	0.00	0.40	0.23	0.35
OM	0.02	0.02	0.71	0.00	0.01	0.01	0.01	0.01	0.01	0.65	0.25
Other n.e.c.[d]	0.02	0.00	0.20	0.00	0.00	0.01	0.00	0.02	0.00	0.16	0.77

[a] Excludes Wholesale & retail trade and Printing, publishing & recorded media. [b] See Johnson (2002) for details of the OECD Technology Concordance (OTC). [c] For industry abbreviations see table A.2. [d] As per definition used by ABS.

Source:

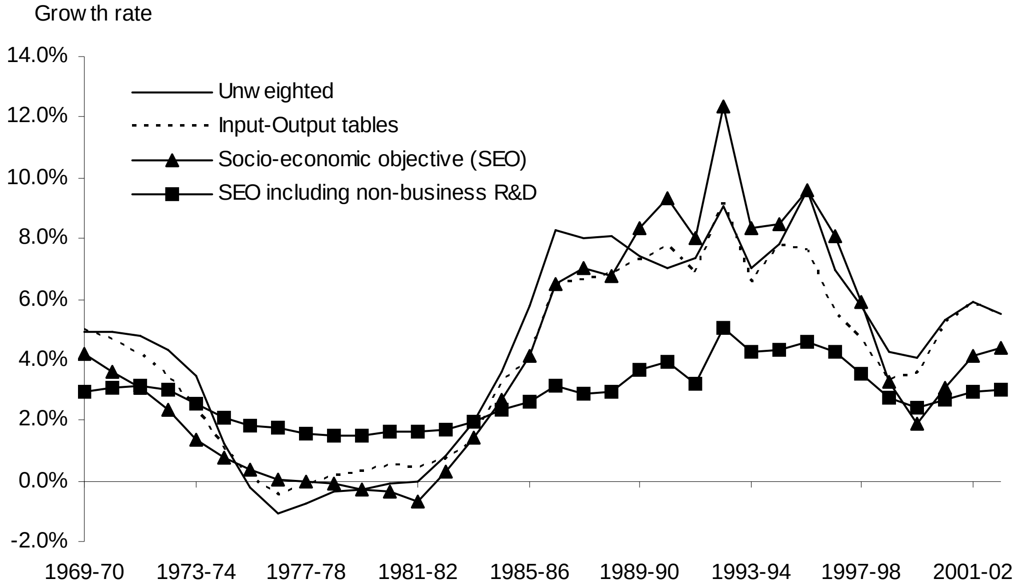
Growth in the inter-industry spillover pools

Figure C.1 show the growth patterns in the domestic potential spillover pool for Mining, Total manufacturing, Wholesale & retail trade and Other industries. The measures are unweighted, input-output table weighted, SEO weighted and SEO weighted including higher education and government R&D.

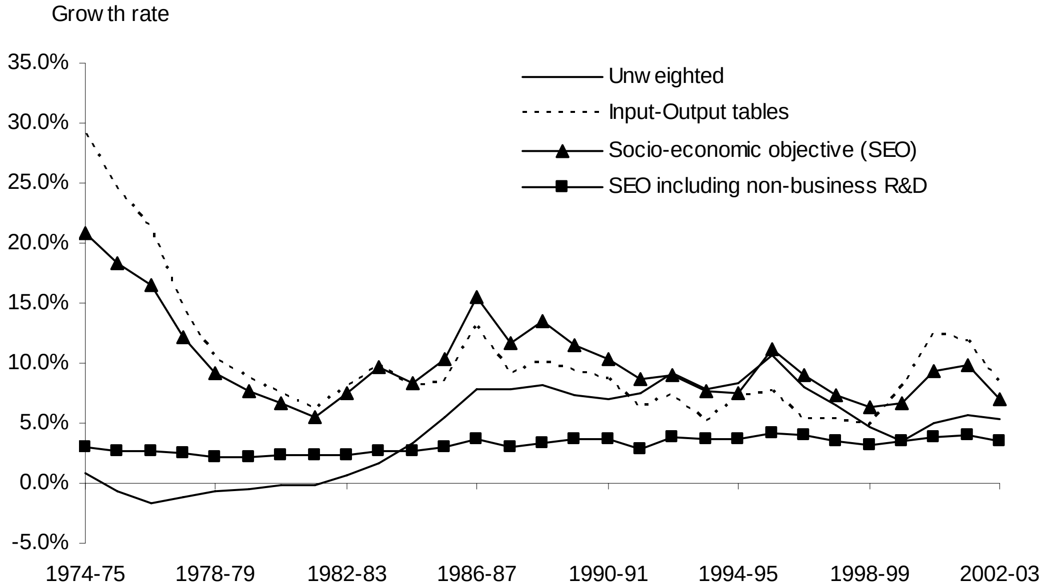
Figure C.1 **Growth in inter-industry potential spillover pools, by industry, various periods**

Stocks based on BERD. PIM methodology, depreciation rate of 10 per cent.

Mining



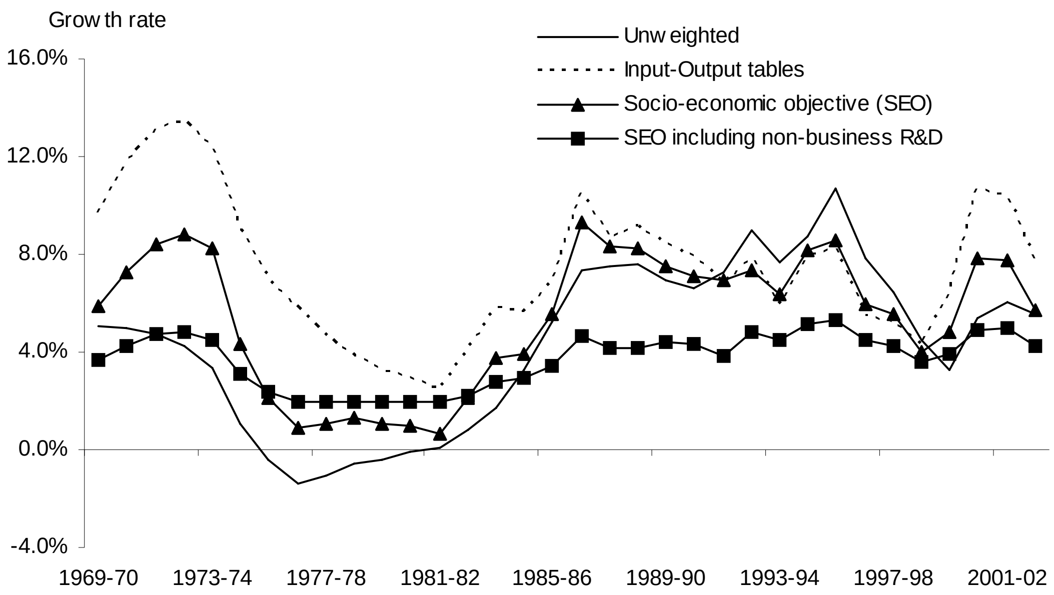
Total manufacturing



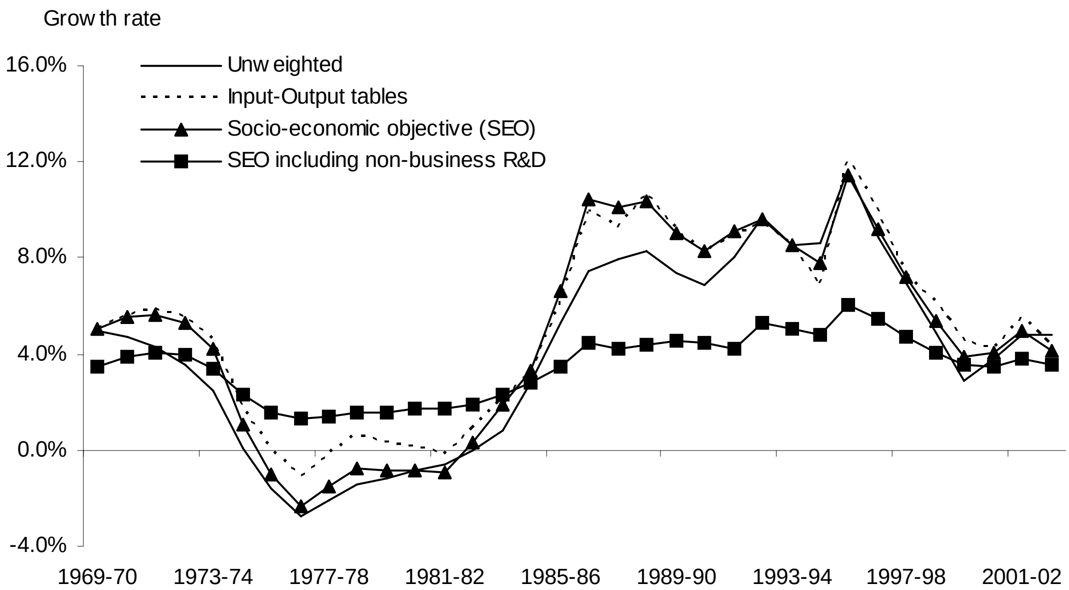
(Continued on next page)

Figure C.1 **(continued)**

Wholesale & retail trade



Other industries



Data sources: ABS (*Research and Experimental Development, All Sector Summary, Australia*, Cat. no. 8112.0); ABS (*Research and Experimental Development, Businesses, Australia,* Cat. no. 8104.0); ABS unpublished data; Commission estimates.

D Data for control variables

D.1 Infrastructure

Mechanisms by which infrastructure affects productivity

The theoretical and empirical literature on the link between infrastructure, output and productivity suggests that infrastructure can have three main effects on productivity (see, for example, Aschauer 1989; Otto and Voss 1994; Gillen 2001; Nadiri and Nandi 2001).

- Public infrastructure, which is not subject to user charges, is a free input into production and therefore directly affects private-sector output and productivity.
- Public or private infrastructure can have an indirect effect through its effect on other inputs — it can be a complement to or substitute for these other inputs and affect their productivity.
- Public or private infrastructure can have other spillover effects or externalities — it can, for example, be an enabler for innovation, allowing firms to do what they do now in a better way or to do new things.

In this paper, the first and third effects are examined by the inclusion of infrastructure variables in models of market sector and industry level multifactor productivity (MFP).

The level of aggregation affects the extent to which public infrastructure is already included in the ABS capital estimates used in the calculation of MFP and, therefore, the extent to which the 'free' input effect of public infrastructure is captured in the standard MFP estimates.

For the market sector, the 'usual' capital estimate includes core[1] public infrastructure (such as roads, railways, etc).[2] The 'free' input effect of this infrastructure is therefore already accounted for in the estimation of MFP. However, there may be other spillovers, beyond those from the direct use of a 'free' input, such as improvements in the organisation of production facilitated by better public infrastructure. To capture this effect, public infrastructure can be included as an additional explanatory variable of market sector MFP. The interpretation of the coefficient on this variable is as an 'excess' effect from public infrastructure.

At the industry level it is more complicated. For an industry, the 'usual' capital of that industry can include some public infrastructure (this varies across industries). The 'usual' capital therefore already accounts for the 'free' input effect of that part of public infrastructure, but not any other spillovers from it. None of the effects of public infrastructure allocated to the capital of *other* industries are captured. One example is roads, which are allocated by the ABS to Transport & storage but are also used by other industries.

To capture these additional contributions of public infrastructure, an extra variable related to public infrastructure can be included in the MFP equation for an individual industry. The inclusion of a variable measuring public infrastructure allocated to *all* market sector industries captures the 'free' input effect of public infrastructure allocated to the capital of *other* industries plus all other spillover effects of public infrastructure allocated to the capital of this and other industries.[3] The interpretation of the coefficient of this variable is as a combination of the 'free' input effect of some public infrastructure and any 'excess' effect from all public infrastructure.

Privately-owned infrastructure (or publicly-owned infrastructure for which user fees are paid) may also provide benefits, such as network externalities, beyond those for which direct fees are paid. The main type of infrastructure of interest in this

[1] Not all infrastructure is equally important to the production relationship. The concept of core infrastructure is commonly used to refer to a subset of infrastructure considered to be the element that is likely to contribute most to growth and productivity. This is not to suggest that non-core infrastructure has no effect. For example, education and health infrastructure may have long-term spillovers through the effect on the human capital of the labour force.

[2] The ABS allocates general government owned infrastructure to the main using industries in its construction of industry and market sector capital estimates (for example, roads are allocated to Transport & storage). Non-core infrastructure (for example, education and health infrastructure) is allocated to industries in the non-market sector.

[3] An alternative would be to examine the 'own' public infrastructure and 'other' public infrastructure effects separately (see table D.2).

category is communications infrastructure.[4] The approach employed in studies of communications infrastructure (for example, Nadiri and Nandi 2001) is to treat privately funded communications infrastructure capital as an unpaid input in the production function of each industry. In the same way as for public infrastructure, communications infrastructure, although already counted in the usual capital stock of the market sector, can be included separately to capture spillovers from communications infrastructure. For an individual industry, communications infrastructure can also be included to capture benefits beyond those for which the industry pays direct fees.

Definitions of infrastructure

For this modelling exercise, public infrastructure and communications infrastructure are considered separately. As already noted, the public infrastructure variable is focused on core infrastructure owned by general government (not public corporations) that is included in the market sector (for example, roads but not health and education). The communications infrastructure variable covers capital of the Communications services industry, not communications assets owned by any industry.

There is no consensus about which asset types constitute infrastructure. While traditionally ‘infrastructure’ consisted primarily of construction (or structures), the nature of modern economies and technological change has led to an expanded definition, which also includes machinery and equipment contained within or attached to the construction (Swimmer 2001). Australian studies, such as Otto and Voss (1994) and Paul (2003), include machinery and equipment with non-dwelling construction in their measures of public infrastructure.

However, for this modelling exercise the asset coverage is varied in two ways (see table D.1). For both public and communications infrastructure, computer hardware and software are excluded to allow separate examination of IT capital.[5] The subset of assets allocated to the communications infrastructure is narrowed further (with the exclusion of road vehicles and other transport equipment) to more closely reflect

4 Electricity, gas and water infrastructure is of interest, in principle, as a source of possible spillovers. There may be some spatial effects, from the extension of distribution networks, that affect business location. The interconnection of electricity, gas and water services between states may have increased quality/reliability of supply, affecting business productivity. However, these spillovers are not expected to be as significant as those from communications infrastructure and are not discussed further here.

5 Alternatives including IT capital were also tested.

those assets that are directly related to the provision of communication services with potential spillovers.[6]

For the industry level modelling, the scope of the infrastructure is varied to separately test the significance of the elements of public infrastructure allocated to the industry being modelled ('own' infrastructure) compared with that allocated to all other industries in the market sector ('other' infrastructure).

Table D.1 **Scope of infrastructure[a]**

	Description
Public infrastructure	General government capital allocated by the ABS to market sector industries (selected asset types: non-dwelling construction plus all machinery and equipment less computer hardware)
'Own' public infrastructure	General government capital allocated by the ABS to $industry_i$ (selected asset types: non-dwelling construction plus all machinery and equipment less computer hardware)
'Other' public infrastructure	General government capital allocated by the ABS to all industries in the market sector except $industry_i$ (selected asset types: non-dwelling construction plus all machinery and equipment less computer hardware)
Communications infrastructure	Communication services industry capital (selected asset types: non-dwelling construction plus all machinery and equipment less computer hardware less road vehicles less other transport equipment)

a Alternative scopes of infrastructure include IT capital (computer hardware and computer software) in the selected asset types within these definitions.

Data

Capital services indexes have been constructed for public infrastructure and communications infrastructure (as defined above), to reflect the flow of capital services from these types of infrastructure. This has been done using unpublished ABS national accounts data and ABS methodology, but with the inclusion of an adjustment factor to reflect changes in the usage of infrastructure by the market sector and by individual industries.

6 The ANZSIC industry Communications services includes postal and courier services, which are likely to account for a large share of the road vehicles and other transport equipment assets of the industry. However, it is the telecommunications part of this industry that is the most likely source of spillovers.

Capital services methodology

The ABS methodology for the construction of capital services indexes is described in detail in ABS (2000, chapter 27). In brief, the productive capital stock of each asset type (j) in each institutional sector[7] within each industry (i) is weighted and summed to form an index for aggregate capital services. The *productive capital stock* of an asset over time is the volume of capital, adjusted for efficiency losses related to age. The weights are based on *rental prices*, which can be thought of as estimates of the rates each asset type would attract if the assets were leased in a commercial arrangement.

Thus the capital service flow index from period t-1 to period t is:

$$c_{it} = c_{it-1} * \exp\left[\sum_j \left(\ln\left(K_{ijt} / K_{ijt-1}\right) * w_{ijt}\right)\right]$$

where K_{ijt} are the real productive capital stocks and w_{ijt} are the capital stock weights

$$w_{ijt} = 0.5 * \left(\frac{r_{ijt} . K_{ijt}}{\sum_j r_{ijt} . K_{ijt}} + \frac{r_{ijt-1} . K_{ijt-1}}{\sum_j r_{ijt-1} . K_{ijt-1}} \right)$$

and where r_{ijt} are the rental prices.

For the total capital services index for the market sector, the ABS includes all market sector industries, all asset types and all institutional sectors. For the estimation of capital services indexes for public infrastructure and communications infrastructure, the relevant industries, asset types and institutional sectors vary. For public infrastructure, only the general government institutional sector is included. The ABS allocates general government capital across a number of industries but only those in the market sector are included to arrive at core public infrastructure for the market sector. For individual industries, this can be split into 'own' infrastructure and 'other' infrastructure. The subset of assets included is non-dwelling construction and five of the six types of machinery and equipment (electrical and electronic equipment, industrial machinery and equipment, other plant and equipment, road vehicles and other transport equipment). Computer hardware is excluded.

[7] For its aggregate capital services indexes the ABS uses two institutional sectors — corporate and unincorporated. For this paper, the ABS provided unpublished data in which it split the productive capital stock of the corporate sector into general government and other corporate. Separate rental prices are not available for these two sub-sectors, so the rental prices for the corporate sector in total have been used for both general government and other corporate.

For communications infrastructure, the only relevant industry is Communication services and the corporate and unincorporated institutional sectors are included.[8] The subset of assets included is non-dwelling construction and three of the six types of machinery and equipment (electrical and electronic equipment, industrial machinery and equipment, and other plant and equipment). Computer hardware, road vehicles and other transport equipment are excluded.

Usage adjustment factor

While many studies use a simple stock measure and assume usage of infrastructure is directly proportional to that stock, other studies make an adjustment to the stock measure to reflect the degree of usage. For example, Paul (2003) suggests that while the amount of services a firm receives from public infrastructure is not observable, the degree of usage is dependent on the level of a firm's activities. He used the industry's or sector's share of total national output as a proxy and applied this to the stock of public infrastructure.[9]

For this paper, the main adjustment factor used for the market sector is the market sector's share of total value added.[10] Similarly, for each of the industries examined (Agriculture, Mining, Manufacturing and Wholesale & retail trade) the adjustment factor is the industry's share of total value added. The industry gross value added data used to construct these shares are from the ABS national accounts (Cat. no. 5204.0).

For communications infrastructure, an alternative adjustment factor was also tested. This was based on the share of intermediate usage of communications services by the market sector or an individual industry. The data used to calculate these shares are from published ABS input-output tables (Cat. no. 5209.0) from 1974-75 to 1993-94 and unpublished ABS supply-use tables from 1994-95 to 2002-03.

The adjustment factors were applied to the productive capital stocks used in the calculation of the capital services indexes rather than included as separate variables. This was to conserve degrees of freedom in the regressions.

8 There is no general government allocation to Communications services so there is no overlap with public infrastructure.

9 Paul (2003, p. 455) tested alternative indexes of usage, with $U(\theta)=U^{\theta}$, where $\theta=1.1$ (usage rate of infrastructure services increases more than proportionately with the increase in its share in national output, $\theta=1$ (proportionate), $\theta=0.9$ (less than proportionate), $\theta=0$ (services equal to stock). He found no difference in the sign of the effect of infrastructure on output or cost but his preferred model was the inclusion of a proportionate usage index ($\theta=1$).

10 For the market sector, the adjustment factor series was smoothed using a 3-period moving average.

The variable construction and data sources are summarised in table D.2.

Table D.2 **Infrastructure variables**

Explanatory variable	*Description*	*Source*
Public infrastructure (I3)	Capital services index for selected general government capital assets (non-dwelling construction plus all machinery and equipment except computer hardware) allocated by the ABS to the market sector	Commission estimates based on published and unpublished ABS national accounts data.
Usage of public infrastructure (I3usage2)[a]	Capital services index for selected general government capital assets (non-dwelling construction plus all machinery and equipment except computer hardware) allocated by the ABS to the market sector, adjusted by market sector/industry$_i$ share of value added	Commission estimates based on published and unpublished ABS national accounts data.
Usage of public infrastructure (I3usage2s)	Capital services index for selected general government capital assets (non-dwelling construction plus all machinery and equipment except computer hardware) allocated by the ABS to the market sector, adjusted by market sector/industry$_i$ *smoothed* share of value added	Commission estimates based on published and unpublished ABS national accounts data.
Usage of 'Own' public infrastructure (own I3usage)	Capital services index for selected general government capital assets (non-dwelling construction plus all machinery and equipment except computer hardware) allocated by the ABS to industry$_i$, adjusted by industry$_i$ share of value added	Commission estimates based on published and unpublished ABS national accounts data.
Usage of 'Other' public infrastructure (other I3usage)	Capital services index for selected general government capital assets (non-dwelling construction plus all machinery and equipment except computer hardware) allocated by the ABS to all industries in the market sector except industry$_i$, adjusted by industry$_i$, share of value added	Commission estimates based on published and unpublished ABS national accounts data.
Communications infrastructure (ci5)	Capital services index for selected capital assets (non-dwelling construction plus all machinery and equipment except computer hardware, road vehicles and other transport equipment) of Communication services industry	Commission estimates based on published and unpublished ABS national accounts data.

(continued on next page)

Table D.2 **(continued)**

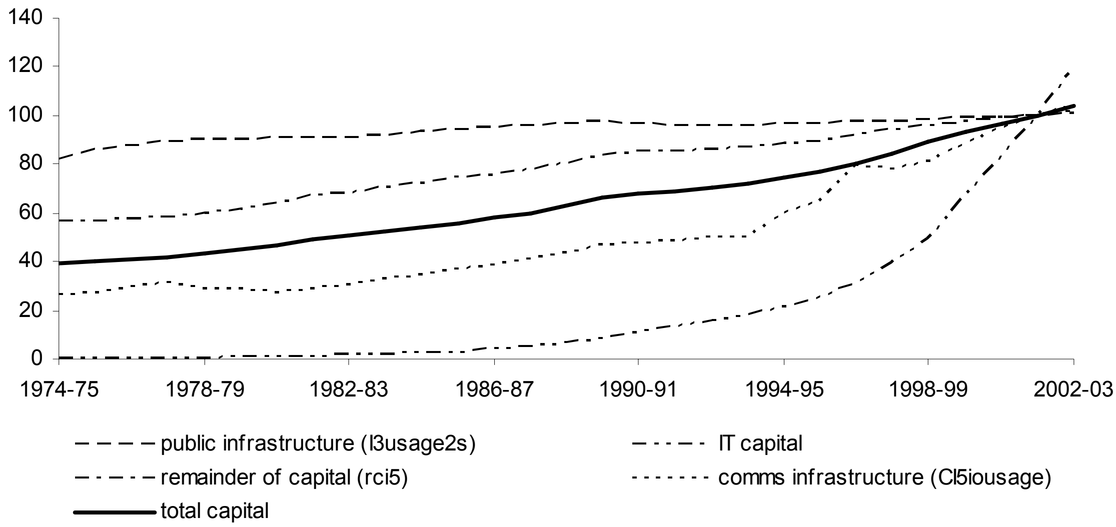
Explanatory variable	*Description*	*Source*
Usage (VA share) of Communications infrastructure (ci5vausage)	Capital services index for selected capital assets (non-dwelling construction plus all machinery and equipment except computer hardware, road vehicles and other transport equipment) of Communication services industry, adjusted by market sector (including Communication services)/ $industry_i$ share of value added	Commission estimates based on published and unpublished ABS national accounts data.
Usage (IO share) of Communications infrastructure (ci5iousage)[a]	Capital services index for selected capital assets (non-dwelling construction plus all machinery and equipment except computer hardware, road vehicles and other transport equipment) of Communication services industry, adjusted by market sector (excluding communications)/ $industry_i$ share of intermediate usage of communications services	Commission estimates based on published and unpublished ABS national accounts data.

a Alternatives extending selected asset types to include IT asset types (computer hardware and computer software), I8usage2 and ci8iousage, were used in manufacturing panel estimates (see appendix J for details).

The trends in the main capital services indexes are shown in figures D.1 to D.3. Figure D.1 shows the relevant infrastructure variables for the market sector, in comparison with the non-infrastructure capital variables. The main capital services indexes for the individual industries are shown in figure D.2 for the selected public infrastructure variables and figure D.3 for communications infrastructure.

Figure D.1 **Capital services indexes for components[a] of market sector capital, 1974-75 to 2002-03**

Indexes 2001-02 = 100

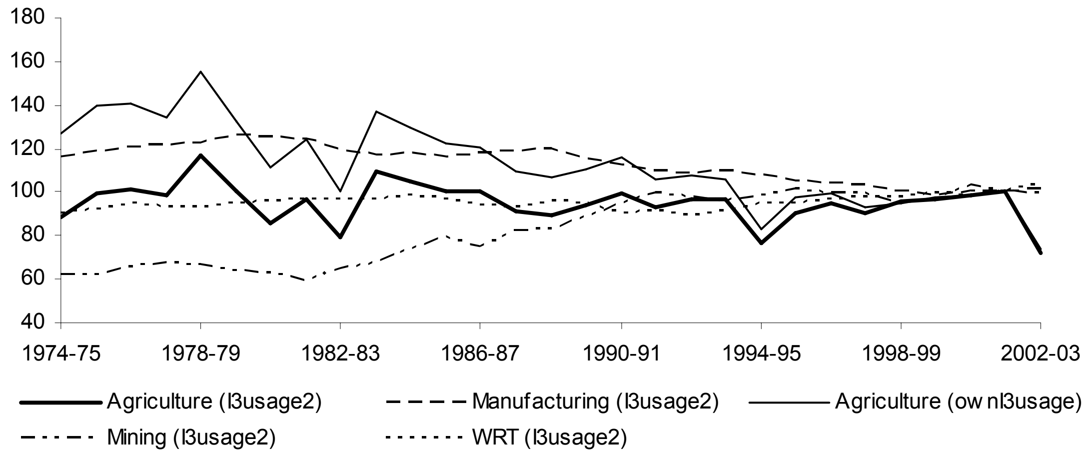


[a] Public infrastructure and communications infrastructure as defined in table D.2. IT capital is all computer hardware and software of the market sector (public and privately owned). 'Remainder of capital' is total market sector capital less those capital groups listed and will include most private sector capital other than IT capital and selected Communication services capital.

Data source: Commission estimates based on published and unpublished ABS national accounts data.

Figure D.2 **Capital services indexes for usage of public infrastructure[a], by industry, 1974-75 to 2002-03**

Indexes 2001-02 = 100

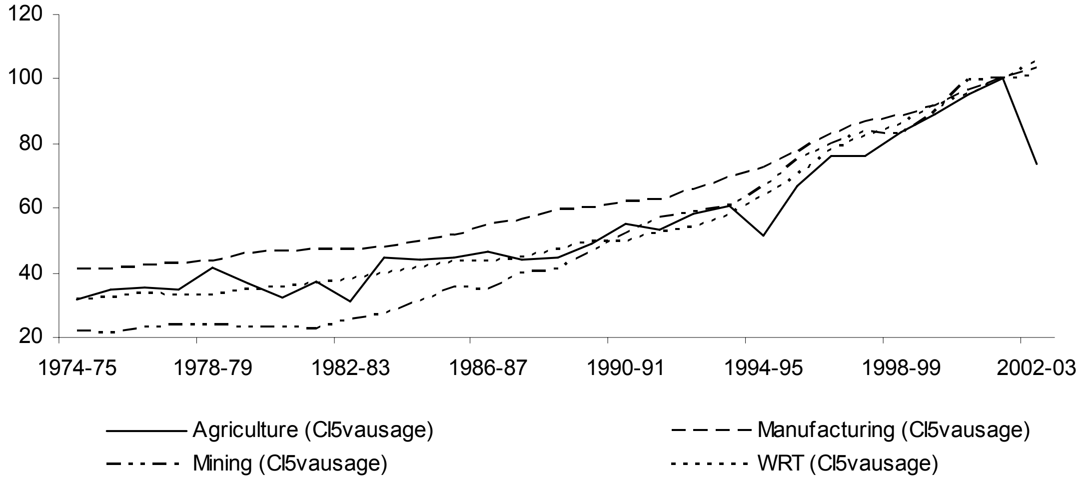


[a] Public infrastructure variables as defined in table D.2.

Data source: Commission estimates based on published and unpublished ABS national accounts data.

Figure D.3 **Capital services indexes for usage of communications infrastructure[a], by industry, 1974-75 to 2002-03**

Indexes 2001-02 = 100



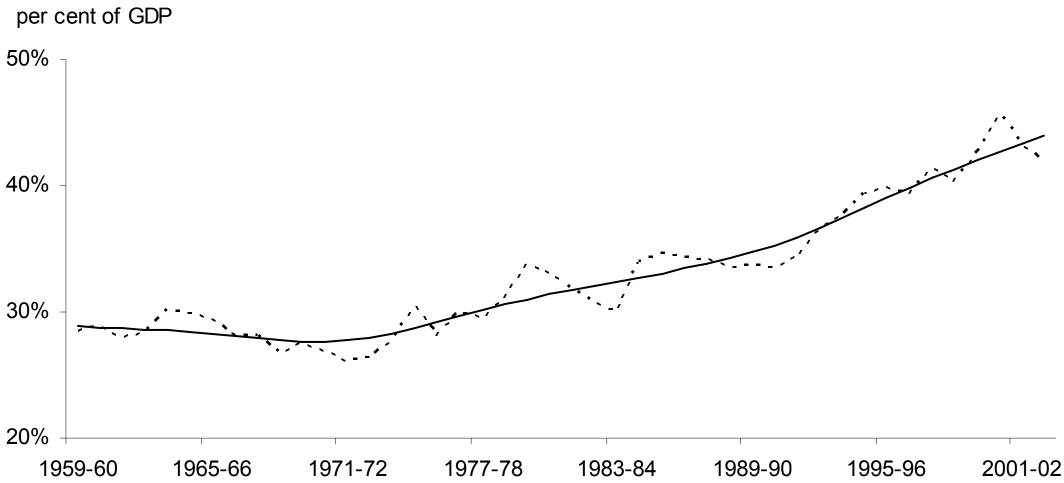
[a] Communications infrastructure variables as defined in table D.2.

Data source: Commission estimates based on published and unpublished ABS national accounts data.

D.2 Trade openness, terms of trade and international competitiveness

The most commonly used index of trade openness is the ratio of combined imports and exports over GDP (figure D.4). A recent paper (Bolaky and Freund 2004) finds that, among relatively unregulated economies, such as Australia, an increase in this measure of trade openness is associated with an increase in GDP per person.

Figure D.4 **Trade openness index, 1959-60 to 2002-03**
(Imports + Exports)/GDP



Data source: ABS (*Australian System of National Accounts*, Cat. no. 5204.0).

The reasons why trade openness may be expected to be associated with productivity growth[11] are:

- increased competition;
- specialisation; and
- transfer of knowledge.

However, there are a number of counter-arguments.

- Trade cannot induce growth if factor movements are restricted, for example, where there are regulations preventing firm entry/exit and labour movement (Bolaky and Freund 2004).
- Governance and institutional quality are dominant determinants of economic growth (see, for example, Rodrik, Subramanian and Trebbi 2002).[12]
- The proxies for openness used in empirical studies are more reflective of geographic factors than trade-related policy measures.

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[11] Berg and Krueger (2003) provides further discussion of the channels through which openness may lead to higher productivity including: the diffusion of knowledge through the import of machinery and equipment; spurs to productivity improvement at the firm and industry level as a result of increased import competition and efforts to penetrate export markets; and increases in average productivity growth as a result of resources shifting to exporting firms with relatively higher productivity.

[12] The focus of much of this literature is on explaining the differences in income levels between developed and developing countries.

The following examination of some of the empirical literature on openness and growth is not intended to be a survey of this debate, but is merely intended to demonstrate the range of results arising from such studies. Baldwin (2003), who does provide a detailed examination of the state of this debate, notes that the disagreements among economists concerning the nature of the empirical relationship between openness and growth arise for a number of reasons including:

- different definitions of the concept of openness;
- differences in the quality and details of data; and
- the use of different types of econometric models and sensitivity testing.

Differences in the concept of openness are an important part of the debate. Studies focusing on policy-induced trade barriers (such as tariff and non-tariff barriers), rather than on more general measures of openness (such as the ratio of combined imports and exports to GDP), have been the subject of particular criticism. Rodriguez and Rodrik (1999), for example, argue that this empirical literature, that finds that countries with lower policy-induced barriers to international trade grow faster, is subject to methodological problems and mismeasurement of trade orientation. However, the use of the more general openness measures (such as trade intensity) is not without criticism, since exports are a component of GDP, the usual measure of economic growth, and this raises the problem of the direction of causation (Baldwin 2003, p. 29).

Some studies, including Levine and Renelt (1992), suggest that the results of these empirical studies are fragile to the variables included, and that the correlation between growth and openness is weakened when the investment share is included in the regression. Openness is correlated with the investment share, which is in turn correlated with growth, suggesting openness affects growth partly through increasing investment rates (see also Dowrick 1998). However, a more recent study (Dowrick and Golley 2004) of the dynamic benefits of trade suggest these benefits are obtained directly through productivity growth, with only minor effects operating through the investment channel.[13]

Empirical studies, while generally finding a positive relationship between growth and openness, produce a wide range of results for the size of the effect. Table D.3 provides details of a few recent studies of openness and growth, most of which focus on general measures of openness rather than policy-induced trade barriers.

[13] The size of the positive effect is inversely related to initial income of the country in the 1960-80 period, with richer countries experiencing lower productivity growth increases from increased trade than poorer countries, but is reversed in the 1980-2000 period.

Table D.3 **The effect of trade openness on productivity**

Study	*Data and methods*	*Key findings*	*Elasticity range*
Alcala and Ciccone (2004)	Model of level of LP and TFP; Level of real openness = (M+X)/(PPP GDP); Controls for geography; cross country study 1985; 2SLS.	Trade has a statistically significant robust positive effect on productivity.	1.2 for LP 0.84 for TFP
Bolaky and Freund (2004)	Model of level of real per capita income at PPP (year 2000) with openness = total trade/GDP (nominal and real terms tested); Model of average growth (1990s) of real per capita income at PPP with change in openness; Several instruments including measure of regulations; Cross-section levels regressions and decadal growth regressions; up to 133 countries; OLS and IV.	Trade does not stimulate growth in economies with excessive regulation. Controlling for the effect of domestic regulation increases the positive estimates of the effect of trade.	Levels: nominal openness -0.08 to 1.23 real openness 0.03 to 1.00 Growth: nominal and real openness 0.01 to 0.06
Dowrick and Golley (2004)	Structural model with real GDP per capita growth equation, investment equation and openness equation. Growth of real GDP per capita; openness = level of trade/GDP; Two 20-year periods 1960-2000, up to 127 countries.	Most of the dynamic benefits of trade are obtained through productivity growth, with a small contribution through increased investment. Size of effect varies by level of development, trade specialisation and time.	Marginal impact of trade depends on initial income of country 1960-80: 0.013 ppts. at mean (0.11 $-0.012*\ln RGDP_0$) 1980-2000: 0.007 ppts. at mean ($-0.072 + 0.0091*\ln RGDP_0$)
Valadkhani (2003)	Model of long term LP with trade openness =(real X + real M)/ hrs worked; Model of short term LP growth with growth in openness; Data for Australia 1970-2001.	Labour productivity level and growth improved by trade openness.	Long term LP: 0.109 (2SLS) to 0.110 (OLS) Short term LP growth: 0.176
Frankel and Romer (1999)	Model of real income per person; Level of trade = (X+M)/GDP; Countries' geographic attributes used as instruments to identify trade's impact on income; Cross country regressions, 98-150 countries, 1985.	Trade has a quantitatively large and robust, though only moderately statistically significant, positive effect on income.	1.5 to 2.0[a]
Edwards (1998)	Model of TFP growth; 9 alternative level of openness indexes and composite index (reflecting degree of trade intervention and distortions); panel data for up to 93 countries 1960-90; Weighted least squares and Instrumental weighted least squares.	More open countries experience faster productivity growth and results robust to use of different indicators of openness.	Effects on MFP growth from 0.0020 to 1.67

(continued on next page)

Table D.3 **(continued)**

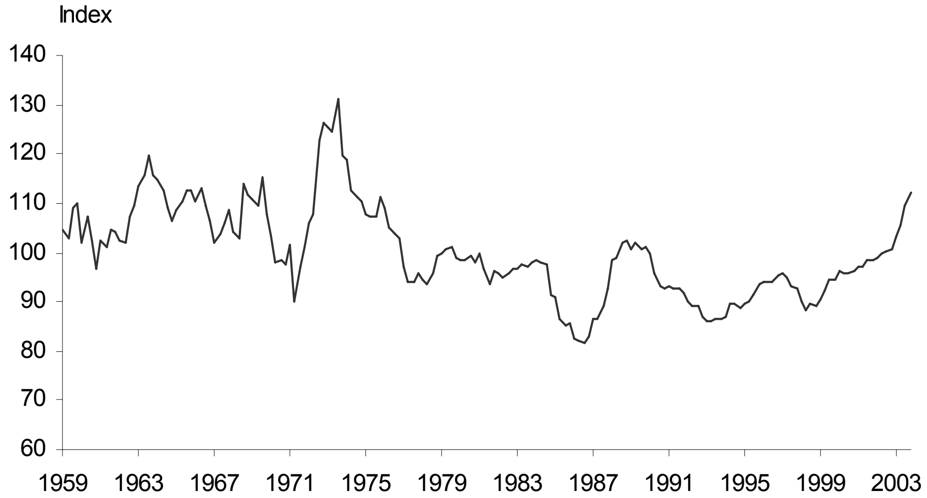
Study	*Data and methods*	*Key findings*	*Elasticity range*
Dowrick (1998)	Model of real GDP growth; Openness measure as in Dowrick (1994); Panel 21 OECD countries, periods between 1960 to 1996.	Openness does not appear to contribute to growth directly but likely to have indirect effects on investment	Insignificant
Dowrick (1994a)	1) GDP per capita growth model using cross country averages 1960-1990; 2) Labour productivity growth model using panel estimation; Derived measure of level of openness (residuals to regression of trade shares on population).	Consistent evidence that high outward orientation does increase growth prospects, even when country-specific factors are taken into account.	1) 0.013 to 0.021 2) 0.006 to 0.014 Suggests 0.010 as a conservative estimate.

[a] Lewer and Van den Berg (2003) note that the growth equivalent of this result, 0.24 of a percentage point, is close to the average result they found in their survey of growth regressions using direct measures of trade (0.22 of a percentage point increase in economic growth from a 1 percentage point increase in trade growth).

These studies demonstrate the range of results, although the various specifications of the empirical analysis mean that the results are not directly comparable in all cases.

Australia's terms of trade is expressed as an index and is calculated by dividing the implicit price deflator (IPD) for exports by the IPD for imports, multiplied by 100 (figure D.5). An increase in the index suggests an improvement in Australia's terms of trade, enabling it to purchase more imports from the same amount of exports. A decline in the index suggests a deterioration in Australia's terms of trade, requiring it to export more to purchase the same amount of imports. Indexes are available for both goods and services.

Figure D.5 **Goods and services terms of trade (seasonally adjusted), September 1959 to June 2004**



Data source: ABS (*Balance of Payments and International Investment Position, Australia*, Cat. no. 5302.0).

Policy measures

The nominal rate of assistance on outputs is the percentage change in gross returns per unit of output relative to the (hypothetical) situation of no assistance. The nominal rate measures the extent to which consumers pay higher prices and taxpayers pay subsidies to support local output.

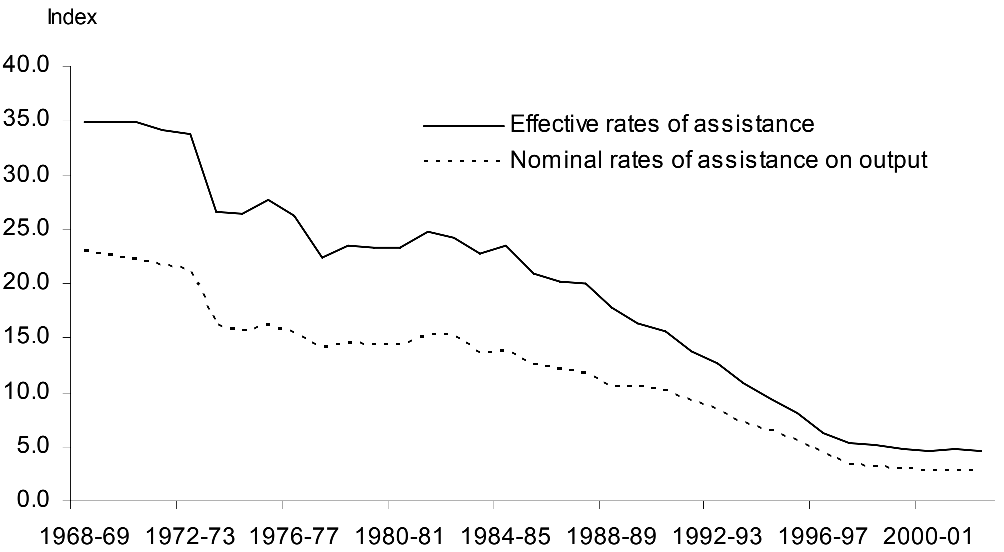
The effective rate of assistance is the percentage change in returns per unit of output to an activity's value-adding factors due to the assistance structure. The effective rate measures net assistance, by taking into account the costs and benefits of government intervention on inputs, direct assistance to value-adding factors and output assistance.

At an industry level, the nominal and effective rates of assistance may be correlated with trade openness. Changes in the nominal rates of assistance are driven by changes in the level of tariff protection, and may be correlated to trade openness in that particular sector. The effective rate of assistance also takes into account the effect of protection and assistance on input costs. In some cases, output assistance — such as tariffs on imported products — may be less than, or equal to the negative assistance — the increased price of inputs resulting from tariff protection of input producing industries. Where this is the case, assistance may seem low (or negative); however it is unlikely that these industries are as 'trade-open' as unprotected industries.

The nominal rates of assistance on output and effective rates of assistance indexes are the best available measures of trade openness at the industry level. Indexes are available at a detailed level for manufacturing covering the time period 1968-69 to 2002-03. Agriculture, forestry & fishing is available from 1970-71 to 2002-03, and Mining is available from 1997-98 to 2002-03.

After being relatively steady in the latter half of the 1970s and into the 1980s, the rate of decline in effective rates of assistance accelerated around 1984 and continued to fall rapidly until around 1997 (figure D.6). Nominal rates of assistance declined more steadily throughout 1968-69 to 2002-03.

Figure D.6 **Nominal and effective rates of assistance for total manufacturing, 1968-69 to 2002-03**



Data source: Commission estimates.

D.3 Human capital

Human capital has been proxied in empirical studies using a variety of measures, including various educational measures and experience measures. For the R&D modelling two alternative measures have been used — the ABS measure of quality adjusted labour inputs (QALI), which is available only for the market sector in total, and the share of employed persons with post-school qualifications, which is available for the market sector and individual ANZSIC industries. These measures are described in the following sections, followed by a brief survey of the results of empirical studies of human capital and growth.

The quality adjustment of labour inputs for the market sector

When a labour quantity input measure is used in estimation of productivity growth, the effect of a shift in skill composition toward the skilled on output growth is captured in higher productivity growth and not higher labour input growth. Accounting for changes in composition of the workforce as 'embodied' increases in labour input would make productivity estimates more accurate and representative of actual 'disembodied' improvements in productivity. An outline of the growth accounting framework is provided in box D.1.

Box D.1 **Framework for analysis of changes in skill composition**

Growth in labour services is equal to growth in labour quantity plus the change in the skill composition of labour. The contribution of skill composition to output growth and productivity growth is equal to the change in skill composition multiplied by the labour income share. These relationships can be demonstrated using the following Cobb-Douglas function

$$Y = AK^{\alpha}L^{1-\alpha}$$

where output (Y) is a function of capital (K), labour services (L) and multifactor productivity (A).

Taking the log of this function and converting to growth rates

$$y = a + \alpha k + (1-\alpha)l$$

where $l = l_{sc} + h$, that is, growth in labour services (l) is equal to growth in labour quantity (h) and growth in skill composition (l_{sc}).

It is assumed that the output elasticities are equal to the factor shares, s_k and s_l, therefore

$$y = a + s_k k + s_l l_{sc} + s_l h$$

Now expressing in terms of labour productivity growth

$$y - h = a + s_k k - s_k h - (1 - s_k)h + s_l h + s_l l_{sc}$$

Which simplifies to

$$y - h = a + s_k(k - h) + s_l l_{sc}$$

Therefore, labour productivity growth is equal to multifactor productivity growth, plus capital deepening ($s_k(k-h)$) plus the contribution of changes in skill composition ($s_l l_{sc}$).

The ABS recently released experimental estimates of a labour services measure that accounts for changes in skill composition. The estimation method used by the ABS is similar to that already being used by the Bureau of Labor Statistics (BLS) in the United States. The ABS method distinguishes between labour force groups on the basis of skill. Groups are defined by educational attainment, work experience and gender. Work experience is used as a proxy for the on-the-job training and skill development that workers receive while employed. The gender distinction accounts for any differences in the productivities of males and females in different educational attainment and experience groups.[14]

While it is assumed that differences in the skill level between workers result in differences in marginal products, these differences are very difficult to observe directly. The ABS has assumed that these differences can be observed indirectly through differences in wage rates. This is based on the assumption that, in competitive markets, firms will pay workers according to their marginal product. And so, wage rate differences reflect productivity differences.

The relative wages of the different labour groups are used as weights to aggregate the hours worked by each group to form an aggregate labour services measure. With the assumption that wages reflect marginal products, the labour services measure reflects the different productivities of the hours worked by the different groups. The greater the education level and experience a classification of worker has, the greater will be the corresponding wage level and the greater will be the weighting in the labour services input index. A shift in composition toward skill will shift the aggregate labour services measure further above the aggregate hours worked measure.

Whilst the ABS methodology is largely similar to the framework used by the BLS, one major difference is the estimation of the work experience measure. The BLS is able to use data on actual work experience, but these data are not available in Australia. Instead potential experience is calculated, based on age, years of education and the number of children in the case of female workers.[15] This measure regards education years and work experience years as mutually exclusive and therefore will not capture work experience gained whilst studying, such as from part-time employment.

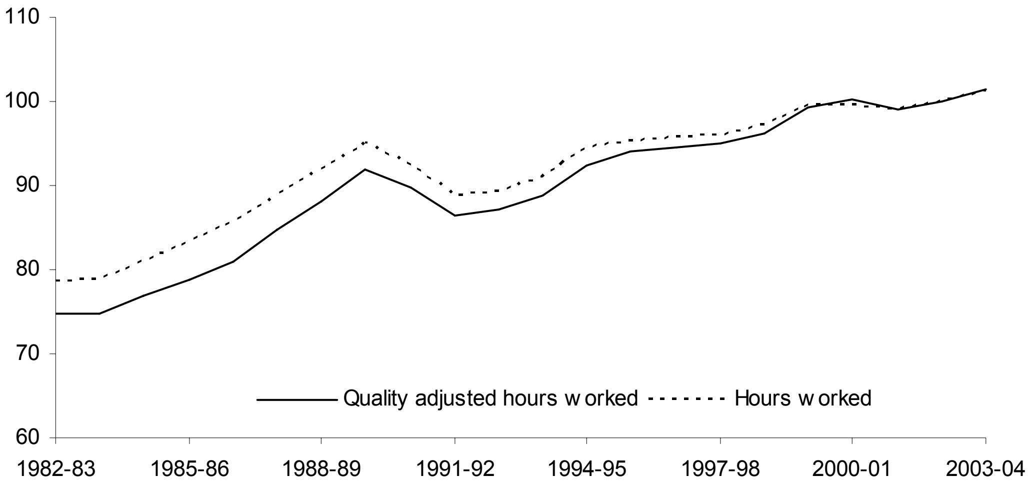
[14] Differences in male and female experience levels due to females taking time out to have children and the higher proportion of females in part-time work are the main reasons why the ABS decided to have separate male and female wage regressions.

[15] Potential experience = Age – 5 – Education Years − (Number of children). The relationship between age and experience is not linear as the wage regression involves diminishing returns to experience.

Figure D.7 compares quality adjusted hours worked with unadjusted hours worked. The quality adjustment increase the rate of growth in hours worked as 'effective' hours worked are higher due to increase in the quality of labour.

Figure D.7 **Hours worked and quality adjusted hours worked, market sector, 1982-83 to 2003-04**

Indexes 2002-03 = 100



Data source: ABS (*Australian System of National Accounts*, Cat. no. 5204.0).

Education indicators for changes in the quality of labour

Various educational indicators can be used as proxies for changes in the quality of labour at the whole-of-economy, market sector, and/or industry-level. Two common indicators are: the proportion of employed persons with secondary school qualifications; or the percentage of employed persons (15-64) with post-school qualifications. The post-school qualifications measure is used in the R&D modelling. It is defined to include employed persons with:

(a) a degree or higher (a bachelor degree, a graduate or post-graduate diploma, masters degree or a doctorate); and

(b) other qualifications (including vocational or trade qualifications).

This series is based on data from the ABS supplementary survey to the Labour Force Survey, Survey of Education and Work. There are several minor changes in the series, details of which are provided in *Education and Work* (ABS Cat. no. 6227.0). However, there is a major break in the series in 1993, with the introduction of the ABS Classification of Qualifications. This involved a reclassification by the ABS of people holding qualifications earned as a result of less than one semester's full-time study from the 'with post-school qualifications' group to the 'without post-school qualifications' group. This change, combined with another change to the wording of the questionnaire, is estimated by the ABS to have *lowered* the total for the 'with post-school qualifications' group in 1993 by 400 000 to 500 000 compared with the old methodology (ABS 1993).

For the R&D modelling, this structural break in the series was adjusted for by estimating the following econometric model

$$E_t = \alpha + \beta(t) + \delta(d) + \varepsilon_t$$

where E is the proportion of employed with post-school qualifications at year t, α is the intercept, t is a time trend, d is an intercept dummy equal to 0 prior to 1992-93 and 1 from 1992-93 onwards, and ε_t is the residual.

A consistent series is constructed using the estimated parameters and is defined to be

$$E_t - \delta(d) = \alpha + \beta(t) + \varepsilon_t$$

This effectively makes the later observations in the series consistent with the earlier observations. Further background to the construction of the education time series is provided in box D.2.

Box D.2 **Additional details on the construction of education time series**

There is a range of other data quality issues.

The two and three digit data are sourced from an ABS data request, and for this reason may not be structurally identical to one digit data, which is sourced from ABS publications.

For the years 2001 and 2002, the ABS changed educational classifications. A change from 'level of highest non-school qualification' to 'level of highest educational attainment' resulted in the reclassification of individuals who had post-school certificates from the certificate I/II and certificate n.f.d. classification to the Year 12 or below classification. There is sufficient information to reallocate these units, if it is assumed that the proportion of people in the labour force who have such certificates is the same as that for the population. This has been done.

To extend the series for the industry group 'Other Sectors', ANZSIC K has been used from 1997-98 onwards, because separate data on ANZSIC 73 and 74 were not available. This is equivalent to assuming that the proportion of units with post-school qualification in ANZSIC K is similar to that in ANZSIC 73+74, which should be a reasonable assumption given that ANZSIC 73 and 74 make up the majority of ANZSIC K. This has not caused a noticeable break in the series.

There is a small difference between the sum of classifications and the totals columns in the ABS's publications. This gap has been allocated to 'non-post school'. The effect of this allocation of the gap is a less than one percentage point change in the proportion of employed with post school qualifications.

For 1978-79 to 1982-83, education data by ASIC industry classification have been converted to ANZSIC using the Gretton and Fisher concordance (see Gretton and Fisher 1997, appendix A). Due to data availability and concordance issues, 'Other sectors', for this period, is the sum of ANZSIC categories D, E, H, I, J and P.

The share of employed persons with some form of post-school qualifications increased from under 40 per cent in 1978-79 to nearly 60 per cent in 2002-03 (figure D.8). There is significant variation by industry — manufacturing subdivisions together with Mining have the highest share of employed with post-school qualifications (figures D.8 and D.9).

Figure D.8 **Proportion of employed persons with post-school qualifications[a], aggregate and industry divisions, 1978-79 to 2002-03**

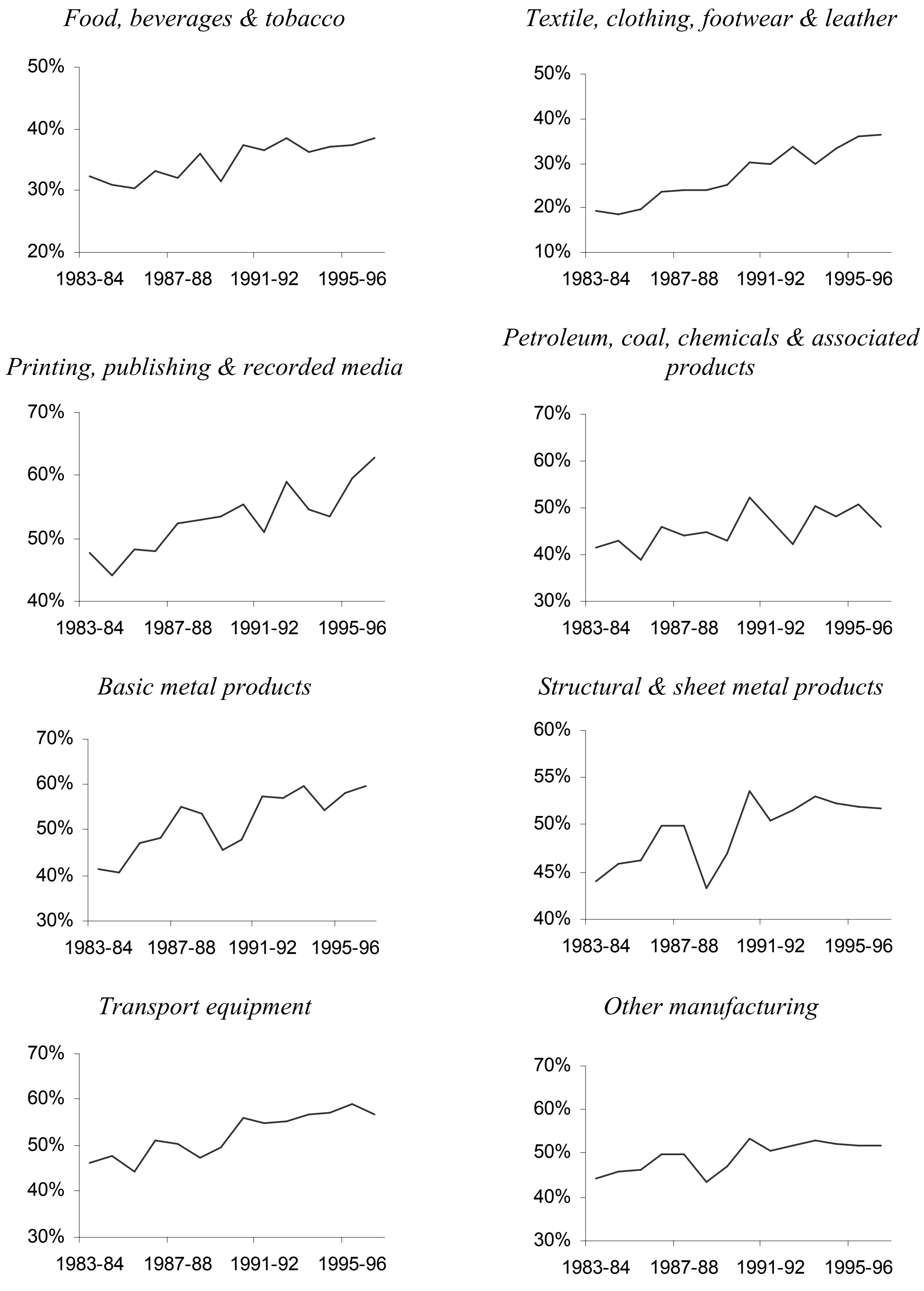
Percentage share

[a] Adjustments have been made to obtain a consistent time series; they are detailed above, in the text.

Data sources: Based on ABS (*Education and Work, Australia,* Cat. no. 6227.0); Commission estimates.

Figure D.9 **Proportion of employed persons with post-school qualifications, manufacturing subdivisions and groups[a], 1983-84 to 1996-97**

Percentage share



[a] Gretton and Fisher manufacturing industries see table A.2.

Data sources: Based on ABS unpublished data; Commission estimates.

Empirical studies of the effect of human capital on productivity

The empirical evidence of the link between human capital and growth is not clear cut. Sianesi and Van Reenen (2003) in their survey of the returns to education in macroeconomic studies note the difficulty of comparing across studies because of the differences in methodology, dependent variables, human capital measures and samples (particularly where developing and developed countries are pooled). However, they highlight the following ranges of results.

- Studies of the flow of investment in human capital (cross-country 'Barro' type growth regressions).
  - A 1 percentage point increase in school enrolment rates leads to an increase in GDP per capita growth of 1-3 percentage points (for example, Barro 1991, Levine and Renelt 1992 and Englander and Gurney 1994).
- Studies of the stock of human capital — empirical literature on whether the *stock* of education affects the long run level or growth rate of the economy is divided. An increase of 1 year in the average education of the population raises:
  - the *level of output* per capita by 3-6 per cent according to augmented neo-classical specifications (for example, Mankiw, Romer and Weil 1992, de la Fuente and Domenech 2000 and Bassanini and Scarpetta 2001); and
  - the *output growth rate* by over 1 percentage point according to new-growth theories (for example, Barro and Lee 1994, Gemmel 1996 and Barro 1997).

Dowrick (2002) examines this literature from an Australian perspective. He notes that early cross-section studies found a significant positive impact of schooling on the rate of output growth but subsequent studies using panel data failed to find any significant relationship between the rate of increase of educational capital and the rate of economic growth. This was attributed to problems of data quality, particularly where data from the least and most developed economies were pooled. Dowrick therefore examines the results of studies restricted to OECD countries. He also translates these results into predicted increases in the level of output or long-run economic growth for an additional year of schooling in the adult population. Table D.4 provides a summary of studies surveyed by Dowrick.

Table D.4 **The effect of human capital on productivity**

Study	*Data and methods*	*Key findings*	*Elasticity range*	*Predicted increase from an additional year of schooling*
Level effects – change in the stock of human capital affects the level of output				
Bassanini and Scarpetta (2002)	Years of schooling; Panel data (21 OECD countries, 1971-98); Pooled mean group estimator.	Positive impact of human capital accumulation, with size of impact consistent with micro evidence on private returns of schooling. Data quality affects results.	0.6	6% level effect
Mankiw et al. (1992)	Proportion of workforce enrolled in secondary school; Cross section OECD countries.	Countries' steady-state income levels are a function of investment in both physical and human capital.	0.76	8% level effect
Growth effects - change in the stock of human capital affects the growth rate, through effect on domestic innovation (α) and absorption of technological spillovers from technologically leading country (β).[a]				
Benhabib and Spiegel (1994)	Years of schooling of labour force; TFP growth 1965-85, richest third of countries in sample (26).	The level of the stock of human capital affects TFP growth.	α=0.0021 β=0.0007	0.3%pts growth effect
Frantzen (2000)	Average years of schooling of population aged over 25; TFP growth 1961-91, business sectors of 21 OECD countries.	The level and growth rate of human capital affect productivity growth.		0.8%pts growth effect
Dowrick and Rogers (2002)	Average years of schooling in population; GDP per worker growth 1970-90, sample of 35 and 51 countries.	Education facilitates technology transfer.	α=0.01 β=0.005 to 0.012	0.2-0.4%pts growth effect

a TFP growth in country$_i$= α(average years of schooling)+ β(average years of schooling)(ratio of productivity in technologically leading country relative to country$_i$). Results in last column assume a US to Australia productivity ratio of 1.5.

Source: Adapted from Dowrick (2002) with additional details from cited papers.

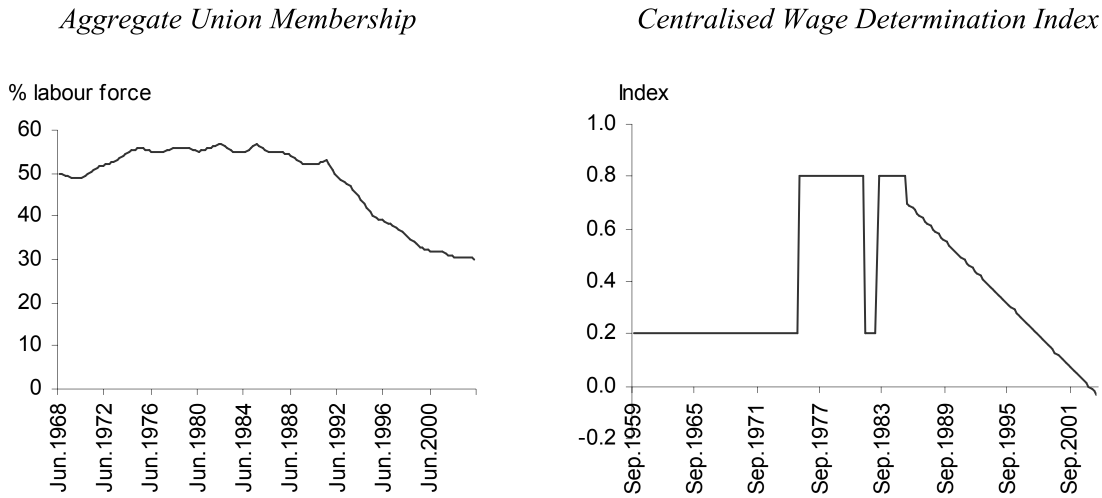
The education measure used in the R&D models in this paper is not directly comparable to the school enrolment rates and average years of education used in other studies. But a similar translation to that used by Dowrick can be applied to the results for comparison purposes. The elasticity of education estimates from the R&D models in chapter 7 range from 0.18 to 0.29 and are statistically significant. According to Dowrick (2002) Australia has average schooling of ten years — an increase of one year in this average equates to a 10 per cent increase, which would give a level of output increase of between 1.8 and 2.9 per cent. Also, Industry Commission (1995), which used a comparable education variable (percentage of labour force with post-secondary education), reported an elasticity of 0.072 for MFP for Australia over the period 1975-76 to 1990-91.

D.4 Centralised wage bargaining and unionisation

Indicators of union membership and the degree of centralisation in wage determination are sourced from the TRYM modeller's database (figure D.10). The centralised wage determination index is a subjective indicator:

> The TRYM wage equation also includes a dummy variable (QCC) that attempts to capture the effect of various institutional arrangements such as wage indexation (between 1975 and 1981), the Wages Pause (introduced in 1982) and various Prices and Income Accord agreements (since 1983). This dummy attempts to measure the degree of centralisation in various wage regimes, set to 0.8 in highly centralised periods and 0.2 in relatively decentralised periods. The values broadly represent the proportion of movements in the average minimum wage rate attributable to the national wage case decisions. Since 1987, with the movement towards productivity based enterprise bargaining, QCC has been assumed to be slowly declining. The interest with this dummy is the effect that the degree of centralisation in wage fixation may have had on sources of wage pressure. Allowance has also been made for the Metal Trades wage decision in the third quarter of 1974. (Stacey and Downes 1995, p. 15)

Figure D.10 **Union membership and wage centralisation, various years**



Data source: ABS (*Modeller's database-TRYM*, Cat. no. 1364.0.15.003).

E Times series characteristics and stability tests

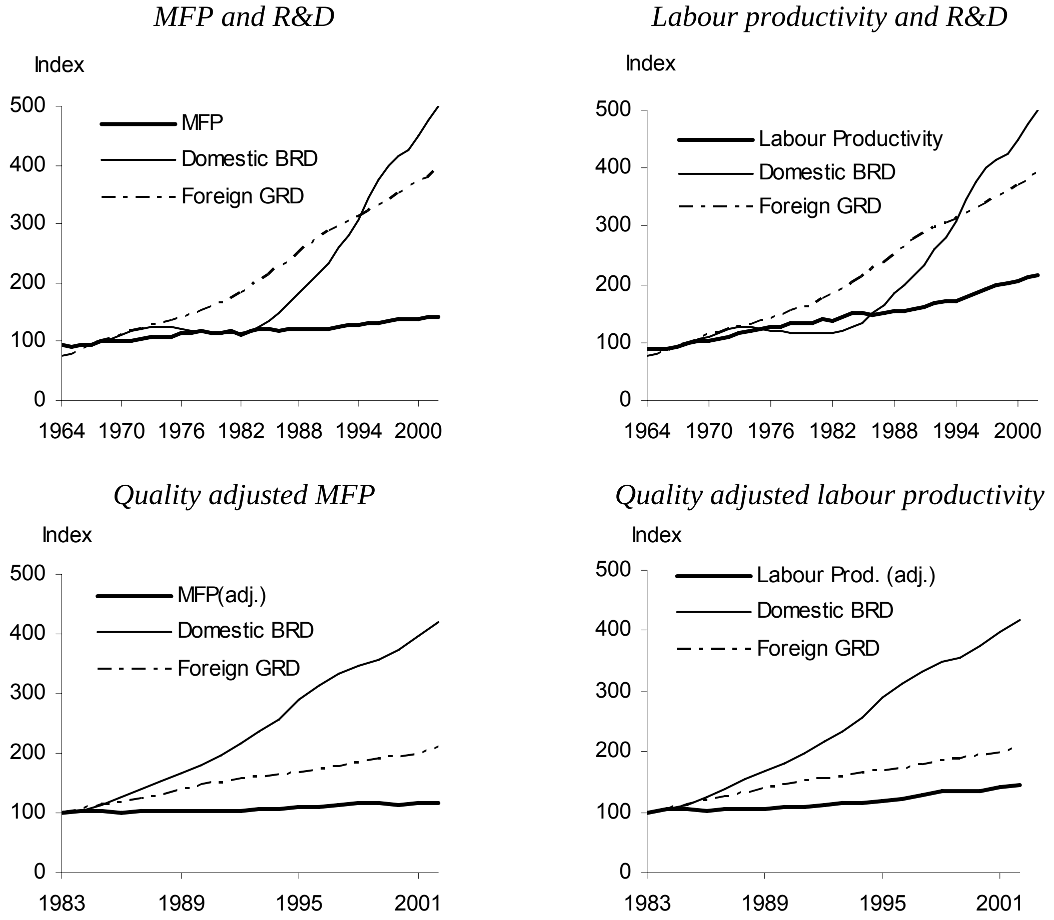
E.1 Correlations between R&D and productivity

The levels relationship: ln(MFP) — ln(K)

The level of R&D expenditure and of multifactor productivity (MFP) and labour productivity (LP) have drifted apart over time (figure E.1). A large wedge between the indexes begins to open up in the early 1980s as the rate of investment in R&D stocks accelerated rapidly. The rate of foreign investment in business R&D also increased strongly and somewhat earlier. All foreign business R&D (BRD) and gross R&D (GRD) trends in this appendix are based on the 14 countries used in construction of foreign knowledge stocks (appendix F). The ABS quality adjusted productivity series also shows the series drifting apart from 1983 (bottom panels).

Figure E.1 **Levels of domestic and foreign R&D stocks and productivity[a], various periods**

Indexes 1964-65 = 100. Stocks depreciated at 15 per cent. Foreign stocks are weighted by Elaborately Transformed Manufactures (ETM) import shares.



Financial years beginning 1 July of year specified. [a] The quality adjusted MFP and labour productivity measures are the official indexes available from the ABS. The quality-adjusted labour input (QALI) index is used for adjustment of labour inputs.

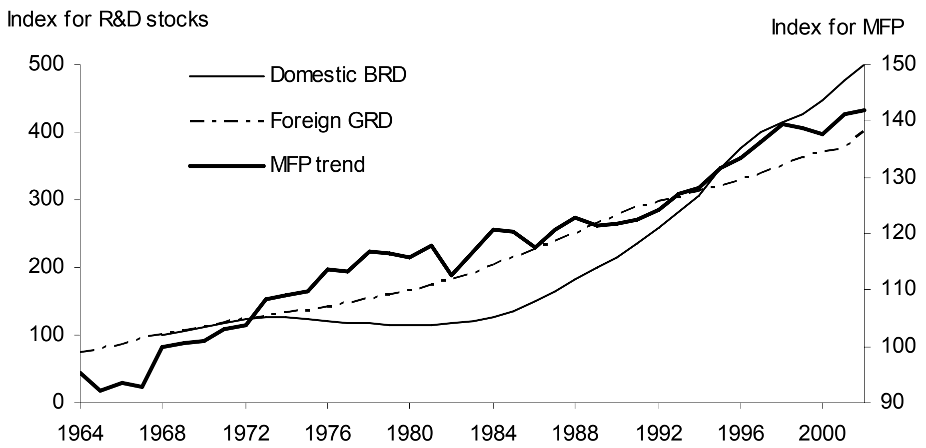
Data sources: ABS (*Australian System of National* Accounts, Cat. no. 5204.0); ABS (*Research and Experimental Development, All Sector Summary, Australia*, Cat. no. 8112.0); ABS (*Research and Experimental Development, Businesses, Australia*, Cat. no. 8104.0); ABS unpublished data; OECD (Analytical Business Enterprise Research and Development, ANBERD, database); Commission estimates.

If the elasticity of productivity with respect to R&D is expected to be well under unity (say, 0.03 to 0.06), the divergence in the indexes is to be expected. Figure E.2 shows the level of MFP and R&D graphed on separate scales, with the left and right-hand scales adjusted so that the MFP and R&D indexes are in proximity. This provides a better descriptive comparison of the correlation between movements in MFP and R&D.

From the early 1970s to the mid-1980s, the stock of Australian BRD grew much more slowly than foreign GRD (and even declined in real terms when knowledge depreciation rates are assumed to be greater than 5 per cent). From the mid-1980s, growth in the index accelerates rapidly.

Figure E.2 **Levels of R&D stocks and MFP, rescaled, 1964-65 to 2002-03**

Indexes 1968-69 = 100. Stocks depreciated at 15 per cent



Financial years beginning 1 July of year specified.

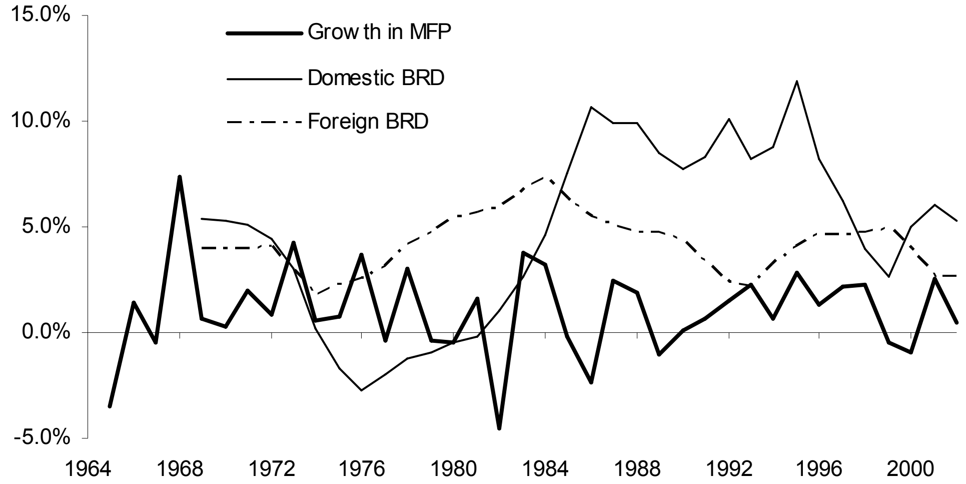
Data source: ABS (*Australian System of National* Accounts, Cat. no. 5204.0); ABS (*Research and Experimental Development, All Sector Summary, Australia*, Cat. no. 8112.0); ABS (*Research and Experimental Development, Businesses, Australia*, Cat. no. 8104.0); ABS unpublished data; OECD (Analytical Business Enterprise Research and Development, ANBERD, database); Commission estimates.

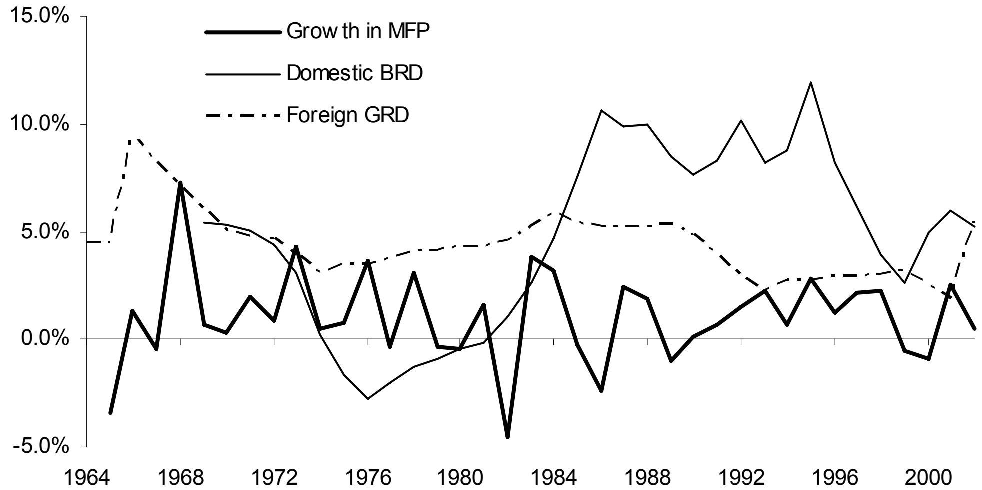
The productivity and BRD relationships in growth rates

The 1970s was a period of weak R&D investment in Australia (figure E.3). Assuming the perpetual inventory methodology and a depreciation rate of 15 per cent provides a reasonably accurate picture of the true and unobserved technological knowledge stock (at least that portion generated by R&D), the rate of investment was insufficient to offset depreciation and the stock declined. From the early to mid-1980s onwards, and particularly to the mid-1990s, growth in R&D investment was very strong, with *net* growth sustained at over 6 per cent per year.

Figure E.3 **Annual growth in MFP and R&D stocks, 1964-65 to 2002-03**

Stocks depreciated at 15 per cent





Financial years beginning 1 July of year specified.

Data sources: ABS (*Australian System of National* Accounts, Cat. no. 5204.0); ABS unpublished data; Commission estimates.

The strength of the long-run increase in R&D investment is not mirrored in MFP data as there is no equivalent increase in the rate of MFP growth. From 1968-69 to 2002-03, there does not appear to be a stable relationship between the rate of growth in R&D expenditure and MFP growth.

Foreign BRD grew at an above average growth rate from roughly 1978 to 1990. This was a period of weak MFP performance in Australia. The period of accelerating growth in foreign BRD coincided with a sustained period of weak growth in MFP in the late 1970s and early 1980s. The growth rate in foreign BRD dipped early in the 1970s, but then increased steadily right through to the mid-1980s. MFP growth was volatile, but overall it weakened during this period. Growth in foreign BRD then declined from the mid-1980s to 1993 before increasing again to around an average growth rate of 4 per cent per year for much of the 1990s. Foreign GRD shows an overall similar pattern, but it highlights the weakness in non-business foreign R&D in the 1990s, which was a period of improved MFP performance in Australia.

The simple plotting of the MFP and R&D growth patterns suggest, if anything, a negative relationship. However, this does not take into account other influences on MFP which, when controlled for, might show a positive relationship. It also does not take into lags in the accumulation of knowledge and innovation processes.

Bi-variate correlations between growth rates

The correlation between growth rates in Australian business R&D (BRD) are much higher with Australian higher education and government-performed R&D than they are with foreign BRD or gross expenditure on R&D (GRD) growth rates (table E.1). The equivalent correlations between the levels of the stocks are all 0.98 or greater given that the stocks are all strongly trending upwards.

Table E.1 **Pair-wise correlation coefficients between the growth rates of R&D stocks for the market sector[a]**

	Australian BRD	*Foreign BRD*	*Foreign GRD*	*Higher education*	*Government performed*
Australian BRD	1.00				
Foreign BRD	0.07	1.00			
Foreign GRD	0.03	0.62	1.00		
Higher education	0.63	-0.21	-0.29	1.00	
Government performed	0.45	-0.16	0.04	0.62	1.00

a Assumed decay rate for domestic and foreign BRD, and foreign GRD of 15 per cent. Foreign stocks ETM weighted. Assumed decay rate for Australian higher education and Government R&D of 10 per cent.

Sources: ABS (*Research and Experimental Development, Businesses,* Australia, Cat. no. 8104.0); ABS unpublished data; OECD (Analytical Business Enterprise Research and Development, ANBERD, database); Commission estimates.

The productivity and R&D intensity relationships

The general pattern of weak R&D investment in the 1970s followed by a period of very strong investment is also evident in the Australian BRD intensity series (figure E.4). Net additions to the Australian stock of BRD as a proportion of output recovered rapidly in the 1980s following the weak rates of investment in the 1970s (upper panel). The stock as a proportion of output was flat to declining for a long period before steadily rising from 1984 (lower panel). Net additions to the international potential spillover pool relative to Australian market sector output has remained quite stable.

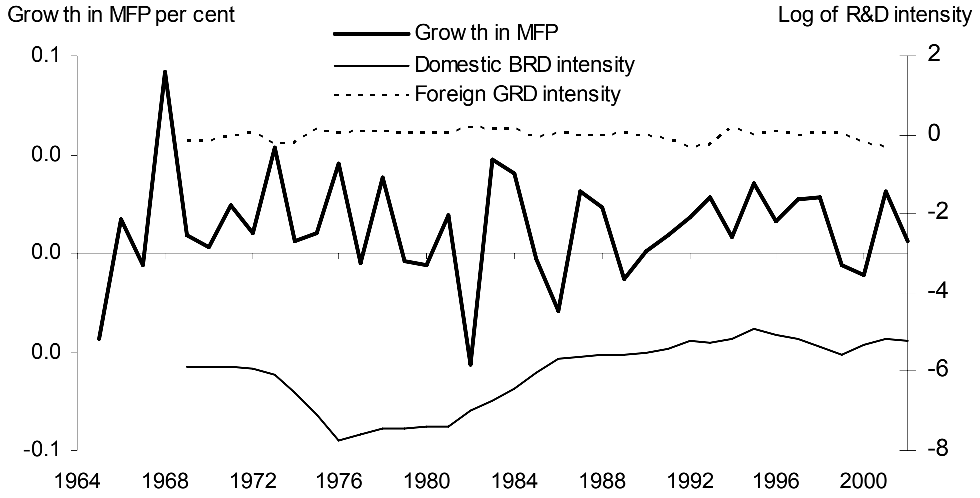
Compared with MFP, the intensity measures show very little year-to-year variation which may hinder the use of statistical techniques in identifying a casual relationship between productivity and R&D.

The decline and weak rates of accumulation in the stock of Australian business R&D during the 1970s and early 1980s might be viewed as a possible cause of weakening MFP performance during that period. The following sustained increases in rates of investment, with MFP responding after some lag in the 1990s, might be a possible cause of, or necessary as part of a process of, the improved performance of the 1990s.

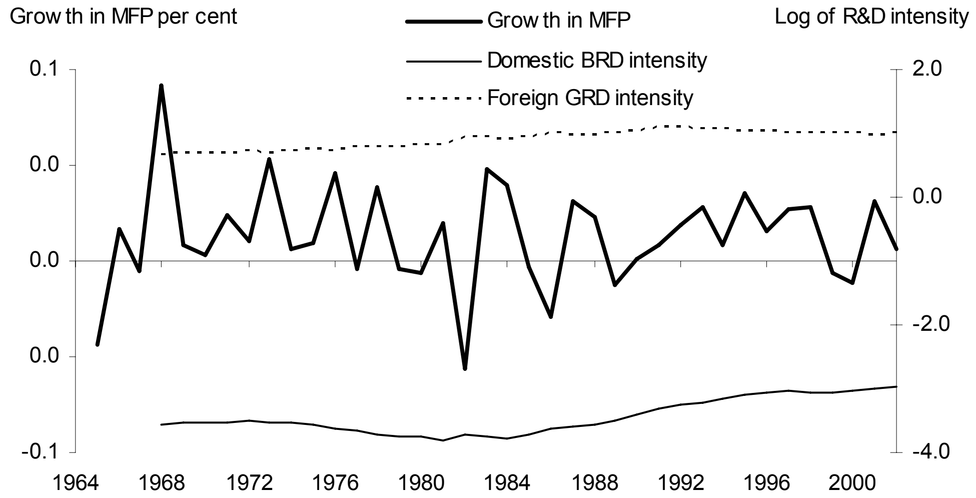
Figure E.4 **Annual growth in MFP and R&D intensity, 1964-63 to 2002-03**

Per cent per year

Intensity measured as ln(ΔK/Y)[a]



Intensity measured as ln(K/Y)[b]



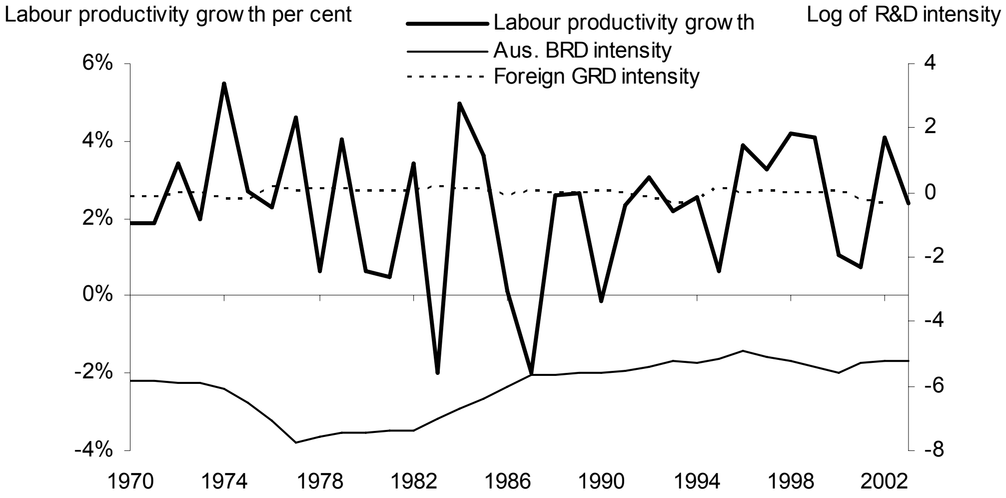
Financial years beginning 1 July of year specified. [a] Assumed decay rate for Australian BRD of 5 per cent, and foreign GRD of 15 per cent. [b] Assumed decay rates of 15 per cent.

Data sources: ABS (*Australian System of National* Accounts, Cat. no. 5204.0); ABS unpublished data; Commission estimates.

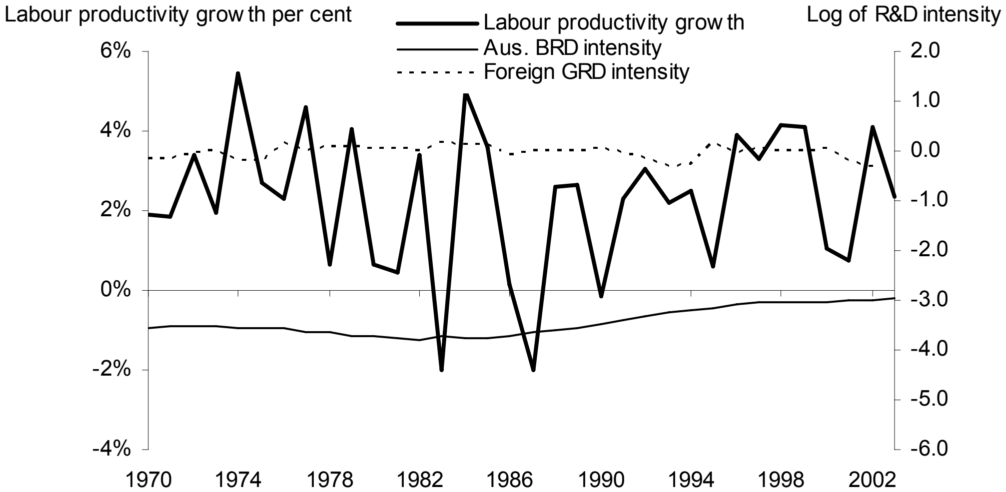
Labour productivity growth over the period 1968-69 to 2002-03 can be divided into two periods — a trend decline in growth rates until roughly the mid-1980s followed by a trend increase in rates thereafter (figure E.5). The decline and subsequence increase is correlated with the weak R&D investment until the early to mid-1980s followed by sustained higher rates of investment.

Figure E.5 **Growth in labour productivity and R&D intensity, 1970-71 to 2002-03**

Intensity measured as ln(ΔK/Y)[a]



Intensity measured as ln(K/Y)[b]



Financial years beginning 1 July of year specified. [a] Assumed decay rate for Australian BRD of 5 per cent, and foreign GRD of 15 per cent. [b] Assumed decay rates of 15 per cent.

Data sources: ABS (*Australian System of National* Accounts, Cat. no. 5204.0); ABS unpublished data; Commission estimates.

Bi-variate correlations between intensities

The pair-wise correlation coefficients for R&D intensities, measured as the level of the knowledge stock as a proportion of output, are all high (table E.2). Australian business R&D intensity is highly positively correlated with higher education R&D and negatively correlated with government-performed R&D.

Table E.2 **Pair-wise correlation coefficients for R&D intensity ln(K/Y)[a]**

	Australian BRD	*Foreign BRD*	*Foreign GRD*	*Higher education*	*Government performed*
Australian BRD	1.00				
Foreign BRD	0.66	1.00			
Foreign GRD	0.56	0.98	1.00		
Higher education	0.81	0.91	0.87	1.00	
Government performed	-0.79	-0.83	-0.75	-0.92	1.00

[a] Assumed decay rate for domestic and foreign BRD, and foreign GRD of 15 per cent. Foreign stocks ETM weighted. Assumed decay rate for Australian higher education and Government R&D of 10 per cent.

Sources: ABS (*Research and Experimental Development, Businesses,* Australia, Cat. no. 8104.0); ABS unpublished data; OECD (Analytical Business Enterprise Research and Development, ANBERD, database); Commission estimates.

The pair-wise correlation coefficients for R&D intensities, measured as the change in the knowledge stock as a proportion of output, are much lower than the correlations between the level of the stocks as a proportion of output (table E.3). Australian business R&D intensity is highly positively correlated with higher education R&D.

Table E.3 **Pair-wise correlation coefficients for R&D intensity ln(ΔK/Y)[a]**

	Australian BRD	*Foreign BRD*	*Foreign GRD*	*Higher education*	*Government performed*
Australian BRD	1.00				
Foreign BRD	0.36	1.00			
Foreign GRD	0.08	0.48	1.00		
Higher education	0.85	0.35	-0.20	1.00	
Government performed	0.13	-0.30	-0.03	-0.12	1.00

[a] Assumed decay rate for Australian business, Australian higher education, and Australian Government R&D of 5 per cent, and foreign BRD and GRD of 10 per cent.

Sources: ABS (*Research and Experimental Development, Businesses,* Australia, Cat. no. 8104.0); ABS unpublished data; OECD (Analytical Business Enterprise Research and Development, ANBERD, database); Commission estimates.

E.2 The time series properties of the data

Unit root tests and the order of integration

The R&D-based growth theories predict that R&D and productivity will track one another through time. Therefore, the R&D and productivity series will have the same order of integration, which can be established using unit root tests. The tests provide a formal method for discriminating between alternative predictions. However, the lower power of the tests with small samples, and the possibility of the presence of structural breaks, means that there is uncertainty about the true order of integration of the series.

MFP and labour productivity are I(1), meaning that the data must be differenced once to be made stationary (table E.4). The stock of Australian and foreign BRD are I(2) meaning that the growth rates of the series are not stationary. R&D intensity as the net accumulation in the knowledge stock as a proportion of output and its logged equivalent are I(1). R&D intensity as the knowledge stock as a proportion of output tested as I(2).

The presence of structural change in individual time series can impact on the findings of the unit root tests. A series of unit root tests allowing for various types of structural break were conducted on the productivity and R&D variables. The main result of the tests is that the introduction of structural breaks introduces a large degree of uncertainty about the true order of integration for each of the series.

Table E.4 **Unit root test[a] findings for the market sector, 1968-69 to 2002-03**
5 per cent decay rate used for ln(ΔK/Y) stocks. Assumed decay rate of 15 per cent for all other stocks.

	ln(X)	*Intensity ΔK/Y*	*Intensity ln(ΔK/Y)*	*Intensity ln(K/Y)*
MFP	I(1)			
Labour productivity	I(1)			
Australian BRD	I(2)	I(1)	I(1)	I(2)
Foreign GRD (ETM weights)	I(2)	I(1)	I(1)	I(1)

a The unit root tests included: the Augmented Dickey-Fuller (ADF) test: the Phillips-Perron test: the Kwiatowski, Phillips, Schmidt, and Shin (KPSS) 1992 test: and the Dickey-Fuller generalised least squares test. The selection of the lag length was undertaken using a combination of inspection of the correlogram, a testing down procedure and the following statistics provided by the Stata command 'findlag': mean squared error of the regression (RMSE); Akaike's Information Criterion (AIC); Amemiya's Prediction Criterion; and Schwarz's Information Criterion (SC).

Source: Commission estimates.

Tests indicated that the own-industry stock of BRD was I(2) for each of Manufacturing, Mining, Wholesale & retail trade, and Agriculture, forestry & fishing. The growth rates of MFP were stationary in each industry.

Table E.5 **Unit root test findings for the market sector industries, 1974-75 to 2002-03[a]**

Assumed decay rate of 15 per cent

	Manufacturing	*Mining*	*Wholesale & retail trade*	*Agriculture, forestry & fishing*
MFP	I(1)	I(1)	I(1)	I(1)
Industry BRD stock	I(2)	I(2)	I(2)	I(2)
Inter-industry BRD stock[b]	I(2)	I(2)	I(2)	I(2)

a see table E.4. **b** Weighted by inter-industry trade using input-output tables.

Source: Commission estimates.

One common feature of these variables (in log level) is that they are all highly trending. Thus, they are likely to be non-stationary. This is confirmed by the standard unit-root tests applied to these variables. Based on the tests, all the R&D stock variables are integrated of order two. While the presence of non-stationary variables in the regression calls for caution against spurious regression results, the linear combination of these non-stationary variables can still yield non-spurious estimates if they are co-integrated. Consequently, the residuals from the following regression equations have all been tested for non-stationarity.

It must be noted that the standard unit root tests have notoriously low power against the trend stationary alternatives, and the size of the sample being used in this study is relatively small. Thus, it is very difficult to reject the unit root hypothesis for the relatively short annual data under examination. Some researchers, for example, Connolly and Fox (2004), Rogers (1995) and Otto and Voss (1994), prefer not to use the unit root tests, and thus they do not consider the non-stationarity issue in their work using small sample time series data. In this study, the residuals are tested for non-stationarity in each industry-level regression model. However, the further step of estimating some forms of error-correction model is not taken because it critically depends on the results from unit-root tests.

Unit root tests allowing for structural breaks

The presence of structural change in individual variables can impact on the findings of unit root tests (Hansen 2001). This section extends the unit root testing above to allow for certain types of breaks.

Zivot and Andrews (1992) (ZA) developed a test which allows for a one-time break in the level, trend or level and trend of a series under the assumption that the break point is unknown prior to testing. The null hypothesis of the ZA unit root test[1] is a unit root process with drift that excludes structural change. The alternative hypothesis is a trend stationary process (TSP) that allows for a one-time break in the intercept, trend, or both. The ZA tests reject the presence of a unit root process in favour of a TSP process with a one-time break in trend for MFP, labour productivity and the stock of BRD. The integration findings for R&D intensity, foreign BRD and foreign BRD intensity are unchanged.

The Clemente, Montanes, Reyes (1998) test allows for a single or two structural break(s) in the mean of the variable. There are two versions of the test: the first is the additive outliers model which seeks to capture a sudden change in a series; and the second is the innovational outliers model which allows for a gradual shift in the mean of the series. The test results reported are for the innovational outliers model.

The main result of the innovational outliers model and ZA tests is that the introduction of structural breaks further complicates identifying the true order of integration for each variable. Allowing for breaks, and different types of breaks, can lead to very different conclusions about the order of integration of a time series (table E.6).

1 The null hypothesis of the Zivot and Andrews (1992) unit root test is a unit root process with drift that excludes structural change. The alternative hypothesis is a trend stationary process (TSP) that allows for a one-time break in the trend. The objective of the test is to estimate the breakpoint that gives the most weight to the trend-stationary alternative. The tests are undertaken using ADF-type tests.

Table E.6 **Unit root test findings for the market sector, 1968-69 to 2002-03**

Decay rate of 15 per cent applied to R&D stocks and. Critical values of 5 per cent used for tests. '*' denotes innovational outliers breaks not significant at 10 per cent.

	Unit root test: no breaks[a]	*ZA: single break in trend*[b]	*Innovational outliers: single structural break in mean*[c]	*Innovational outliers: two structural breaks in mean*[c]
MFP, log	I(1)	I(0), 1981	I(1), 1981*	I(1), 1977/81*
Labour productivity, log	I(1)	I(0), 1982	I(1), 1985*	I(1), 1981*/85*
Australian BRD -				
Stock ln(K)	I(2)	I(0), 1976	I(3), 1997*	I(3), 1988*/97
Intensity (ΔK/Y)	I(1)	I(1), 1977	I(1), 1994	I(1), 1976/94
Intensity ln(ΔK/Y) (5% dep'n rate)[d]	I(1)	I(0), 1981	I(0), 1980	I(1), 1975/94
Intensity ln(K/Y)	I(2)	I(2), 1985	I(1), 1983	I(1), 1983/95
Foreign GRD (ETM weights) -				
Stock ln(K)	I(2)	I(2)	I(1), 1993	I(2), 1981/89
Intensity (ΔK/Y)	I(1)	At least I(3)	At least I(3)	At least I(3)
Intensity ln(ΔK/Y)	I(1)	I(2), 1980	I(2), 1991	At least I(3)
Intensity ln(K/Y)	I(1)	I(0), 1976	I(1), 1990	I(1), 1981*/90

[a] The unit root tests included: the Augmented Dickey-Fuller (ADF) test; the Phillips-Perron test; the Kwiatowski, Phillips, Schmidt, and Shin (KPSS) (1992) test; and the Dickey-Fuller generalised least squares test. The selection of the lag length was undertaken using a combination of inspection of the correlogram, a testing down procedure and the following statistics provided by the Stata command 'findlag': mean squared error of the regression (RMSE); Akaike's Information Criterion (AIC); Amemiya's Prediction Criterion; and Schwarz's Information Criterion (SC). [b] Zivot and Andrews (1992). Null is a unit root process with drift. The alternative hypothesis is a trend stationary process with a one-time break in trend. [c] Clemente, Montanes, Reyes (1998) test. [d] Unit root test on sample from 1973.

Source: Commission estimates.

Implications for the predicted long-run relationships

This section contrasts the orders of integration of the key productivity and R&D variables and considers implications for the predicted long-run relationships. The comparisons do not take into account structural breaks which, as seen above, can introduce significant uncertainty as to the true order of integration of some of the series.

It is difficult to pin down the true order of integration of the individual series. The low power of unit root tests, the sensitivity of unit root tests to lag length selection, and the possible presence of one or more structural breaks in mean, trend, or both mean and trend, introduces uncertainty as to the true order of integration of the individual series.

All of the empirical models would appear to involve mismatches in the order of integration between the dependent and explanatory variables and/or between the explanatory variables themselves (table E.7). It is possible that Australian BRD and foreign GRD may be co-integrated, which would lower the combined order of integration for the explanatory variables. Co-integration is tested in chapter 7.

The Jones prediction requires that both MFP and the stock of BRD be I(1) so that the growth rates are stationary. This condition may hold, but the unit root tests, at least prior to the consideration of structural breaks, provide support for the R&D stocks being I(2) variables. The rate of growth in the stock of business R&D is markedly different in the period prior to and after the early to mid-1980s.

The Young prediction requires that growth in MFP be stationary (in other words, the level of MFP is I(1), which it is) and the level of R&D intensity also be stationary or I(0). However, both Australian and foreign GRD intensities have been rising are I(1).

For both the Young and Howitt models, there may be less likelihood of achieving robust results where intensities are constructed as the knowledge stock over output. Australian BRD is I(2) and foreign GRD is I(1). For the models where intensities are constructed as the net growth in the knowledge stock over output, both intensities are I(1).

The Howitt prediction implies that a constant R&D intensity can result in steadily rising labour productivity. R&D intensity has not been constant, but has been increasing. This would lead to an expectation that the rate of growth in labour productivity is accelerating until such time as long-run equilibrium is restored (when R&D intensity is constant). This implies that labour productivity would be at least I(2) which is not supported by any of the tests.

Table E.7 **Implications of the unit root tests for the long-run relationships**[a]

Not including consideration of structural breaks

		Matching orders of integration?		
Model[b]	*Long-run relationship*	*Dependent variable*	*Australian BRD*	*Foreign GRD*
Levels	$\ln(MFP_t) = \ln(K_t)$	I(1)	I(2)	I(2)
Direct Rate of Return	$\Delta\ln(MFP_t) = \frac{K_t - K_{t-1}}{Y_t}$	I(0)	I(1)	I(1)
Jones	$\Delta\ln(MFP_t) = \Delta\ln(K_t)$	I(0)	I(1)	I(1)
Young	$\Delta\ln(MFP_t) = \ln(\frac{K_t - K_{t-1}}{Y_t})$	I(0)	I(1)	I(1)
Young	$\Delta\ln(MFP_t) = \ln(\frac{K_t}{Y_t})$	I(0)	I(2)	I(1)
Howitt	$\Delta\ln(LP_t) = \ln(\frac{K_t - K_{t-1}}{Y_t * hrs})$	I(0)	I(1)	I(1)
Howitt	$\Delta\ln(LP_t) = \ln(\frac{K_t}{Y_t * hrs})$	I(0)	I(2)	I(1)

a Orders of integration are usually made with reference to the level of the variable. For example, the level of MFP is I(1) meaning that it needs to be differenced once to be made stationary. In the table, if a growth rate is stationary, it is labelled I(0). Foreign GRD is weighted by Elaborately Transformed Manufactures. Intensity calculated as weighted foreign GRD stock or change in stock over Australian market sector Gross Value Added. **b** As discussed in chapter 2.

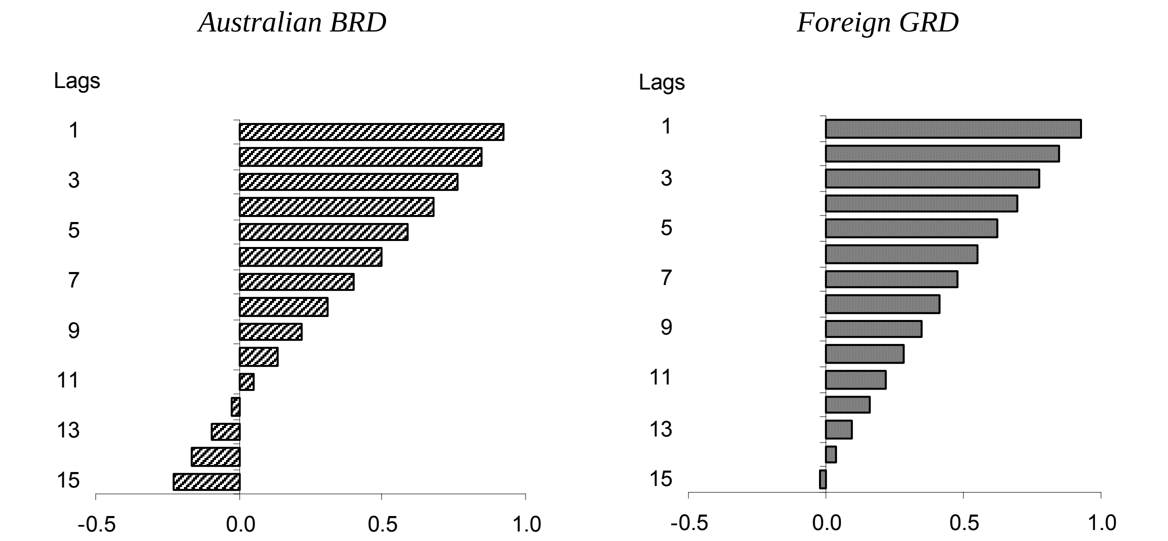
Source: Commission estimates.

Persistence in R&D expenditure

Multi-collinearity can limit the ability of distributed lag models to identify individually statistically significant lags, although estimates of the long-run impact should be unaffected. The correlogram shows the degree of persistence or autocorrelation in the R&D stocks (figure E.6). Prior-period values are highly autocorrelated with the contemporaneous stock, with the coefficient on the fifth lag greater than 0.5 for both stocks.

Figure E.6 **Autocorrelations in the stock of Australian BRD and foreign GRD, 1968-69 to 2002-03**

Stocks depreciated at 15 per cent



Data sources: ABS (*Research and Experimental Development, Businesses,* Australia, Cat. no. 8104.0); ABS unpublished data; OECD (ANBERD database); Commission estimates.

E.3 Weak evidence of a co-integrating relationship

The unit root testing and comparison of the orders of integration in the long-run relationships indicated that the regressions would probably involve mixed orders of integration. Variables which are integrated of a different order will diverge by ever-larger amounts, rather than tending to revert to one another. However, mixed orders of integration between the dependent and explanatory variables does not necessarily rule out co-integration as the explanatory variables may be jointly co-integrated, altering the integration of the combined explanatory variables. For example, in the basic ln(MFP) models, the R&D stocks are probably I(2) while MFP is I(1). It is possible that Australian business R&D stock and foreign or gross R&D stocks are co-integrated, which could allow the overall model to produce reliable estimates of the long-run effect of R&D.

Formal testing for co-integration of the long-run levels relationships provides no support for co-integration. Tests indicated that the level of MFP is not co-integrated with either of the business R&D stocks individually, and that the R&D stocks are not mutually co-integrated. Alternative weighting schemes for the foreign stocks did not alter the results of the tests. The stock of Australian GRD is also not individually co-integrated with MFP or with international GRD. Tests also indicate that the variance of the error term was not constant over time.

The lack of a strong equilibrating relationship in the data between productivity and R&D variables is the source of the residual serial correlation problem in the basic levels models. The result is probably not surprising given:

- the relatively short time series;
- the significant amount of change which has taken place in the Australian economy which could be expected to have impacted on structural relationships between R&D and productivity, making the identification of a permanent or long-run effect difficult;
- the heavy reliance which is placed on the construction of the knowledge stock, particularly the linear accumulation methodology of the perpetual inventory method (PIM), the assumed rate at which appropriable revenues decay, and the aggregation of so many different types of knowledge into a single stock; and
- the low power of statistical tests to identify unit roots, which places uncertainty on identification of the true order of integration (particularly once tests start to allow for breaks).

The residuals of the basic productivity growth model relationships were also tested for stationarity using the Augmented Dickey-Fuller test. As the productivity variables are differenced and the R&D variables are either differenced or in intensities, the underlying data may be I(0) in which case the identification of the long-run effect does not rely on a co-integration interpretation.

The tests indicated that a regression of the various relationships produced stationary errors, except for the relationship between Australian BRD and foreign GRD. Tests were also undertaken for foreign BRD without changing the results (table E.8).

Table E.8 **ADF tests for stationary residuals[a], 1968-69 to 2002-03**
Foreign stock weighted by import shares

Long-run relationship ln(MFP) = ln(K)	*Residuals stationary?*	*Long-run relationship Δln(MFP) = Δln(K)*	*Residuals stationary?*
BRD = Foreign BRD	No	ΔBRD = ΔForeign GRD	No
MFP = BRD	No	ΔMFP = ΔBRD	Yes
MFP = Foreign BRD	No	ΔMFP = ΔForeign GRD	Yes
MFP = BRD + Foreign BRD	No	ΔMFP = ΔBRD + ΔForeign GRD	Yes
Model BL1 with cycle	No	Model J1	Yes
Long-run relationship - Δln(MFP) = ln(ΔK/Y)	*Residuals stationary?*	*Long-run relationship - Δln(LP) = ln(ΔK/Y)*	*Residuals stationary?*
BRDint = Foreign GRDint	No	BRDint = Foreign GRDint	No
ΔMFP = BRDint	Yes	ΔLP = BRDint	Yes
ΔMFP = Foreign GRDint	Yes	ΔLP = Foreign GRDint	Yes
ΔMFP = BRDint + Foreign GRDint	Yes	ΔLP = BRDint + Foreign GRDint	Yes
Model Y2	Yes	Model H2	Yes

[a] Augmented Dickey-Fuller tests were used to test the residuals of each regression. Test statistics were compared with the adjusted critical values from Davidson and MacKinnon (1993, p. 722). The test is whether the unit root was rejected at 5 per cent or greater.

Source: Commission estimates.

E.4 Expectations of a long-run relationship between Australian business R&D and foreign R&D

The testing for co-integration of the relationship between Australian BRD knowledge stocks and foreign knowledge stocks did not support co-integration, irrespective of whether the relationship is specified in levels, growth rates, or intensity levels. The difference between the stocks is not stationary over the available time period. The tests for co-integration are in large part a test of co-integration of Australian business R&D investment with US investment as US R&D expenditures heavily influence the total expenditure of the fourteen countries used in the construction of the foreign knowledge stocks.

There are at least two broad mechanisms through which foreign R&D affects the incentives facing Australian businesses to undertake R&D which would support an expectation of a long-run relationship between Australian business investment and foreign investment in R&D.

- *Competition*: Australian firms compete with foreign firms in both domestic and export markets. The R&D of foreign firms is undertaken to support the competitive strategies of those firms, including whether they adopt a strategy of competing through some combination of price competitiveness (with a focus on cost minimisation), improving the quality of existing products, and introducing new products. Competitive responses by Australian firms could be expected to lead to changes in their demand for the various inputs to the innovation process, including R&D.

- *Technological opportunities and knowledge spillovers*: foreign R&D which increases the world stock of knowledge alters the potential knowledge transfer pool for Australian firms. Foreign knowledge can be both a substitute for or a complement to domestic R&D investment. However, the technological opportunities provided by foreign R&D would lead to an expectation that the net long-run effect would be to increase businesses' demand for R&D in Australia (see chapters 9 and 10 for a further investigation of the relationships between foreign R&D and domestic business R&D).

A number of factors could impede or weaken a long-run relationship between Australian business investment in R&D and foreign R&D.

- Specialisation in low R&D intensity industries linked to cross-country patterns of trade and comparative advantage.
- Policy settings which seek to insulate domestic firms from changing market conditions which are being driven, in part, by the innovative activities of foreign firms.
- Differences in the institutional composition of gross expenditure on R&D in Australia versus the average of other countries. The larger share of higher education and government-performed R&D in Australia (see appendix G) might mean that these sectors play a relatively larger role in the absorption of overseas technology, and the transfer of technology to the private sector, than is common in the OECD. This might weaken any direct relation between business R&D and overseas R&D.
- Differences in the 'production technology' of innovation. There are many different inputs to the innovation process and there may be scope for substitution opportunities as well as complementarities between inputs. To achieve a given innovation, firms may be able to choose different bundles of inputs — depending on their relative prices, which is partly dependent upon their capabilities — where R&D plays a lesser or greater role. An example is where there are substitution possibilities between performing R&D and sourcing new technological knowledge externally.

E.5 Parameter stability tests

Parameter stability in the basic market sector models

To check whether the estimated coefficients on Australian BRD are stable or whether they vary over sub-samples of the data, the basic models of chapter 6 were recursively estimated (figure E.7). The first observation in each chart represents the coefficient estimate from a regression using all available observations. The second point is from a regression of all observations dropping the first observation. The third point is from a regression of all observations after dropping the first two observations and so on. All of the regressions include 2002-03. Therefore, coefficient estimates further to the right are based on fewer observations. For example, the coefficient for 1990-91 is based on a regression including 13 observations for the sample period 1990-91 to 2002-03. An alternative methodology would be to set a fixed 'window' of a certain number of observations and move it through the sample.

The coefficient on Australian business R&D in model BL1 is 0.055 for the full regression period 1969-70 to 2002-03 (the initial value for Australian business R&D is the lagged 1968-69 value). Then, as the sample is reduced by successively dropping the earliest observation from the regression, the estimate of the coefficient steadily increases. The same general pattern of an increasing coefficient is evident in models J1 and H2. In model BL1, the coefficient remains fairly steady until observations from the early to mid-1980s begin to be dropped from the sample. The 95 per cent confidence interval does not encompass zero or negative values.

The instability of the parameters in model BL1 points to a lack of robustness in the model as different elasticities can be obtained purely by picking the time period to include in the regressions. Given the known non-stationarity of the data and the strong residual serial correlation in the model, very little confidence can be attached to the estimates from model BL1.

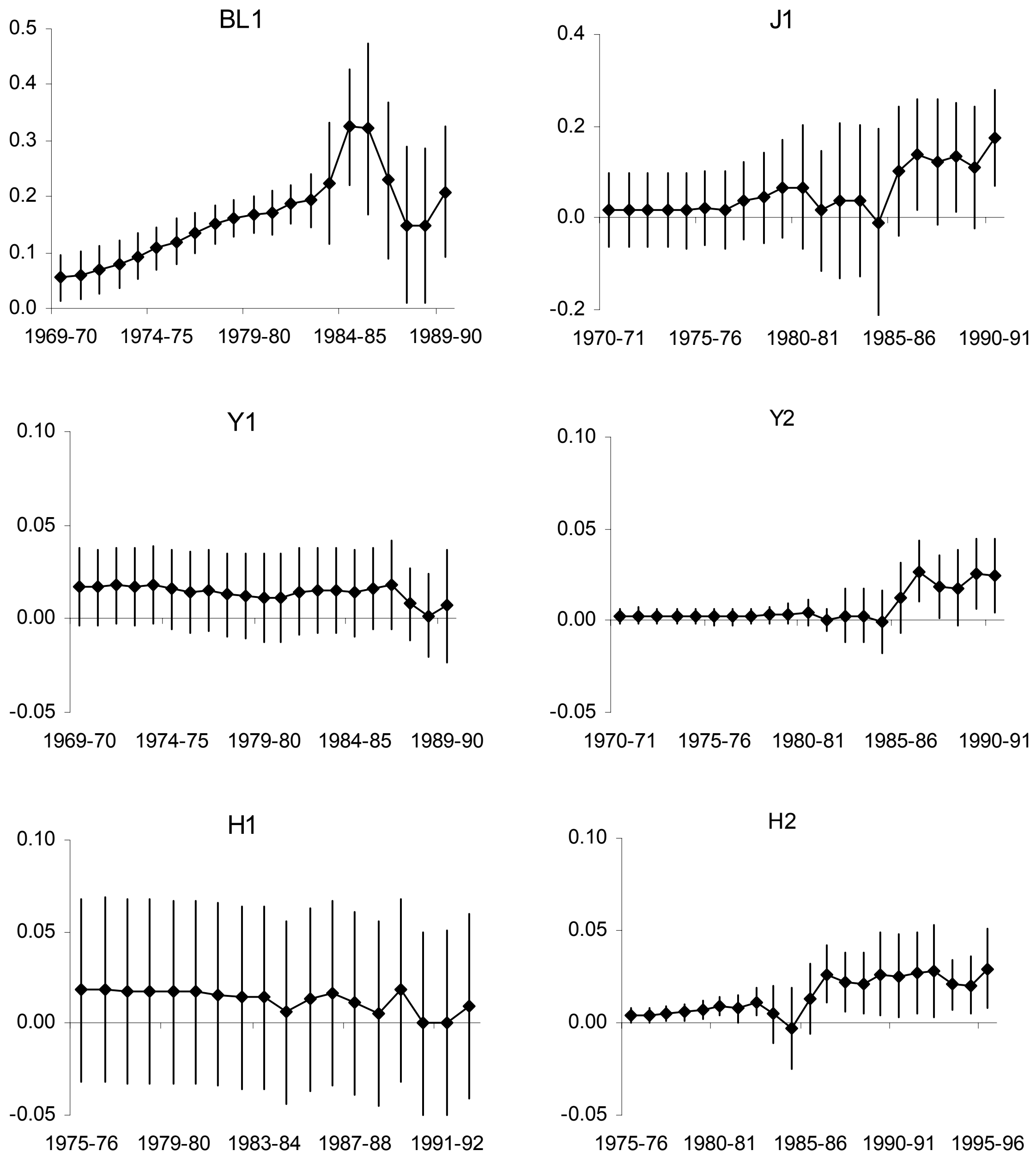
The coefficient estimates from the productivity growth models are more stable, but their 95 per cent confidence intervals generally encompass an estimate of zero.

The stability of the coefficient on Australian business R&D in the basic models varies by model, but a common feature is that, as the observations prior to roughly 1982-83 are removed from the sample, the coefficient moves strongly (except in models Y1 and H1). The period 1982-83 to 1985-86 is when business R&D investment accelerated rapidly. Models H1 and Y1, where intensity is defined as the knowledge stock over output, do not show this pattern.

Except for model BL1, earlier point estimates tend to fall within the confidence band of later period estimates. Therefore, there is not clear evidence of parameter instability, but this is a result of imprecisely estimated parameters.

Figure E.7 **Stability of the coefficient on Australian business R&D in the basic models**

Regression sample successively shortened by dropping the earliest observations. 95 per cent confidence interval shown.



Data source: Commission estimates.

Parameter stability in the extended ln(MFP) market sector models

Tests of the stability of the estimated coefficients for model L1 from chapter 7 show that, as observations are successively dropped, beginning with 1969-70, the magnitude of the coefficient estimate for Australian BRD is stable up until about 1984-85 (figure E.8, top row, right-hand panel). As the observations in the mid-1980s are removed, the coefficient spikes upward sharply and the standard errors widen dramatically. Although the graph gives the impression that the coefficient on Australian BRD is estimated reasonably well until observations from the mid-1980s begin to be dropped, the lower and upper bound of the confidence interval translates into a very wide band on the implied rate of return to BRD.

In general, the imprecision of the estimates — the wide confidence intervals — make it difficult to say with certainty that the partial effect of a parameter is increasing or decreasing over time because the confidence intervals from different sample periods overlap.

If model L1 is re-estimated with the stock of Australian BRD depreciated at 5 per cent rather than 15 per cent, then the coefficient is slightly better estimated, but it follows the same pattern (bottom row, right-hand panel).

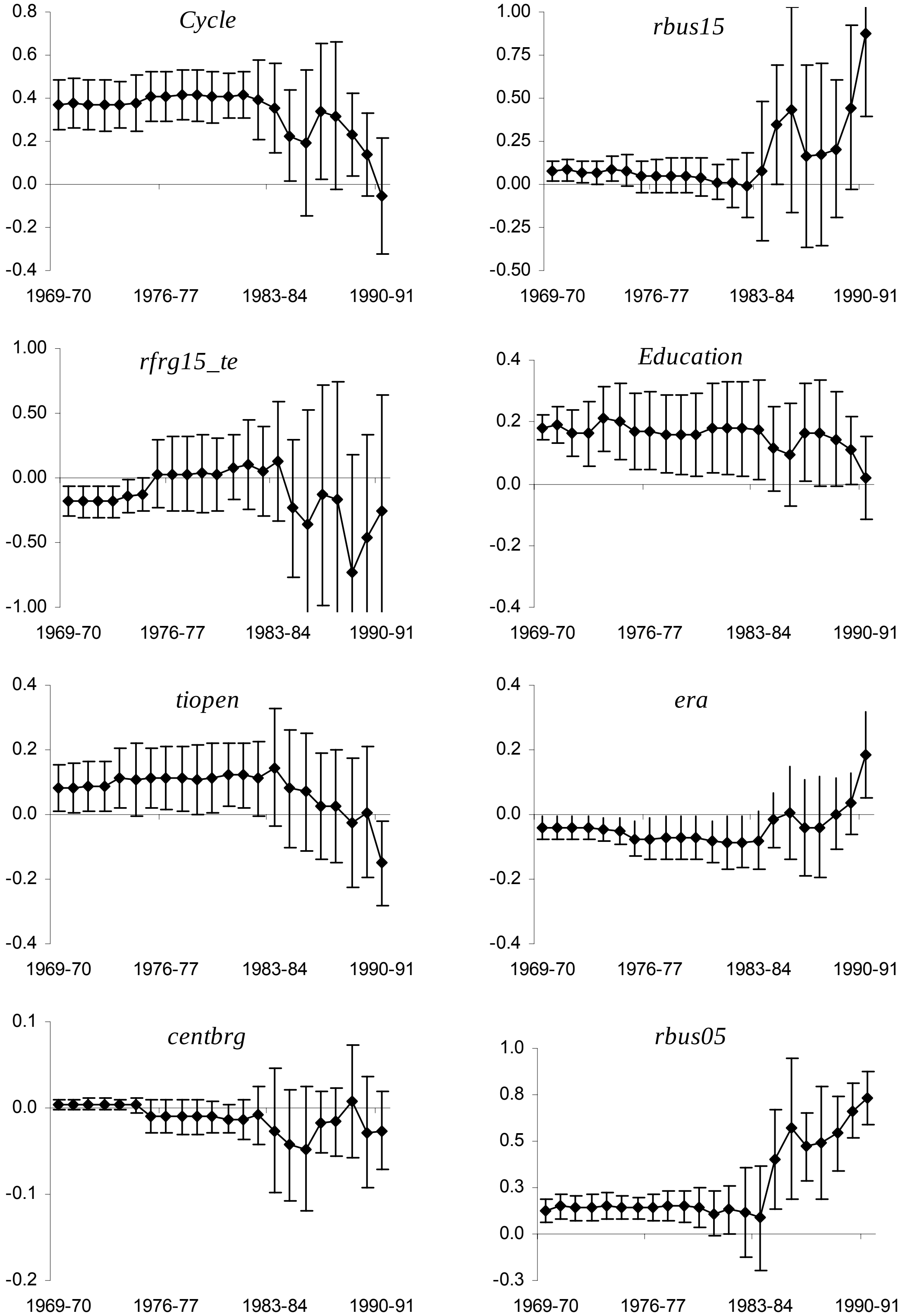
The final observation for each of the graphs is based on a regression covering the period 1990-91 to 2002-03 only. With fewer and fewer observations, the confidence intervals naturally widen. However, the graphs clearly show a sharp increase in instability in the R&D coefficients as the regression is based on post-1984 data.

CUSUM tests are presented for both the sum of the residuals test and the squares of the residuals test. The sum of the residuals test detects a systematic structural break in the model. The squares of the residuals test detects “haphazard” breaks. Compared with Chow tests, CUSUM tests do not require prior specification of the date of the structural break, but the power of the tests is lower.

CUSUM tests are shown for the two basic ln(MFP) models BL3s and BL4, as well as the extended model L1. The tests do not detect either systematic or haphazard breaks (the test does not cross either the upper or lower boundaries) (figure E.9).

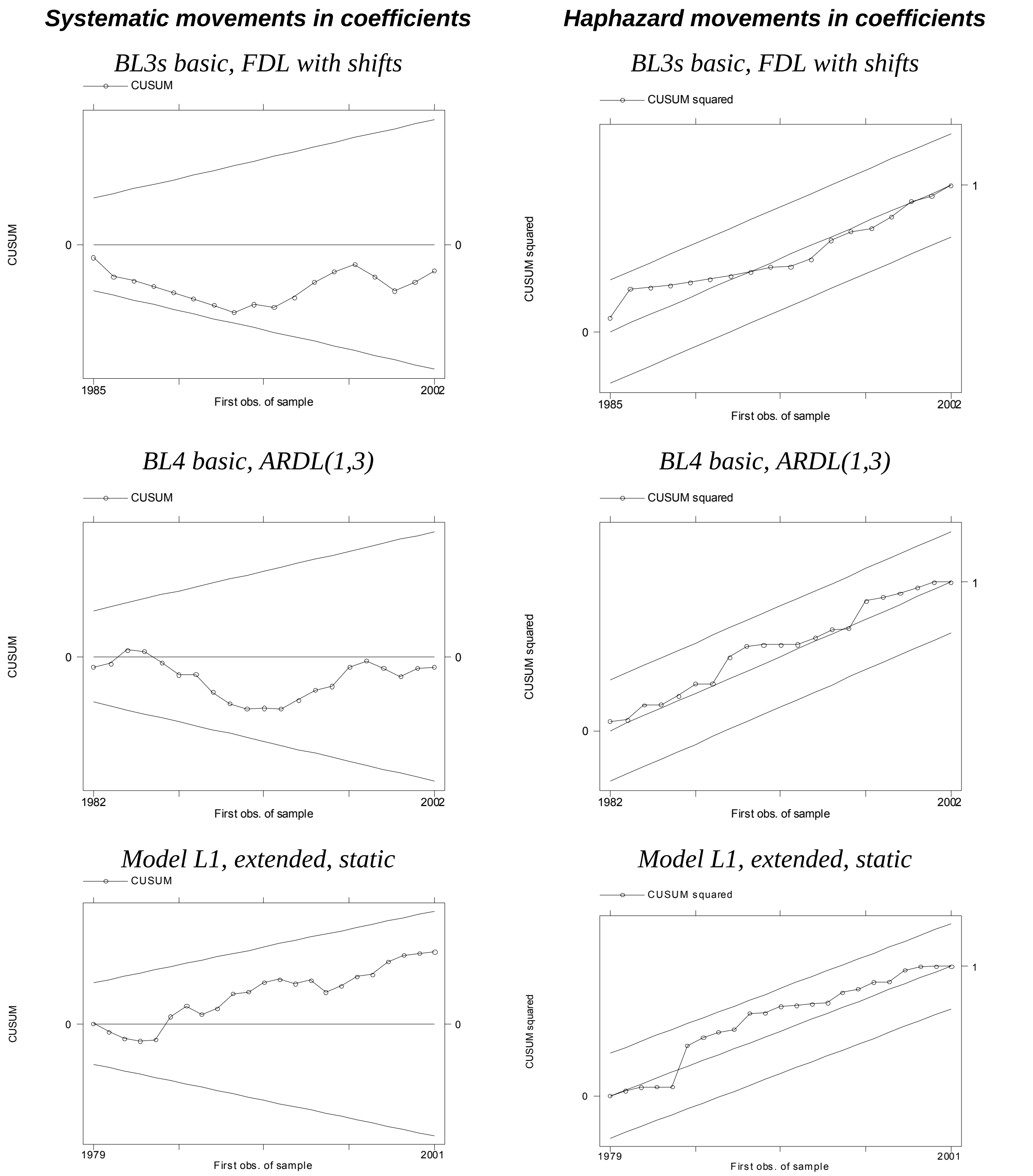
Figure E.8 **Stability of coefficients for model L1**

Regression sample successively shortened by dropping the earliest observations. 95 per cent confidence interval shown.



Data source: Commission estimates.

Figure E.9 **CUSUM tests for market sector ln(MFP) models**



Data source: Commission estimates.

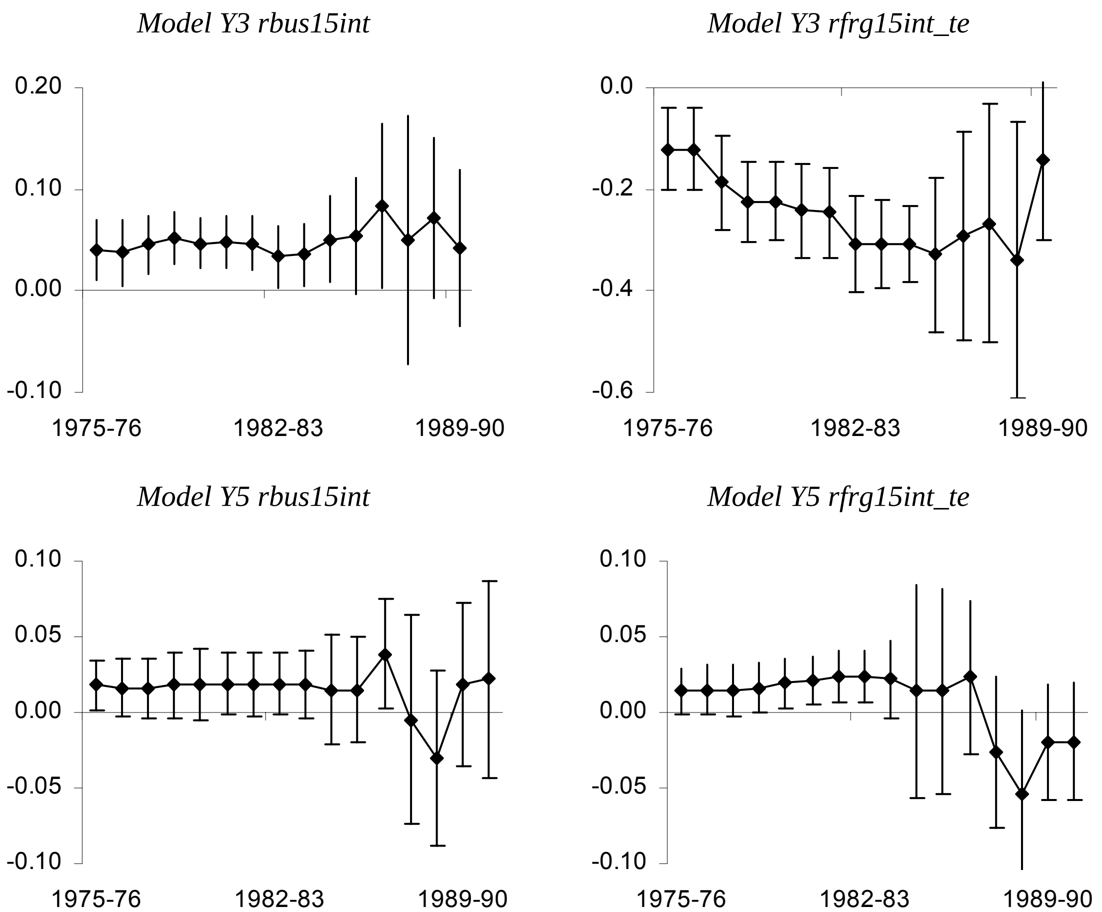
Parameter stability in the productivity growth models

The estimated coefficients on Australian business R&D in models Y3 and Y5 from chapter 7 are reasonably stable (figure E.10). Model Y3 investigates the relationship between MFP growth and the level of the knowledge stock as a proportion of output. Model Y5 investigates the relationship between MFP growth and growth in the knowledge stock as a proportion of output. Both models are extended to include a range of control variables. For model Y5, the lower bound of the confidence interval generally encompasses an estimate of zero. The foreign coefficient in model Y5 is more stable than in model Y3 and is of the expected sign up until the end of the series.

The CUSUM tests do not detect clear breaks in the MFP growth models.

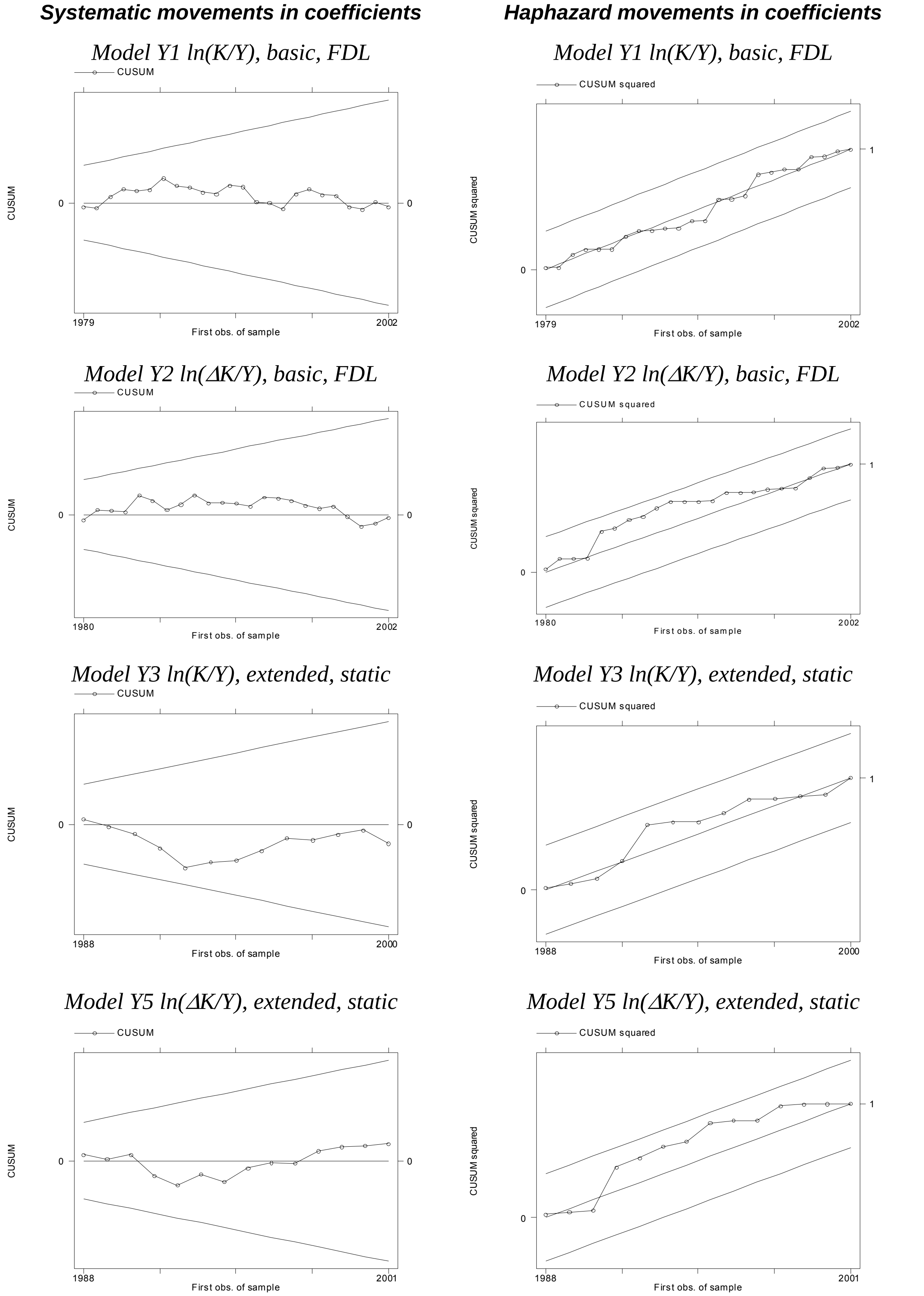
Figure E.10 **Stability of R&D coefficients for model Y3 and Y5**

Regression sample successively shortened by dropping the earliest observations. 95 per cent confidence interval shown.



Data source: Commission estimates.

Figure E.11 **CUSUM tests of MFP growth models**



Data source: Commission estimates.

Parameter stability in the two-equation system models

Recursive estimation of the system models is severely restricted by the number of observations available. In most models, relatively few observations can be dropped before there is insufficient observations to estimate the model.

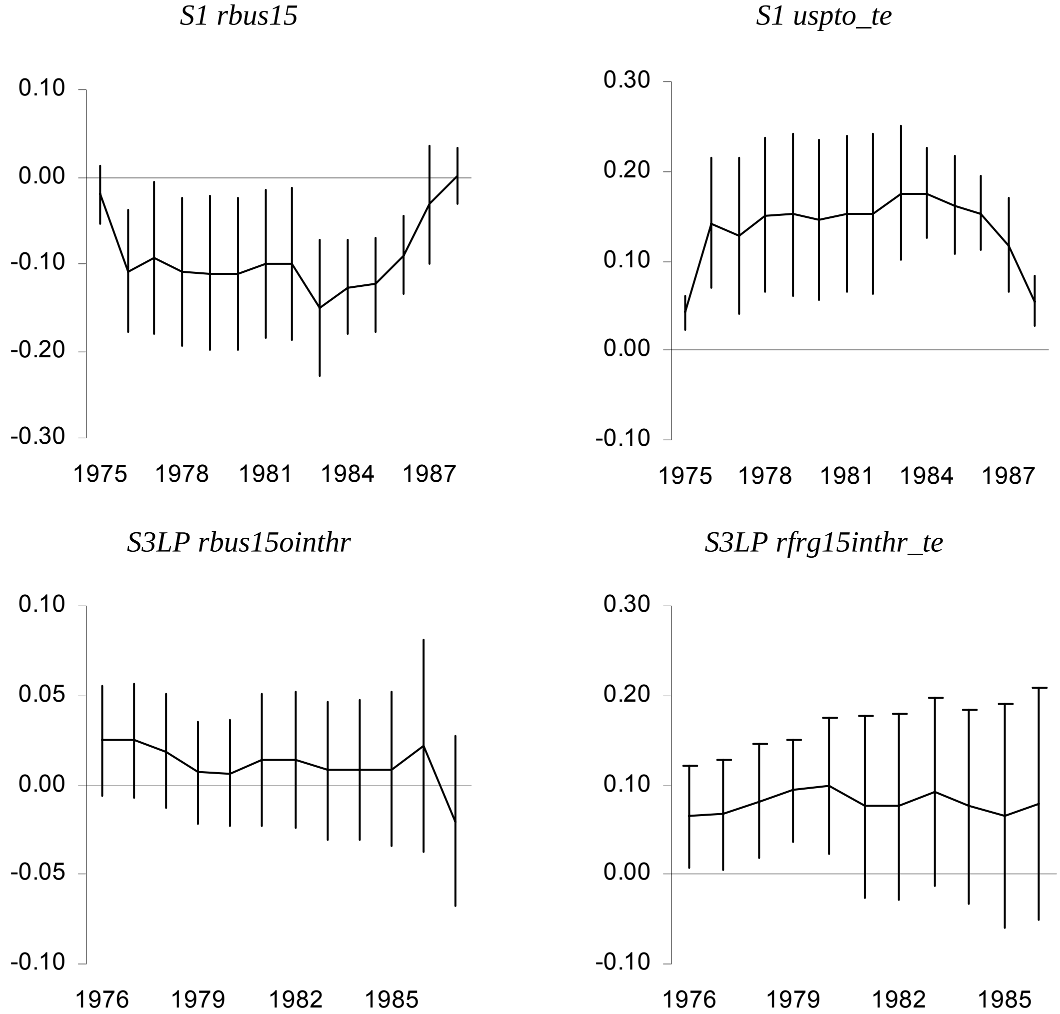
Model S1 was recursively estimated with the variable USPTO patents granted included in the regression in place of the knowledge stock (figure E.12). At the beginning of the sample, the partial effect of Australian business R&D is slightly negative and insignificant, and the coefficient on USPTO patents is positive and significant. As observations are dropped from the front of the sample, the coefficient on Australian BRD becomes more negative and significant, while the effect of USPTO patents becomes more positive. As the observations from the mid-1980s are dropped, the coefficients appear to be tending back towards zero.

Model S1 investigates the long-run relationship between the level of MFP and the level of the knowledge stocks. Separate testing of a quadratic relationship often produced profiles of the total effect of Australian BRD which was initially negative in the 1970s, followed by a transition period to a strong positive effect in the latter half of the sample. This pattern of 'negative to positive' has been observed in the testing of other models and is discussed in appendix O.

The parameters on the effect of Australian BRD and gross foreign R&D on labour productivity are stable as the regression is sequentially shortened. Both effects are positively signed. However, the bottom of the confidence intervals usually take in an estimate of zero.

Figure E.12 **Stability of the coefficient on Australian own-financed business R&D and foreign R&D in the system models**

Regression sample successively shortened by dropping the earliest observations. 95 per cent confidence interval shown.



Data source: Commission estimates.

F Construction of the foreign knowledge stocks

Fourteen countries were included in the construction of the foreign knowledge stocks, including: Canada; Denmark; Finland; France; Germany; Ireland; Italy; Japan; Netherlands; Norway; Spain; Sweden; United Kingdom; and the United States. The perpetual inventory method (PIM) was used for construction of the stocks with various weighting schemes used in aggregating stocks across countries.

F.1 The 'potential' spillover pool

Empirical studies which use stocks combine the R&D activity of a set of countries or industries into a single explanatory variable. This is done in response to degrees of freedom constraints in the regressions and the impact of multi-collinearity on the precision of estimates, as R&D time series across countries and industries tend to have common upward trends.

An unweighted aggregation procedure implicitly assumes that the technological knowledge obtained from a dollar of R&D in country *x* is equally as relevant to Australia as that obtained for a dollar of R&D in country *j*. The 'potential' spillover pool is obtained by summing all stocks equally.

Various weighting mechanisms can be employed to capture the idea that the R&D generated knowledge of different countries is not equally relevant to Australia. The selection of the weighting mechanism is a search for the factors that drive these differences in 'relevance'. Some of the factors include: a common language; bilateral trade patterns; similarities in industry structure; similarities in the concentration of R&D expenditures by research field; similarities in the concentration of patenting activity by technology class; and foreign direct investment relationships.

Embodied and disembodied knowledge

Griliches (1979) identifies two main types of externalities created by R&D activities.

- *Rent* spillovers: When inputs are purchased by firms at less than their full quality adjusted price, due to, for example, the presence of competitive pressures in imperfectly monopolistic markets, there is a 'rent' transfer from the innovating firm to the purchasing firm. If innovating firms could perfectly discriminate, output prices would reflect the full additional value of the embodied quality improvements. In the case of imported inputs by Australian firms, a rent spillover is a real benefit to Australia.
- *Knowledge* spillovers: These arise because of the imperfect appropriability of knowledge arising from innovation. They occur when ideas or knowledge are 'borrowed' by one firm from another without the transfer of knowledge being necessarily related to an economic transaction. The borrowed knowledge contributes to the innovation processes of the borrowing firm. They occur across institutional sectors, industries, and countries.[1]

Rent spillovers are due to the mismeasurement of economic transactions. They compound the difficulty of properly identifying pure price change from quality change in the formulation of price indexes and construction of volume estimates of inputs to the production process.

van Pottelsberghe (1997) distinguishes between three different channels through which economic transactions can result in rent spillovers: input-related rent spillovers; investment-related rent spillovers; and patent-related rent spillovers (for example, patent licensing) (figure F.1). Whether a rent spillover eventuates depends on the transaction price charged by the innovation producing firm.

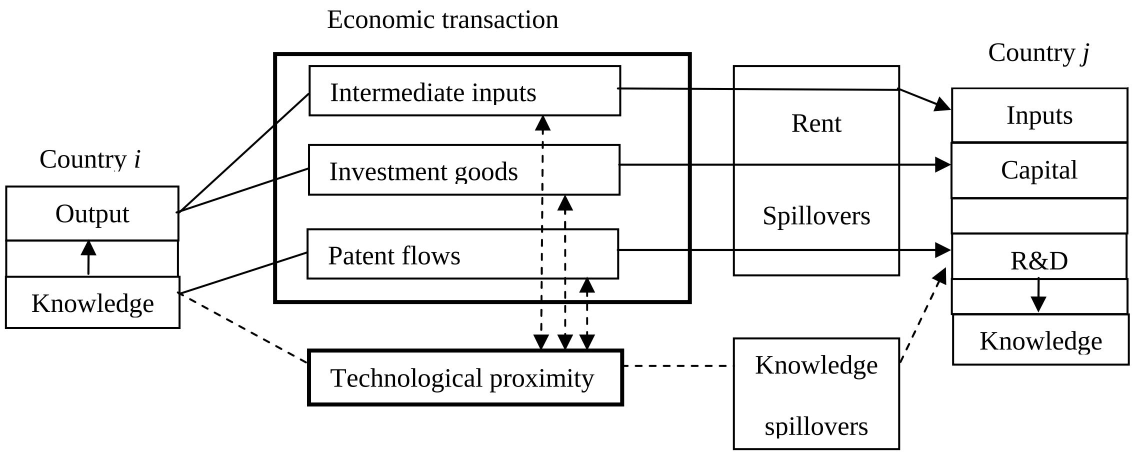
Intermediate inputs and patent flows are most clearly linked with embodied knowledge. Technological proximity is associated with disembodied knowledge spillovers.

To the extent that both types of spillovers are identifying an increment to the stock of knowledge in Australia, both types of spillovers can have effects on productivity growth. Rent spillovers represent a welfare gain to Australia.

[1] Cincera (2005) and Cincera and van Pottelsberghe (2001).

Figure F.1 **Distinction between rent and knowledge spillovers**

R&D spillovers associated with economic transactions.



Data source: van Pottelsberghe (1997).

However, the distinction between the different types of spillovers is empirically difficult to disentangle:

> If the distinction between the two spillover concepts appears to be clear-cut from the analytical point of view, it is likely to be more ambiguous conceptually, or once an empirical analysis is to be implemented. The ambiguity is due to the fact that it is a difficult task to dissociate empirically rent spillovers from knowledge spillovers. Two reasons lie behind this empirical barrier. First, rent spillovers are approximated through economic transactions which may also be associate to – or imply – some knowledge transfers. Second, the two types of R&D spillovers might not be combined but their respective profiles across industries [or countries] might be similar. Therefore, since each type of R&D spillover is estimated under a common econometric procedure, serious collinearity bias might emerge. This may explain, at least partly, why very few studies try to distinguish rent from knowledge spillovers, preferring to rely on the broader concept of R&D spillovers. (van Pottelsberghe 1997, p. 157)

Both types of spillovers would appear to play some role in contributing to further increments to the Australian knowledge stock either directly or by motivating secondary innovation processes to adapt, imitate or create complementary assets.

Using trade shares as weights

There are a number of different methodologies for constructing trade weighted foreign knowledge stocks (box F.1).

Box F.1 **Alternative trade weighting methodologies**

Coe and Helpman (1995) measure the foreign R&D capital stock for a country as the sum of every other country's R&D capital stock weighted by bilateral import shares. The underlying assumption is that trade is a mechanism which disseminates knowledge between countries.

$$K_{it}^{F} = \sum_{j \neq i} \frac{m_{ijt}}{m_{it}} \bullet K_{jt} \qquad \text{"[var]\_td"} \qquad \text{(F1)}$$

where K_{it}^{F} is the foreign knowledge stock of country *i* at period *t*, m_{ijt} is the imports of country *i* from country *j*, m_{it} is country *i's* total imports, $\frac{m_{ijt}}{m_{t}}$ is the import share of country *j* in country *i's* imports, and K_{jt} is the knowledge stock of country *j*. The weights sum to one.

Their preferred specification scales equation (F1) by country *i's* import intensity on the assumption that a country's level of imports relative to its GDP affects the benefits a country receives from foreign R&D:

$$K_{it}^{F} = \frac{m_{it}}{y_{it}} \sum_{j \neq i} \frac{m_{ijt}}{m_{it}} \bullet K_{jt} \qquad \text{"[var]\_tch"} \qquad \text{(F2)}$$

where $\frac{m_{it}}{y_{it}}$ is country *i's* total imports over its GDP ratio.

Lichtenberg and van Pottelsberghe (1998) identify two problems with equations (F1) and (F2):

- the specifications are not invariant to the level of data aggregation — combining any two country's stocks in (F1) would always increase the stock of foreign R&D; and
- the addition of the term $\frac{m_{it}}{y_{it}}$, combined with transforming the level of R&D stocks into indexes and taking logs, results in equation (F2) being misspecified.

They propose the alternative formulation:

$$K_{it}^{F} = \sum_{j} \frac{m_{ijt}}{y_{jt}} \bullet K_{jt} \qquad \text{"[var]\_ti"} \qquad \text{(F3)}$$

where y_{jt} is country *j's* GDP. In this formulation, the stock of R&D that country *i* receives from country *j* is country *j's* R&D stock times the fraction of country *j's* output that is exported to country *i*.

Source: Coe and Helpman (1995); Lichtenberg and van Pottelsberghe (1998).

Adjusted to suit time series rather than panel data, equations (F1) to (F3) were constructed using ABS unpublished data on imports to Australia. A spliced time series was available from 1980-81 combining Balance of Payments Basis data classified by Broad Economic Categories (BEC) and Standard International Trade Classification (SITC) data. Data were available separately for consumption goods, capital goods, intermediate goods, and other goods.

The import share weighted stocks using equations (F1), (F2) and (F3) were based on imports of capital and intermediate inputs and excluded consumption and other imports. The rationale for focusing on the former were that they were the categories of imports most likely to transfer embodied knowledge to Australia, and that knowledge spillovers may follow embodied knowledge. The R&D variables relating to the three equations are denoted [var]_td, [var]_tch and [var]_ti, respectively. “[var]” can be foreign business R&D (BRD) or foreign gross R&D (GRD) expressed in levels, or growth rates or intensities, and with depreciation rates of 5, 10 or 15 per cent. Import share data prior to 1980-81 were obtained by extrapolating backwards assuming a continuation of the linear trends in country import shares.

The import shares based on capital and intermediate goods show very little change over time when comparing the earliest and latest years of the data (table F.1). However, for a number of countries, there are steadily increasing or decreasing trends in shares until 1997-98, with patterns then sharply reversing. The shares of the United States and Japan are markedly higher than for any other country.

Foreign R&D stocks based on equation (F1) were also constructed using import shares of elaborately transformed manufactures (ETMs) data obtained from the Department of Foreign Affairs and Trade (DFAT) (denoted [var]_te):

$$K_t^F = \sum_{j=1to14}^{14} \frac{m_{jt}}{m_t} \bullet K_{jt} \qquad \text{(F4)}$$

where K_t^F is the foreign potential spillover pool for Australia at period *t*, $\frac{m_{jt}}{m_t}$ is the ETM import share of country *j* in total Australian ETM imports, and K_{jt} is the knowledge stock of country *j* at period *t*.

Table F.1 **Import shares in capital and intermediate inputs, 1968-69 to 2002-03**

Proportion of capital and intermediate imports of R&D stock countries.[a]

Year	*Canada*	*Denmark*	*Finland*	*France*	*Germany*	*Ireland*	*Italy*	*Japan*	*Netherlands*	*Norway*	*Spain*	*Sweden*	*UK*	*USA*
1968-69	.037	.006	.013	.038	.092	.005	.037	.271	.016	.006	.005	.027	.096	.350
1969-70	.037	.006	.013	.038	.092	.005	.037	.271	.016	.006	.005	.027	.096	.350
1970-71	.037	.006	.013	.038	.092	.005	.037	.271	.016	.006	.005	.027	.096	.350
1971-72	.037	.006	.013	.038	.092	.005	.037	.271	.016	.006	.005	.027	.096	.350
1972-73	.037	.006	.013	.038	.092	.005	.037	.271	.016	.006	.005	.027	.096	.350
1973-74	.038	.006	.013	.038	.092	.005	.037	.271	.016	.006	.005	.027	.096	.350
1974-75	.038	.006	.013	.038	.092	.005	.037	.271	.016	.006	.005	.027	.096	.349
1975-76	.038	.006	.013	.038	.092	.005	.037	.271	.016	.006	.005	.027	.096	.349
1976-77	.038	.006	.013	.038	.092	.005	.037	.272	.016	.006	.005	.027	.096	.349
1977-78	.038	.006	.013	.038	.092	.005	.037	.272	.016	.006	.005	.027	.096	.349
1978-79	.038	.006	.013	.038	.092	.005	.037	.272	.016	.006	.005	.027	.096	.349
1979-80	.038	.006	.013	.038	.092	.005	.037	.272	.016	.006	.005	.027	.096	.349
1980-81	.038	.006	.013	.038	.092	.005	.037	.272	.016	.006	.005	.027	.096	.349
1981-82	.038	.006	.013	.037	.092	.005	.037	.272	.016	.006	.005	.027	.096	.349
1982-83	.037	.006	.013	.037	.093	.005	.037	.272	.016	.006	.005	.027	.095	.350
1983-84	.037	.006	.013	.037	.093	.005	.037	.271	.016	.006	.005	.027	.095	.352
1984-85	.037	.006	.013	.037	.093	.005	.037	.270	.016	.006	.005	.027	.095	.354
1985-86	.037	.006	.013	.037	.093	.005	.037	.269	.016	.006	.005	.027	.094	.356
1986-87	.036	.006	.013	.037	.093	.005	.037	.267	.016	.006	.005	.027	.093	.359
1987-88	.036	.006	.013	.036	.094	.005	.037	.264	.016	.006	.005	.027	.092	.363
1988-89	.035	.006	.013	.036	.094	.005	.037	.261	.015	.006	.005	.027	.091	.368
1989-90	.035	.006	.013	.036	.095	.005	.037	.258	.015	.005	.005	.027	.090	.373
1990-91	.034	.006	.013	.036	.095	.006	.037	.254	.015	.005	.005	.027	.089	.378
1991-92	.033	.006	.014	.036	.096	.006	.037	.249	.015	.005	.005	.028	.088	.383
1992-93	.033	.006	.014	.036	.096	.007	.037	.244	.015	.004	.006	.028	.087	.387
1993-94	.032	.006	.014	.036	.096	.007	.038	.239	.015	.004	.006	.029	.087	.391
1994-95	.032	.006	.014	.036	.097	.008	.039	.232	.015	.004	.006	.029	.086	.394
1995-96	.032	.006	.015	.037	.097	.009	.039	.226	.015	.004	.007	.029	.086	.398
1996-97	.032	.006	.015	.037	.097	.010	.041	.219	.015	.004	.007	.029	.086	.401
1997-98	.032	.007	.015	.038	.098	.011	.042	.212	.015	.004	.008	.029	.085	.404
1998-99	.032	.007	.015	.039	.098	.011	.043	.206	.015	.004	.008	.029	.085	.406
1999-00	.033	.007	.015	.040	.099	.012	.045	.201	.016	.004	.009	.029	.084	.408
2000-01	.033	.008	.015	.041	.100	.013	.047	.196	.016	.004	.010	.028	.082	.409
2001-02	.033	.008	.015	.043	.101	.014	.048	.190	.016	.004	.010	.028	.081	.409
2002-03	.033	.008	.014	.045	.102	.015	.050	.185	.017	.004	.011	.027	.079	.410

a For each year, proportions sum to 1 less rounding. Data were smoothed using the Hodrick-Prescott filter.

Source: ABS unpublished data.

ETM shares potentially provide a better weighting measure if it is believed that it is the transfer of knowledge from countries closer to the technological frontier(s) which is important to Australia growth, and that ETM shares provide a better indicator of this than does the combined capital and intermediate categories used above.

In 2002-03, countries with higher ETM shares than capital and intermediate input shares include Denmark, France, Germany, Ireland, Italy, and Spain (table F.2). The US import share for capital and intermediate inputs was 34.9 per cent, and 33.1 per cent for ETMs (up from 27.6 per cent in 1968-69). Many of the other countries also recorded increased ETM shares at the expense of Japan and UK shares.

Most market sector models use foreign GRD weighted by ETM shares based on equation (F4). Equations (F1)-(F3) are used in various tests. While stocks were constructed for equation (F2) to test the fit of the alternative methodologies and for comparative purposes to previous studies (including Coe and Helpman 1995, Dowrick 1994b and Rogers 1995), it was not favoured as a benchmark model because it combines separate ideas on the appropriate weighting methodology and the hypothesis that trade openness or intensity will condition the effect foreign knowledge has on domestic productivity. Trade openness is included as a separate explanatory variable in many of the models, while the interaction between the foreign knowledge stocks and trade openness is explicitly investigated in chapter 9.

Weights based on measures of technological 'proximity'

The trade relationships between firms, industries, or countries ('units') may not be a good indicator of the flows of technological knowledge. While trade will embody technological advances, knowledge spillovers may be transmitted in ways not directly related to trade.

Eaton and Kortum (1999) find that trade is not the major source for the spread of new technologies, except for small countries very close to the information source. The benefits of innovation spread through the transmission of disembodied ideas.

Table F.2 **Import shares in elaborately transformed manufactures, 1968-69 to 2002-03**

Proportion of ETM imports from R&D stock countries (based on equation 1).[a]

Year	*Canada*	*Denmark*	*Finland*	*France*	*Germany*	*Ireland*	*Italy*	*Japan*	*Netherlands*	*Norway*	*Spain*	*Sweden*	*UK*	*USA*
1968-69	.014	.004	.001	.018	.096	.001	.030	.331	.015	.001	.003	.022	.187	.276
1969-70	.014	.004	.001	.019	.097	.001	.031	.328	.015	.001	.003	.022	.185	.279
1970-71	.015	.004	.001	.019	.098	.001	.031	.325	.015	.001	.003	.023	.183	.282
1971-72	.015	.004	.001	.020	.098	.002	.032	.322	.015	.001	.003	.023	.180	.284
1972-73	.015	.004	.001	.021	.099	.002	.032	.319	.015	.001	.003	.023	.177	.288
1973-74	.016	.004	.001	.021	.099	.002	.033	.317	.015	.001	.003	.023	.173	.291
1974-75	.016	.004	.001	.022	.099	.002	.033	.315	.015	.001	.003	.024	.169	.294
1975-76	.017	.004	.001	.023	.100	.002	.034	.314	.015	.001	.003	.024	.164	.298
1976-77	.017	.004	.001	.024	.100	.002	.035	.314	.014	.001	.004	.024	.158	.301
1977-78	.017	.005	.001	.025	.100	.003	.035	.316	.014	.001	.004	.024	.152	.304
1978-79	.018	.005	.002	.026	.100	.003	.036	.318	.014	.001	.004	.024	.144	.306
1979-80	.018	.005	.002	.027	.099	.003	.036	.323	.014	.001	.004	.024	.136	.308
1980-81	.018	.005	.002	.028	.099	.004	.037	.328	.013	.001	.004	.025	.128	.308
1981-82	.018	.005	.002	.029	.099	.004	.038	.335	.013	.001	.004	.025	.121	.307
1982-83	.017	.005	.002	.030	.099	.004	.038	.341	.013	.001	.004	.025	.114	.306
1983-84	.017	.005	.003	.030	.099	.005	.039	.345	.014	.001	.004	.025	.108	.305
1984-85	.017	.006	.003	.031	.099	.005	.039	.348	.014	.002	.004	.025	.104	.304
1985-86	.017	.006	.003	.032	.100	.005	.039	.349	.014	.002	.004	.026	.100	.305
1986-87	.016	.006	.004	.032	.100	.005	.039	.347	.014	.002	.004	.026	.097	.307
1987-88	.016	.006	.004	.033	.100	.005	.039	.344	.014	.002	.004	.027	.095	.311
1988-89	.016	.006	.004	.033	.099	.005	.039	.339	.014	.002	.004	.027	.094	.317
1989-90	.017	.006	.005	.034	.099	.005	.038	.333	.014	.002	.004	.028	.093	.323
1990-91	.017	.007	.005	.034	.098	.005	.038	.326	.013	.002	.005	.028	.092	.329
1991-92	.017	.007	.006	.034	.098	.006	.038	.318	.013	.002	.005	.029	.092	.336
1992-93	.018	.007	.006	.035	.098	.006	.038	.310	.013	.002	.006	.029	.093	.341
1993-94	.018	.007	.007	.035	.098	.006	.038	.302	.013	.002	.006	.030	.093	.345
1994-95	.019	.007	.007	.036	.098	.007	.039	.293	.013	.002	.007	.030	.094	.349
1995-96	.020	.007	.007	.036	.099	.008	.040	.285	.013	.002	.007	.030	.095	.351
1996-97	.020	.007	.008	.037	.100	.008	.041	.278	.013	.002	.008	.030	.096	.352
1997-98	.021	.008	.008	.038	.101	.009	.043	.272	.013	.002	.009	.030	.096	.352
1998-99	.021	.008	.008	.039	.102	.011	.045	.267	.013	.002	.009	.029	.096	.350
1999-00	.022	.008	.008	.041	.104	.012	.047	.263	.013	.002	.010	.029	.095	.347
2000-01	.022	.009	.008	.043	.106	.013	.049	.260	.013	.002	.011	.028	.094	.342
2001-02	.022	.009	.008	.045	.109	.015	.051	.257	.013	.002	.011	.027	.093	.337
2002-03	.022	.010	.008	.048	.111	.016	.053	.255	.014	.002	.012	.027	.091	.331

[a] For each year, proportions sum to 1 less rounding.

Source: DFAT Stars database.

Alternative indicators of technological relationships include:

- the flow of R&D personnel between units;
- the use of patents patented by other units;
- use of innovations discovered by other units;
- citations contained in patent documents;
- the incidence of R&D cooperation agreements between units; and
- technological 'distance' or proximity measures, including those based on:
  - patents classified by technology class; and
  - R&D activity decomposed by research field or socio-economic objective.[2]

The proximity measures are based on constructing and comparing vectors characterising the unit's technological 'position' into different 'spaces'. Jaffe (1986) used the distribution of a firm's patents over technology classes to characterise the technological position of the firm. The proximity of two units *i* and *j* is measured by the angular separation or uncentred correlation of the vectors f_i and f_j. The proximity measure can be written as:

$$w_{ij} = \frac{f_i f_j^{'}}{[(f_i f_j^{'})*(f_j f_j^{'})]^{1/2}} \qquad \text{(F5)}$$

The proximity measure is unity for units whose position vectors are identical, zero for units whose vectors are orthogonal, and is bounded between 0 and 1 for all other pairs. The more two units are technologically close to one another, the higher is the weight.

The approach assumes that an equal fraction of each sector's spillover pool may leak out to the recipient industry and that each sector is equally capable of absorbing knowledge from other sectors. To the extent that this is not true, the spillover pool is poorly measured.[3]

Potential spillover pools were constructed using equation (F5) and data from the European Patent Office (EPO) on patent applications (denoted [var]_pe) and United States Patent and Trademark Office (USPTO) on patent grants (denoted [var]_pu). The counts of patents were classified by International Patent Classification (IPC) technology classes at the class level (box F.2).

[2] Mohnen (1996) and Cincera (2005).

[3] See Cincera (2005) for a discussion of the limitations of Jaffe's approach and alternative technological proximity measures.

Box F.2 Background to the International Patent Classification system

Industrial property offices classify patent documents according to various technology classification systems. The purpose of the classification systems is to help the offices assess patent applications by making search processes for ‘prior art’ more efficient.

The *Strasbourg Agreement Concerning the International Patent Classification* (IPC) entered into force in 1975. In January 2000, 45 countries were party to the IPC. The World Intellectual Property Organisation (WIPO) administers the agreement.

The IPC contains 8 sections, 120 classes, 628 subclasses and almost 69 000 technology groups. The 8 sections are:

- Section A: Human necessities
- Section B: Performing operations; transporting
- Section C: Chemistry, metallurgy
- Section D: Textiles, paper
- Section E: Fixed constructions
- Section F: Mechanical engineering, lighting, heating, weapons, blasting
- Section G: Physics
- Section H: Electricity.

Source: WIPO (2005).

van Pottelsberghe (1997, p. 154) notes that the use of patent data imposes three important restrictions because it assumes that: every patent has the same weight in summing each unit’s number of patents; every innovation is patented; and the propensity to patent is equal across units.

Australian external patenting activity at the USPTO is most similar to that of the United States, followed by Canada, France and the United Kingdom (table F.3). Similarities in USPTO patents granted have increased over time between Australia and Canada, France, Italy, Spain, United Kingdom and the United States.

Table F.3 **Proximity based on USPTO patent grants[a], 1968-69 to 2002-03**

Year	*Canada*	*Denmark*	*Finland*	*France*	*Germany*	*Ireland*	*Italy*	*Japan*	*Netherlands*	*Norway*	*Spain*	*Sweden*	*UK*	*USA*
1968-69	.758	.776	.520	.720	.717	.495	.476	.696	.620	.536	.495	.723	.717	.756
1969-70	.761	.773	.524	.720	.718	.495	.484	.694	.619	.538	.497	.725	.719	.758
1970-71	.765	.769	.530	.721	.720	.496	.496	.692	.618	.540	.500	.729	.722	.762
1971-72	.771	.765	.538	.723	.722	.498	.511	.688	.617	.544	.505	.735	.726	.766
1972-73	.778	.759	.549	.725	.724	.502	.531	.683	.616	.550	.511	.742	.731	.771
1973-74	.787	.754	.561	.727	.728	.507	.554	.677	.614	.558	.519	.750	.737	.777
1974-75	.798	.748	.577	.731	.732	.514	.582	.669	.614	.568	.530	.759	.744	.785
1975-76	.809	.743	.594	.734	.737	.523	.612	.659	.613	.580	.542	.770	.753	.793
1976-77	.821	.740	.611	.738	.743	.534	.642	.649	.614	.595	.555	.781	.761	.801
1977-78	.833	.739	.629	.743	.748	.548	.671	.638	.616	.611	.570	.791	.769	.808
1978-79	.843	.741	.646	.748	.754	.563	.696	.627	.618	.629	.586	.801	.778	.815
1979-80	.852	.746	.661	.755	.761	.579	.719	.617	.622	.647	.605	.811	.787	.822
1980-81	.860	.754	.674	.763	.767	.594	.737	.608	.627	.666	.625	.822	.796	.828
1981-82	.866	.765	.684	.771	.773	.609	.752	.599	.632	.685	.648	.832	.805	.834
1982-83	.872	.776	.690	.780	.778	.622	.763	.591	.637	.702	.671	.841	.814	.839
1983-84	.876	.789	.693	.789	.783	.634	.772	.583	.643	.719	.694	.851	.823	.845
1984-85	.880	.802	.693	.799	.786	.646	.779	.576	.649	.735	.718	.860	.833	.851
1985-86	.882	.814	.690	.808	.789	.659	.786	.568	.656	.748	.741	.868	.842	.856
1986-87	.884	.824	.683	.818	.791	.672	.791	.559	.664	.761	.763	.875	.850	.862
1987-88	.885	.832	.671	.826	.791	.685	.796	.551	.672	.771	.784	.879	.858	.866
1988-89	.885	.837	.656	.834	.791	.695	.799	.541	.680	.777	.802	.881	.864	.869
1989-90	.884	.840	.636	.839	.789	.703	.801	.532	.688	.778	.818	.878	.868	.871
1990-91	.882	.838	.613	.842	.785	.709	.800	.524	.696	.776	.831	.872	.869	.871
1991-92	.879	.834	.587	.844	.779	.715	.796	.517	.702	.771	.841	.861	.869	.869
1992-93	.874	.827	.560	.845	.773	.720	.790	.513	.708	.763	.846	.847	.867	.866
1993-94	.867	.817	.533	.843	.765	.725	.781	.511	.711	.753	.848	.829	.863	.863
1994-95	.859	.804	.509	.840	.757	.728	.769	.513	.713	.742	.847	.809	.859	.858
1995-96	.851	790	.487	.835	.747	.732	.754	.517	.711	.729	.841	.787	.854	.854
1996-97	.843	.773	.469	.829	.737	.735	.737	.524	.707	.716	.832	.764	.850	.850
1997-98	.836	.754	.456	.823	.726	.739	.717	.534	.700	.703	.820	.741	.846	.849
1998-99	.832	.736	.448	.817	.717	.743	.697	.545	.690	.690	.805	.719	.845	.850
1999-00	.831	.718	.443	.812	.708	.746	.676	.555	.679	.679	.788	.698	.845	.853
2000-01	.830	.700	.439	.807	.700	.748	.656	.566	.667	.667	.771	.679	845	.857
2001-02	.830	.683	.437	.802	.691	.750	.635	.576	.654	.657	.753	.660	.846	.861
2002-03	.831	.666	.435	.798	.683	.753	.615	586	.641	.646	.736	.642	.846	.865

a Data were available for the period 1974-75 to 1999-00. Data were extrapolated for years at the beginning and end of the series, and was smoothed using the Hodrick-Prescott filter. Weights do not sum to 1.

Sources: USPTO data accessed through OECD Patent database; Commission estimates.

Guellec and van Pottelsberghe (2001) estimate a large, positive foreign effect on domestic productivity using a technological proximity weighted foreign R&D stock based on patents granted by the USPTO:

> The long-term elasticity of foreign R&D on productivity is in the range of 0.45 to 0.5. This figure may seem surprisingly high, as this is essentially low cost technology for the economy (the direct cost of absorbing new technology *when the domestic conditions are right* must be substantially lower than the cost of inventing it, which is the *raison d'etre* for technology transfers). Estimates by Coe and Helpman (1995), although lower, are in the same order of magnitude: 0.29. This is high also as compared with the elasticity of domestic R&D reported above, leading to the conclusion that for any one country, other countries' R&D matter more than domestic R&D for the purpose of productivity growth, provided that the country has the capacity to absorb technology from abroad. (p. 113)

The external patenting activities of US inventors and Australian inventors at the EPO is more similar than is Australian-US patenting activity at the USPTO (table F.4). The EPO proximity measures are higher for most countries compared with the equivalent USPTO measures, and have changed less over time.

The sample of Australian patents granted by the USPTO by technology class is quite small compared with the much larger sample of real standard patent applications to IP Australia. As there is a large possibility that the applications granted by the USPTO are not representative of the distribution of R&D activity in Australia by technology class, the sectors of Australian USPTO patent grants by technology class was replaced with equivalent patent applications information from IP Australia. The stocks were recalculated based on equation (F5).

The broader spectrum of R&D activity covered by the IP Australia data could well be important for identifying or understanding the effect of foreign R&D. For example, if the absorptive capacity role of Australian R&D is important, then R&D activity in technology classes that do not lead to much overseas patenting activity should also be taken into account when considering the best indicator of a potential spillover pool to Australia.

Table F.4 **Proximity based on EPO patent applications[a], 1968-69 to 2002-03**

Year	*Canada*	*Denmark*	*Finland*	*France*	*Germany*	*Ireland*	*Italy*	*Japan*	*Netherlands*	*Norway*	*Spain*	*Sweden*	*UK*	*USA*
1968-69	.440	.480	.079	.700	.721	.223	.634	.405	.720	.420	.449	.624	.730	.718
1969-70	.442	.481	.081	.700	.720	.223	.635	.407	.720	.419	.447	.625	.730	.718
1970-71	.445	.483	.086	.700	.720	.224	.637	.410	.720	.418	.446	.627	.731	.718
1971-72	.450	.487	.095	.701	.719	.226	.641	.415	.720	.419	.444	.631	.732	.718
1972-73	.459	.494	.110	.703	.719	.232	.646	.423	.720	.422	.443	.637	.733	.718
1973-74	.472	.504	.133	.707	.718	.241	.654	.433	.720	.427	.444	.646	.736	.719
1974-75	.489	.519	.163	.711	.719	.255	.663	.447	.719	.435	.445	.658	.740	.719
1975-76	.512	.539	.202	.717	.720	.274	.675	.464	.718	.447	.449	.674	.745	.720
1976-77	.539	.563	.251	.724	.722	.299	.690	.483	.717	.463	.455	.694	.751	.722
1977-78	.571	.593	.307	.734	.724	.330	.706	.505	.716	.485	.464	.717	.759	.724
1978-79	.606	.626	.370	.744	.729	.367	.723	.527	.714	.512	.478	.742	.768	.726
1979-80	.642	.662	.435	.755	.735	.408	.739	.548	.712	.544	.497	.767	.779	.729
1980-81	.676	.698	.495	.767	.742	.453	.753	.564	.709	.578	.520	.792	.789	.732
1981-82	.707	.732	.549	.778	.751	.498	.764	.577	.705	.613	.546	.815	.799	.735
1982-83	.735	.763	.591	.788	.760	.541	.773	.586	.701	.645	.573	.835	.808	.740
1983-84	.761	.790	.623	.797	.768	.581	.780	.591	.698	.672	.601	.851	.817	.745
1984-85	.784	.812	.644	.806	.776	.618	.785	.594	.696	.695	.630	.865	.825	.753
1985-86	.803	.830	.654	.813	.783	.652	.789	.596	.696	.712	.658	.875	.833	.763
1986-87	.820	.842	.656	.819	.789	.682	.792	.597	.697	.725	.684	.881	.841	.775
1987-88	.834	.852	.651	.825	.794	.708	.794	.597	.700	.732	.710	.884	.848	.787
1988-89	.845	.858	.641	.829	.796	.730	.795	.595	.704	.736	.732	.883	.854	.799
1989-90	.854	.862	.626	.833	.798	.747	.796	.594	.708	.738	.752	.880	.859	.812
1990-91	.862	.865	.608	.837	.798	.762	.795	.594	.713	.737	.769	.873	.863	.824
1991-92	.868	.868	.587	.841	.796	.776	.793	.596	.719	.735	.782	.865	.867	.837
1992-93	.872	.870	.566	.846	.795	.789	.790	.600	.725	.736	.792	.855	.871	.849
1993-94	.876	.872	.544	.850	.792	.802	.786	.607	.730	.738	.799	.846	.875	.861
1994-95	.878	.874	.524	.854	.791	.815	.783	.615	.735	.743	.804	.836	.879	.872
1995-96	.879	.878	.506	.858	.789	.829	.780	.626	.738	.751	.808	.829	.883	.883
1996-97	.880	.881	.492	.861	.788	.843	.777	.638	.739	.760	.811	.823	.888	.893
1997-98	.880	.884	.481	.865	.787	.857	.774	.652	.738	.771	.815	.821	.893	.904
1998-99	.880	.887	.474	.868	.788	.870	.770	.668	.736	.782	.818	.821	.899	.914
1999-00	.881	.890	.470	.872	.790	.883	.767	.686	.732	.794	.823	.824	.905	.923
2000-01	.881	.894	.469	.876	.793	.896	.765	.706	.728	.806	.829	.830	.911	.933
2001-02	.883	.899	.470	.880	.798	.909	.764	.726	.725	.819	.837	.837	.918	.943
2002-03	.885	.904	.472	.885	.803	.922	.764	.747	.722	.832	.844	.845	.926	.952

a Data were based on EPO patent applications to the European Patent Office. Only direct filings plus Patent Cooperation Treaty (PCT) applications entering regional phase are included. Data were available for the period 1977-78 to 2001-02. Data were extrapolated for years at the beginning and end of the series, and were smoothed using the Hodrick-Prescott filter. Weights do not sum to 1.

Sources: EPO data accessed through OECD Patent database; Commission estimates.

The hybrid USPTO-IP Australia weights possibly suffer from two distortions.

- Data on the patenting activity of foreign countries other than the United States were not equivalently sourced from home patent offices. This means that the non-US distributions of patents by technology class are distorted towards the relatively few innovations patented abroad by these countries. However, knowledge spillovers to Australia might be more closely linked with the types of foreign patents which are patented overseas.
- The direct comparison of the distribution of USPTO grants by foreign country and technology class with IP Australia applications data by technology class for Australia potentially introduces distortions if there are different 'success rates' for technology classes resulting in the distribution of applied for and granted applications being different.

The hybrid weights (denoted [var]_pa) suggest that Australian R&D activity has become more 'technologically close' with Canada, Denmark, Ireland, Norway, Spain and Sweden (table F.5). It is less close with Germany, Italy, Japan, the United Kingdom and the United States.

An additional proximity matrix was created using information from IP Australia on Australian and foreign country patenting activity in Australia (denoted [var]_z) (table F.6). Patent applications were restricted to non-Patent Cooperation Treaty (PCT) applications and PCT applications entering national phase. The proximity weights were calculated using equation (F5). The idea behind the weights is that knowledge spillovers may be linked to the innovations for which patent protection is sought in Australia. Patent protection is often sought where companies intend to market their innovations. Imported products which embody new knowledge can spur imitation and adaptation.

Table F.5 **Proximity based on USPTO patent grants with Australian data based on IP Australia real standard patent applications[a] , 1968-69 to 2002-03**

Year	*Canada*	*Denmark*	*Finland*	*France*	*Germany*	*Ireland*	*Italy*	*Japan*	*Netherlands*	*Norway*	*Spain*	*Sweden*	*UK*	*USA*
1968-69	.679	.643	.445	.843	.872	.493	.878	.652	.685	.592	.616	.619	.871	.846
1969-70	.678	.642	.444	.843	.872	.493	.877	.652	.685	.592	.615	.618	.871	.846
1970-71	.678	.641	.444	.843	.872	.492	.877	.652	.685	.591	.614	.617	.871	.846
1971-72	.677	.639	.443	.843	.872	.491	.877	.653	.685	.591	.613	.617	.871	.846
1972-73	.677	.638	.442	.842	.872	.490	.877	.653	.684	.591	.612	.616	.870	.846
1973-74	.677	.638	.442	.842	.873	.490	.877	.654	.684	.590	.611	.615	.870	.846
1974-75	.677	.637	.443	.842	.873	.490	.878	.654	.684	.589	.611	.615	.870	.846
1975-76	.678	.638	.444	.842	.873	.491	.878	.655	.685	.588	.610	.615	.869	.846
1976-77	.679	.639	.447	.842	.874	.493	.879	.656	.686	.587	.611	.616	.869	.846
1977-78	.681	.642	.452	.842	.874	.496	.880	.656	.687	.586	.612	.618	.868	.847
1978-79	.685	.648	.458	.842	.875	.501	.881	.657	.689	.586	.616	.622	.868	.847
1979-80	.689	.655	.467	.843	.876	.509	.883	.656	.692	.585	.621	.628	.868	.848
1980-81	.695	.666	.479	.844	.877	.520	.885	.655	.696	.585	.629	.636	.868	.849
1981-82	.703	.681	.494	.846	.878	.533	.888	.653	.701	.586	.639	.646	.869	.850
1982-83	.711	.699	.511	.848	.878	.549	.891	.650	.707	.588	.654	.659	.870	.851
1983-84	.721	.721	.530	.851	.878	.568	.893	.644	.714	.592	.671	.675	.872	.852
1984-85	.732	.746	.549	.855	.878	.588	.896	.637	.720	.598	.692	.693	.876	.853
1985-86	.742	.772	.568	.859	.877	.609	.898	.627	.728	.605	.716	.712	.880	.853
1986-87	.753	.797	.584	864	.875	.628	.898	.615	.735	.615	.742	.732	.886	.853
1987-88	.763	.820	.597	.870	.871	.644	.897	.601	.742	.625	.769	.752	.891	.853
1988-89	.774	.841	.606	.875	.865	.657	.893	.586	.750	.634	.794	.770	.897	.852
1989-90	.784	.859	.611	.880	.858	.668	.888	.569	.757	.642	.818	.786	.902	.850
1990-91	.793	.874	.612	.884	.849	.677	.880	.552	.765	.650	.837	.799	.906	.847
1991-92	.803	.886	.609	.888	.838	.686	.871	.536	.772	.658	.852	.809	.908	.844
1992-93	.811	.897	.603	.891	.826	.695	.859	.521	.778	.666	.862	.815	.909	.840
1993-94	.818	.906	.595	.892	.812	.704	.845	.507	.783	.674	.867	.817	.908	.834
1994-95	.822	.915	.584	.892	.796	.715	.830	.494	.785	.681	.867	.814	.905	.828
1995-96	.823	.923	.572	.890	.780	.725	.813	.482	.784	.689	.863	.808	.900	.821
1996-97	.822	.931	.559	.885	.762	.735	.795	.470	.779	.696	.855	.798	.893	.813
1997-98	.819	.939	.546	.879	.743	.746	.776	.458	.769	.702	.844	.785	.886	.805
1998-99	.815	.946	.532	.872	.725	.756	.757	.446	.755	.708	.833	.770	.877	.798
1999-00	.811	.953	.519	.864	.707	.765	.738	.434	.739	.713	.820	.754	.868	.791
2000-01	.807	.960	.505	.856	.689	.774	.720	.422	.721	.717	.807	.737	.859	.785
2001-02	.802	.966	.492	.848	.672	.782	.702	.411	.702	.722	.793	.721	.851	.779
2002-03	.798	.972	.478	.840	.655	.790	.685	.399	.684	.726	.780	.704	.842	.773

a ‘Real standard’ patent applications are standard patent applications plus PCT applications entering national phase. Data were available for the period 1982-83 to 1999-00. Data were extrapolated for years at the beginning and end of the series and smoothed using the Hodrick-Prescott filter. Weights do not sum to 1.

Sources: USPTO; IP Australia; Commission estimates.

Table F.6 **Proximity based on patent applications to IP Australia[a], 1968-69 to 2002-03**

Real standard patent applications and PCT applications entering national phase.

Year	*Canada*	*Denmark*	*Finland*	*France*	*Germany*	*Ireland*	*Italy*	*Japan*	*Netherlands*	*Norway*	*Spain*	*Sweden*	*UK*	*USA*
1968-69	.022	.005	.005	.044	.116	.001	.018	.145	.033	.003	.002	.015	.132	.460
1969-70	.022	.005	.005	.044	.116	.001	.018	.144	.032	.003	.002	.015	.132	.460
1970-71	.022	.005	.005	.044	.116	.001	.018	.144	.032	.003	.002	.015	.132	.460
1971-72	.022	.005	.005	.044	.116	.001	.018	.144	.032	.003	.002	.015	.132	.460
1972-73	.022	.005	.005	.044	.116	.001	.018	.144	.032	.003	.002	.015	.132	.460
1973-74	.022	.005	.005	.044	.116	.001	.018	.144	.032	.003	.002	.015	.132	.460
1974-75	.022	.005	.005	.044	.116	.001	.018	.144	.033	.003	.002	.016	.132	.461
1975-76	.022	.005	.005	.044	.116	.001	.018	.144	.033	.003	.002	.016	.131	.461
1976-77	.022	.005	.005	.044	.115	.001	.018	.144	.033	.003	.002	.016	.131	.462
1977-78	.022	.005	.005	.044	.115	.001	.019	.145	.033	.003	.002	.016	.130	.463
1978-79	.021	.005	.005	.044	.114	.001	.019	.146	.033	.003	.002	.016	.128	.464
1979-80	.021	.004	.005	.044	.113	.001	.019	.146	.034	.003	.002	.016	.126	.465
1980-81	.021	.004	.005	.044	.111	.002	.020	.148	.034	.002	.002	.015	.124	.467
1981-82	.021	.004	.005	.045	.110	.002	.020	.149	.035	.002	.002	.015	.121	.469
1982-83	.021	.004	.005	.045	.108	.002	.020	.152	.036	.002	.002	.015	.118	.471
1983-84	.021	.004	.005	.046	.106	.002	.020	.154	.037	.002	.003	.014	.114	.473
1984-85	.021	.004	.005	.046	.104	.002	.020	.157	.037	.002	.003	.014	.111	.475
1985-86	.021	.003	.005	.047	.102	.002	.020	.159	.038	.002	.003	.013	.107	.478
1986-87	.021	.003	.005	.048	.100	.002	.020	.162	.039	.002	.003	.012	.103	.480
1987-88	.020	.003	.005	.049	.098	.002	.020	.165	.040	.002	.003	.011	.098	.484
1988-89	.020	.003	.005	.050	.095	.002	.020	.168	.040	.002	.003	.011	.093	.488
1989-90	.019	.003	.005	.051	.093	.002	.019	.171	.040	.002	.004	.010	.088	.492
1990-91	.018	.003	.006	.053	.091	.002	.019	.175	.039	.002	.004	.009	.082	.497
1991-92	.018	.003	.006	.054	.089	.002	.018	.178	.038	.002	.004	.009	.076	.502
1992-93	.018	.003	.006	.056	.087	.002	.018	.182	.036	.002	.004	.008	.071	.507
1993-94	.018	.003	.006	.057	.085	.002	.018	.187	.034	.002	.004	.008	.065	.511
1994-95	.018	.003	.006	.058	.084	.002	.018	.191	.032	.002	.004	.007	.060	.515
1995-96	.018	.003	.006	.060	.082	.002	.018	.196	.029	.002	.004	.007	.056	.519
1996-97	.018	.003	.006	.060	.080	.002	.018	.200	.026	.002	.004	.007	.051	.523
1997-98	.018	.003	.006	.060	.079	.002	.018	.204	.024	.002	.004	.006	.047	.527
1998-99	.019	.003	.005	.059	.078	.002	.018	.208	.022	.002	.004	.006	.044	.532
1999-00	.019	.003	.005	.058	.077	.001	.018	.211	.020	.001	.004	.006	.040	.538
2000-01	.019	.003	.005	.055	.076	.001	.018	.212	.018	.001	.004	.006	.037	.545
2001-02	.020	.002	.005	.051	.076	.001	.018	.213	.017	.001	.004	.006	.033	.553
2002-03	.020	.002	.004	.047	.075	.001	.018	.213	.016	.001	.004	.006	.030	.563

a The data were available for the period 1980-81 to 2002-03. Data extrapolated for years at the beginning of the series. Data smoothed using the Hodrick-Prescott filter. Weights do not sum to 1.

Sources: IP Australia; Commission estimates.

Patent citations to map disembodied knowledge flows

Patent application information can also be used to map the process of knowledge transfer between firms, industries and countries. A growing number of studies use patent citations in investigating the patterns and importance of knowledge transfer (for example, see Jaffe, Trajtenberg and Henderson 1993; Jaffe and Trajtenberg 1996, 2002; and Thompson and Fox-Kean 2005). The source of the citations data is patents filed with the USPTO. Through the detailed tracking of the characteristics of citing and cited patents, including references to other forms of prior art, a 'map' of disembodied knowledge transfer can be established.

The data might be used to analyse which countries are most commonly cited for those USPTO applications involving either Australians as owners or inventors. This would give an indication of the relative importance of the R&D performed in foreign countries as a source of disembodied knowledge spillovers. However, the method was not pursued for this paper, partly due to having to draw boundaries around the project, but also because the 'map' would reflect the sources of disembodied knowledge for Australian overseas patenting activity at the USPTO. This may or may not be representative of the foreign sources of disembodied knowledge for the much larger range of R&D activity undertaken in Australia.

An analysis of citations information collected by IP Australia and its predecessors was considered, but the citations information is fairly scant compared with the USPTO recording of references to prior art. Generally, IP Australia records three references with a tendency to select references to patents. However, this information may still provide insights into the transfer of knowledge to Australia.

Weights based on foreign direct investment shares

Foreign direct investment (FDI) and the operation of foreign companies (MNEs) may be important mechanisms for the transfer of knowledge to Australia. Both have long been linked to changes in productivity and the R&D performance of a host country. FDI/MNEs are generally welcomed by most countries because there is an expectation that they will provide the host economy with a range of benefits, including the transfer of technological and other forms of knowledge.

When an MNE sets up in a new location it expects to achieve a higher rate of return than those firms already operating in the market. This higher return is achieved by some form of advantage. It can be in the form of superior technology, advanced management skills or access to international markets. MNEs will not willingly hand over this advantage. However, these advantages can be difficult to retain and over time some of the MNE advantage will spillover to the local firms and economy.

Four productivity spillover channels have been identified in the literature (table F.7). The table illustrates the spillover channel by which MNEs can make an indirect contribution to host country productivity growth, the source of the productivity gain (often related to technology), and a simple example or description of the mechanism involved.

Table F.7 **Spillover channels of FDI**

Driver	*Source of the productivity gain*	*Example or Description*
Imitation or demonstration effect	Adoption of new production methods. Adoption of new management practices.	The local firms learn by imitating an MNE.
Competition effect	Reduction in X-inefficiency. Faster adoption of new technology.	The local firms have to improve their performance because of competition from more efficient/productive MNEs.
Training (Human capital)	Increased productivity of complementary labour. Tacit knowledge.	MNE trained workers move to local firms or set up their own firms.
Exports	Scale economies. Exposure to technological frontier.	MNE may generate export information externalities and may provide a demonstration effect to local firms.

Sources: Blomstrom and Kokko (1998); Görg and Greenaway (2001); Görg and Strobl (2002); Görg and Greenaway (2003).

Equation (F5) was used with the FDI shares to construct an investment weighted foreign knowledge stock (denoted [var]_f). The United Kingdom and United States combined account for roughly three quarters of the FDI from the R&D stock countries (table F.8). Canada's share has declined significantly while the Netherland's share has showed similar increases. The Scandinavian countries and Spain have shares close to zero over the entire period. The UK share of FDI is weighted much more heavily than its share under trade weighted measures.

F.2 The foreign knowledge stock indexes

The foreign knowledge stock indexes for GRD and BRD are provided below (table F.9 and F.10). All indexes are based on stocks with an assumed decay rate of at 15 per cent.

Table F.8 **FDI shares, 1968-69 to 2002-03**[a]

Proportions for R&D stock countries.

Year	*Canada*	*Denmark*	*Finland*	*France*	*Germany*	*Ireland*	*Italy*	*Japan*	*Netherlands*	*Norway*	*Spain*	*Sweden*	*UK*	*USA*
1968-69	.079	.000	.000	.020	.033	.002	.004	.114	.030	.000	.000	.008	.338	.372
1969-70	.080	.000	.000	.020	.033	.002	.004	.114	.030	.000	.000	.008	.338	.372
1970-71	.080	.000	.000	.020	.034	.002	.004	.114	.030	.000	.000	.008	.338	.372
1971-72	.080	.000	.000	.020	.034	.002	.004	.113	.029	.000	.000	.008	.338	.372
1972-73	.080	.000	.000	.020	.034	.002	.004	.113	.029	.000	.000	.008	.338	.372
1973-74	.080	.000	.000	.020	.034	.002	.004	.113	.029	.000	.000	.008	.338	.372
1974-75	.080	.000	.000	.020	.034	.002	.004	.113	.029	.000	.000	.008	.338	.372
1975-76	.081	.000	.000	.020	.034	.002	.004	.113	.029	.000	.000	.008	.338	.372
1976-77	.081	.000	.000	.020	.034	.002	.004	.112	.029	.000	.000	.008	.338	.372
1977-78	.081	.000	.000	.020	.034	.002	.004	.112	.029	.000	.000	.008	.338	.372
1978-79	.081	.000	.000	.020	.034	.002	.004	.112	.029	.000	.000	.008	.339	.372
1979-80	.081	.000	.000	.020	.033	.002	.004	.113	.029	.000	.000	.008	.339	.372
1980-81	.080	.000	.000	.020	.033	.002	.004	.113	.029	.000	.000	.008	.340	.372
1981-82	.079	.000	.000	.019	.033	.002	.004	.115	.029	.000	.000	.008	.341	.371
1982-83	.078	.000	.000	.019	.032	.002	.004	.116	.029	.000	.000	.008	.342	.370
1983-84	.076	.000	.000	.019	.032	.002	.004	.119	.030	.000	.000	.008	.344	.369
1984-85	.073	.000	.000	.018	.031	.002	.004	.122	.030	.000	.000	.007	.345	.368
1985-86	.069	.000	.000	.018	.030	.002	.003	.126	.031	.000	.000	.007	.346	.366
1986-87	.065	.000	.000	.018	.029	.002	.003	.131	.033	.000	.000	.007	.347	.365
1987-88	.061	.000	.000	.017	.027	.001	.003	.137	.035	.000	.000	.007	.348	.363
1988-89	.056	.000	.000	.017	.026	.001	.003	.143	.038	.000	.000	.007	.348	.361
1989-90	.051	.000	.000	.017	.026	.001	.003	.149	.041	.000	.000	.007	.346	.360
1990-91	.046	.000	.000	.017	.025	.001	.003	.154	.044	.000	.000	.007	.343	.361
1991-92	.041	.000	.000	.017	.025	.001	.003	.157	.048	.000	.000	.007	.339	.363
1992-93	.037	.000	.000	.018	.025	.001	.002	.158	.052	.000	.000	.007	.334	.367
1993-94	.033	.000	.000	.019	.026	.001	.002	.156	.055	.000	.000	.007	.329	.371
1994-95	.029	.000	.000	.021	.027	.002	.002	.153	.059	.000	.000	.007	.324	.376
1995-96	.025	.000	.000	.023	.029	.002	.002	.148	.062	.000	.000	.007	.321	.381
1996-97	.022	.000	.000	.025	.030	.002	.002	.142	.064	.000	.000	.007	.319	.386
1997-98	.019	.000	.000	.028	.032	.003	.002	.135	.066	.000	.000	.007	.318	.390
1998-99	.016	.000	.000	.030	.034	.003	.002	.127	.068	.000	.000	.007	.319	.394
1999-00	.013	.000	.000	.032	.036	.003	.002	.119	.070	.000	.000	.007	.321	.397
2000-01	.011	.000	.000	.034	.038	.004	.002	.111	.072	.000	.000	.007	.323	.398
2001-02	.008	.000	.000	.037	.040	.004	.002	.103	.074	.000	.000	.007	.327	.399
2002-03	.006	.000	.000	.039	.042	.004	.002	.096	.076	.000	.000	.007	.330	.400

a Data were available from 1986-87. Earlier data were extrapolated backwards assuming the 1986-87 shares. The shares were smoothed using the Hodrick-Prescott filter.

Sources: ABS unpublished data; Commission estimates.

Table F.9 **Foreign knowledge stock indexes, GRD, 1968-69 to 2002-03**

Base year = 2001-02. Assumed decay rate of 15 per cent.

Year	*Rfrg15 _u*	*Rfrg15 _td*	*Rfrg15 _tch*	*Rfrg15 _ti*	*Rfrg15 _te*	*Rfrg15 _pe*	*Rfrg15 _pu*	*Rfrg15 _pa*	*Rfrg15 _f*	*Rfrg15 _z*
1968-69	28.8	27.3	17.7	36.3	26.5	22.6	27.1	33.4	31.3	26.8
1969-70	30.3	28.8	18.5	38.3	28.1	23.7	28.7	35.1	32.8	28.1
1970-71	31.8	30.0	18.9	40.1	29.6	24.8	30.1	36.7	34.0	29.1
1971-72	33.1	31.2	18.3	41.8	31.0	25.8	31.5	38.2	35.1	30.2
1972-73	34.5	32.5	17.4	43.6	32.5	26.9	33.0	39.7	36.2	31.2
1973-74	35.7	33.5	21.6	45.1	33.8	27.8	34.3	41.0	37.2	32.1
1974-75	36.7	34.2	24.6	46.4	34.9	28.6	35.5	42.1	37.8	32.7
1975-76	37.8	35.2	22.8	47.8	36.1	29.7	36.8	43.3	38.7	33.5
1976-77	39.0	36.2	25.7	49.3	37.4	30.8	38.2	44.6	39.7	34.4
1977-78	40.2	37.3	26.4	51.0	38.8	32.0	39.7	46.1	40.7	35.4
1978-79	41.7	38.7	28.9	52.9	40.4	33.6	41.5	47.8	42.0	36.7
1979-80	43.3	40.1	30.9	55.0	42.1	35.2	43.3	49.6	43.4	38.0
1980-81	45.2	41.8	33.8	57.3	44.0	37.1	45.4	51.7	45.0	39.6
1981-82	47.1	43.6	35.7	59.8	45.9	39.1	47.7	54.0	46.6	41.3
1982-83	49.3	45.8	34.7	62.5	48.1	41.3	50.1	56.5	48.6	43.3
1983-84	51.9	48.4	35.3	65.6	50.7	43.8	53.0	59.5	51.0	45.7
1984-85	54.9	51.5	43.1	69.1	53.7	46.8	56.3	62.9	53.8	48.6
1985-86	57.8	54.5	47.9	72.4	56.7	49.8	59.5	66.2	56.5	51.4
1986-87	60.6	57.5	47.9	75.5	59.8	52.8	62.7	69.4	59.0	54.0
1987-88	63.4	60.5	48.7	78.4	63.0	55.8	65.8	72.5	61.4	56.7
1988-89	66.3	63.6	52.1	81.1	66.4	58.8	68.8	75.5	63.8	59.4
1989-90	69.3	66.9	55.2	83.7	70.0	62.0	71.7	78.4	66.4	62.3
1990-91	72.0	70.0	54.4	85.8	73.4	65.0	74.3	81.1	68.9	65.1
1991-92	74.4	72.6	57.2	87.3	76.4	67.6	76.4	83.2	71.2	67.7
1992-93	76.2	74.6	64.0	88.4	78.7	69.8	77.9	84.6	73.2	69.7
1993-94	77.7	76.3	67.4	89.4	80.4	71.9	79.0	85.5	75.1	71.5
1994-95	79.6	78.5	75.1	90.9	82.7	74.2	80.4	86.7	77.5	73.9
1995-96	81.7	80.8	75.1	92.4	84.9	76.8	82.0	87.9	80.1	76.5
1996-97	84.0	83.6	75.5	94.0	87.4	79.7	83.9	89.3	83.1	79.5
1997-98	86.6	86.6	84.5	95.5	90.0	83.0	86.3	90.9	86.3	82.9
1998-99	89.6	89.9	88.8	96.9	92.7	86.7	89.3	92.9	89.9	86.8
1999-00	93.0	93.7	97.4	98.3	95.7	91.0	92.8	95.3	93.8	91.4
2000-01	96.3	97.1	102.4	99.0	98.2	95.3	96.3	97.5	97.2	95.8
2001-02	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
2002-03	108.5	105.4	108.1	105.3	105.7	109.0	107.6	105.8	104.1	106.6

Source: ABS unpublished data; DFAT (Stars database); USPTO and EPO data accessed through OECD Patent database; IP Australia (unpublished data); Commission estimates.

Table F.10 **Foreign knowledge stock indexes, BRD, 1968-69 to 2002-03**

Base year = 2001-02. Assumed decay rate of 15 per cent.

Year	*Rfrb15 _u*	*Rfrb15 _td*	*Rfrb15 _tch*	*Rfrb15 _ti*	*Rfrb15 _te*	*Rfrb15 _pe*	*Rfrb15 _pu*	*Rfrb15 _pa*	*Rfrb15 _f*	*Rfrb15 _z*
1968-69	30.5	25.8	16.8	39.6	24.7	23.8	28.3	35.5	31.4	24.9
1969-70	31.5	26.8	17.2	40.9	25.7	24.6	29.3	36.7	32.4	25.8
1970-71	32.6	27.9	17.5	42.2	26.7	25.4	30.4	37.9	33.5	26.8
1971-72	33.7	28.9	16.9	43.6	27.8	26.3	31.6	39.2	34.6	27.8
1972-73	34.9	30.1	16.1	45.1	29.0	27.2	33.0	40.5	35.7	28.8
1973-74	35.8	30.9	19.9	46.1	29.8	28.0	34.0	41.5	36.6	29.6
1974-75	36.3	31.4	22.5	46.7	30.4	28.5	34.9	42.1	36.9	30.1
1975-76	37.0	32.1	20.8	47.4	31.1	29.2	35.8	42.8	37.5	30.8
1976-77	37.6	32.9	23.4	48.2	31.9	29.9	36.8	43.6	38.1	31.6
1977-78	38.5	33.8	23.9	49.2	32.9	30.9	38.0	44.6	39.0	32.5
1978-79	39.8	35.1	26.2	50.9	34.2	32.2	39.6	46.1	40.1	33.7
1979-80	41.3	36.6	28.2	52.7	35.9	33.8	41.4	47.8	41.4	35.1
1980-81	43.1	38.5	31.1	55.0	37.9	35.6	43.5	49.9	42.9	36.8
1981-82	45.2	40.6	33.1	57.5	40.1	37.6	45.8	52.2	44.7	38.8
1982-83	47.4	42.9	32.5	60.3	42.5	39.7	48.3	54.8	46.7	40.9
1983-84	50.1	45.8	33.4	63.5	45.5	42.3	51.3	57.9	49.2	43.6
1984-85	53.4	49.2	41.2	67.5	49.0	45.5	54.9	61.7	52.3	46.8
1985-86	56.5	52.5	46.1	71.2	52.1	48.7	58.3	65.2	55.1	49.7
1986-87	59.5	55.7	46.3	74.5	55.1	51.8	61.7	68.6	57.7	52.6
1987-88	62.6	58.9	47.4	77.7	58.0	55.0	64.9	71.9	60.3	55.4
1988-89	65.6	62.1	50.8	80.7	60.8	58.1	68.0	75.0	62.7	58.1
1989-90	68.7	65.5	54.0	83.6	63.7	61.3	71.0	78.1	65.3	61.1
1990-91	71.6	68.7	53.4	85.9	66.5	64.4	73.7	80.8	67.9	64.0
1991-92	73.8	71.4	56.2	87.4	68.8	67.0	75.7	82.8	70.2	66.5
1992-93	75.3	73.1	62.7	88.2	70.5	68.9	76.8	83.8	71.9	68.3
1993-94	76.6	74.6	65.8	88.9	72.0	70.7	77.7	84.5	73.5	69.9
1994-95	78.4	76.7	73.4	90.3	74.4	73.0	79.0	85.6	75.8	72.2
1995-96	80.7	79.4	73.7	92.1	77.5	75.8	80.8	87.0	78.7	75.0
1996-97	83.4	82.6	74.6	94.2	81.1	79.0	83.2	88.8	82.1	78.5
1997-98	86.4	86.1	84.0	96.1	85.0	82.7	86.0	90.8	85.8	82.3
1998-99	89.8	89.9	88.8	97.9	89.1	86.9	89.4	93.3	89.9	86.7
1999-00	93.8	94.2	97.9	99.7	93.6	91.7	93.5	96.2	94.3	91.8
2000-01	97.3	97.7	103.0	100.6	97.4	96.3	97.2	98.6	97.8	96.4
2001-02	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
2002-03	102.9	102.3	104.9	99.4	102.6	103.9	102.8	101.2	101.8	103.8

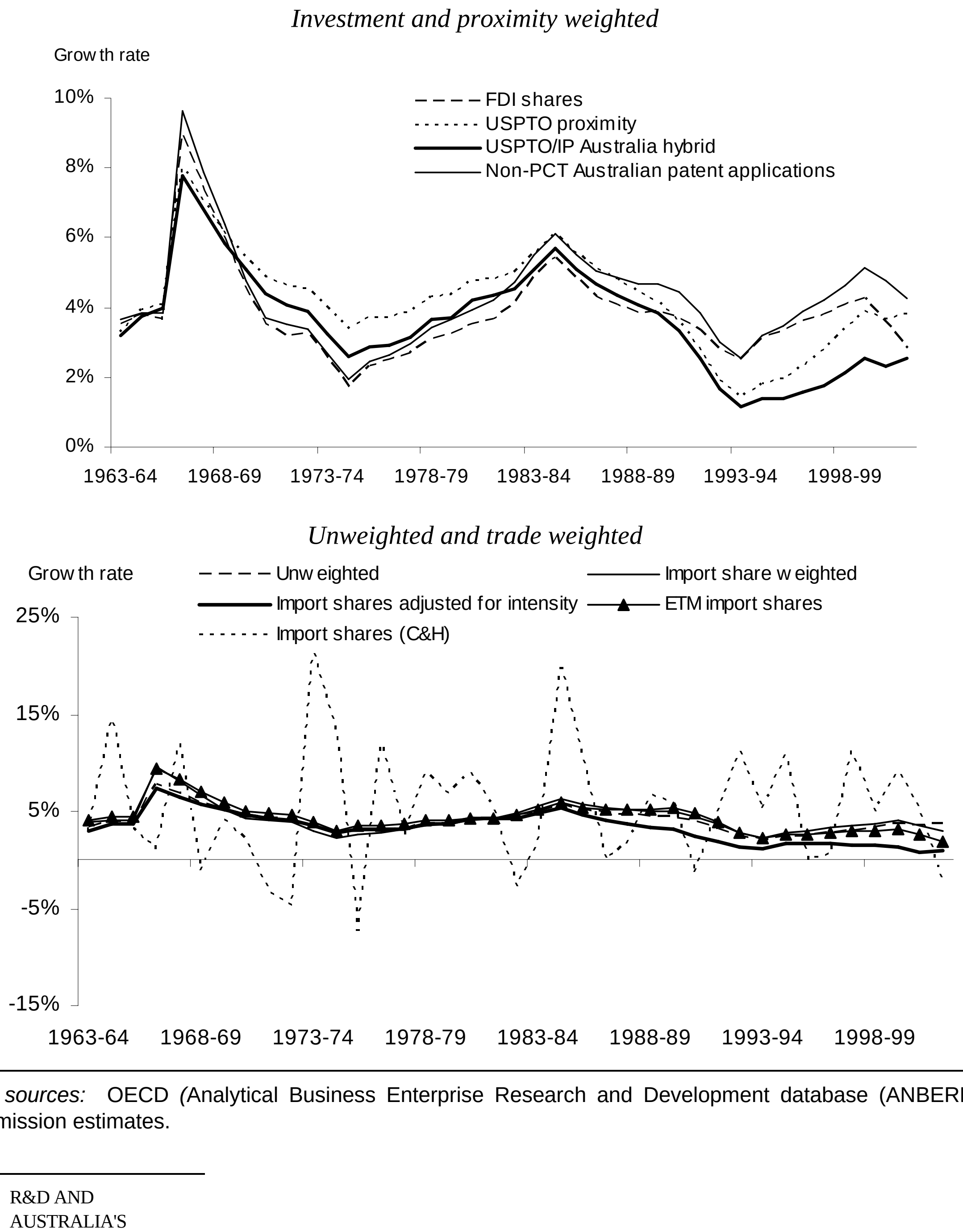
Source: ABS unpublished data; DFAT (Stars database); USPTO and EPO data accessed through OECD Patent database; IP Australia (unpublished data); Commission estimates.

F.3 Comparison of growth rates in the foreign weighted knowledge stocks

The growth patterns in the GRD stocks are very similar (figure F.2), except for the stocks weighted by FDI shares and those scaled by Australian import intensity (as per Coe and Helpman's (C&H) approach). The levels of the stocks all trend upwards together.

Figure F.2 **Growth in Australia's potential spillover pool, foreign GRD, 1963-64 to 2001-02**

Based on PIM methodology and assumed depreciation rate of 15 per cent.



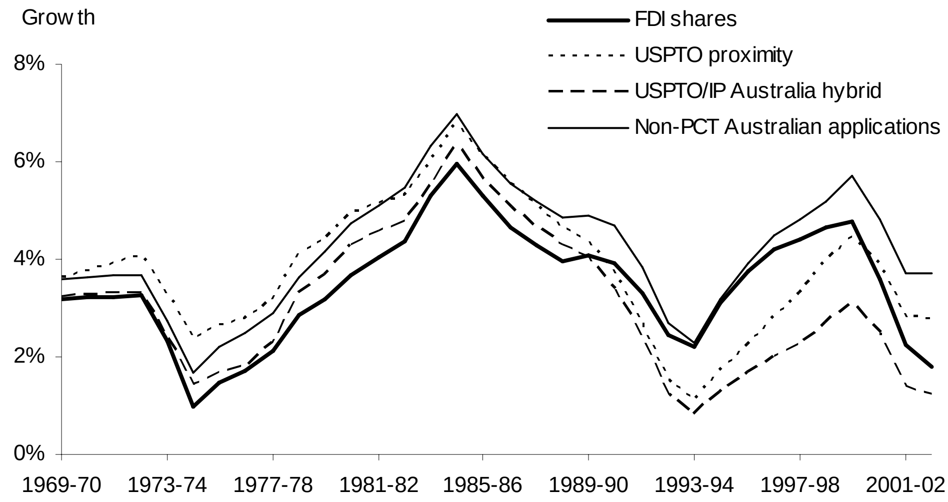
Data sources: OECD (Analytical Business Enterprise Research and Development database (ANBERD)); Commission estimates.

As with the foreign stocks based on GRD, the overall growth patterns for the weighted foreign BRD stocks are very similar (figure F.3). A few of the stocks do diverge from the group in the 1990s: the two proximity measures using USPTO data; and the import share measure based on equation (F3).

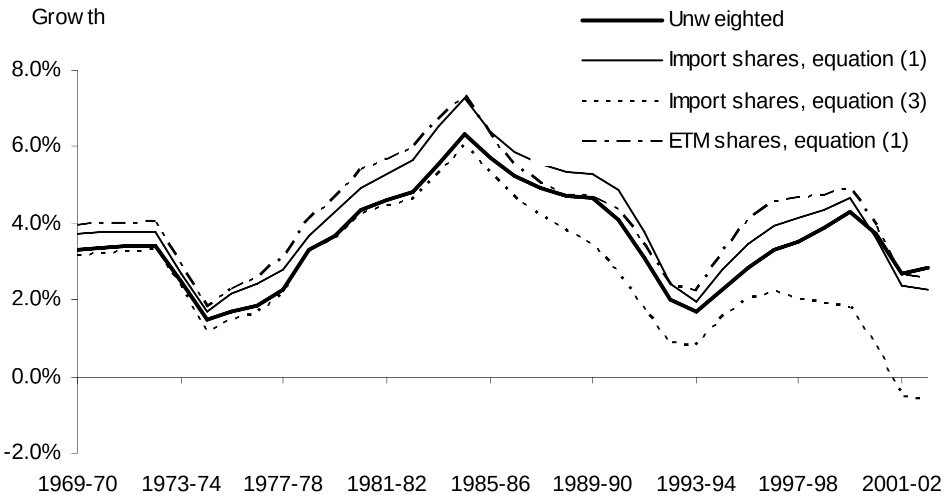
Figure F.3 **Growth in Australia's potential spillover pool, foreign BRD, 1969-70 to 2002-03**

Based on PIM methodology and assumed depreciation rate of 15 per cent.

Unweighted and trade weighted



FDI shares and proximity weighted



Data sources: OECD (Analytical Business Enterprise Research and Development database (ANBERD)); Commission estimates.

Foreign knowledge stocks constructed from industry level data

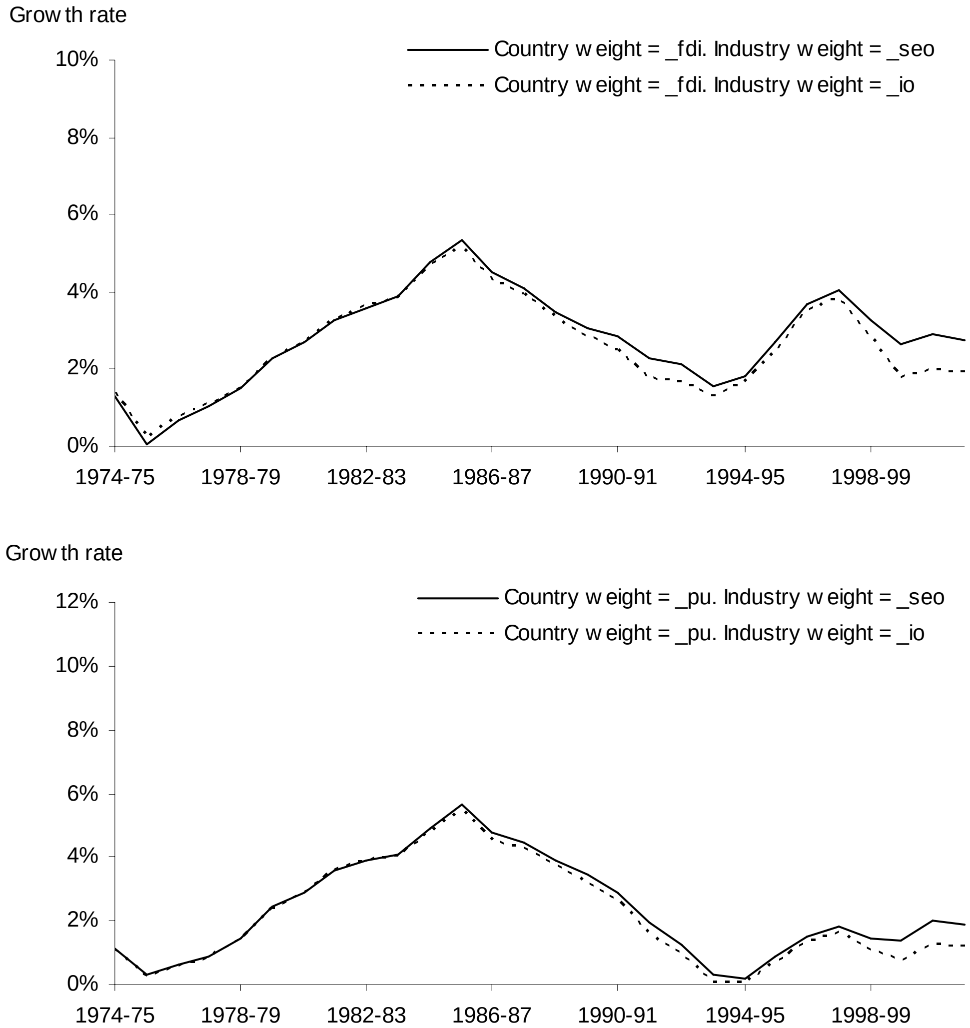
For the construction of foreign knowledge stocks for industry level analysis, both inter-industry and inter-country relationships can be taken into account. The measures of inter-country relationships outlined above can be combined with the measures of inter-industry relationships outlined in appendix C. "_seo" denotes inter-industry weights obtained by creating a technological proximity measure using the expenditures of Australian industries decomposed by Socio-Economic Objective (SEO). "_io" denotes inter-industry weights obtained from the Australian System of National Accounts (ASNA) input-output tables. The resulting growth rates in the international spillover pool for total manufacturing are shown in figure F.4.

The different weighting schemes do give different estimates of the growth in the potential international spillover pool to Australian manufacturing (note: the vertical scale differs for the charts with _tch and _fdi country weights). The differences in patterns across the graphs are being driven by the country weights applied and not the inter-industry weights. In the case of the _tch weighted stocks, the scaling by (M/Y) has the effect of introducing higher frequency variation into the growth rate of the foreign stock.

Figure F.4 **Growth in international spillover pool for total manufacturing, country and inter-industry weighted, 1974-75 to 2001-02**

(continued on next page)

Figure F.4 **(continued)**



Data sources: OECD (ANBERD database); Commission estimates.

G Trends in international R&D investment

G.1 International trends in aggregate R&D activity

World R&D is highly concentrated in three regions — the United States, Europe and Japan — which together account for around 90 per cent of all R&D undertaken in the OECD (table G.1).[1] The United States is by far the largest R&D performer, accounting for a massive 44 per cent of OECD R&D activity. Just four countries — the United States, Japan, Germany, and France — account for around three-quarters of total OECD R&D effort. A further four countries — United Kingdom, Korea, Canada and Italy — account for half of the remainder. And there are only four more countries — Sweden, the Netherlands, Australia and Spain — that each contribute more than one per cent of the OECD total.

The dominant role played by the United States in global R&D activity can be seen in figures G.1 and G.2. The pattern of gross investment in gross expenditure on R&D (GERD) in the United States drives the overall pattern of investment in GERD for the sub-set of R&D performing countries used to construct the R&D stocks used in this paper (figure G.1). The pattern of growth in gross investment in business expenditure on R&D (BERD) is also very closely tied to growth rates in the United States (figure G.2).

[1] The 29 OECD countries spent US$645 billion on R&D in 2001 (OECD 2003b).

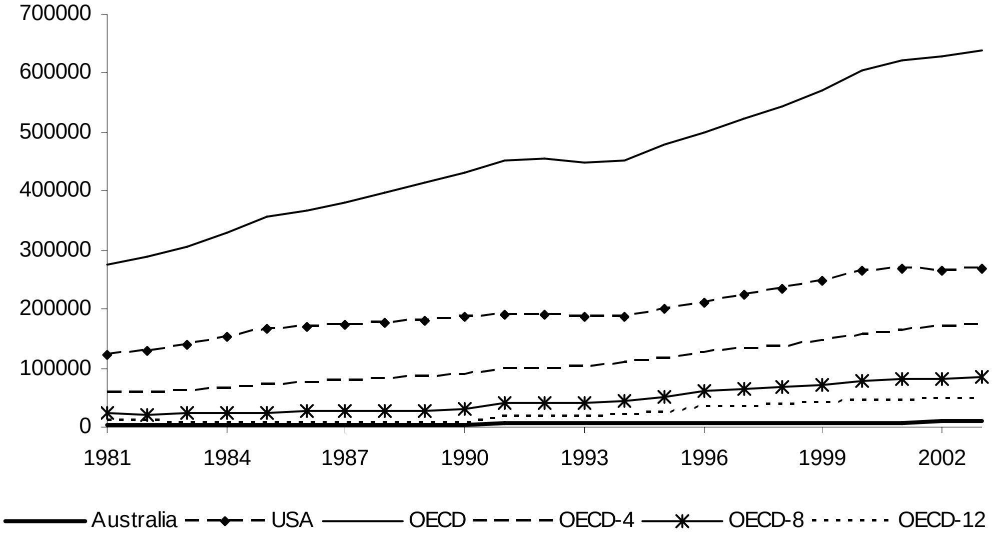
Table G.1 **The locus and intensity of R&D spending in the OECD area, 2001**

Country	*Share of total OECD R&D expenditure, 2001 or latest year*	*R&D intensity (GERD as a percentage of GDP), per cent, 2001 or latest year*	*Ranking by R&D intensity*	*Ranking by contribution to total OECD R&D expenditure*
United States	43.7	2.8	6	1
European Union	*28.1*	*1.9*		
Japan	16.7	3.1	3	2
Germany	8.3	2.5	8	3
France	5.3	2.2	9	4
United Kingdom	4.2	1.9	15	5
Korea	3.4	3.0	5	6
Canada	2.8	1.9	12	7
Italy	2.4	1.1	20	8
Sweden	1.6	4.3	1	9
Netherlands	1.4	1.9	13	10
Australia	***1.3***	***1.5***	***17***	***11***
Spain	1.2	1.0	22	12
Switzerland	0.9	2.6	7	13
Belgium	0.9	2.0	11	14
Finland	0.7	3.4	2	15
Austria	0.7	1.9	14	16
Denmark	0.6	2.2	10	17
Mexico	0.6	0.4	29	18
Turkey	0.5	0.6	28	19
Norway	0.4	1.6	16	20
Poland	0.4	0.7	26	21
Czech Republic	0.3	1.3	18	22
Ireland	0.2	1.2	19	23
Hungary	0.2	1.0	23	24
Portugal	0.2	0.8	24	25
Greece	0.2	0.7	25	26
New Zealand	0.1	1.0	21	27
Slovak Republic	0.1	0.7	27	28
Iceland	0.0	3.1	4	29
Total OECD	**100**	**2.3**		

Sources: OECD Main Science and Technology Indicators database; OECD (2003b, table A2, p. 19).

Figure G.1 **Total GERD at constant prices, 1981 to 2003**[a]

US$m 2000 prices

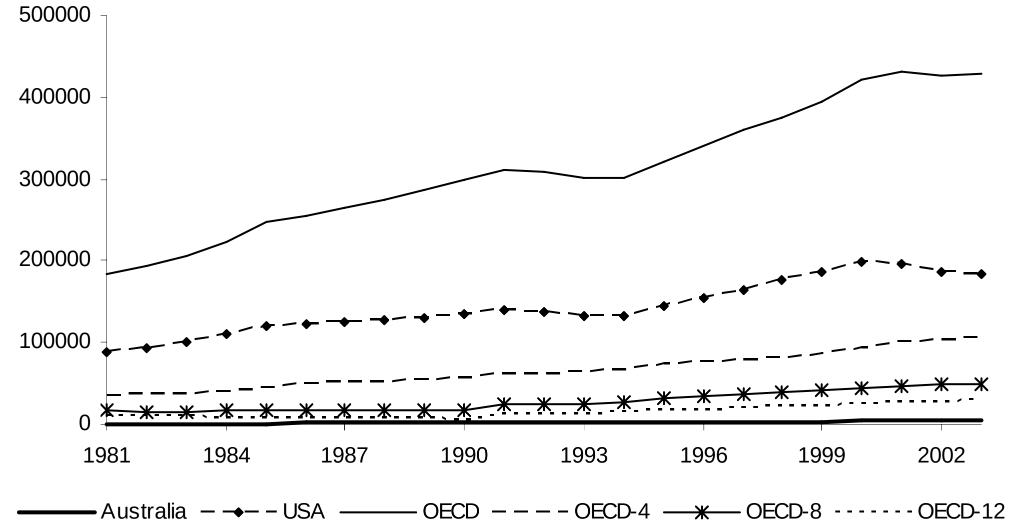


[a] OECD 4 = Total OECD less United States, France, Japan and Germany. OECD-8 = OECD-4 less United Kingdom, Korea, Canada and Italy. OECD-12 = OECD-8 less Sweden, Netherlands, Australia and Spain.

Data sources: OECD Main Science and Technology Indicators database; Commission estimates.

Figure G.2 **Total BERD at constant prices, 1981 to 2003**[a]

US$m 2000 prices

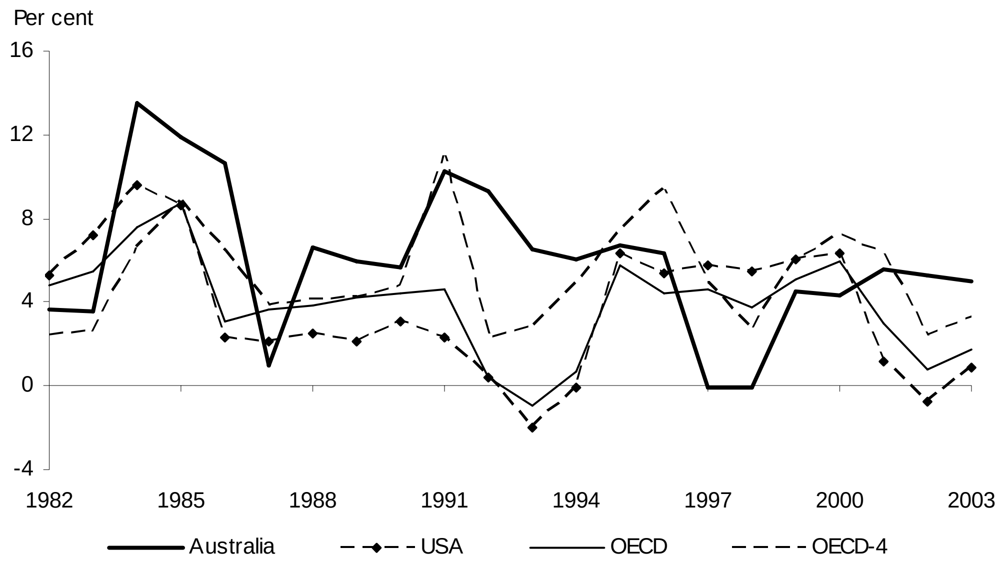


[a] OECD 4 = Total OECD less United States, France, Japan and Germany. OECD-8 = OECD-4 less United Kingdom, Korea, Canada and Italy. OECD-12 = OECD-8 less Sweden, Netherlands, Australia and Spain.

Data sources: OECD Main Science and Technology Indicators database; Commission estimates.

There are a number of differences in the pattern of Australian BERD and GERD and that for other OECD countries as a whole. First, the Australian acceleration in gross BERD and GERD investment in the early to mid-1980s lagged the increase in international growth rates (figure G.3 shows annual growth rates from 1981 and figure G.4 shows smoothed growth rates from 1969-70 for the 14 countries used in the foreign R&D stocks). However, the foreign R&D stocks are dominated by a small number of countries. Once the four major R&D performing countries (the United States, Japan, Germany and France) are removed, the Australian growth rate in GERD follows a similar pattern to the OECD. The main difference is that the amplitude of the time series for GERD growth rates in Australia is much larger than that for the OECD-4 series (figure G.3).

Figure G.3 **GERD growth rates, 1982 to 2003**[a]



[a] OECD 4 = Total OECD less United States, France, Japan and Germany.

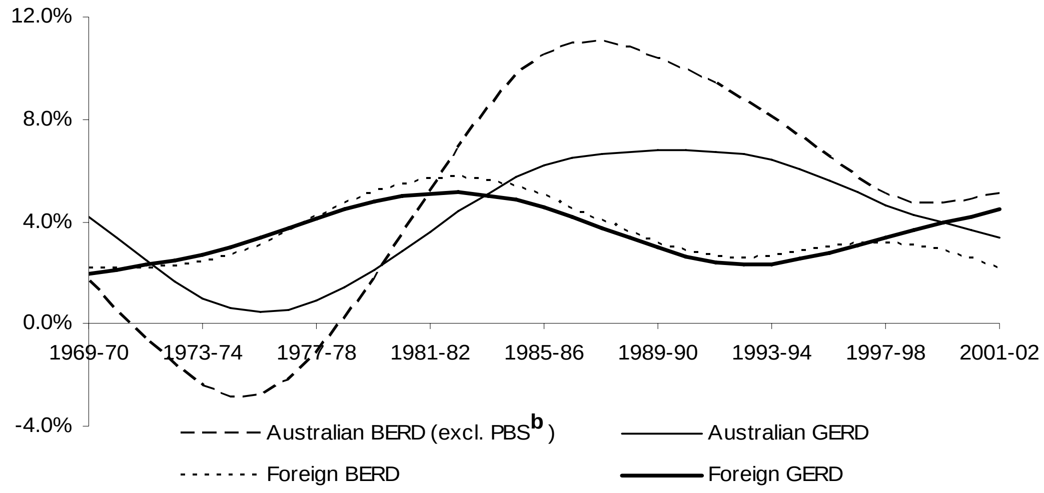
Data sources: OECD Main Science and Technology Indicators database; Commission estimates.

Second, the Australian rates of growth have been sustained at a higher level for a longer period than the average of the R&D stock countries. This is reflected in the greater amplitude for the smoothed Australian BERD and GERD series in figure G.4, although it is more noticeable for BERD than it is for GERD. Third, the difference between BERD and GERD growth rates has been much higher in Australia than internationally.[2] These differences might be partly explained by compositional differences between Australian R&D and that of the major R&D

[2] Note that the GERD and BERD data that are illustrated in figure G.10 have been smoothed using the Hodrick-Prescott (H-P) filter (Hodrick and Prescott 1980, 1997). The H-P filter extracts an unobserved smooth nonlinear time trend from the original data by removing much of the high frequency variation in that data.

performing countries in the OECD. These compositional differences are briefly considered in section G.2 of this appendix.

Figure G.4 **Growth rate in gross R&D investment[a], Australian versus subset of international countries, 1969-70 to 2001-02**



[a] Smoothed using Hodrick-Prescott filter. Foreign expenditure based on the 14 countries used in construction of foreign knowledge stocks. [b] Property & business services.

Data sources: ABS (*Research and Experimental Development, All Sector Summary, Australia,* Cat. no. 8112.0); OECD ANBERD database.

Differences in R&D expenditure between Australia and some other countries might also be explained, in part, by scale effects. Indeed, R&D intensity varies across countries according to a somewhat different pattern than R&D investment levels. R&D intensity is highest in two small R&D performing countries — Sweden and Finland.[3] Only four of the eight major R&D performing countries — Japan (rank 3), South Korea (rank 5), the United States (rank 6) and Germany (rank 8) — have R&D intensities above the OECD average. The United States and Japan, of course, have a particularly strong influence on the OECD average, because of their relatively large R&D spends. Most countries — 21 out of the 29 listed in table G.1 — have R&D intensities below the OECD average. Australia's R&D intensity is around the OECD average, excluding the top four R&D-performing countries.[4]

From the early 1990s, net investment in BERD as a proportion of GDP was higher in Sweden and Japan than in the United States. Over this period, Finland, Ireland,

[3] Two other countries have R&D intensities above the OECD average — Iceland (rank 4) and Switzerland (rank 7).

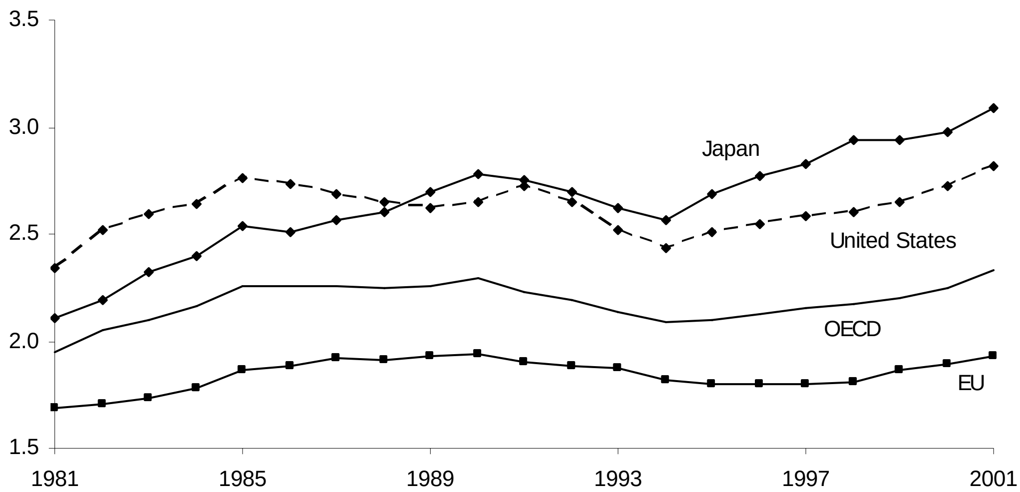
[4] According to OECD estimates, Australia's R&D intensity in 2001 was 1.5 per cent, compared with 1.6 per cent across OECD countries, excluding the top 4 R&D performers.

and Denmark recorded net growth in their stocks at roughly the same rate as the United States, after recording lower rates throughout the 1970s and 1980s.

Trends in the intensity of Australia's GERD over the 1980s and 1990s were detached from trends in the OECD as a whole. Net increases in the stock of business R&D as a proportion of GDP in Australia were less than international rates for all of the 1970s and 1980s.[5] Australian rates were briefly higher in the first half of the 1990s before dipping below again in the latter half of the 1990s, and increasing from 1999-00. The intensity of R&D activity declined generally in the OECD area between the mid-1980s and mid-1990s (figure G.5) — the opposite to the Australian trend (figure G.6). OECD R&D intensity was flat in the second half of the 1980s (as an increase in intensity in Japan and, to a lesser extent, in Europe offset a decline in United States intensity). The OECD average then declined in the early 1990s (with falls in all three regions, especially the United States). In the second half of the 1990s, when Australian R&D intensity stabilised, OECD intensity increased, with an upturn in the United States and Japan from 1994 and in Europe from 1998. At 2002-03, rates of accumulation in the business R&D stock were very similar. These patterns are also evident in relative GERD performance.

Figure G.5 **Trends in R&D intensity by area[a], 1981 to 2001**

Percentage of GDP

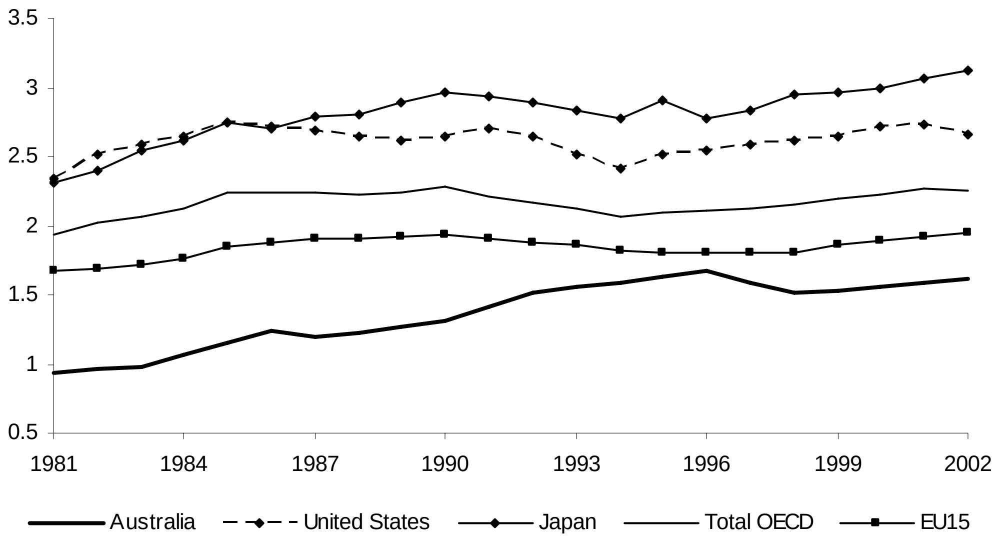


a R&D intensity is Gross domestic expenditure on R&D as a percentage of GDP. For Japan the data were adjusted up to 1995. For the European Union, an estimate was used for 1982 because there were no data available.

Data sources: OECD Main Science and Technology Indicators database; OECD (2003b).

5 In this paper, R&D intensity is measured as the percentage of GDP that is devoted to R&D investment. Note that this is different from the net addition to the R&D stock as a percentage of GDP unless the depreciation rate used in the perpetual inventory method (PIM) calculations underlying the R&D stock is zero. However, these two measures should have a strong positive correlation.

Figure G.6 **GERD intensity by region[a], 1981 to 2002**
Percentage of GDP



a R&D intensity is Gross domestic expenditure on R&D as a percentage of GDP.

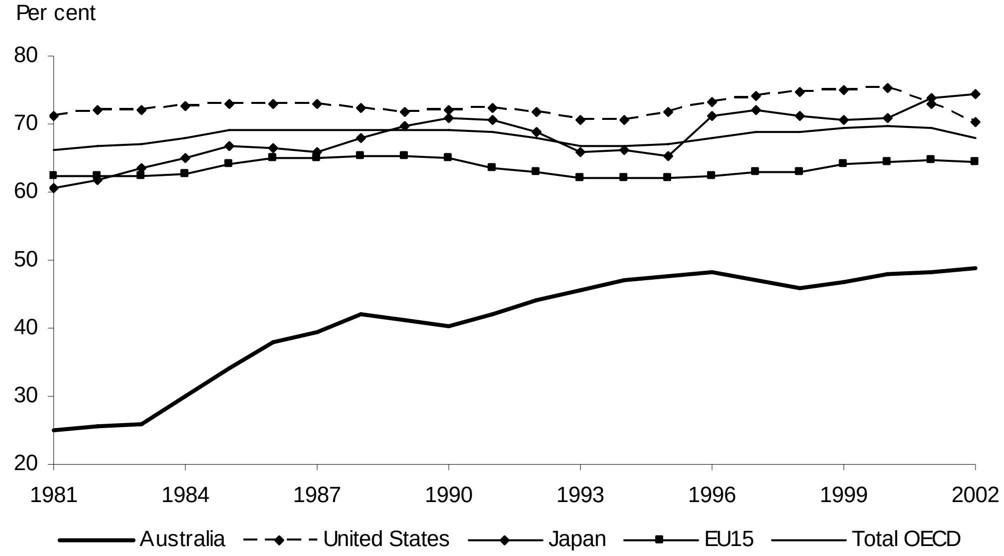
Data sources: OECD Main Science and Technology Indicators database; Commission estimates.

G.2 International trends in sectoral R&D activity

There are both similarities and differences between Australian and overseas trends in the structure of R&D activity in terms of the performance and functions of R&D by institutional sectors.

Variations in business R&D have tended to be the major factor behind the trends in total R&D effort for many OECD countries, including Australia, with business R&D assuming greater importance over the past two decades. The rate of increase was steady in the OECD generally, until it dropped back in the early 1990s, but then picked up more strongly in the second half of the 1990s (figures G.7 and G.8). The changes in the 1990s were largely driven by changes in US BERD activity. Despite the increasing importance of business R&D activity and funding in Australia (table G.2), it remains far less prominent than it is many other OECD countries. In 2002–2003 businesses performed nearly 70 per cent of all R&D in the OECD area, but only 47 per cent in Australia.

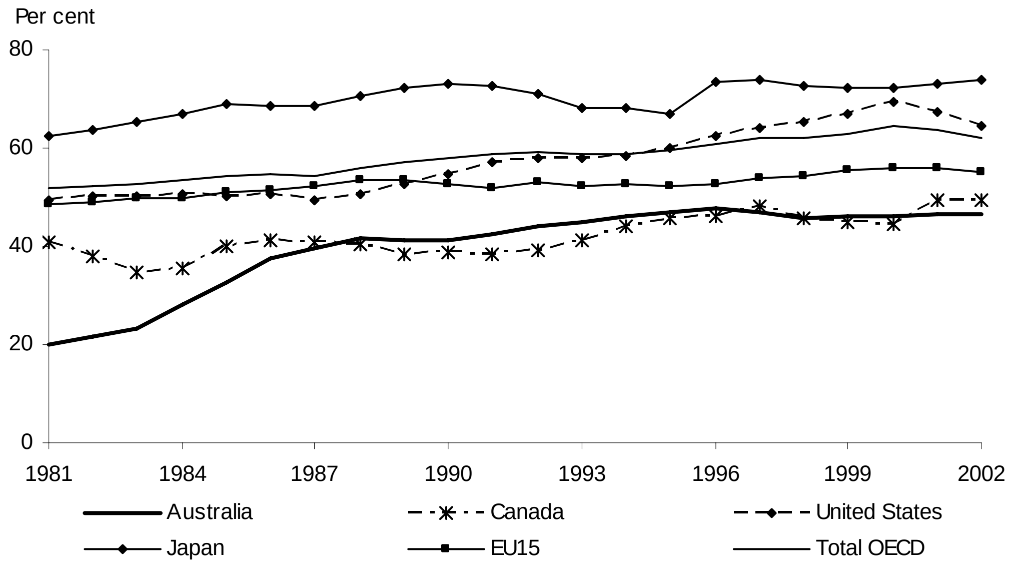
Figure G.7 **Share of GERD performed by business enterprises, 1981 to 2002[a]**



a EU15 countries are Austria, Belgium, Denmark, France, Finland, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, Sweden and the United Kingdom.

Data source: OECD Main Science and Technology Indicators database; Commission estimates.

Figure G.8 **Share of GERD funded by industry, 1981 to 2002**



Data source: OECD Main Science and Technology Indicators database; Commission estimates.

Table G.2 **Sources of R&D funds by institutional sectors, Australia, various years**

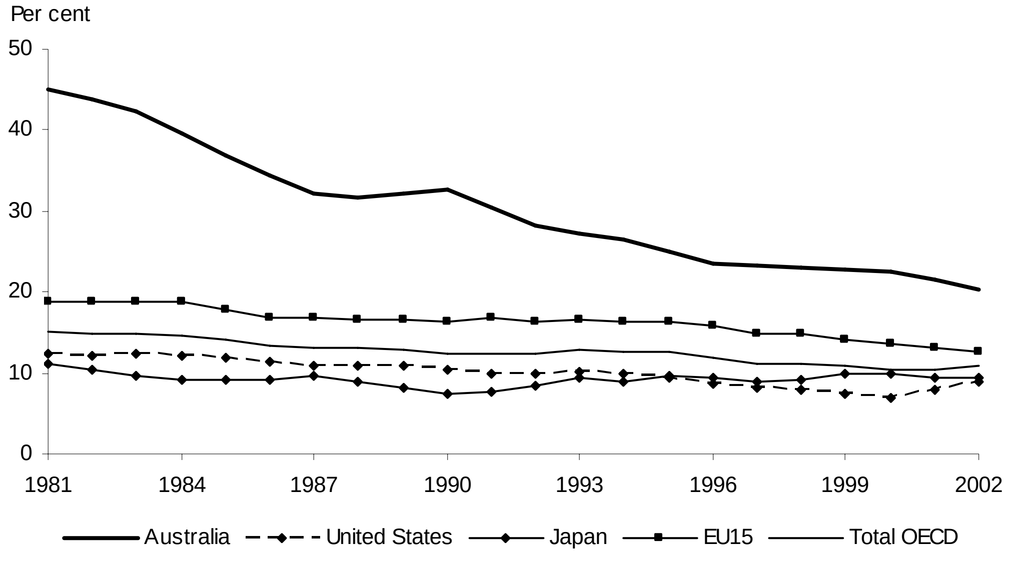
	1978-79	*1984-85*	*1996-97*	*2002-03*
	%	%	%	%
Total funds sourced from:				
Business	**20.6**	**28.0**	**47.8**	**46.4**
Government	**76.5**	**68.5**	**45.8**	**44.4**
Private non-profit	**1.3**	**2.4**	**4.4**	**4.9**
Overseas	**1.6**	**1.1**	**2.1**	**4.3**
	100.0	**100.0**	**100.0**	**100.0**
Business funds sourced from:				
Business	85.2	88.4	92.8	89.6
Government	10.9	9.8	2.6	4.3
Private non-profit	0.2	0.1	1.5	0.7
Overseas	3.7	1.8	3.2	5.4
	100.0	100.0	100.0	100.0
Government agency funds sourced from:				
Business	1.0	2.3	5.7	5.2
Government	97.9	96.2	85.1	80.3
Private non-profit	0.3	1.1	8.5	12.6
Overseas	0.9	0.4	0.7	1.9
	100.0	100.0	100.0	100.0
Higher education funds sourced from:				
Business	0.9	1.6	5.2	5.1
Government	96.2	92.4	90.3	88.7
Private non-profit	2.3	5.2	3.4	2.9
Overseas	0.5	0.8	1.1	3.3
	100.0	100.0	100.0	100.0
Private non-profit funds sourced from:				
Business	3.1	4.5	17.1	8.8
Government	49.3	58.6	39.6	40.0
Private non-profit	33.3	27.7	40.3	41.0
Overseas	14.3	9.3	3.0	10.3
	100.0	100.0	100.0	100.0

Sources: ABS (*Research and Experimental Development, All Sector Summary, Australia*, Cat. no. 8112.0); ABS (*Australian System of National Accounts*, Cat. no. 5204.0); Commission estimates.

Coincident with this increase in the importance of business R&D activity has been a decline in government funding for R&D. Government funding has declined from 44 per cent of total OECD funds in 1981 to 29 per cent in 2001. In a mirror image of the trends in business R&D, the prominence of both government R&D and higher education R&D in Australia is above the OECD average (figures G.9, G.10 and G.11). With less business prominence, Australia's R&D effort is also less skewed toward experimental development, which accounts for around 60 per cent of all

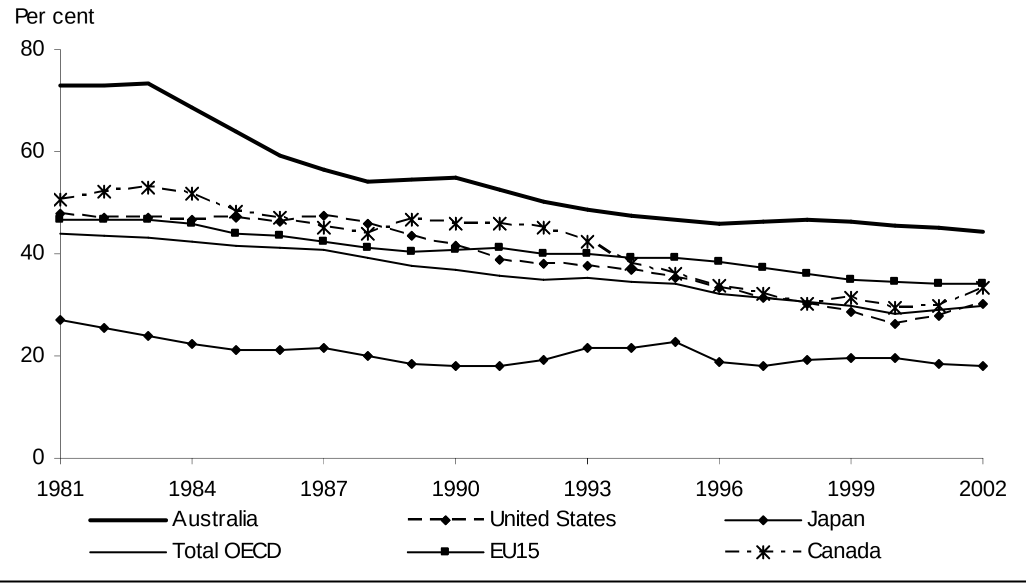
R&D in the United States, Japan, South Korea and France, but only 40 per cent in Australia. However, Australia's proportion is in line with other smaller R&D performing countries.

Figure G.9 **Share of GERD performed by Government, 1981 to 2002**



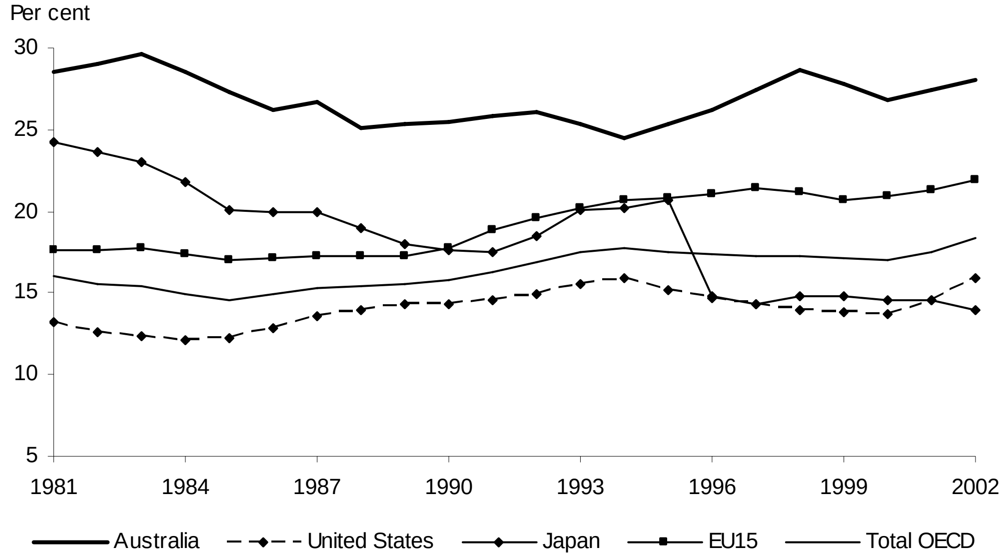
Data sources: OECD Main Science and Technology Indicators database; Commission estimates.

Figure G.10 **Share of GERD funded by Government, 1981 to 2002**



Data sources: OECD Main Science and Technology Indicators database; Commission estimates.

Figure G.11 **Share of GERD performed in higher education institutions, 1981 to 2002**



Data sources: OECD Main Science and Technology Indicators database; Commission estimates.

It is worth noting that, while a lower percentage of Australian R&D is conducted by businesses than that of the OECD, the general upward trend in this proportion is similar in Australia to that observed in the OECD as a whole and in the major R&D performing countries. Similarly, while the proportion of Australian R&D that is conducted by government is higher than that of the OECD, the general downward trend in this proportion in the OECD as a whole and in the major R&D performing countries can be observed in Australia as well. Indeed, the downward trend in the proportion of R&D performed by government is much steeper than that of the OECD as a whole (figure G.9).

G.3 International trends in R&D activity by industry

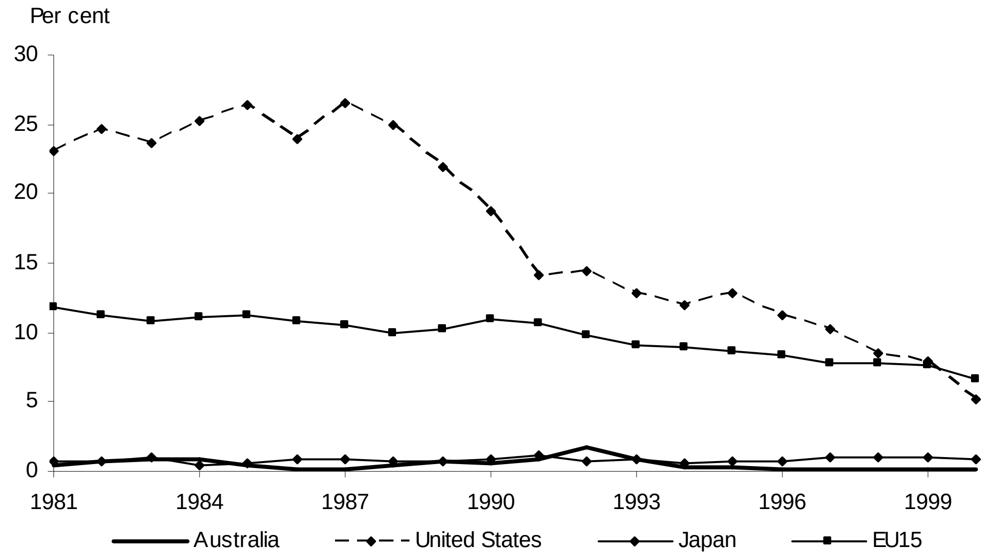
International comparisons of R&D performance tend to be biased towards countries that have a comparative advantage in manufacturing and away from countries that have a comparative advantage in agriculture or mining. There are a number of reasons for this. First, data on agriculture and mining R&D tend to understate the amount of R&D that actually takes place. In particular, it does not include soil research for agricultural purposes, oceanography research that serves the fishing industry and research concerning the exploitation of sources of raw materials, fuel and energy (Lederman and Maloney 2003, p. 19). Furthermore, R&D activity in the agriculture and mining industries is not explicitly reported in the OECD Analytical Business Enterprise Research and Development (ANBERD) database, which is possibly the most comprehensive database on world R&D that is currently available. Instead, it must be estimated as the difference between total BERD and the sum of BERD from other industries (OECD 2002, p. 15). Finally, R&D intensities in the agriculture and mining sectors are lower than R&D intensities in the manufacturing sector (NSF 2004).

Given that Australia has a comparative advantage in primary industries, such as agriculture and mining, the relatively low level of BERD compared with the major R&D performing countries may simply be due to differences in industrial structure of the respective economies. As such, trends in R&D activity in various industries are examined in this section. Unfortunately, international data on primary industries are not available. However, comparisons can be made in the following industries:

- Aerospace;
- Electronics;
- Office machinery and computers;
- Pharmaceuticals;
- Instruments; and
- Services.

Unsurprisingly, a very small portion of Australian BERD takes place in the Aerospace industry (figure G.12). However, Australia is not alone here. Outside of the United States and the European Union, very few countries conduct much R&D in this industry. This is true even for a major R&D performing country such as Japan.

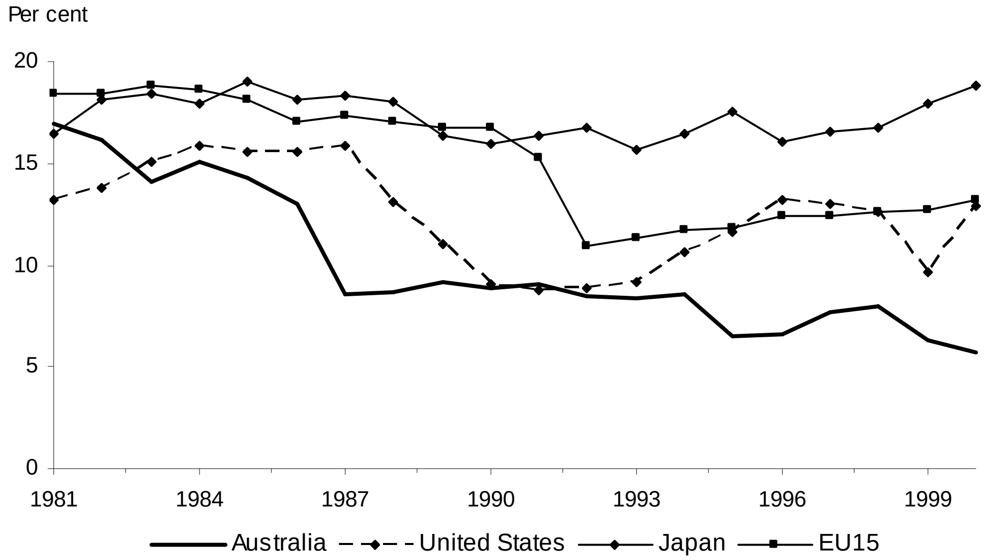
Figure G.12 **Share of BERD devoted to the Aerospace industry, 1981 to 2000**



Data sources: OECD Main Science and Technology Indicators database; Commission estimates.

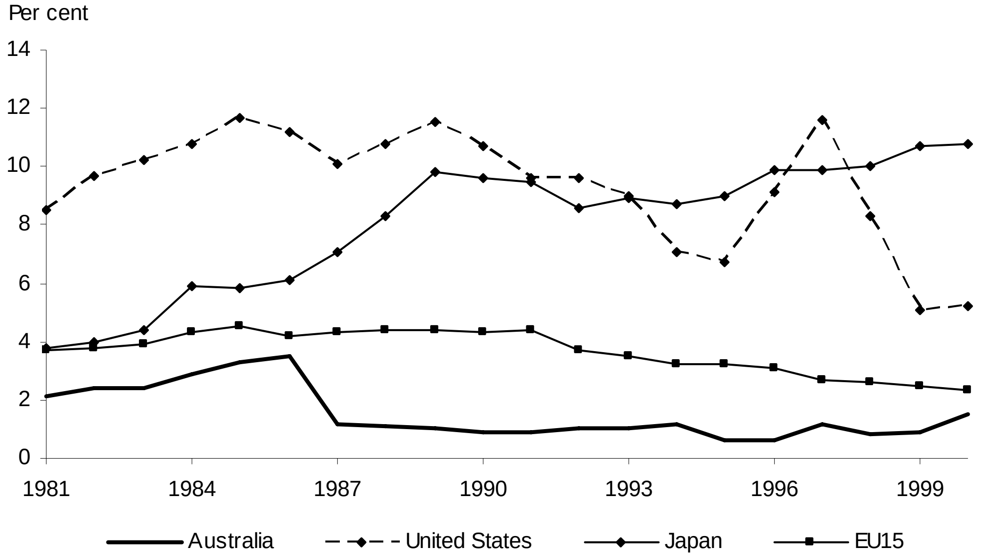
The percentage of Australian BERD that is devoted to electronics, office machinery and computers is also low compared with that in the major R&D performing countries. However, while the actual proportion of BERD devoted to these industries in Australia may be low, the trends in these industries are reasonably similar to those in the United States and the European Union (see figures G.13 and G.14).

Figure G.13 **Share of BERD devoted to the electronics industry, 1981 to 2000**



Data sources: OECD Main Science and Technology Indicators database; Commission estimates.

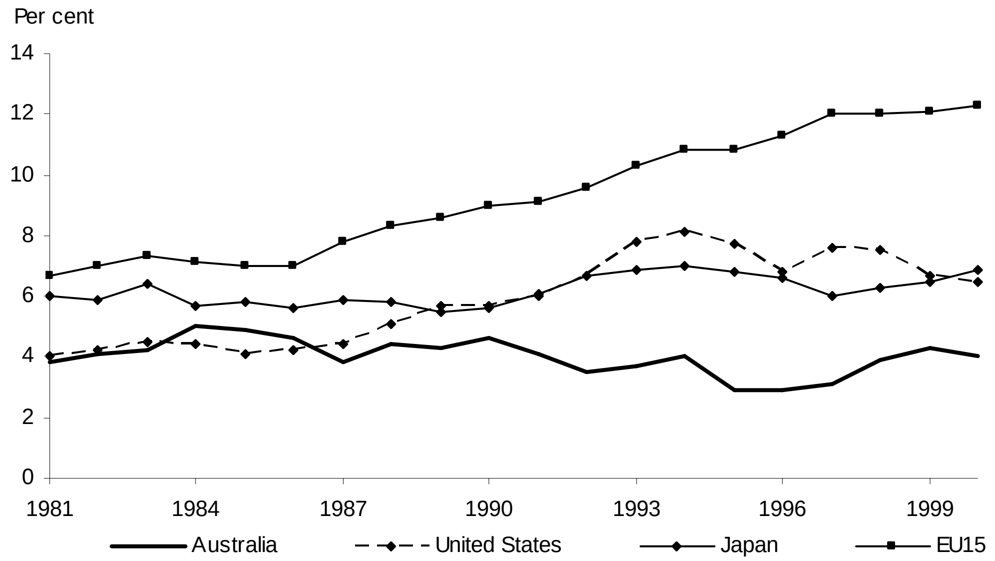
Figure G.14 **Share of BERD devoted to office machinery and computers, 1981 to 2000**



Data sources: OECD Main Science and Technology Indicators database; Commission estimates.

Up until the mid-1980s, Australia was devoting a similar share of BERD to pharmaceuticals R&D as the United States, although this was less than that in the European Union and Japan. However, in the period since then Australia has fallen behind the United States and further behind the European Union, largely because both of these regions increased the percentage of BERD that they devoted to pharmaceuticals, while Australia maintained this percentage at its previous levels (figure G.15).

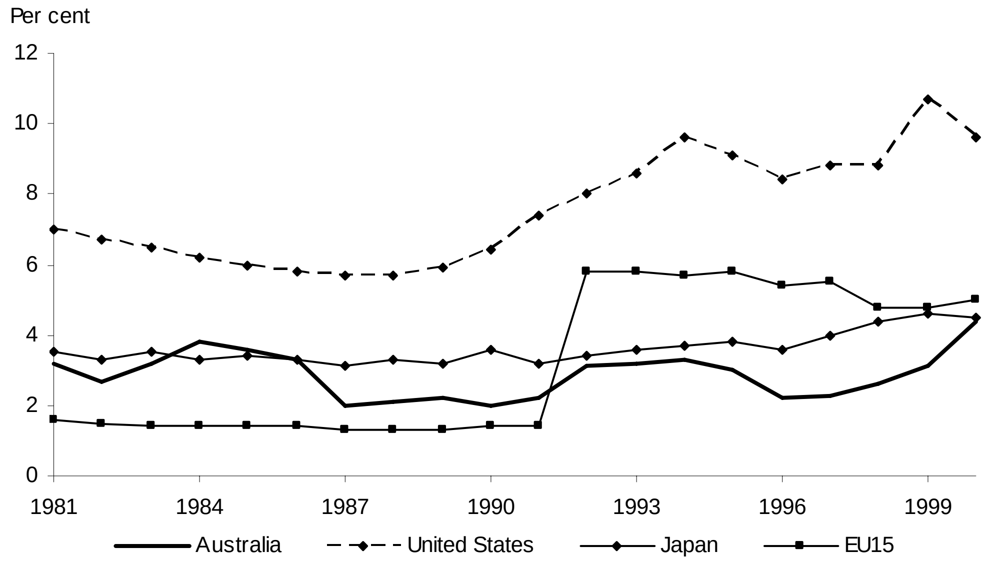
Figure G.15 **Share of BERD devoted to pharmaceuticals, 1981 to 2000**



Data sources: OECD Main Science and Technology Indicators database; Commission estimates.

Compared with the United States, Australian instruments R&D makes up a relatively low percentage of its total business R&D expenditure. However, this may largely be due to the fact that the percentage of BERD devoted to instruments in the United States is high by world standards. Indeed, the percentage of BERD that is devoted to the instruments industry in Australia has been similar to that in the European Union and Japan over the last couple of decades (figure G.16).

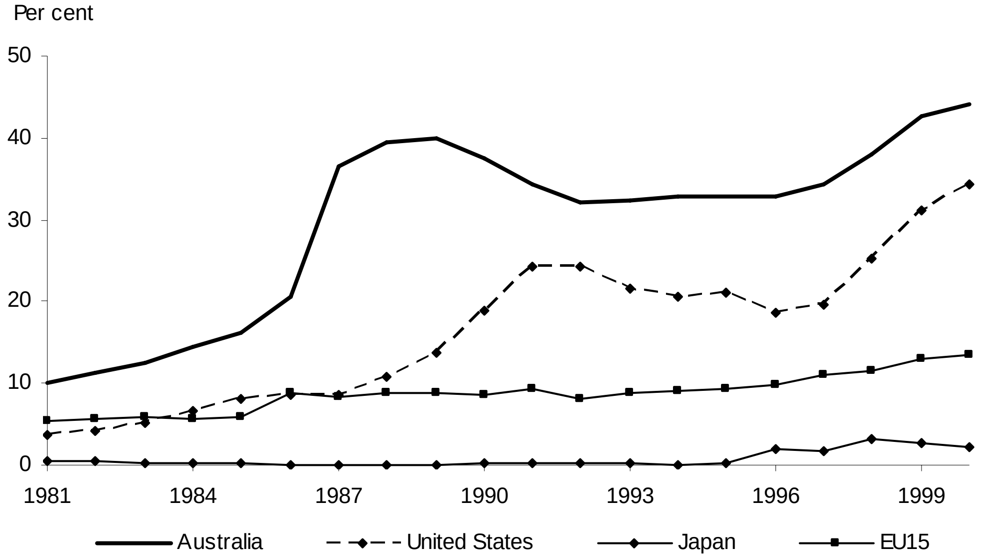
Figure G.16 **Share of BERD devoted to instruments, 1981 to 2000**



Data source: OECD Main Science and Technology Indicators database; Commission estimates.

While Australia has devoted a relatively low percentage of its business R&D towards the industries considered so far, this is not universally true. Australia devotes a much larger percentage of its BERD to R&D in service industries compared with the United States, Japan or the European Union (figure G.17).

Figure G.17 **Share of BERD devoted to services, 1981 to 2000**



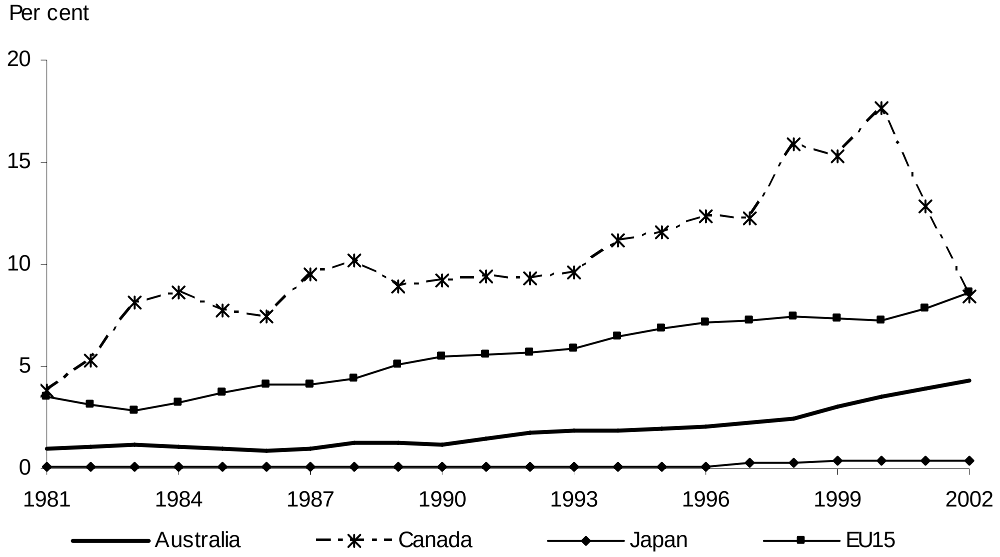
Data sources: OECD Main Science and Technology Indicators database; Commission estimates.

G.4 The internationalisation of R&D

Australia has participated, to a certain extent, in the growing internationalisation of R&D. This is reflected in increased overseas funding of Australian R&D and in growing trade in knowledge and R&D services.

Overseas funding of Australian R&D increased in the 1990s. Foreign sources increased the proportion of funding in all institutional sectors from 1.1 per cent in 1984-85 to 4.3 per cent in 2002-03 (table G.2 and figure G.18). Overseas funding has increased in all sectors and has reached 5.4 per cent of business sector funding, 3.3 per cent of university funding and 10.3 per cent of private non-profit funds.

Figure G.18 **Share of GERD funded by foreign sources, 1981 to 2002**



Data sources: OECD Main Science and Technology Indicators database; Commission estimates.

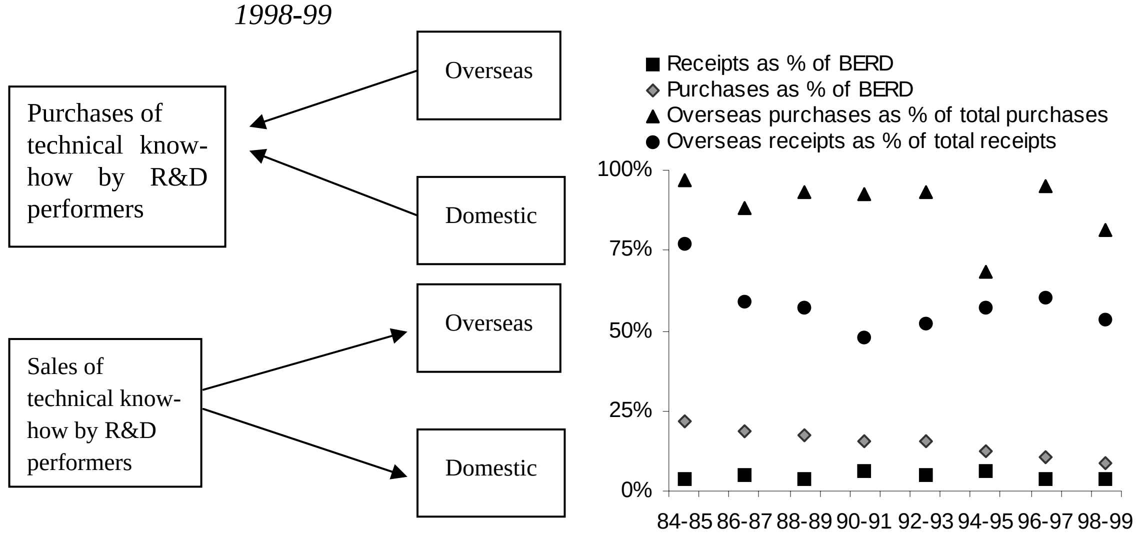
The majority of purchases and sales of technical know-how by Australian R&D performing businesses are from and to overseas entities (figure G.19). In 1998-99, the last year of the series, about 81 per cent of technical know-how was sourced from overseas, while roughly 54 per cent was sold overseas. However, the proportion of technical know-how that businesses source from overseas has been somewhat volatile. At least in some years, businesses have sourced larger proportions of their technical know-how within Australia.

The majority of sales of technical know-how are to entities based in other countries. The domestic proportion of sales increased markedly in the mid-1980s, but has since remained relatively stable. The proportion of technical know-how that is sold abroad has declined from 77 per cent in 1984-85, to 54 per cent in 1998-99.

A small trade surplus in R&D services has developed since 1996-97, due to stronger growth in exports than in imports (figure G.20).[6] However, in proportion to BERD, trade in R&D services remains very small.

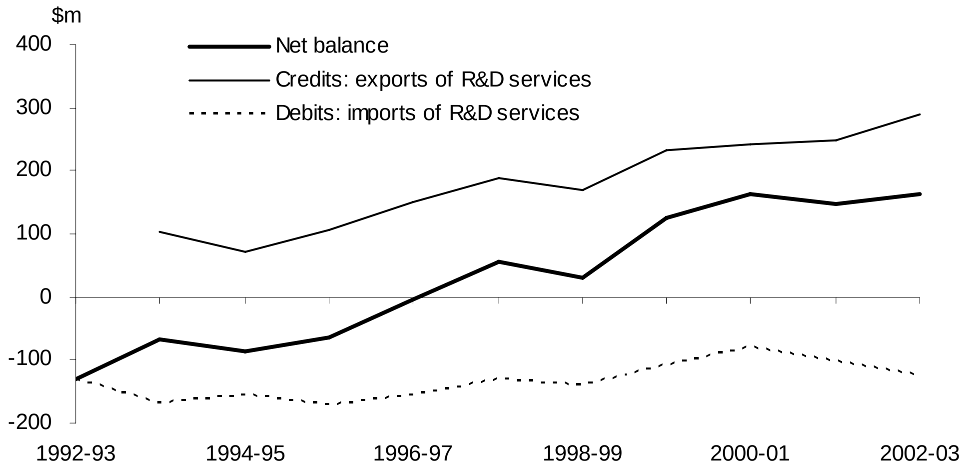
[6] R&D services include cross-border flows of finance between Australia and other countries to finance the performance of R&D, funds provided by multinational companies to finance R&D performed in subsidiaries, flows between unrelated firms conducting joint R&D, and R&D performed jointly between private-sector concerns and university laboratories.

Figure G.19 **Overseas purchase and sale of technical know-how, 1984-85 to 1998-99**



Data source: ABS (*Research and Experimental Development, All Sector Summary, Australia*, Cat. no. 8112.0).

Figure G.20 **International trade in R&D services, Australia and Rest-of-world, 1992-93 to 2002-03**

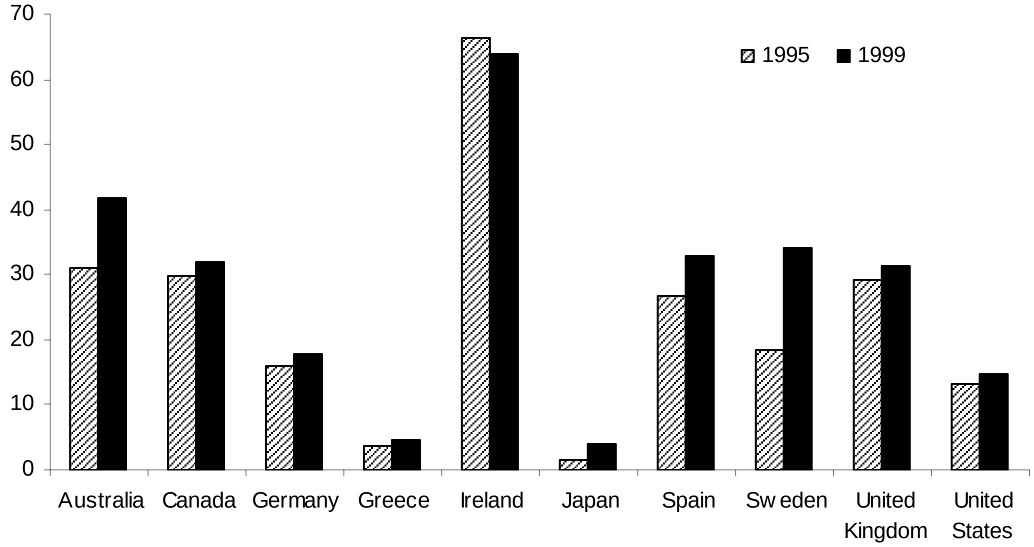


Data source: ABS (*International Trade in Goods and Services*, Cat. no. 5368.0).

A significant portion of global industrial R&D is conducted by foreign affiliates of overseas firms. In 1994, foreign affiliates were responsible for more than 15 per cent of total BERD in 15 OECD countries that together are responsible for more than 95 per cent of all OECD BERD (OECD 1998, p. 16). These countries are Australia, Canada, France, Finland, Germany, Greece, Ireland, Japan, the Netherlands, Poland, Spain, Sweden, Turkey, the United Kingdom and the United

States. Australia participates to a much greater extent in this aspect of the globalisation of industrial R&D activity. An above average portion of Australian BERD is generated by foreign affiliates (figure G.21).

Figure G.21 **R&D expenditure by foreign affiliates, 1995 and 1999**
Percentage of total BERD



Data source: OECD Main Science and Technology Indicators database.

The data reported in table G.3 suggests that there is no strong relationship between R&D intensities and foreign ownership. While in many industries, foreign-owned firms do invest more in R&D per employee than domestically-owned firms, this is not true for all industries. The fact that foreign-owned firms seem to invest much more per employee than domestically-owned firms on an economy-wide basis may simply be an artefact of aggregation. It is possible that foreign firms tend to have a higher R&D intensity than domestically-owned firms simply because they tend to be located in industries that are relatively R&D intensive.

The lack of a clear relationship between R&D intensities and foreign ownership is consistent with the results of previous empirical studies. According to Lofts and Loundes (2000, p. 3), there are studies that find a positive relationship (Bertschek 1995 and Love et al. 1996), studies that find essentially no relationship (Rogers 1998b and Rogers 2000) and studies that find a negative relationship (Harris 1991, Drago and Wooden 1994 and Rogers 1998a). Lofts and Loundes (2000, p. 15) themselves found that '… parent companies located offshore are not particularly interested in using their Australian arms as a vehicle for innovation'.

Table G.3 **The relationship between R&D intensity and foreign ownership**

Industry	*Majority domestically-owned firms* Total employees	R&D per employee	*Majority foreign-owned firms* Total employees	R&D per employee
	('000)	($A)	('000)	($A)
Mining and Services to mining	24.0	7,333	11.0	8,791
Manufacturing	319.0	3,512	292.0	3,191
Wholesale & retail trade	139.0	626	25.0	10,616
Property & business services	33.0	11,894	21.0	15,590
Scientific research	2.0	96,250	0.2	88,000
Other	338.0	1,144	34.0	1,512
Total	**855.0**	**2,754**	**383.0**	**4,414**

Sources: ABS (*Research and Experimental Development, Businesses, Australia,* Cat. no. 8104.0); unpublished ABS data from 1999-2000, linked to the ABS Survey of Investment.

The growing international orientation of R&D is reflected strongly in international patent statistics. While patent statistics only provide a partial picture of R&D activities (in particular, much of the output of R&D activity for many industries is not patented), they suggest increased integration of ownership and R&D activity and increased coordination of R&D production across national borders. The OECD views these trends as being linked with trends in production:

> As firms progressively relocate their production and research facilities abroad as part of their internationalisation strategies, an increasing share of technology is owned by firms of a country that is not the inventor's country of residence. (OECD 2003a, p. 28)

Data on the lodgement of patent applications to the European Patent Office (EPO) and the United States Patent and Trademark Office[7] (USPTO) suggest that Australia has participated in these international trends. Specifically, the series in figure G.22 suggest:

- Australian researchers are increasingly undertaking R&D activity in conjunction with a foreign co-inventor;[8]

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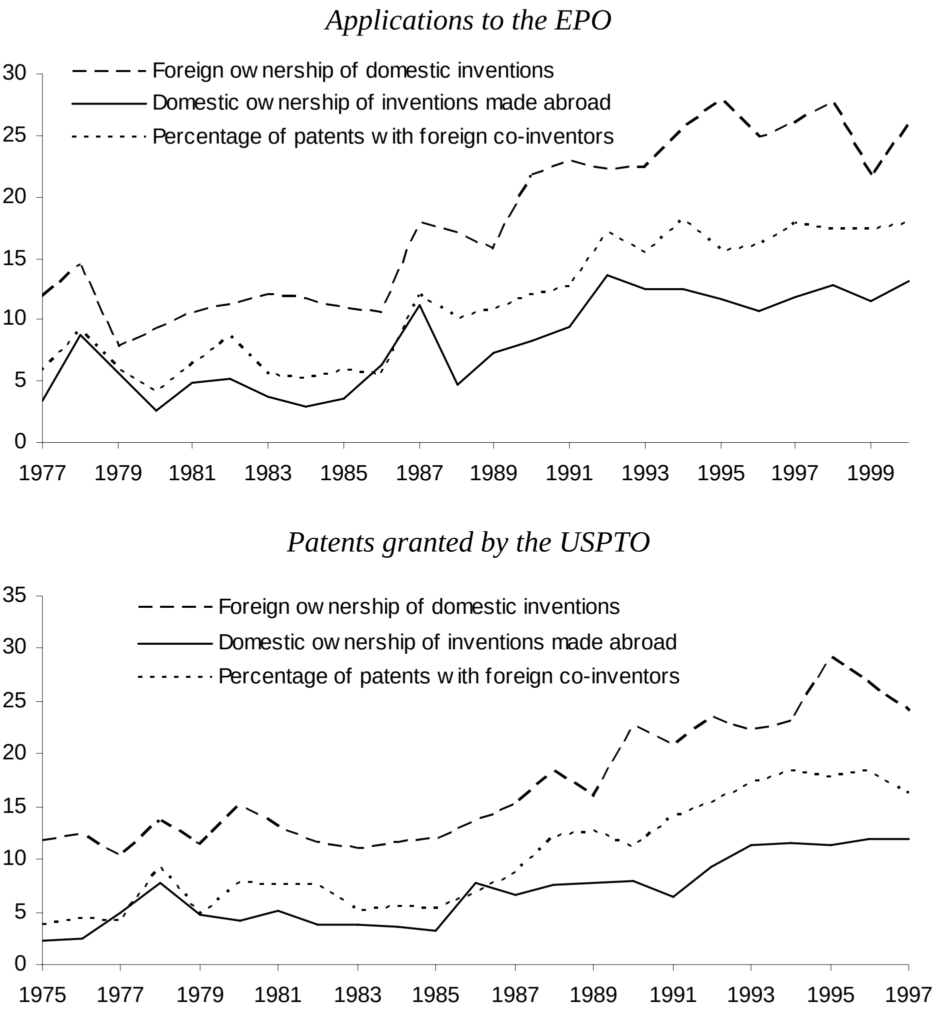
[7] IP Australia data do not record residency of inventors.

[8] Measured as patents with foreign co-inventors: the percentage of patent applications to the EPO (or granted patents by the USPTO) involving an Australian resident inventor and an inventor resident in another country.

- The proportion of external patents involving Australian resident inventors owned by a foreign party has increased;[9] and
- The proportion of external patents owned by an Australian resident and involving only a foreign resident inventor has also increased.[10]

Figure G.22 **The internationalisation of R&D as evidenced by overseas Australian patent data**

Average for priority years 1998-99[a]



[a] The priority year is the year of the first filing of the original application worldwide.

Data source: OECD Patent Database, July 2003.

[9] Measured as domestic ownership of inventions made abroad: the number of applications to the EPO (or granted patents by the USPTO) where the applicant was a resident of Australia, but the inventor(s) were not, over the number of Australian resident applications.

[10] Measured as foreign ownership of domestic inventions: the number of applications to the EPO (or granted patents by the USPTO) where the inventor, or one of the inventors, was a resident of Australia, but the applicant was not a resident of Australia, over the number of patents with an Australian resident inventor.

G.5 International R&D data

Foreign R&D expenditure data were obtained from the OECD Analytical Business Enterprise Research and Development (ANBERD) database. ANBERD is designed to provide analysts with a comprehensive and internationally comparable dataset on industrial R&D expenditures.

Data have been collected under both the International Standard Industrial Classification (ISIC) system Revision 2 and Revision 3. Revision 2 data cover the period 1973 to 1997-98, while Revision 3 data cover the period 1987 onwards. To construct as long a time series as possible, the ANBERD ISIC Revision 3 series was extended back in time using the growth patterns in the ISIC Revision 2 data. The series are provided in table G.4. It should be noted that the currency corrections have been made on the basis of purchasing power parity information at the gross domestic product level, rather than attempting to calculate R&D-specific purchasing power parities.

These data were used to construct foreign R&D stocks by applying the permanent inventory methodology that was employed when constructing the Australian R&D stocks used in this paper as well (see appendix F).

Table G.4 **International BERD, 1968-69 to 2002-03[a,b]**

PPPs in millions, constant 2000 prices

Year	*Canada*	*Denmark*	*Finland*	*France*	*Germany*	*Ireland*	*Italy*
1968-69	1200	296	262	7930	7704	76	5793
1969-70	1281	316	284	8183	8014	84	5884
1970-71	1366	338	308	8443	8336	92	5978
1971-72	1458	361	335	8711	8671	102	6072
1972-73	1556	386	363	8988	9019	112	6168
1973-74	1569	373	327	9129	9214	115	5656
1974-75	1612	363	335	8975	10290	111	5883
1975-76	1553	386	321	8930	10942	101	5116
1976-77	1648	384	333	8917	11699	97	4742
1977-78	1835	393	370	8873	13622	100	4463
1978-79	2085	432	414	9275	16223	108	4729
1980-81	2295	447	459	9596	17194	126	4512
1981-82	2791	466	500	10171	18627	129	4705
1982-83	3013	518	558	10743	19423	131	4901
1983-84	2994	566	615	10935	19757	135	5253
1984-85	3367	616	727	11681	20387	162	5652
1985-86	3930	665	807	12533	22835	189	6538
1986-87	4223	736	881	12749	23482	211	6926
1987-88	4356	791	964	13322	24799	224	7340
1988-89	4442	843	1043	14055	25657	234	7891
1989-90	4385	868	1150	15199	26619	260	8396
1990-91	4595	947	1210	16190	26861	301	8842
1991-92	4627	1028	1118	16607	28188	366	8169
1992-93	4898	1054	1121	17186	27177	430	7947
1993-94	5402	1093	1155	17010	25579	520	7211
1994-95	6288	1160	1353	16946	24930	606	6788
1995-96	6489	1228	1419	16766	25290	680	6698
1996-97	6392	1348	1718	17005	25402	766	6833
1997-98	6907	1466	1946	17010	26809	834	6780
1998-99	7677	1679	2210	17119	27822	893	6793
1999-00	8109	1837	2599	18015	30686	966	6871
2000-01	9127	2033	2987	18505	32573	1005	7380
2001-02	9779	2228	3037	19530	32818	1032	7676
2002-03	8811	2383	3093	19178	32853	1028	7616

(continued on next page)

Table G.4 **(continued)**

Year	*Japan*	*Netherlands*	*Norway*	*Spain*	*Sweden*	*UK*	*US*
1968-69	10252	1624	241	848	1227	17223	57784
1969-70	10900	1678	253	897	1294	17335	60064
1970-71	11589	1734	265	949	1365	17448	62434
1971-72	12322	1791	279	1004	1439	17562	64897
1972-73	13101	1850	293	1063	1518	17676	67458
1973-74	11892	1977	310	1200	1660	16827	66616
1974-75	11997	1986	376	1213	1681	13502	64412
1975-76	12241	1964	404	1199	1699	13358	68002
1976-77	12850	1895	413	1027	1712	12939	70700
1977-78	13738	1950	437	915	1694	13333	73640
1978-79	16486	2105	486	839	1784	14059	78010
1980-81	19145	2211	489	936	1854	12659	83164
1981-82	22518	2377	502	846	2034	12415	88582
1982-83	24532	2394	551	1054	2199	12216	94430
1983-84	27057	2574	601	1049	2363	12017	101080
1984-85	29534	2599	718	1186	2676	12706	111689
1985-86	33382	2972	845	1433	2988	13396	121878
1986-87	33830	3371	876	1662	3099	15061	124297
1987-88	35796	3616	906	1802	3210	15232	126575
1988-89	39491	3677	874	2193	3230	15651	128865
1989-90	44024	3623	842	2400	3251	16099	130580
1990-91	48385	3424	839	2881	3277	16273	135062
1991-92	49418	3129	836	2937	3304	14924	138931
1992-93	47715	3023	864	2796	3543	14404	137985
1993-94	44946	3125	893	2610	3782	14963	133002
1994-95	44541	3416	954	2420	4200	14941	132689
1995-96	46842	3593	1014	2563	4618	15008	143431
1996-97	50530	3792	1066	2693	4867	14809	154021
1997-98	53390	4131	1118	2785	5116	14798	164532
1998-99	54149	4068	1142	3391	5422	15269	174521
1999-00	54102	4591	1165	3489	5727	16646	185802
2000-01	56375	4618	1277	3984	6508	16716	198731
2001-02	60362	4632	1390	4063	7289	17512	195072
2002-03	61755	4357	1372	4684	6351	18037	187144

a Data prior to 1972-73 extrapolated using trend growth rate. **b** Combined ISIC series for R&D stock countries.

Source: OECD, ANBERD Database, 2002.

H The effect of R&D in an 'expanded' market sector

The models in chapters 6 to 10 are based on an industry coverage corresponding to the ABS definition of the market sector for which official estimates of multifactor productivity (MFP) are available. This appendix presents results based on an ‘expanded’ market sector which was constructed by Diewert and Lawrence (2005) under contract to the Department of Communications, Information, Technology and the Arts (DOCITA).

For the market sector, Property & business services was separately identifiable in the R&D data over time and was removed from the R&D expenditure series used to construct the knowledge stocks as it is not currently part of the market sector. The industry Scientific research is part of Property & business services and was also separately identifiable. As it provides R&D services to other industries, its expenditure was allocated to market sector industries based on a decomposition of its expenditure by Socio-Economic Objective. However, Education, Health & community services and Personal & other services could not be separately identified and are included in the knowledge stocks even though these industries are excluded from the market sector. This is one source of ‘noise’ in the regressions.

Diewert and Lawrence constructed a new productivity database aimed at addressing a number of problems they identified with ABS National Accounts used for productivity measurement in Australia (Diewert and Lawrence 2005). In particular, the Diewert and Lawrence database aimed to address: the use of inconsistent rates of return when forming an index of aggregate inputs for each sector; the use of inappropriate prices in the aggregation of outputs and inputs; inadequate measurement of intermediate input flows between sectors; the exclusion of significant market sector service activities; and the use of inconsistent methodology in the formation of stocks and flows of capital and inventory inputs.

Diewert and Lawrence (2005) computed productivity estimates for an ‘expanded market sector’, including Property & business services, Education, Health & community services and Personal & other services. The dataset can be used to investigate the effects of R&D at the whole-of-economy level less Government administration & defence. All the various domestic knowledge stocks and infrastructure measures were re-constructed to match the broader industry classification, which aligns better with published business R&D data.

H.1 Differences between Diewert and Lawrence and ABS productivity databases

Diewert and Lawrence (2005) outline four main differences between their database and that used by the ABS in producing its MFP estimates.

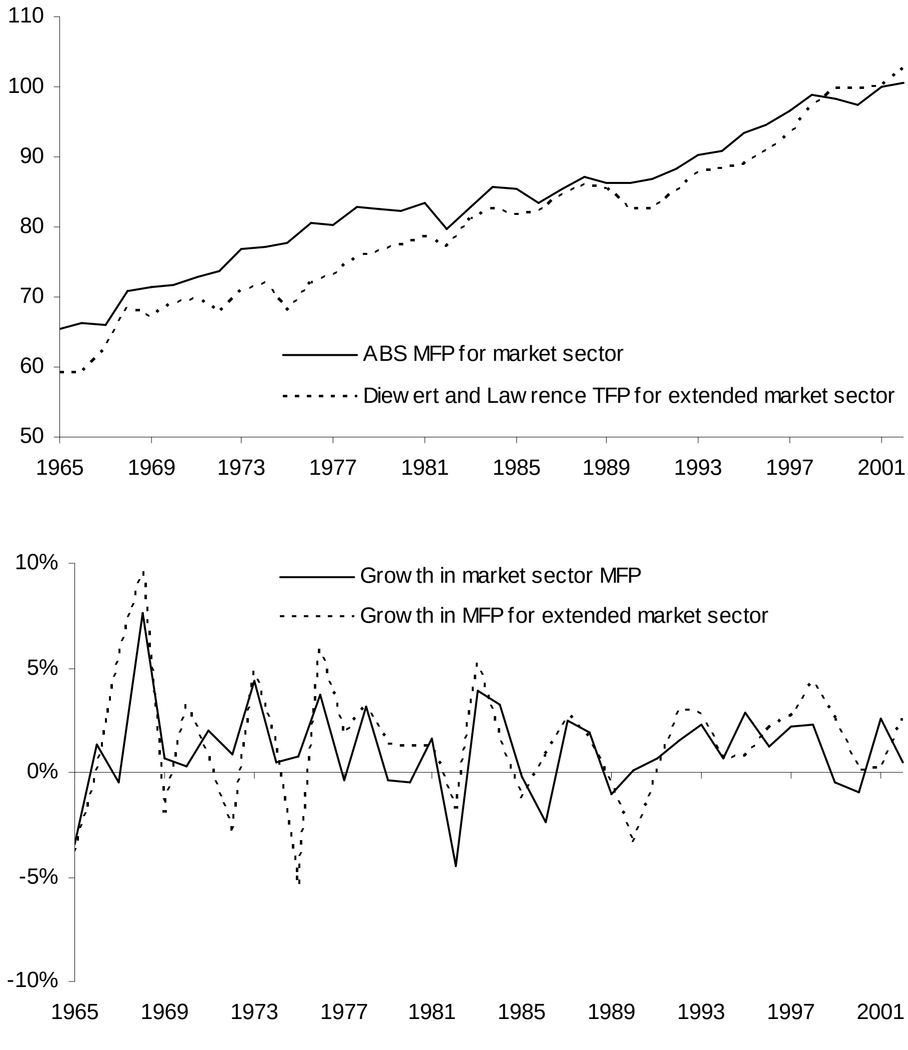
- Broader coverage of the economy.
  - Diewert and Lawrence include an extra four ANZSIC industry divisions that are not part of the ABS market sector (Health &community services, Education, Property & business services and Personal & other services). The Diewert and Lawrence database covers 95 per cent of value added in the economy compared with ABS market sector coverage of around two-thirds of value-added. Government administration & defence is not included in either database.
- Method of construction of the output measure.
  - Diewert and Lawrence build up an output measure from final consumption components rather than sectoral gross value added. They suggest that this creates a more accurate output measure because interindustry flows of intermediates are netted out and more accurate records are available for end consumption components.
- Expression of both outputs and inputs in terms of producer prices.
  - Diewert and Lawrence note that in production theory (the theoretical basis for making productivity comparisons) the appropriate prices are the prices that producers face, which should not include final demand tax wedges but should include commodity taxes on inputs and subsidies.
- Consistent capital and inventory input series.
  - Diewert and Lawrence use the Jorgenson geometric depreciation approach to forming stocks and flows rather than the US Bureau of Labor Statistics methodology used by the ABS.
  - Diewert and Lawrence also smooth the depreciation rates used by the ABS and push back some ABS capital stock estimates that start at substantial non-zero values part way through the time period.

H.2 A comparison of MFP trends

The Diewert and Lawrence productivity series grows at a faster rate on average than the ABS series (figure H.1). Inputs in general have increased more rapidly in the Diewert and Lawrence expanded market sector than the ABS market sector. Labour inputs, in particular, have increased much more rapidly, while capital inputs have increased marginally less rapidly in the Diewert and Lawrence expanded market sector than the narrower ABS market sector. This reflects the relative labour intensity of the key services sectors not included in the ABS coverage.

Figure H.1 **Diewert and Lawrence and ABS productivity indexes, 1964-65 to 2001-02**

Index 2000-01 = 100



Data sources: Based on Diewert and Lawrence (2005) and ABS National Accounts.

H.3 Bi-variate relationships in the expanded market sector

All of the knowledge stocks possess strong trends which result in the pair-wise correlation coefficients between the levels of the stocks indicating near linear relationships (table H.1). The contemporaneous correlation between the growth rates of the stocks are much more variable (table H.2). Growth in the stock of Australian business R&D (BRD) capital is highly correlated with growth in the stock of higher education and government-performed R&D, and less so with the stock of foreign business R&D or gross R&D (GRD).

Table H.1 **Pair-wise correlations between the levels of knowledge stocks[a]**

Australian BRD is for the expanded market sector. Foreign stocks Elaborately Transformed Manufactures (ETM) weighted.

	Australian BRD	*Foreign BRD*	*Foreign GRD*	*Higher education*	*Government performed*	*USPTO patents*
Australian BRD	1.00					
Foreign BRD	0.948	1.00				
Foreign GRD	0.934	0.997	1.00			
Higher education	0.969	0.988	0.986	1.00		
Government performed	0.961	0.990	0.990	0.998	1.00	
USPTO patents	0.974	0.969	0.971	0.981	0.985	1.00

a Assumed decay rates of 15 per cent for business and foreign stocks, and 10 per cent for higher education and Government stocks. US Patent and Trademark Office (USPTO) patents granted is a simple count measure of the number of patents granted for the fourteen countries used in the construction of foreign knowledge stocks.

Sources: ABS (*Research and Experimental Development, Businesses, Australia*, Cat. no. 8104.0); ABS unpublished data; OECD (Analytical Business Enterprise Research and Development, ANBERD, database); Commission estimates.

Table H.2 **Pair-wise correlations between the growth rates of the knowledge stocks[a]**

Australian BRD is for the expanded market sector. Foreign stocks ETM weighted.

	Australian BRD	*Foreign BRD*	*Foreign GRD*	*Higher education*	*Government performed*
Australian BRD	1.00				
Foreign BRD	0.100	1.00			
Foreign GRD	0.085	0.620	1.00		
Higher education	0.656	-0.213	-0.291	1.00	
Government performed	0.513	-0.163	0.036	0.618	1.00

a Assumed decay rates of 15 per cent for business and foreign stocks, and 10 per cent for higher education and Government stocks. US Patent and Trademark Office (USPTO) patents granted is a simple count measure of the number of patents granted for the fourteen countries used in the construction of foreign knowledge stocks.

Sources: ABS (*Research and Experimental Development, Businesses, Australia*, Cat. no. 8104.0); ABS unpublished data; OECD (Analytical Business Enterprise Research and Development, ANBERD, database); Commission estimates.

Correlations between the level of the knowledge stocks as a proportion of Australian output show high positive correlations between Australian BRD, foreign BRD, foreign GRD and higher education intensities, and negative correlations with Government performed intensities (table H.3). Growth in government-performed R&D has been slower than growth in GDP resulting in a declining intensity (although Governments fund and affect the level of R&D undertaken in Australia in many other ways).

In terms of correlations between growth in knowledge stocks as a proportion of output, Australian BRD is highly positively correlated with higher education R&D, and modestly positively correlated with foreign BRD and government-performed intensities (table H.4).

Table H.3 Pair-wise correlations between the level of the knowledge stocks as a proportion of Australian output ln(K/Y)[a]

Australian BRD is for the expanded market sector. Foreign intensities ETM weighted.

	Australian BRD	*Foreign BRD*	*Foreign GRD*	*Higher education*	*Government performed*
Australian BRD	1.00				
Foreign BRD	0.715	1.00			
Foreign GRD	0.622	0.976	1.00		
Higher education	0.853	0.912	0.866	1.00	
Government performed	-0.848	-0.833	-0.755	-0.918	1.00

a Assumed decay rates of 15 per cent for business and foreign stocks, and 10 per cent for higher education and Government stocks. US Patent and Trademark Office (USPTO) patents granted is a simple count measure of the number of patents granted for the fourteen countries used in the construction of foreign knowledge stocks.

Sources: ABS (*Research and Experimental Development, Businesses, Australia*, Cat. no. 8104.0); ABS unpublished data; OECD (Analytical Business Enterprise Research and Development, ANBERD, database); Commission estimates.

Table H.4 Pair-wise correlations between change in the knowledge stocks as a proportion of Australian output ln(ΔK/Y)[a]

Australian BRD is for the expanded market sector. Foreign intensities ETM weighted.

	Australian BRD	*Foreign BRD*	*Foreign GRD*	*Higher education*	*Government performed*
Australian BRD	1.00				
Foreign BRD	0.357	1.00			
Foreign GRD	0.041	0.476	1.00		
Higher education	0.882	0.353	-0.202	1.00	
Government performed	0.107	-0.296	0.029	-0.118	1.00

a Assumed rate of decay for Australian BRD, higher education and Government intensities of 5 per cent, and 10 per cent for foreign intensities.

Sources: ABS (*Research and Experimental Development, Businesses, Australia*, Cat. no. 8104.0); ABS unpublished data; OECD (Analytical Business Enterprise Research and Development, ANBERD, database); Commission estimates.

H.4 The effect of R&D in an expanded market sector

Results from ln(MFP) models

Estimation of a basic model produces an insignificant coefficient on Australian BRD and a negative coefficient for foreign BRD (model EM1) (table H.5). If the linear time trend is dropped, then the coefficient on Australian BRD is insignificant (coefficient = 0.002 and standard error = 0.023). However, foreign BRD becomes positive and highly significant (coefficient = 0.445 and standard error = 0.044). The problem of separately identifying the effect of foreign R&D when a time trend was included was also encountered in the market sector models (see chapter 6).

Market sector model results are highly sensitive to the introduction of dynamics. When estimated as a finite distributed lag (FDL) model and tested down, both R&D variables are positive and highly significant. A ten per cent increase in the stock of Australian BRD is estimated to increase the level of MFP by 0.54 per cent.

Extending the basic static model produces highly significant control variables, but the R&D variables are insignificant (model EM3). Education, communications infrastructure and IT capital all have positive effects which are statistically significant at greater than one per cent. The effective rate of assistance (ERA) to manufacturing has a negative and significant impact on MFP in the expanded market sector.

The test for functional form in model EM3 indicates possible model misspecification. Re-estimating model EM3 with Australian BRD specified as a quadratic function has little impact on the control variables, but improves the significance of the coefficients on both R&D variables (model EM4). The coefficient for Australian BRD evaluated at the full sample mean is 0.121 with a standard error of 0.034 (giving statistical significance greater than one per cent), and the coefficient on foreign BRD becomes 0.219 with a standard error of 0.118 and significance at ten per cent.

The quadratic specification for Australian BRD is not dependent on the inclusion of a foreign knowledge stock or patent measure. Dropping foreign BRD from model EM4 results in a coefficient on Australian BRD, evaluated at the full sample mean, of 0.092 with a standard error of 0.031 and significance at greater than one per cent (model EM5). Information criteria indicate that the model with foreign BRD fits the data better overall.

Table H.5 **The effect of R&D on MFP in the 'expanded' market sector[a]**

Heteroskedastic robust standard errors in brackets. All variables in logs

Lags =	*Aus.=(t-1) For.=(t)*	*FDL: Aus. = 2 For. = 2*	*Aus.=(t-1) For.=(t)*	*Aus.=(t-1) For.=(t)*	*Aus.=(t-1)*	*Aus.=(t-1) For.=(t)*
Assumed decay rate (%) =	*Aus. = 15 For. = 15*	*Aus. = 15 For. = 15*	*Aus. = 15 For. = 15*	*Aus. = 15 For. = 15*	*Aus. = 15*	*Aus. = 15*
	EM1	*EM2*	*EM3*	*EM4*	*EM5*	*EM6*
Cycle (Growth in output)	0.584*** (0.145)	0.524*** (0.128)	0.462*** (0.074)	0.445 (0.082)	0.420*** (0.069)	0.393*** (0.099)
Linear time trend	0.026*** (0.006)		-0.027** (0.010)	-0.045*** (0.012)	-0.029*** (0.007)	-0.022** (0.009)
Aus. BRD	0.012 (0.020)	0.054** (0.020)	0.063 (0.041)	-0.473** (0.178)	-0.337* (0.165)	0.043 (0.052)
Aus. BRD squared				0.081*** (0.027)	0.058** (0.023)	
Foreign BRD (ETM weighted)	-0.192 (0.118)	0.306*** (0.035)	0.023 (0.230)	0.219* (0.118)		
USPTO patents granted						0.021 (0.020)
education			0.426*** (0.136)	0.403*** (0.110)	0.295** (0.122)	0.361** (0.130)
Ci5iousage			0.353*** (0.050)	0.221*** (0.055)	0.241*** (0.063)	0.333*** (0.086)
itcap			0.036** (0.013)	0.073*** (0.019)	0.072*** (0.020)	0.035* (0.018)
ERA			-0.093*** (0.026)	-0.084*** (0.020)	-0.041** (0.017)	-0.058** (0.025)
Dummy81			-0.018*** (0.005)	-0.017*** (0.005)	-0.023*** (0.005)	-0.022*** (0.005)
Shift1985	-0.025* (0.014)		-0.029*** (0.008)	-0.021*** (0.007)	-0.017** (0.007)	-0.028*** (0.009)
Shift1989	-0.056*** (0.011)	-0.059*** (0.011)	-0.047*** (0.008)	-0.041*** (0.007)	-0.041*** (0.006)	-0.046*** (0.007)
Shift1992	-0.021* (0.012)		0.035** (0.014)	0.050*** (0.012)	0.037*** (0.011)	0.034** (0.013)
Shift1995			-0.025** (0.009)	-0.022*** (0.007)		
Constant	4.492*** (0.354)	3.025*** (0.066)	2.031** (0.863)	3.096*** (0.740)	3.504*** (0.875)	2.022** (0.768)
Test statistics						
# of observations	29	29	29	29	29	29
R^2	0.990	0.992	0.998	0.999	0.998	0.998
1st order s.c.[a]	1.601	1.690	2.457	2.704	2.216	2.212
White test for heteroskedasticity[a]	27 (0.363)	29 (0.413)	29 (0.413)	29 (0.413)	29 (0.413)	29 (0.413)
RESET[a] F(3,Z)	1.57 (0.232)	0.44 (0.730)	4.09 (0.033)	1.37 (0.304)	1.06 (0.400)	2.317 (0.112)
AIC*n (BIC) [a]	-171(-117)	-176(-121)	-199(-140)	-207(-144)	-199(-139)	-192(-135)

[a] See table 6.3.

Source: Commission estimates.

Replacing the foreign business knowledge stock with a measure of the count of USPTO patents granted, both Australian BRD and USPTO patents granted are positive, but statistically not significant (model EM6). The elasticity estimates for the other variables change little and continue to be well estimated.

All of the models include at least one time dummy or shift in the intercept.

Results from productivity growth models

The effect of R&D intensity on productivity growth in the expanded market sector is positive, with the economic magnitude of the effect and the statistical significance varying by model (table H.6). However, the coefficients on Australian BRD are not well estimated, with the confidence interval based on two standard deviations including zero in all models except EM9. Models EM7 and EM8 investigate the effect of the knowledge stock as a proportion of output on MFP growth. A constant was not significant in the regressions and was dropped. EM9-EM11 investigate labour productivity growth. Definitions for the variables are provided in chapter 7.

The model results are highly sensitive to the dating of the control variables. In model EM7, all controls are entered contemporaneously and none of them are statistically significant. However, both Australian BRD intensity and foreign BRD intensity are positive and significant at ten per cent or more. In model EM8, the controls are allowed to enter contemporaneously or lagged one or two periods with the result that coefficient estimates and model fit are significantly improved.

The labour productivity growth models EM9 and EM10 produce plausible coefficients on the capital variables which are measured ‘per hour worked’. General government infrastructure was not significant and tested out of the models. The coefficient on private capital (rci5hr) is around 0.3, with the coefficient on communications infrastructure between 0.1-0.2. The sign on the coefficient for IT capital is sensitive to inclusion of foreign BRD or foreign GRD. Together, the coefficients are not inconsistent with capital’s share of factor income in the Australian System of National Accounts. In model EM11, the capital coefficients are too large.

Australian BRD intensity is positive and significant in model EM9. The inclusion of higher education and government-performed intensities results in Australian business R&D capital being poorly estimated (model EM10). The problem lies with the high degree of collinearity between Australian business R&D and higher education intensities shown above, combined with weakness in the long-run relationship between the variables. Replacing foreign BRD with foreign GRD again produces an insignificant effect of Australian business R&D (model EM11).

Table H.6 **The effect of R&D on productivity growth in the 'expanded' market sector[a]**

Dep. variable = *R&D variable =*	*Δln(MFP)* *ln(K/Y)*	*Δln(MFP)* *ln(K/Y)*	*Δln(LP)* *ln(K/(Y*hrs))*	*Δln(LP)* *ln(K/(Y*hrs))*	*Δln(LP)* *ln(K/(Y*hrs))*
	EM7	*EM8*	*EM9*	*EM10*	*EM11*
Cycle	0.379** (0.169)	0.440** (0.174)	0.418*** (0.095)	0.436*** (0.133)	0.536*** (0.127)
Aus. BRD (t-1)	0.019* (0.010)	0.011 (0.006)	0.076*** (0.021)	0.010 (0.047)	0.011 (0.030)
Foreign BRD (t) (ETM weighted)	0.223* (0.119)	0.206*** (0.070)	0.197*** (0.043)	0.327*** (0.093)	
Foreign GRD (t) (ETM weighted)					0.098*** (0.037)
Higher education R&D (t)				0.038 (0.077)	
Government-performed R&D (t)				-0.179** (0.069)	
Δeducation	0.198 (0.147)	0.211** (0.084)	0.141* (0.075)	0.266*** (0.078)	0.187** (0.076)
Δrci5			0.386*** (0.132)	0.273*** (0.078)	0.633*** (0.136)
ΔCi5iousage	0.083 (0.096)	0.098 (0.112)	0.006** (0.002)	0.015*** (0.004)	0.006** (0.002)
Δitcap	0.020 (0.046)	-0.069** (0.032)	0.054 (0.038)	-0.019 (0.045)	0.101* (0.056)
ΔERA	-0.059 (0.036)	-0.078** (0.031)	-0.034 (0.025)	-0.079* (0.039)	-0.023 (0.026)
ΔCentbrg	0.012 (0.009)			0.026*** (0.008)	-0.013** (0.005)
Intercept			1.987*** (0.492)	1.735** (0.683)	1.025** (0.374)
Dummy81	-0.017 (0.011)	-0.020* (0.011)			
Dummy82	0.031** (0.014)	0.039** (0.014)	0.033** (0.016)	0.040** (0.018)	
Shift1982	-0.058* (0.032)	-0.056*** (0.018)	-0.041** (0.017)	-0.080*** (0.026)	-0.015 (0.009)
Shift1985			0.023 (0.014)		0.030*** (0.009)
Shift1989	-0.025 (0.018)	-0.032** (0.011)	-0.031*** (0.007)	-0.035*** (0.010)	-0.029*** (0.007)
Shift1992					0.034*** (0.011)
Test statistics					
# of observations	28	26	28	28	28
R^2	0.846	0.911	0.899	0.911	0.916
1st order s.c.[b]	1.630	2.312	2.549	2.591	2.513
White test for heteroskedasticity[b]	28 (0.411)	26 (0.408)	28 (0.411)	28 (0.411)	28 (0.411)
AIC*n (BIC)[b]	-156	-164	-172(-27)	-171(-25)	-175(-26)

a Heteroskedastic robust standard errors in brackets. All variables in logs. All stocks decayed 15 fifteen per cent, except for higher education and Government which are decayed at ten per cent. **b** See table 6.3.

Source: Commission estimates.

Overall, results favour a positive effect of Australian BRD intensity on productivity in the non-market sector, although it is sensitive to model specification. The results for foreign R&D show a large positive effect. The significance of all of the control variables is sensitive to the dating of the variables. As a strong, lagged effect of these variables on productivity growth is plausible (if not expected), the results in EM8-EM10 are preferred.

The percentage of the workforce with post-school qualifications has a strong, positive effect in all models, while ERA has a negative effect under all specifications. The estimate of the economic magnitude of the partial effect of communications infrastructure varies widely by model, but is positive in all cases. The findings for IT capital are more sensitive to model specification with the sign of the effect changing.

Compared with the results for the market sector for the equivalent set of models, the sign and magnitudes of the coefficients on the R&D variables align better with expectations. Both domestic and foreign R&D are positively signed with the effect of foreign R&D being consistently large and statistically significant.

I Firm size and industry concentration of R&D spending

Studies of the drivers of innovative effort have traditionally included consideration of the influence of firm size and competitive pressures on R&D investment decisions. There is a long history of such studies which have provided mixed results, particularly in relation to the role of firm size. A more recent tradition focuses on the importance of technological opportunity and demand and appropriability conditions in influencing innovative effort.

This appendix provides background information on:

- the number of R&D performing enterprises;
- growth in R&D expenditure by enterprise size;
- the intensity of R&D effort by firm size;
- shares in business expenditure on R&D (BERD) by firm size;
- growth in R&D expenditure decomposed between firm entry and increases in expenditure per firm; and
- measures of the concentration of R&D activity.

How R&D expenditure is distributed across firms matters. For example, greater depth of expenditure per firm and increased specialisation of R&D effort may assist access to any economies of scale in R&D activity. On the other hand, in some market areas, the responsiveness of small-scale operations may enhance innovation.

The appendix covers firms in the business sector, but not other institutional sectors.

I.1 The number of R&D performing enterprises by size

The number of large enterprises performing R&D has decreased from 1988-89 to 2001-02 (table I.1) in absolute terms in contrast to the increase in the number of small enterprises. The table does not include the early to mid-1980s which was a period of very rapid growth in the number of enterprises performing R&D.

Table I.1 **Growth[a] in the number of enterprises performing R&D, by total employment and industry[b], 1988-89 to 2001-02**

Industry	*Less than 10*	*10 to 19*	*20 to 49*	*50 to 99*	*100 to 199*	*200 to 499*	*500 to 999*	*1000 or more*	*Total*	*Total 2001-02*
	%	*%*	*%*	*%*	*%*	*%*	*%*	*%*	*%*	*No.*
Mining	36	500	57	125	71	54	0	17	54	108
Manu.	-23	11	21	0	-8	3	-20	-41	-6	1 760
FBT	44	400	200	50	-7	88	-47	-14	28	136
TCF	100	-	-9	-11	0	10	-25	-100[c]	-7	43
WPP	83	100	-45	117	-56	-40	-57	-17	-3	73
PCCAP	2	66	87	37	39	-6	46	33	35	349
NMP	-58	60	450	-33	600	40	-13	-50	16	52
MP	-11	-25	42	8	-35	-6	-21	-87	-7	174
TE	-23	20	-6	0	240	75	-7	-50	3	127
PSE	87	85	267	100	-43	33	200	100	97	138
AE	-52	-24	-29	-29	-24	-5	-29	-79	-38	361
IME	-31	33	8	-10	-29	-15	-40	-100[c]	-11	231
Other manu.	26	-8	-19	-55	-67	-79	-100a	-100[c]	-35	76
Services	91	95	77	41	22	34	23	-20	71	1 891
WRT	57	40	11	-9	-50	-41	25	-33	14	334
PBS	93	113	120	107	100	87	100	-36	98	1 041
SR	144	223	53	50	33	-	-	-	133	214
Other n.e.c.[d]	73	75	100	26	75	121	-7	-10	53	302
Total	**29**	**49**	**42**	**13**	**2**	**13**	**-10**	**-30**	**23**	**3 759**
Number of enterprises in 2001-02										
Mining	19	12	11	9	12	20	11	14	108	
Manu.	423	270	365	223	158	173	82	66	1 760	
Services	873	346	311	123	73	75	38	52	1 891	
Total	**1 315**	**628**	**687**	**355**	**243**	**268**	**131**	**132**	**3 759**	

a Total change over period. **b** For industry abbreviations see table A.3. **c** The industry had one or more enterprises performing R&D in 1988-89 of this size category and zero enterprises in 2001-02. **d** 'Other n.e.c.' includes Other n.e.c. plus Finance. Finance was separated out of Other n.e.c. in 1986-87 and separately identified in ABS publications. However, to obtain a consistent series from 1976-77 to 2001-02, Finance has been re-combined with Other n.e.c. In 1992-93, Services to mining was separated out of Other n.e.c. This has not been controlled for and the result may be a small upward bias for mining, and a small downward bias for Other n.e.c.

Source: ABS unpublished data.

In manufacturing, all size categories with fifty or more employees either declined in numbers or showed virtually no growth. In mining, the number of enterprises increased significantly, but from a small base (which tends to exaggerate the percentage changes). In services, there was a significant increase in the number of enterprises performing R&D. The rate of increase was less as enterprise size increased. For enterprises with total employment greater than a thousand employees, the number of enterprises declined by 20 per cent.

The decrease in the number of large enterprises may be misleading as large businesses may organise their R&D efforts in different ways. If large enterprises shift R&D activities to separate legal entities, either smaller companies for which separate accounts are reported to the ABS or specialised R&D units, then this would result in a reduction in the number of large enterprises and an increase in the number of small to medium sized enterprises. However, this would not mean that the R&D effort of large enterprises has decreased, just that it is undertaken and recorded in official statistics differently.

Other possible explanations for the decreases in the number of large enterprises, which are not specifically related to R&D, include mergers and acquisitions of large enterprises by other large enterprises, reorganisation of large enterprises into smaller management units, and market exits of large enterprises.

International evidence suggests that as enterprise size increases the probability of observing an enterprise undertaking R&D increases. For the largest enterprises, the probability approaches one. Business Longitudinal Survey data collected by the ABS confirm that these patterns are also evident in Australian manufacturing and mining, while being weaker outside these industries. In 1995-96, all mining and 81 per cent of manufacturing enterprises with total employment greater than 1000 employees reported R&D expenditure.

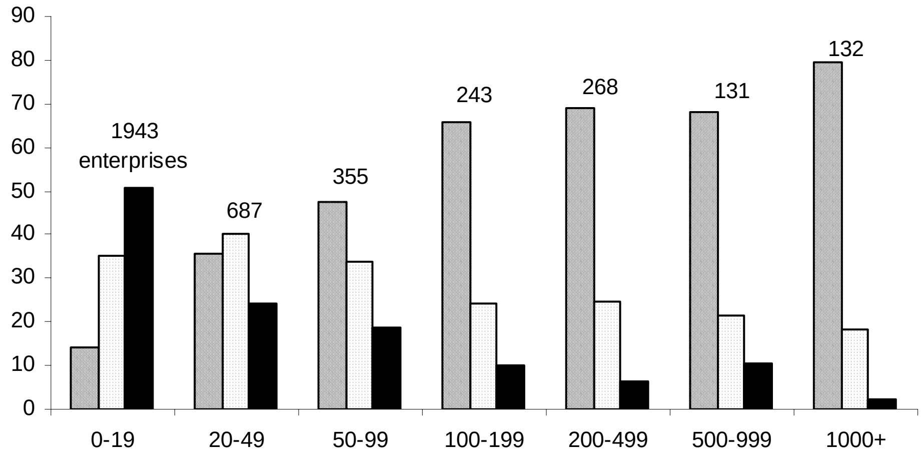
I.2 Enterprise size and the intensity of R&D effort

International studies of the relationship between enterprise size and the intensity of innovative effort suggest that effort rises roughly proportionately with size, above some size threshold. R&D expenditure is usually used to approximate total innovative effort.

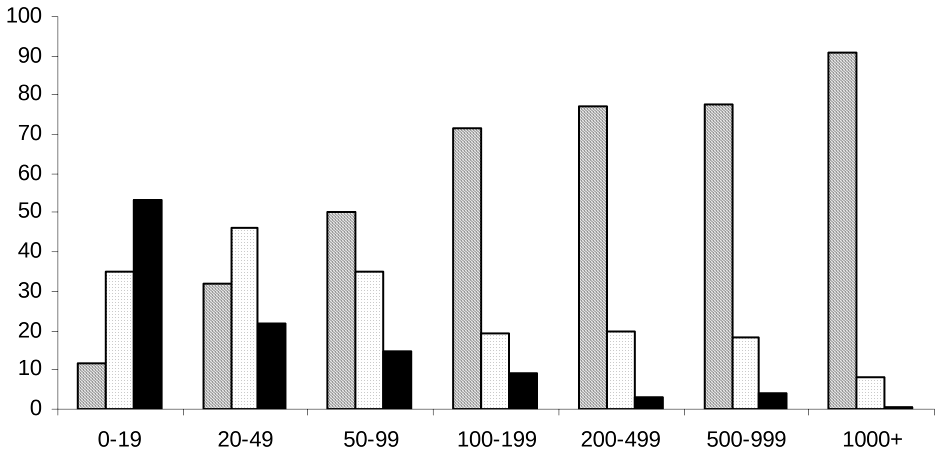
In figure I.1, 3759 enterprises were ranked as having a low, medium or high R&D expenditure per employee relative to other enterprises. The vertical axis measures the proportion of enterprises observed in the bottom third, middle third, or top third of the distribution of intensities. The total number of enterprises in each size category is presented above the bars. 1943 enterprises employed less than twenty full-time equivalents. Enterprises with under twenty full-time equivalents have the lowest likelihood of undertaking R&D, but if they do then the intensity of their effort is high (the third bar is the largest).

Figure I.1 **Ranking of R&D intensity, by enterprise size[a], 2001-02**

Ranked by R&D expenditure per employee



Ranked by R&D person years over total employment



[a] Enterprise size is measured in full-time equivalents. All R&D performers were ranked by their R&D intensity. For each size category, the bars represent, from left to right, the proportion of enterprises in the bottom, middle and top third of ranking.

Data source: ABS unpublished data.

As enterprise size increases, there is a rising likelihood that enterprises will be observed in the lowest one-third of intensities. This pattern holds for both R&D expenditure per employee and R&D person years over total employment. Bureau of Industry Economics (1993), based on ABS R&D manufacturing data for 1990-91, commented that:

> Those small firms which do engage in R&D typically devote a much higher proportion of their resources to this task than their larger counterparts … For manufacturing as a whole, small firms' R&D expenditure per employee is 7.5 times that of larger firms. (p. 10)

The relatively high R&D intensity of smaller enterprises might be explained by the presence of fixed costs in the performance of R&D. The BIE stated that other explanations include that small innovative enterprises tend to be in markets where technological change is rapid, which provides a strong incentive for relatively high R&D investment levels in order for the business to remain competitive. Further, surveys undertaken by the BIE as part of BIE's review of the R&D tax concession indicated that small innovative enterprises tend to focus more on technological aspects of their operations (BIE 1993).

A simple econometric regression of R&D expenditure on total employment highlights that as total employment increases R&D expenditure increases less than proportionally with size (table I.2). For all enterprises from 1992-93 to 2001-02, R&D expenditure increased on average by 0.57 per cent for a 1.0 per cent increase in firm size. Mining increased the least at 0.40 per cent and Scientific research increased the most at 1.03 per cent (however, the distribution of firm sizes for Scientific research was truncated as it contained no enterprises with employment greater than 199 employees). There appears to be some increase in the parameter estimates in the late 1990s.

The model results for all enterprises with employment greater than 100 employees indicates that R&D expenditure increased by 0.8 per cent on average for a 1.0 per cent increase in size. The introduction of the size threshold strengthens the association, but the relationship remains less than proportional.

Klette and Griliches (2000) and Bound et al. (1984) ran models similar to the above on panels of Norwegian and US enterprises, respectively. The models regressed the log of R&D expenditure on the log of sales (as an indicator of enterprise size) and industry and time dummies. The studies found that R&D effort was close to proportional to enterprise size. Bound et al. observed deviations from this general pattern in very small and very large enterprises which tended to have higher R&D intensities.

Table I.2 **Relationship between R&D expenditure and enterprise size[a], 1992-93 to 2001-02**

Enterprise size represented by total employment. All estimates significant at 1 per cent.

	*All enterprises (full sample)***b**	*All enterprises (employment > 100)*	*Mining*	*Manu.*	*WRT*	*PBS*	*Scientific research*	*IT industries*
1992–93	0.537	0.743	0.390	0.535	0.522	0.640	1.145	0.696
1993-94	0.545	0.844	0.504	0.534	0.580	0.604	1.002	0.713
1994–95	0.544	0.816	0.563	0.549	0.556	0.600	0.989	0.671
1995-96	0.544	0.801	0.431	0.582	0.541	0.593	1.025	0.694
1996–97	0.555	0.810	0.531	0.574	0.532	0.597	0.953	0.662
1997-98	0.541	0.827	0.528	0.553	0.505	0.615	1.059	0.658
1998–99	0.561	0.765	0.502	0.588	0.534	0.620	0.906	0.664
1999-00	0.622	0.803	0.407	0.634	0.643	0.715	1.100	0.745
2000–01	0.613	0.839	0.404	0.617	0.611	0.692	1.015	0.716
2001-02	0.591	0.787	0.384	0.609	0.579	0.666	1.075	0.745
Average across periods								
1992-93 to 2001-02	0.565	0.796	0.465	0.576	0.551	0.637	1.025	0.698
Adj. R^2	0.369	0.300	0.309	0.367	0.337	0.350	0.511	0.453
Std. Error	0.004	0.016	0.028	0.008	0.014	0.009	0.010	0.030

a Parameter estimates are from a linear regression of R&D expenditure on total employment, including industry dummies and an error term. The regression was run on the unit records of the R&D business surveys held by the ABS. Sales or value added data were not available as an indicator of enterprise size. **b** Results include all industries and enterprises included in the business surveys.

Sources: ABS unpublished data; Commission estimates.

I.3 Shares in BERD by enterprise size

While larger firms do not undertake proportionally more R&D, and there are many more small to medium sized enterprises, the sheer scale of larger enterprises results in over 50 per cent of real BERD in 2001-02 being accounted for by enterprises with 500 or more employees (table I.3). In contrast, enterprises with under fifty employees account for about 21 per cent of BERD, while representing 70 per cent of all enterprises.

Since 1998-99, the major change in shares has been the seven percentage point increase in the share of enterprises with 500 to 999 employees (table I.3). Enterprises with total employment between 100 to 499 employees and greater than 1000 employees provided the largest decline in shares.

Table I.3 **Shares in real BERD by enterprise size and industry[a], 2001-02**

Industry	*Less than 10*	*10 to 19*	*20 to 49*	*50 to 99*	*100 to 199*	*200 to 499*	*500 to 999*	*1000 or more*
	%	*%*	*%*	*%*	*%*	*%*	*%*	*%*
Mining	3.5	3.6	4.7	7.2	4.8	17.2	11.4	47.5
Manufacturing	3.3	3.5	9.0	8.8	6.8	13.2	19.6	35.7
FBT	1.0	0.3	4.7	4.0	3.1	13.6	9.4	63.8
TCF	2.7	0.4	15.5	8.5	21.2	40.9	10.8	-
WPP	5.9	2.7	n.p.	4.2	0.6	1.8	n.p.	75.1
PCCAP	2.1	2.2	7.1	6.8	11.8	18.3	25.1	26.6
NMP	1.0	4.1	n.p.	0.8	2.8	n.p.	33.0	9.6
MP	2.8	1.0	13.0	13.6	2.8	17.6	5.9	43.4
TE	1.0	0.4	1.0	1.3	4.4	4.7	18.2	69.0
PSE	6.5	5.8	17.4	17.3	3.3	n.p.	25.0	n.p.
AE	4.1	n.p.	9.3	14.6	8.7	12.7	32.8	n.p.
IME	10.5	9.3	23.5	20.3	n.p.	15.5	n.p.	-
Other manu.	19.3	24.0	16.7	13.0	21.4	5.6	-	-
Services	8.6	7.7	12.0	9.0	9.1	9.3	14.0	30.4
WRT	5.4	4.7	10.0	10.8	4.7	9.7	36.2	18.6
PBS	10.8	9.8	15.3	11.7	13.2	11.5	13.7	14.1
SR	20.5	20.8	27.9	14.8	16.0	-	-	-
Other n.e.c.	3.0	1.6	2.9	n.p.	n.p.	9.8	8.3	68.2
Total	**5.8**	**5.5**	**10.0**	**8.7**	**7.7**	**11.7**	**16.2**	**34.3**
Change from 1988-89 share (% points)								
Mining	-0.4	-	-	6.5	2.1	-	6.9	5.1
Manufacturing	-2.1	-1.2	0.1	0.1	-2.3	-0.5	8.1	-2.3
Services	2.1	2.0	0.5	3.0	-3.4	-6.7	7.4	-4.8
Total	**-0.1**	**0.3**	**-0.1**	**1.3**	**-3.0**	**-3.0**	**7.0**	**-2.3**

[a] For industry abbreviations see table A.3.

Sources: ABS (*Research and Experimental Development, Businesses, Australia*, Cat. no. 8104.0); Commission estimates.

I.4 Rising average BERD per firm and periods of rapid firm entry

If scale is important in R&D activities, it would make a potentially important difference if changes in activity occurred through entry of firms into R&D activity, and whether they were small or large in size; or through increases in the scale of R&D operations.

This section examines the sources of change in R&D activity at the firm level:

- the relative importance of firm entry and changes in the average size of R&D operations; and
- changes in the numbers of firms and average spend, according to firm size.

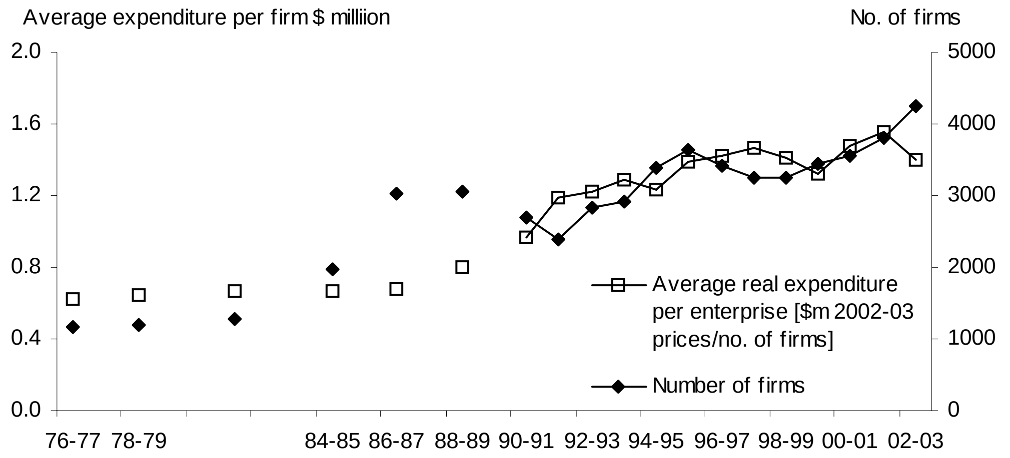
Firm entry into R&D activity has been a more important source of change than growth in the average scale of operations over the long term (figure I.2: panel A). The number of firms grew at an annual average rate of 5 per cent, since the 1970s, whereas average expenditure per firm grew at a rate just over 3 per cent (table I.4). There are now 4260 firms performing $1.4m of R&D on average, compared with 1168 performing $0.6m in the mid-1970s (table I.5).

In certain intervening periods, however, the relative importance of (net) firm entry and average expenditure has differed. Very strong entry around the time of the introduction of the R&D tax concession brought little change in average expenditure. Numbers of firms engaged in R&D activity increased at 17 per cent a year in the early to mid-1980s (table I.4). Net firm entry slowed between the mid-1980s and mid-1990s, as stronger growth in average expenditure per firm took over as the major source of growth in expenditure. In the second half of the 1990s (around the time of modifications to the R&D tax concession scheme), both the number of firms and the average spend declined. Both have recovered in the 2000s, with firm entry in particular picking up strongly.

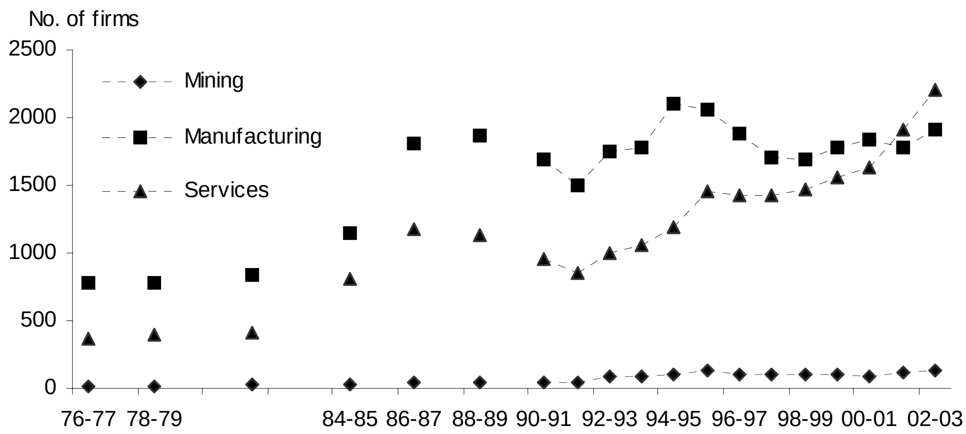
There have also been major differences between sectors and industries within business R&D. The manufacturing and services sectors now have similar numbers of performing firms — around 2000 each (figure I.2: panel B). But the main influx of manufacturing firms came in the early 1980s, whereas entry of services firms has grown steadily since the early 1990s. Average spends have hovered around the $1 million mark in both sub-sectors since the early 1990s (figure I.2: panel C). R&D in mining is performed by a relatively small number of firms with high average spends. The average spend increased in the mid-1990s, but dropped off after 1996-97. There has not been any marked change in numbers of mining firms performing R&D.

Figure I.2 **Number of firms performing R&D and average expenditure per firm, by industry sector, 1976-77 to 2002-03**

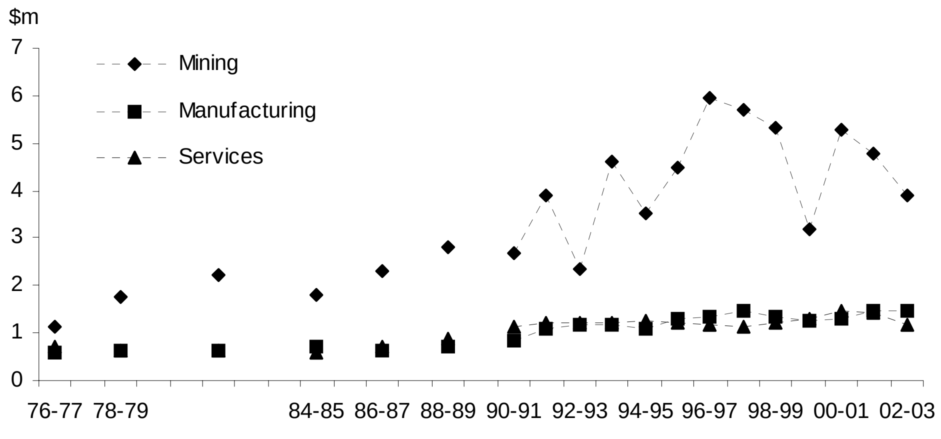
A: Business sector



B: Number of firms in sub-sectors



C: Average expenditure per firm in sub-sector



Data sources: ABS (*Research and Experimental Development, Businesses, Australia*, Cat. no. 8104.0, unpublished data); Commission calculations.

A number of industries within manufacturing are of particular interest. The numbers of firms engaged in R&D in Electronic & electrical equipment soared in the early 1980s (tables I.4 and I.5). They then steadily fell back over the late 1980s and throughout the 1990s. Transport equipment manufacturing stands out as having a high average R&D expenditure. There has been strong growth in average expenditure in this industry since the early 1990s.

Table I.4 **Growth in number of firms undertaking R&D and their average expenditure[a], by industry, various periods**
Per cent per year

	1981-82 to 1986-87	*1986-87 to 1995-96*	*1995-96 to 1999-00*	*1999-00 to 2002-03*	*1976-77 to 2002-03*
TOTAL					
- BERD	17.6	9.9	-2.6	9.2	8.1
- No. of firms	17.3	2.0	-1.4	7.2	5.0
- Av spend	0.4	7.9	-1.2	2.0	3.1
Mining					
- No. of firms	10.6	13.3	-6.1	10.2	7.0
- Av spend	0.5	7.4	-8.6	6.9	4.7
Manufacturing[b]					
- No. of firms	15.4	1.4	-3.7	2.5	3.5
- Av spend	-0.8	8.3	-1.5	5.8	3.7
Transport equipment					
- No. of firms	11.9	4.1	-0.5	1.9	4.6
- Av spend	0.7	5.3	-1.0	14.1	5.5
Electronic and electrical equipment					
- No. of firms	26.2	-4.7	-4.4	5.0	4.1
- Av spend	-4.4	10.0	2.2	-12.7	1.5
Metal products					
- No. of firms	9.3	3.3	-6.7	-1.1	1.8
- Av spend	2.2	7.9	-3.6	11.6	3.7
Petroleum, coal, chemical & associated products					
- No. of firms	-7.1	4.0	4.5	2.0	1.7
- Av spend	14.9	3.5	-2.6	4.2	4.6
Services					
- No. of firms	20.8	2.3	1.7	11.7	6.9
- Av spend	2.9	5.8	1.8	-3.0	2.0
Property & business services					
- No. of firms	20.9	3.2	2.7	12.0	7.4
- Av spend	16.2	7.5	-1.1	-4.3	5.1
Wholesale & retail trade					
- No. of firms	20.5	1.9	-4.0	7.2	5.4
- Av spend	14.1	8.0	6.0	-6.8	4.4

[a] Expenditures are in real terms, based on the GDP price deflator. [b] For industry classification details see table A.3.

Sources: ABS (*Research and Experimental Development, Businesses, Australia*, Cat. no. 8104.0); ABS (*Australian System of National Accounts*, Cat. no. 5204.0); Commission estimates.

Whilst most services industries increased their average expenditure through the 1990s, there have been major differences in numbers of firms entering R&D. Property & business services stands out as showing extremely rapid growth in numbers of firms — from around 400 in 1990-91 to over 1200 in 2002-03. Average expenditure per firm also increased from about $0.63 million in 1990-91 to about $0.83 million in 2003-03. Average expenditure is also relatively high in other services.

Table I.5 **Number of firms undertaking R&D and their average expenditure[a], by industry, various periods**

Number and $ million

	1976-77	*1981-82*	*1986-87*	*1995-96*	*2002-03*
TOTAL					
- BERD					
- No. of firms	1168	1278	3029	3636	4260
- Av spend	0.6	0.7	0.7	1.4	1.4
Mining					
- No. of firms	22	23	39	129	137
- Av spend	1.1	2.2	2.3	4.5	3.9
Manufacturing[b]					
- No. of firms	782	840	1816	2058	1918
- Av spend	0.6	0.6	0.6	1.3	1.5
Transport equipment					
- No. of firms	44	54	98	142	147
- Av spend	1.2	2.0	2.1	3.4	5.0
Electronic and electrical equipment					
- No. of firms	129	159	590	387	378
- Av spend	0.6	0.6	0.5	1.2	0.9
Metal products					
- No. of firms	110	110	175	235	174
- Av spend	0.8	0.7	0.8	1.6	2.0
Petroleum, coal, chemical & associated products					
- No. of firms	115	128	270	369	377
- Av spend	0.8	1.0	0.7	1.0	1.3
Services					
- No. of firms	364	415	1174	1449	2205
- Av spend	0.7	0.6	0.7	1.2	1.2
Property & business services					
- No. of firms	182	206	587	786	1254
- Av spend	0.2	0.2	0.5	1.0	0.8
Wholesale & retail trade					
- No. of firms	90	106	295	350	370
- Av spend	0.4	0.3	0.5	1.1	1.2

a Expenditures are in real terms, based on the GDP price deflator. **b** For industry classification details see table A.3.

Sources: ABS (*Research and Experimental Development, Businesses, Australia*, Cat. no. 8104.0); ABS (*Australian System of National Accounts*, Cat. no. 5204.0); Commission estimates.

Total growth in real BERD has varied considerably across industries and sectors over time. Table I.6 shows total growth in selected periods from the mid-1970s. Table I.7 shows the contributions of growth in firm entry and growth in average expenditure to total growth in these periods.

Table I.6 **Real expenditure by industry[a], various periods**

Total percentage change over period.

	1976-77 to 1984-85	*1984-85 to 1990-91*	*1990-91 to 1996-97*	*1996-97 to 2002-03*	*1976-77 to 2002-03*
	%Δ	%Δ	%Δ	%Δ	%Δ
Mining	**258**	**84**	**546**	**-14**	3544
Manu.	**84**	**66**	**110**	**2**	552
FBT	21	111	144	-10	462
TCF	-13	45	166	12	273
WPP	17	198	343	-53	630
PCCAP	92	34	64	34	467
NMP	71	-7	251	12	527
MP	32	88	108	-19	315
TE	227	13	134	61	1296
PSE	84	74	74	233	1755
AE	103	124	95	-51	335
IME	65	54	108	-5	407
Other manu.	77	84	-50	-1	62
Other	**308**	**139**	**19**	**100**	2211
WRT	83	262	6	87	1206
PBS	337	120	89	78	3113
SR	28	178	25	98	777
Other n.e.c[b]	2357	107	-27	151	9260
Total	**134**	**92**	**87**	**27**	964

a For industry abbreviations see table A.3. **b** Other n.e.c. includes Finance.

Sources: ABS (*Research and Experimental Development, Businesses, Australia,* Cat. no. 8104.0); Commission estimates.

Table I.7 **Firm entry and average spend contributions to growth in real BERD[a], by industry[b], various periods**

Based on constant 2002-03 dollars

	1976-77 to 1984-85			*1984-85 to 1990-91*			*1990-91 to 1996-97*			*1996-97 to 2002-03*			***1976-77 to 2002-03***		
	Entry	*Av. spend*	*Joint*	*Entry*	*Av. spend*	*Joint*	*Entry*	*Av. spend*	*Joint*	*Entry*	*Av. spend*	*Joint*	*Entry*	*Av. spend*	*Joint*
	ppt	ppt	ppt	ppt	ppt	ppt	ppt	ppt	ppt	ppt	ppt	ppt	ppt	ppt	ppt
Mining	60	16	24	35	50	15	30	27	43	228	-190	61	14	15	72
Manu.	31	55	14	18	73	9	80	11	9	2	98	0	30	26	44
FBT	-43	157	-14	85	8	7	30	49	21	24	78	-2	32	28	41
TCF	100	0	0	41	50	9	20	60	20	547	-273	-174	45	24	30
WPP	-79	206	-27	66	15	19	79	6	16	109	-22	12	34	21	45
PCCAP	25	61	14	1	99	0	24	66	10	65	29	6	16	49	36
NMP	93	4	3	57	45	-2	18	56	26	192	-74	-17	35	23	42
MP	53	40	7	38	47	15	72	16	12	25	79	-4	52	18	30
TE	53	21	26	-230	475	-145	71	15	14	64	26	10	25	18	57
PSE	27	60	13	-25	153	-28	15	76	8	59	17	24	9	34	56
AE	-8	118	-10	17	69	14	197	-34	-63	105	-10	5	14	58	28
IME	49	39	12	36	53	10	63	22	15	-35	133	2	41	22	37
Other manu.	40	45	14	29	57	14	54	63	-17	-392	482	10	35	54	12
Other	27	40	33	75	12	13	-110	265	-55	49	35	17	15	19	65
WRT	-18	139	-21	66	13	22	-458	749	-190	97	2	1	18	26	56
PBS	23	44	34	97	1	2	18	70	11	7	89	5	12	19	69
SR	-39	156	-17	49	27	24	-59	187	-28	-23	159	-36	1	90	9
Other n.e.c.[c]	47	4	49	47	35	18	163	-112	49	44	34	22	17	5	78
Total	28	52	20	46	38	16	54	32	15	7	92	2	20	27	53

a Contributions to total growth are growth in no. of firms (or entry) holding average spend constant; plus growth in average spend (holding no. of firms constant); plus joint growth (or change in no. of firms by change in average spend). **b** For industry abbreviations see table A.3. **c** Other n.e.c. includes Finance.

Sources: ABS (*Research and Experimental Development, Businesses, Australia*, Cat. no. 8104.0); Commission estimates.

Evidence to suggest that there has been an increase in the average scale of R&D operations does not stand out. Whilst there was a secular increase in average expenditure, at least some is due to increased non-labour current costs (appendix B), rather than increased size of intramural operations. Appendix B also showed that the average firm has not become any bigger, as measured by its use of labour. The average has remained stable at around 8 person-years.

The available data show that net firm entry over the 1990s — which came after the major period of firm entry in the 1980s — was skewed toward small firms, whereas the numbers of large firms undertaking R&D actually declined (table I.8). (Some of the apparent decline in large firms involved in R&D may, however, be overstated.[1]) The decline in numbers of large firms was particularly prevalent in manufacturing, where firms with 10-49 employees were the only ones to increase in numbers. In mining, the percentage increases in numbers of firms was large, but from a small base. In services, the number of enterprises performing R&D increased, but in smaller proportions in larger firms (and a decline of 20 per cent for enterprises with 1000 or more employees).

Growth in R&D expenditure was more evenly distributed across the size categories than growth in firm numbers (table I.8). Small firms, as well as being over-represented in entry, also had above-average growth in expenditure. The strongest growth in expenditure, however, was among firms in the 500-999 employee category.

Overall, it appears that the entry of small firms has been important in all business sub-sectors. But it also appears that there has been some rationalisation among large firms undertaking R&D, with fewer firms spending more. (See appendix C for more industry detail).

1 First, large businesses may organise their R&D efforts in ways that gives false impression. If large enterprises shift R&D activities to separate and smaller companies, the number of large enterprises engaged in R&D would decrease and the number of smaller enterprises would increase. Second, and not specifically related to R&D, there could be mergers and acquisitions of large enterprises by other large enterprises, reorganisation of large enterprises into smaller management units, and market exits of large enterprises.

Table I.8 **Increase[a] in number of firms and trend rate of growth[b] in expenditure, by industry and firm size[c]**

	<10	10-19	20-49	50-99	100-199	200-499	500-999	1000+	Total
Total									
- No. of firms	29	49	42	13	2	13	-10	-30	23
- Expenditure	14.3	14.5	13.2	9.9	12.5	12.2	15.9	11.2	12.8
Mining									
- No. of firms	36	500	57	125	71	54	0	17	54
- Expenditure	18.4	19.2	22.7	29.9	22.9	21.8	23.6	11.8	14.8
Manufacturing									
- No. of firms	-23	11	21	0	-8	3	-20	-41	-6
- Expenditure	9.9	11.5	11.1	8.6	10.7	11.6	13.9	10.4	11.3
Services									
- No. of firms	91	95	77	41	22	34	23	-20	71
- Expenditure	16.3	16.3	14.0	10	10.1	11.5	17.4	11.4	13.9

a Percentage change. **b** Trend rate of growth (per cent per year). **c** Number of firms covers the period 1988-89 to 2001-02. Expenditure covers the period from 1984-85 to 2002-03, except for Mining which starts at 1988-89.

Sources: ABS (*Research and Experimental Development, Businesses, Australia*, Cat. no. 8104.0); ABS (*Australian System of National Accounts*, Cat. no. 5204.0); Commission estimates.

Growth in R&D expenditure by enterprise size

Trend growth rates in BERD by enterprise size do not show any strong pattern across size categories (table I.9). For mining, manufacturing and services, growth in expenditure increased strongly for all size categories. Growth rates at a more detailed industry level showed greater variation, but without any clear pattern.

Each of the size categories with a negative trend growth rate also experienced a decline in the number of enterprises performing R&D over the same period. However, there are a reasonable number of size categories which experienced decreases in the number of R&D performers, but still posted positive trend growth rates in expenditure. For example, the number of enterprises in Electronic equipment, electrical equipment & appliances (AE) declined in each of the size categories yet trend growth rates by size were at least 3.8 per cent per year.

Considering tables I.1 and **I.9** in conjunction suggests that growth in BERD for small firms was driven by the net entry of firms undertaking R&D, whereas, for larger firms, growth in BERD was driven solely by increases in expenditure levels. The contribution of medium sized firms to BERD resulted from increases in both the number of enterprises and increases in expenditure levels.

Table I.9 **Growth in real R&D expenditure, by industry[a] and enterprise size, 1984-85 to 2002-03**

Trend growth[b]

Industry	*Less than 10*	*10 to 19*	*20 to 49*	*50 to 99*	*100 to 199*	*200 to 499*	*500 to 999*	*1000 or more*	*All firms*
	%	%	%	%	%	%	%	%	%
Mining	18.4	19.2	22.7	29.9	22.9	21.8	23.6	11.8	14.8
Manu.	9.9	11.5	11.1	8.6	10.7	11.6	13.9	10.4	11.3
FBT	14.4	15.5	18.6	10.8*	7.0*	14.6	7.4	13.4	12.7
TCF	2.1**	-	12.8	6.5**	20.3	14.7	7.1**	-	11.4
WPP	21.8	12.9*	15.3*	15.2	-2.3*	8.6*	11.7*	16.2*	15.3
PCCAP	11.9	9.4	9.9	8.5*	14.2	7.5	14.4	10.7	11.1
NMP	1.6**	21.6*	13.8	-4.7**	18.9*	18.5	16.1	6.8*	12.9
MP	10.3*	5.9*	19.6	16.7*	16.3	16.3	11.4*	7.8	9.2
TE	12.5	16.0	10.9	14.0	24.0	18.5	16.9	12.4	13.1
PSE	18.7	18.0	22.1	16.3	11.5*	13.0	-	-	16.2
AE	3.8**	9.6*	5.0*	7.3	9.7*	14.8	18.2	4.1**	8.7
IME	10.7	13.5	12.1	8.2	9.7	8.1	11.6	-	11.7
Other manu.	14.6	16.6	4.8*	-1.1**	2.5**	1.1**	-	-	3.0**
Other Industries	16.3	16.3	14.0	10.1	13.7	11.5	17.4	11.4	13.9
WRT	12.7	12.0	12.5	4.9**	0.2**	11.3	20.2	16.5*	13.8
PBS	15.9	17.4	16.4	12.1	18.6	12.8	17.3	14.7	15.8
SR	19.4	24.1	13.4	12.0	-	-	-	-	14.0
Other n.e.c.	18.0	5.7*	15.4	3.1**	15.5	9.6**	10.5*	9.6	10.8
TOTAL	14.3	14.5	13.2	9.9	12.5	12.2	15.9	11.2	12.8

* R squared less than 50 per cent. ** R squared less than 25 per cent. **a** For industry abbreviations see table A.3. **b** For Mining, trend growth is from 1988-89. For manufacturing and service industries, trend growth is from 1984-85. The data are original data as published.

Sources: ABS (*Research and Experimental Development, Businesses, Australia*, Cat. no. 8104.0); Commission estimates.

I.5 Competition, the 'organisation' of R&D and R&D effort

The size and R&D intensity of firms affect the scale of their R&D activity. Changes in the size of firms and in their R&D intensities could therefore influence the efficiency and effectiveness of R&D spending.

The concentration of production activity within industries may affect R&D intensity and performance. Whereas increases in firm size may bring increases in industry concentration, they may also bring increases in R&D effort. On the other hand, it is mostly found in recent empirical work that increases in competition (often reflected in lower industry concentration) drives more vigorous and focused search for commercial success through R&D.

The evidence examined in this paper is limited to the concentration of R&D effort within industries. This may or may not be related to concentration of production activity.

Box I.1 **'Stylised facts' of the relationship between firm size, concentration and R&D investment**

1. Relatively few firms undertake R&D.
2. The likelihood of a firm reporting positive R&D effort rises with firm size and approaches one for firms in the largest size ranges.
3. Above some threshold, R&D expenditures rise roughly proportionally with firm size.
4. A negative relationship exists across industries between the coefficient of variation of R&D intensity and mean R&D intensity.
5. There is little evidence of a positive relationship between R&D intensity and market concentration.
6. Larger firms produce fewer innovations per dollar.

Construction of the indexes

Herfindahl and four firm concentration indexes were obtained from the ABS for sixty-five industries at various levels of aggregation. The measures were compiled directly from the unit record data of the business surveys. The indexes are based on the concentration of R&D expenditures rather than a measure of industry output, such as value added. A higher score on either of the indexes indicate higher concentration of R&D expenditure.

For the purpose of presenting the indexes in figure I.3, the ratios were aggregated into their respective industry divisions. The aggregation procedure does not alter the patterns or interpretation of the standard Herfindahl index. However, the ‘4 firm’ ratio effectively becomes a ‘4N firm’ ratio, where ‘N’ is the number of sub-industries included in the index. For example, in the case of Mining, the index represents the proportion of Mining R&D expenditure accounted for by the four largest enterprises in each of Coal mining (ANZSIC 11), Metal ore mining (13), Services to Mining (15) and Oil & gas extraction plus Other mining (12 and 14 combined). The ratio is a 16 firm ratio with the constraint that four firms are taken from each 2-digit industry.

Changes in concentration

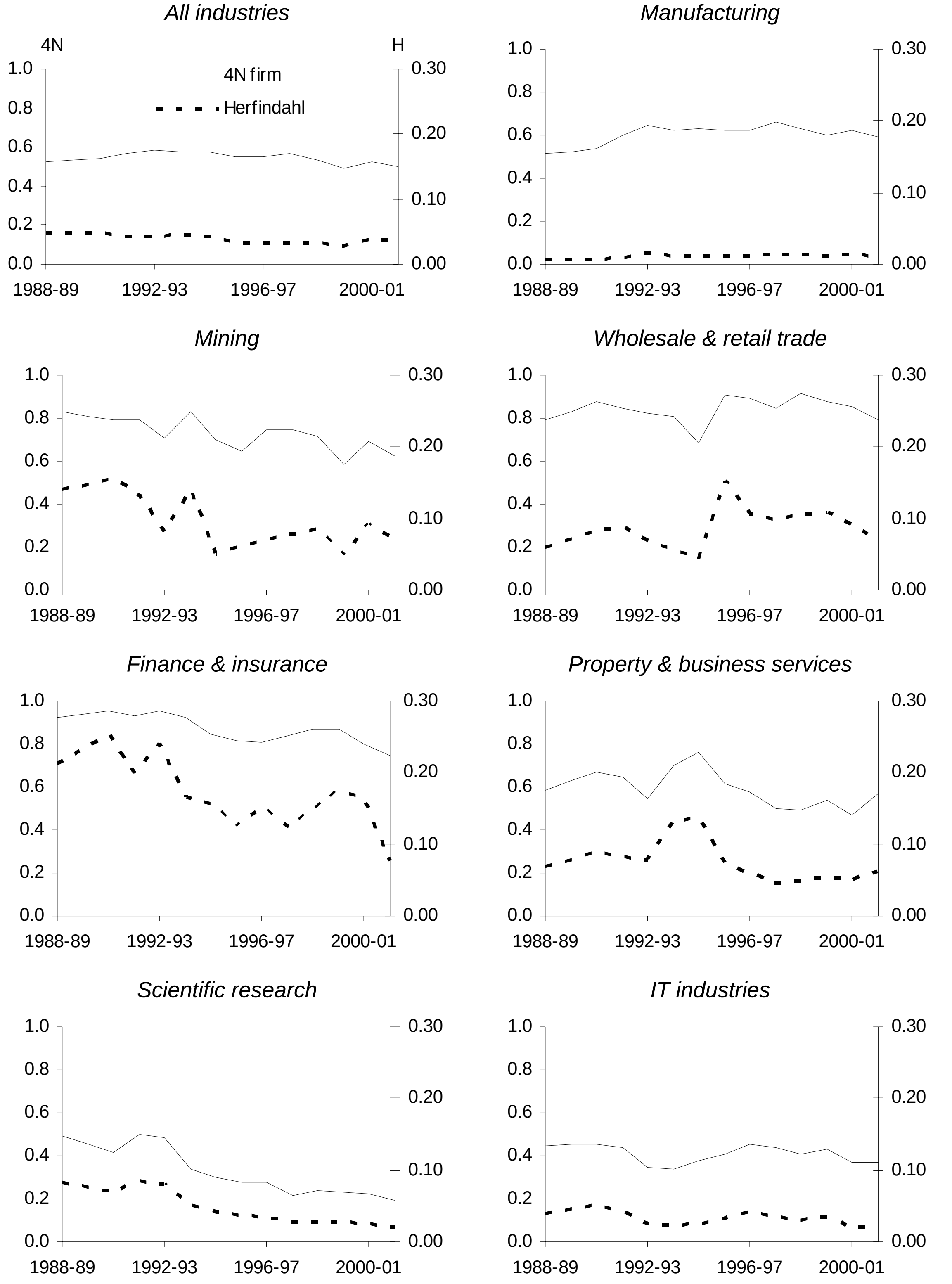
The concentration of R&D activity within industries is decreasing somewhat overall led by, of the industries shown, Mining, Finance & insurance and Scientific research. Other n.e.c. (not shown) also demonstrates a solid trend to lower concentration for both measures. Concentration for Manufacturing as a whole is stable to gradually increasing.

Figure I.4 presents R&D concentration patterns for manufacturing industries. Concentration has decreased overall in Textiles, footwear, clothing & leather and Photographic & scientific equipment. Concentration has increased in Electronic, electrical equipment & appliances and somewhat in Industrial machinery & equipment. Most industries are fairly stable, which is consistent with the overall trend for Manufacturing.

Industries with decreasing concentration are those industries where the percentage change in the number of R&D performing enterprises was significantly greater than the trend growth rate in BERD for the industry. These industries were Mining, Property & business services and Scientific research which recorded growth in the number of enterprises of 54, 98 and 133 per cent versus growth in R&D expenditure of 16, 16 and 14 per cent, respectively. For Property & business services, the wide gap in growth rates leads to only a minor decrease in concentration. In Manufacturing, the number of enterprises decreased by 6.0 per cent, trend growth in BERD was 11.7 per cent, and concentration gradually increased.

Figure I.3 **Concentration of R&D within industries, 1988-89 to 2001-02**

Left axis is 4N index. Right axis is Herfindahl index.[a]

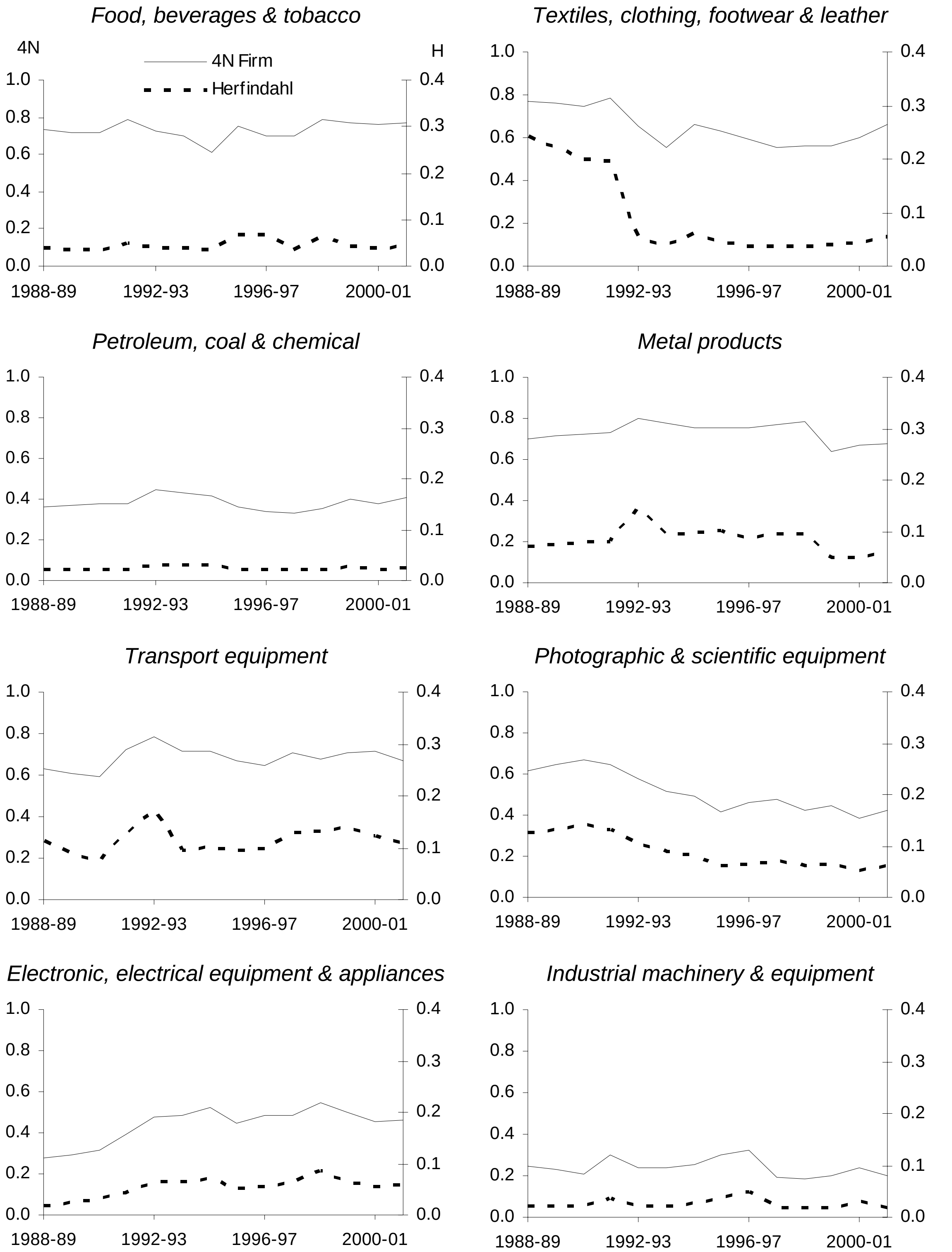


[a] The Herfindahl index is calculated as the sum of the squared shares for all enterprises in an industry, where the share is the enterprise's R&D share in total BERD for the industry.

Data sources: ABS unpublished data; Commission calculations.

Figure I.4 **Concentration of R&D within Manufacturing industries[a], 1988-89 to 2001-02**

Left axis is 4N index. Right axis is Herfindahl index.[b]



[a] For industry classification details see table A.3. [b] The Herfindahl index is calculated as the sum of the squared shares for all enterprises in an industry, where the share is the enterprise's R&D share in total BERD for the industry.

Data sources: ABS unpublished data; Commission calculations.

The percentage change in the number of enterprises for all industries from 1988-89 to 2001-02 (at 23 per cent) was much less than from 1976-77 to 1988-89 (at 161 per cent). Growth rates in expenditure were more similar at 13 and 11 per cent, respectively. There was a much larger gap between growth in the number of enterprises and growth in BERD in the earlier period. While concentration indexes for R&D expenditure are not available for the earlier period, it is likely that there was a more dramatic drop in concentration than is evident from 1988-89.

Both indexes show that R&D activity is concentrated in Mining and Finance & insurance relative to other industries. In Wholesale & retail trade and Manufacturing, the indexes tell different stories. In Wholesale & retail trade the 4N firm index shows relatively high concentration, but the Herfindahl index is indicates average levels of concentration. In Manufacturing, the difference in the indexes is greater with the Herfindahl index indicating levels of concentration lower than for any other industry.

Comparing the indexes of Mining and Manufacturing, the 4N firm index indicates similar levels of concentration of the largest 16 firms for Mining (the four largest firms in each of four Mining industries) and the largest 148 firms for Manufacturing (the four largest firms in each of 37 manufacturing industries). However, the Herfindahl index indicates that concentration in Manufacturing is much lower than in Mining. Relative to Mining, the share of small and medium sized firms in Manufacturing is larger. For example, in 2001 02 small firms accounted for 39 per cent of all firms in Mining and 60 per cent of all firms in Manufacturing.

The computation of the Herfindahl index will be influenced by differences in the size distribution of firms across industries, and this will be a factor driving the distance between the indexes, since the vertical scales are held constant across the panels. The relative distribution of firms by size in Mining versus Manufacturing, and the greater concentration in Mining, also accords with average expenditure levels per enterprise being higher in Mining. The similarity in the indexes in Scientific research partly reflects the fact that there were almost no enterprises with 200 or more employees in this industry over the period; the distribution of firms by size is much more compact.

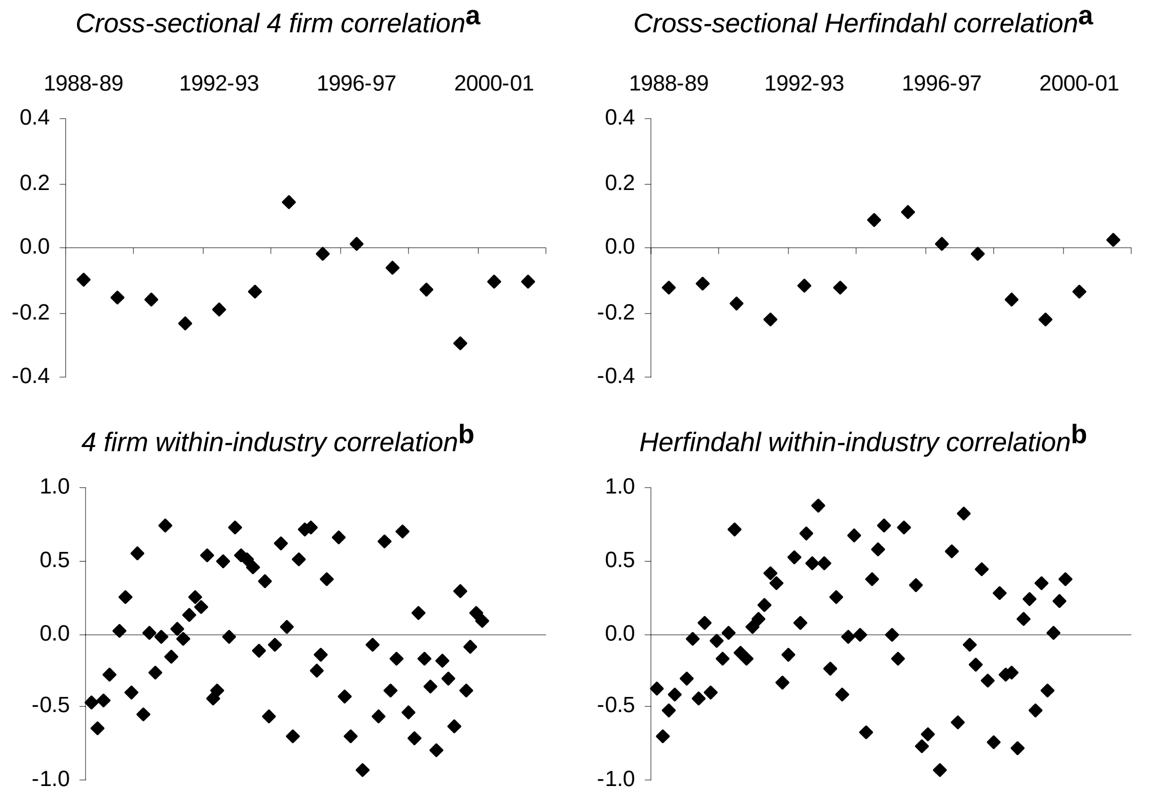
Correlations between R&D concentration and R&D effort

The relationship between the concentration of output in markets and the intensity of innovative effort has been studied extensively. Cohen and Levin (1989) note that some surveys of the literature tend to show that results are largely inconclusive. They suggest that this may be because analysts have not adequately taken account of ‘fundamental influences’ that may determine both market structure and innovative effort, such as the state of technological opportunities prevailing in an industry, the structure of demand and appropriability conditions.

Figure I.5 presents correlations between the concentration of R&D expenditures within an industry in year t and mean R&D intensity in the industry in year t. For each industry, the measure of R&D intensity is the mean of enterprise BERD over total employment across all R&D performing enterprises within the industry.

Figure I.5 **Correlations between mean R&D intensity and the concentration of R&D expenditures, 1988-89 to 2001-02**

Correlation between raw index scores



[a] The cross-sectional correlation is computed as the correlation between industry R&D intensities in period t and concentration index scores in period t for 65 industries. The correlation is computed separately for each year. [b] The industries are ordered along the horizontal axis by their ANZSIC code. The within-industry correlation is the correlation between concentration and R&D intensity over time for each industry.

Data sources: ABS (*Research and Experimental Development, Businesses*, *Australia*, Cat. no. 8104.0, unpublished data); Commission calculations.

The cross-sectional correlations are fairly weak and are more likely to be negative. Across industries, and at a given point in time, the same-period correlation between the concentration of R&D expenditure per employee and the mean level of expenditures tends to be slightly negative. Industries with higher levels of R&D concentration are not generally associated with higher mean R&D intensities. The correlations suggest that concentration in R&D expenditure is not an important explanation for understanding variance across industries in R&D intensities.

The same-period within industry correlations show no generalised pattern. The relationship between concentration and mean R&D intensity appears highly dependent on the industry being examined. For some industries, changes in concentration are positively and highly correlated with changes in mean R&D intensity, while for other industries the correlation is high, but negative. In many industries the correlation is weak. Even where correlations are high they do not necessarily suggest causation as the correlation may be the result of common drivers, such as the 'fundamental influences' noted earlier.

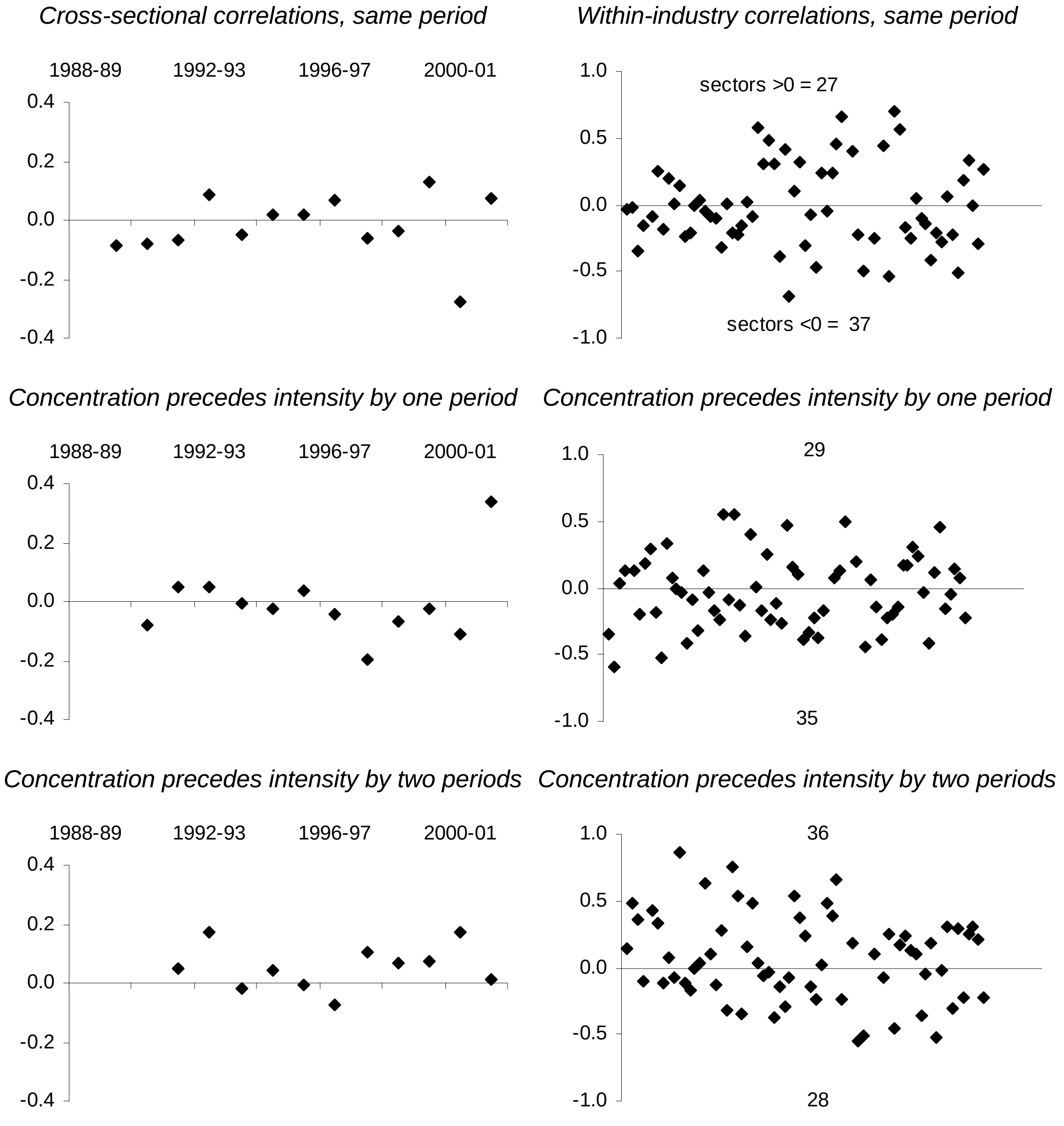
Figure I.6 presents same-period and lagged 4N firm cross-sectional and within-industry correlations based on adjacent period changes in the index scores. The cross-sectional correlations between changes in R&D intensity and prior-period changes in concentration show no strong negative or positive relationship. The within-industry correlations show that fewer industries have correlations greater than 0.5 or less than -0.5. Relative to the raw index scores, industries are bunched closer to 0.0. As changes in concentration are allowed to precede changes in R&D intensity, more industries have positive correlations (27 industries in the right hand top panel versus 36 industries in the right hand bottom panel).

Mean R&D intensity and the coefficient of variation of R&D intensity

The coefficient of variation of R&D intensity is calculated as the standard deviation of R&D intensity over mean R&D intensity. Cohen and Klepper (1992) state as a well established empirical relationship that mean R&D intensity and the coefficient of variation of R&D intensity are negatively correlated across industries. They note that others have viewed this relationship as reflecting strategic matching of innovative effort in 'technologically progressive industries' (p. 774). In industries with high R&D effort, proportionally less variation around the mean level of effort will be observed compared with lower effort industries. A possible reason for this is the higher risk enterprises may face in these industries in adopting strategies of below industry benchmark spending on R&D.

Figure I.6 **Correlations between changes in mean R&D intensity and R&D concentration[a], 1988-89 to 2001-02**

In first differences using the 4N firm indexes

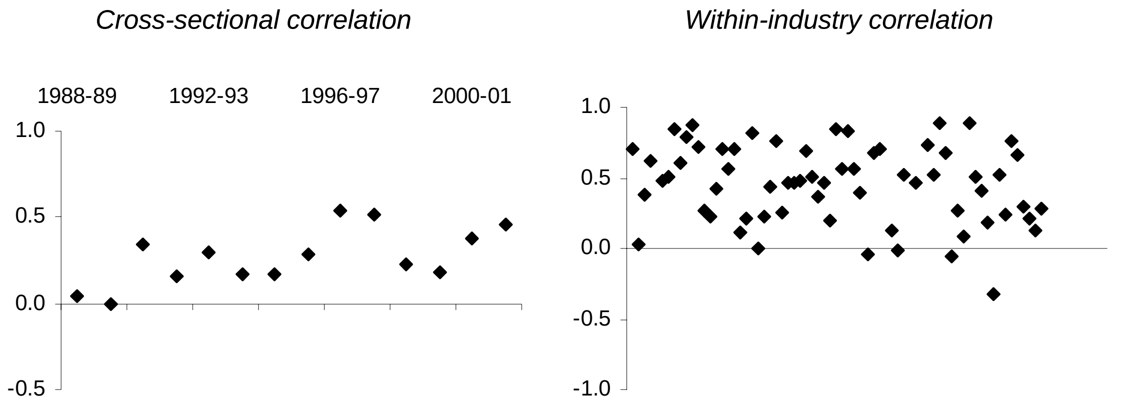


a Upper panels are same-period correlations. Middle panels are the correlation between R&D intensity in period (t) and concentration in period (t-1). Bottom panels based are the correlation between R&D intensity in period (t) and concentration in period (t-2). Using changes in prior-period concentration assumes that R&D intensity follows concentration, rather than the reverse.

Data sources: ABS (*Research and Experimental Development, Businesses, Australia*, Cat. no. 8104.0, unpublished data); Commission calculations.

The Australian evidence does not appear to support the above relationship as the cross-sectional correlations are positive for all years (figure I.7). For each year of the panel, higher mean R&D intensities are not associated with proportionally lower variation in R&D intensity. While interdependent decision making may be a factor in some markets, it does not appear to be a strong enough factor across industries to drive correlations. However, it may be that the level of aggregation of the data obscures the pattern as aggregation combines many different markets within an industry classification.

Figure I.7 **Correlations between mean R&D intensity and the coefficient of variation of R&D intensity[a], 1988-89 to 2001-02**



[a] Coefficient of variation of R&D intensity is the standard deviation of R&D intensity over the mean of R&D intensity.

Data sources: ABS (*Research and Experimental Development, Businesses, Australia*, Cat. no. 8104.0, unpublished data); Commission calculations.

I.6 Key point summary

Expenditure by firm size

- Most business sector R&D activity is undertaken in relatively large firms.
- Large R&D performing firms are far less numerous than small firms. But they have higher probability of being engaged in R&D activity.
- Large firms have lower R&D intensities than small firms. But they spend more on average.

Entry/exit and average scale of R&D activity

- Entry of firms into R&D activity has been more important than growth in average expenditure per firm as a source of growth in total R&D activity.

- Over the long term, the numbers of firms engaged in R&D activity increased at 5 per cent a year, while average expenditure increased at just over 3 per cent a year.
- However, there was considerable variation, particularly in firm entry and exit, at different times.
- There was a strong influx of firms into R&D activity in the early- to mid-1980s, with little change in average spend.
- Both numbers of firms and average spend declined in the mid-1990s.
- Whilst the R&D tax concession may well have played a part in the secular increases in numbers of firms and average spends, the introduction of the scheme and modifications may have contributed to short-term variations.
- The influx of numbers in the 1980s coincided with the announcement and introduction of the scheme.
- The reduction in numbers and average spend in the 1990s coincided with a tightening of the scheme.
- Entry has mostly been by small firms.
- Numbers of large firms declined.

• There is no clear evidence of change in the average scale of operations.

• The concentration of R&D activity in most industries has declined.

Concentration

• But changes in concentration do not appear to have affected intensity of R&D effort.

J Manufacturing panel estimates

This appendix presents estimates of the elasticity of multifactor productivity (MFP) and labour productivity with respect to R&D based on a panel of eight manufacturing industries covering the period 1968-69 to 2000-01. The eight manufacturing industries are: Food, beverages & tobacco (FBT); Textiles, clothing, footwear & leather (TCF); Printing, publishing & recorded media (PPRM); Petroleum, coal, chemical & associated products (PCCAP); Basic metal products (BMP); Structural & sheet metal products (SSMP); Transport equipment (TE); and Other manufacturing (OM).[1]

The manufacturing panel models developed in this appendix are used in chapter 9 in tests of alternative weighting schemes for the construction of spillover pools. They are also used to test whether the effect of foreign R&D on Australian productivity has changed over time, and characteristics of the Australian economy which may condition the effect.

J.1 Manufacturing data

MFP, labour productivity, various capital measures, and hours worked data for the manufacturing panel are updated estimates sourced from the Gretton and Fisher (1997) dataset. Various issues and limitations with the dataset are discussed in Productivity Commission (2003, chapter 7, and appendixes B and I) and Gretton and Fisher (1997, pp. 3–8). For a detailed description of the trends in manufacturing refer to Productivity Commission (2003). Findings particularly relevant to the modelling of the effects of R&D are highlighted below.

- There are differences between the manufacturing information contained in the Gretton and Fisher dataset based on Manufacturing Census data (and used in this appendix), and the manufacturing information that comes from National Accounts data. The output data in the National Accounts are balanced with data on the use of commodities to improve their accuracy, and probably provide a better indication of productivity trends in total manufacturing.

[1] For the relationship between these Gretton and Fisher manufacturing industries and more detailed ANZSIC industries see table A.2.

– Over the period 1969-70 to 2000-01, labour productivity and MFP recorded compound annual growth rates of 3.1 and 1.5 per cent per year, respectively, according to National Accounts data. The Gretton and Fisher equivalents were lower at 2.6 and 1.1 per cent per year, respectively.

- Over the long run, annual average MFP growth in manufacturing has exceeded that of the market sector by around 0.6 percentage points.
- From 1974-75 to 1988-89, and based on National Accounts data, capital deepening contributed more than 30 per cent of the increase in labour productivity (with MFP contributing the rest). From 1988-89 to 2001-02, capital deepening accounted for some 56 per cent of the change in labour productivity.
- Major technological changes that improve the capabilities of capital will increase labour productivity, but not necessarily show up as increases in MFP.

> The ABS method for calculating capital stocks takes (some) account of embodied technological change by altering the price indexes of capital. This has the effect of increasing the capital stock and increasing measured capital intensity, so that MFP may not rise. On the other hand, the adjustments to capital that take account of quality improvements may also sometimes apply to outputs. For example, this would be true for a manufacturer of the relevant capital inputs. In that case, the net effect may still be a gain in MFP. However, the high technology outputs where such quality adjustments are most relevant (such as computers, numerical controllers and robots) are a small component of total production in Australian manufacturing. (PC 2003, pp. 158–9)

- Within manufacturing, there are significant differences in measured labour productivity and MFP performance by manufacturing subdivision. Labour productivity and MFP measures provide a consistent story in relative subdivision performance.
- Productivity growth rates in manufacturing subdivisions are rarely maintained at high or low rates over decades.
- The overall relatively fixed trend for MFP in manufacturing is the net effect of high MFP growth periods for some industries being nullified by low MFP growth periods for other manufacturing industries.

J.2 Description of the variables

The productivity, R&D and various control variables used in the modelling are listed in table J.1. The infrastructure and capital variables are listed in table J.2. Background to the construction of the knowledge stocks is provided in appendix C.

Table J.1 **Description of the variables**

'#' represents the depreciation rate which can be 5, 10 or 15 per cent. 'w' represents the weighting methodology for stock construction.

Variable	*Description*	*Agg*[a]	*Data source*
Labprod	Industry value added per hour worked	S	ABS unpublished data and Commission estimates
MFP	Industry multifactor productivity constructed under usual assumptions	S	ABS unpublished data and Commission estimates
Rown#	Own-industry stock of R&D knowledge	S	ABS (Cat. no. 8104.0 and unpublished data), and Commission estimates
Ryown#	Industry R&D intensity constructed as ln(K/Y) or ln((K(t)-K(t-1))/Y(t)), where K is the knowledge stock and Y is industry value added	S	ABS (Cat. no. 8104.0 and unpublished data), and Commission estimates
Rfrb#_[w]	Foreign stock of business R&D knowledge	S	OECD (ANBERD database) and Commission estimates
Ryfrb#_[w]	Foreign industry R&D intensity constructed as ln(K/Y) or ln((K(t)-K(t-1))/Y(t)), where K is the knowledge stock and Y is Australian industry value added (not foreign industry)	S	OECD (ANBERD database) and Commission estimates
Rext#_[w]	Australian inter-industry or 'external' stock of knowledge weighted by 'w'.	S	ABS (Cat. no. 8104.0) and Commission estimates
Rdperfirm	Business R&D expenditure per R&D performing firm	S	ABS (cat. no. 8104.0) and Commission estimates
Cycle	Control for effects of business cycle: 1st or 2nd difference of industry value added	S	ABS unpublished data and Commission estimates
tiopenetm	Index of imports of ETMs. Single index applied to each subdivision	EW	DFAT (Stars database)
nrao/era	Nominal and effective rates of assistance to industry	S	Commission database
edums	Proportion of the labour force with post-school qualifications for the market sector applied to each subdivision	MS	ABS unpublished data
QALI	ABS Quality Adjusted Labour Index (QALI)	MS	ABS (Cat. no. 5204.0)
centbrg	Centralised wage determination index. Single index applied to all industries	EW	ABS (TRYM Modeller's database)
dubai	Energy Price Index (Oil price - Dubai $US per barrel)	EW	Based on ABARE, *Australian Commodity Statistics* (various issues)

a The level of aggregation of the variables, and, hence, whether the variable differs by subdivision, differs by variable. 'S' represents variables which are specific to each manufacturing subdivision. 'MS' and 'EW' represent variables which are for the market sector or economy as a whole, and do not vary by subdivision.

Source: ABS unpublished data.

Table J.2 **Infrastructure and capital variables**

Each of these variables is specific to the manufacturing subdivisions

Variable	*Description*
ksrvhr	ABS capital services measure by subdivision
nongglTcap	Computer hardware and software of industry (*i*) excluding general government sector
ITshare	Share of information technology (IT) capital in subdivision net capital stock
I3usage2s	Usage of general government infrastructure (non-dwelling construction + all machinery and equipment except computer hardware) allocated to own and other market sector industries (smoothed)
I8usage2	Usage of general government infrastructure (non-dwelling construction + all machinery and equipment + software) allocated to own and other market sector industries
ci5iousage	Usage of Communication services infrastructure = Communication services industry infrastructure (asset types non-dwelling construction+ all machinery and equipment except computer hardware, road vehicles and other transport equipment) multiplied by [industry *(i)* intermediate usage of Communication services in IO tables/(total intermediate usage less Communication services own usage)]
ci8iousage	Usage of Communication services infrastructure = Communication services industry infrastructure (asset types non-dwelling construction+ software + all machinery and equipment except road vehicles and other transport equipment) multiplied by [industry (*i*) intermediate usage of Communication services in IO tables/(total intermediate usage less Communication services own usage)]

Data sources: ABS (*Australian System of National Accounts*, Cat. no. 5204.0); Commission estimates based on ABS unpublished data.

J.3 Output elasticities or rates of return — which to hold constant?

The choice of whether to work in the 'standard framework' in levels or to work in the rate of return framework is often driven by the issue of whether to construct knowledge stocks or use expenditures directly (implicitly assuming a depreciation rate of zero). It is also important to consider which assumption is best: the assumption of constant output elasticities across firms, industries and/or countries (cross-sectional 'units'); or the assumption of constant rates of return across units. In panel analysis, this choice is made more explicit.

The analysis in levels assumes that the estimated elasticity of output with respect to R&D capital ($\gamma = (dY/dK)*(K/Y)$) is constant across units. Given variation in R&D intensities, this implies that the rate of return will vary widely. Estimates of the rate of return to R&D for industries with low R&D intensities are *greater* (($\gamma *$ (Y/K) is larger) than for industries with high R&D intensities. For a given estimated elasticity, the larger the ratio of output over capital, the larger the rate of return. The analysis in growth rates and intensities assumes the rate of return (ρ) is held constant, with output elasticities allowed to vary.

The assumption of a constant total private rate of return, taking into account risk, taxes and the depreciation of R&D capital, is more consistent with optimising firm behaviour. However, if the estimated coefficients capture some or all of the external effects of R&D — for example, spillovers — then there is much less reason to expect returns to be equal at the margin.

The distribution of R&D intensities in 2001-02 is highly skewed towards low R&D intensities, with the largest number of firms consistently located in the left-most 'bin' (that is, the lowest R&D intensity bin or interval (see the footnotes to figure J.1)). The number of enterprises for each bin of the R&D intensity distribution increases from left to right along the horizontal axis. R&D intensity is measured as business expenditure on R&D (BERD) over total employment (R&D expenditure per employee). The business R&D surveys do not collect data on total sales, income or value-added data, which would normally be used in constructing an intensity measure.

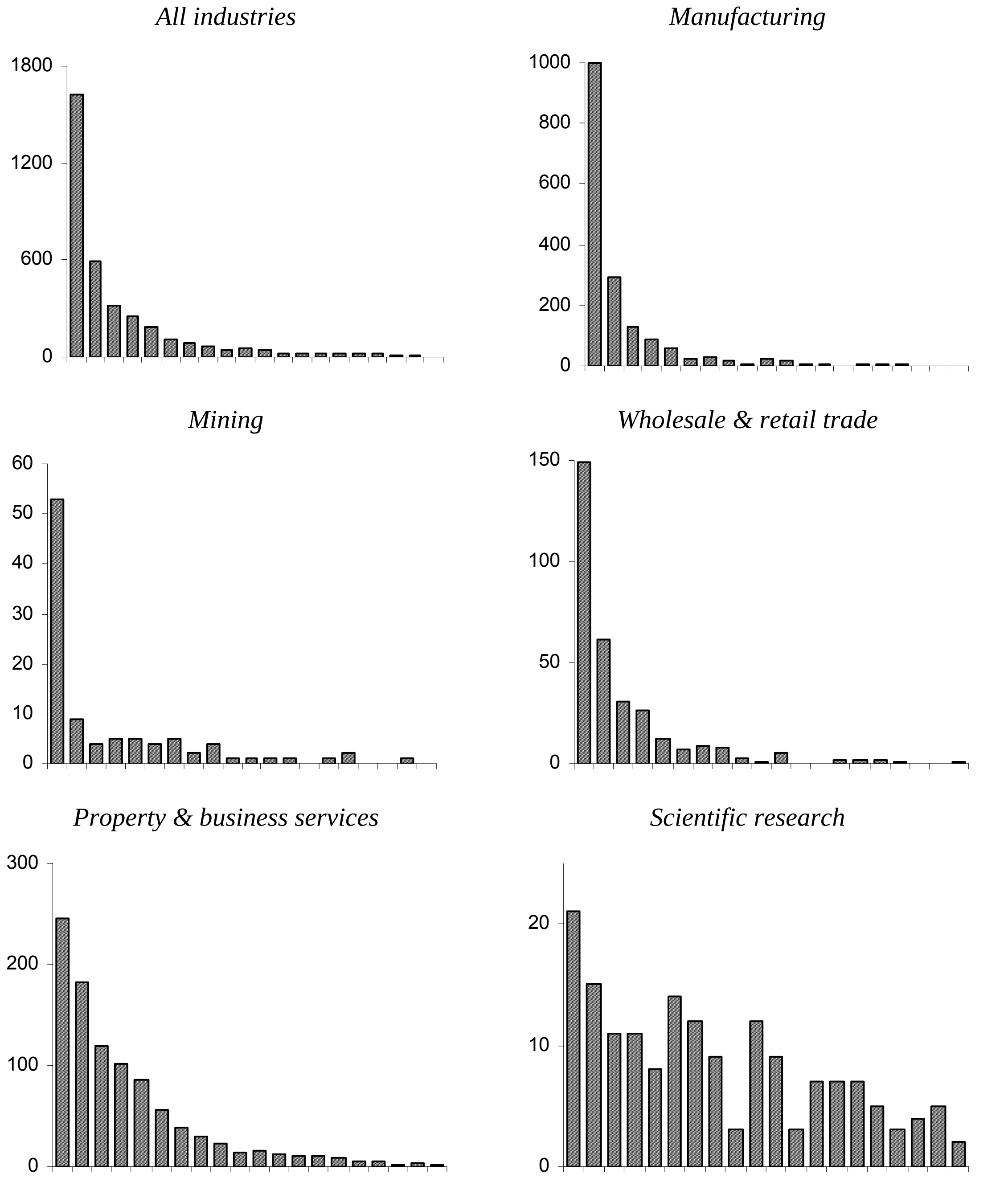
The distributions are uni-modal; a consistently decreasing number of firms are in each bin moving from left to right along the horizontal axis. The distributions have a long right-side tail indicating that there is significant variation in R&D intensities within industries, and that as R&D intensities are increased, fewer and fewer enterprises are observed to have that intensity. The distributions are least skewed in Property & business services and Scientific research.

The distribution pattern of intensities is also seen at lower levels of industry aggregation, through time, and in international studies. The distribution 'snap-shots' do not provide information on how much movement there is between intensity bins — whether the same firms are seen in the same part of the distribution year after year.

Manufacturing industries show the same pattern of highly skewed distributions, with the degree of skewness varying by industry (figure J.2). Compared with other manufacturing industries, Electronic, electrical equipment & appliances and Photographic & scientific equipment have more evenly distributed R&D intensities.

Figure J.1 **Distribution of R&D intensities, 2001-02[a]**

No. of enterprises (vertical axis), R&D expenditure per employee (horizontal axis)

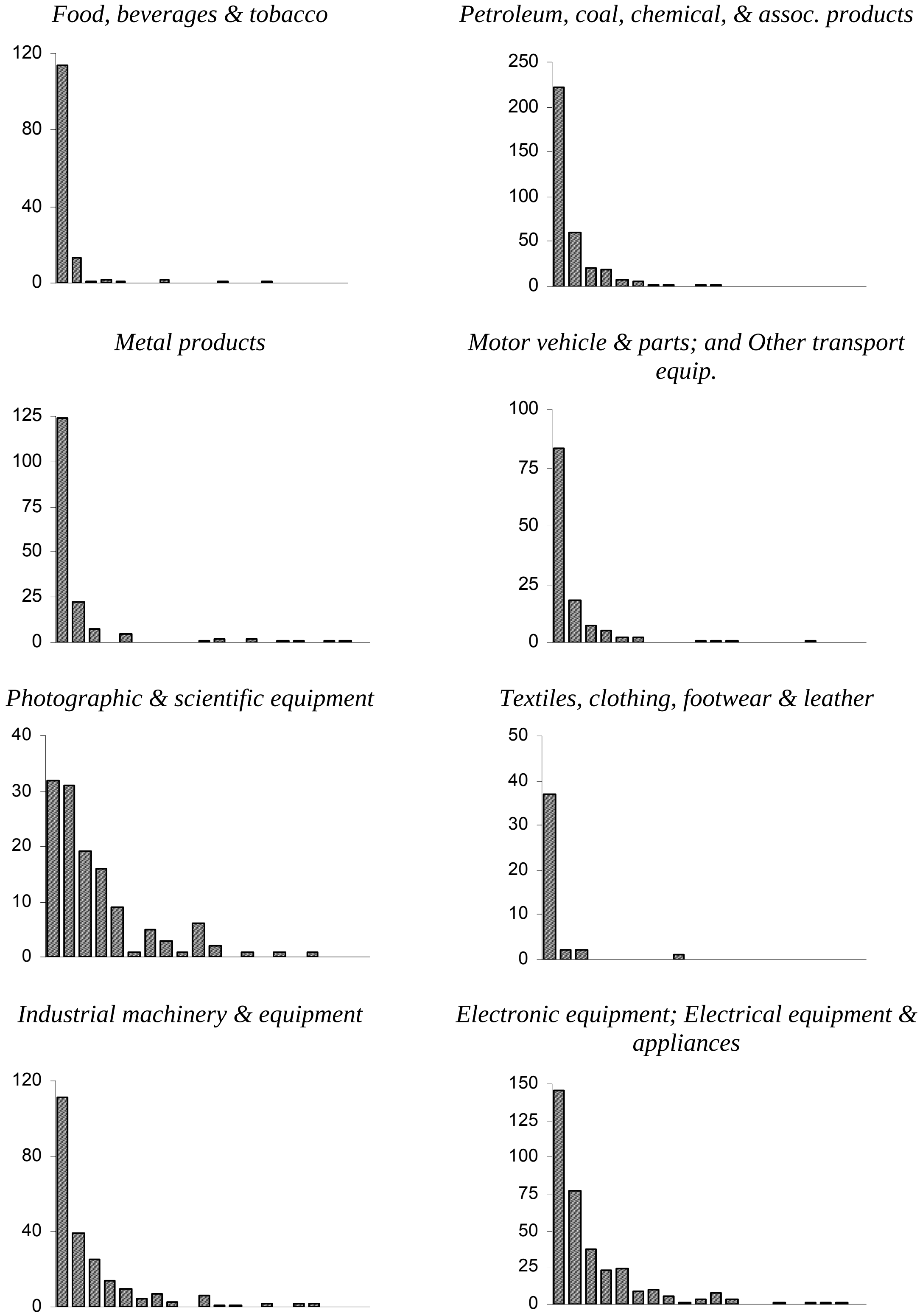


[a] Distributions based on 2001-02 ABS R&D survey of businesses. R&D intensity is measured as BERD per employee, rather than the usual measure of BERD over output. Output data are not included in the unit records. The distribution of R&D intensity was divided into 200 'bins' from lowest to highest. The number of firms in each bin was then counted. For the purpose of presentation in the above graphs, the 200 bins were grouped into sets of 10.

Data source: ABS unpublished data.

Figure J.2 **Distribution of R&D intensities, manufacturing subdivision[a], 2001-02**

No. of enterprises (vertical axis), R&D expenditure per employee (horizontal axis)



[a] These industries differ from the Gretton and Fisher manufacturing industries. See table A.3.

Data source: ABS unpublished data.

If constant elasticities are estimated in the presence of wide differences in R&D intensities, the question becomes why firms do not, if there are such high private rates of return on offer, respond to incentives strongly enough to dissipate those high rates of return. Why is there persistence in the distribution of intensities, rather than a strong tendency to convergence? The production function/perpetual inventory method (PIM) specification implies a pattern of incentives which appears inconsistent with observed behaviour.

Much of the problem may lie with the tools used to analyse the elasticities and returns, rather than the alternative implication that there are very high private returns on offer, but firms do not recognise or respond to them.

Klette (1996) states that it is hard to rationalise persistent differences in R&D intensities across firms and industries using the linear knowledge accumulation process assumed in the PIM, which includes the implicit assumption of constant returns to scale in the production of knowledge. This is because, when combined with a production function, the estimated elasticity and implied rate of return has the implication that:

> … firms with the smallest knowledge-capital-to-output ratio should have the highest rates of return, and therefore the largest incentives to engage in current R&D investment. Such a negative relationship between past R&D investment and current rates of return raises a serious question about the appropriateness of the standard specification. It is a well-established fact that differences in R&D intensity among firms (within a given industry) tend to be highly positively correlated over time. (p. 504)

For analysis on firm-level datasets, Klette utilises a knowledge accumulation equation which introduces complementarity between current investment and accumulated knowledge capital. The equation better rationalises persistent intensity differences between firms (box J.1). The approach cannot be implemented given the data used in this appendix, but it highlights the sources of possible mismeasurement in the PIM-based stocks: the assumption of a linear accumulation methodology and constant returns to scale in knowledge production, when knowledge tends to build on prior knowledge; and specifying a deterministic equation rather than an equation that allows for stochastic shocks, which recognises variation in the relationship between R&D inputs and the outputs from R&D.

While there are arguments for holding the marginal product constant rather than the elasticity, they are weakened as the level of aggregation increases because more of the external effects of R&D are captured. Manufacturing panel models were estimated following the standard rate of return framework, which holds returns constant across panel units. However, similar to the market sector models and most industry models, the models did not work. It is possible that there is greater instability in marginal products through time than in elasticities, and that coefficient instability is stopping direct estimates of the rate of return from being obtained.

Box J.1 **Complementarity in the knowledge accumulation process**

By introducing inter-temporal complementarity into the knowledge accumulation equation, observed cross-sectional differences in intensities, and their persistence, can be better explained:

$$K_{t+1} = K_t^{(p-v)} * R_t^{v} \qquad \text{(J1)}$$

where *K* is the knowledge stock, *v* is a parameter capturing the productiveness of R&D in generating new knowledge, *p* is a parameter representing scale economies in the production of knowledge, and *R* is gross R&D expenditure. The term (*p* - *v*) together reflects the depreciation rate for the private appropriable part of a firm's knowledge capital. For empirical implementation, equation (J1) is specified in logs and a stochastic error term is included representing stochastic shocks in the knowledge accumulation process.

A larger initial stock of knowledge will tend to increase the knowledge obtained from a given additional investment in R&D:

> The complementarity in knowledge production may rationalize why a firm with a high rate of return to knowledge capital still might not want to carry out much or any R&D effort. The firm might have too little knowledge capital or too few R&D skills to get much new knowledge out of its (potential) R&D investment. A firm with a lower rate of return to knowledge capital, on the other hand, might prefer to carry out more R&D, as the knowledge capital it has already acquired makes the current R&D effort very productive in terms of generating additional knowledge capital. (Klette 1996, p. 505)

The positive feedback mechanism between current investment and accumulated knowledge leads to firms with different knowledge capital intensities being able to realise different ex-post returns from similar opportunities:

> … the multiplicative model of knowledge accumulation considered in this section rationalizes why the same firms persistently invest above (or below) average in R&D. The main reason identified here is the inter-temporal complementarity in the R&D activity; past experience makes current R&D effort more productive. We have formally shown that this mechanism leads to a pattern of persistent differences in R&D intensities between firms, a well known empirical pattern which is hard to rationalize in the standard framework. (Klette and Johansen 2000, p. 372)

Klette's modelling approach portrays a process whereby there is a tendency for differences in productivity across firms/plants to disappear due to knowledge spillovers, in the absence of additional R&D effort. However, the feedback mechanism between additional investments in R&D and the accumulated intensity of knowledge gives incentives to firms with higher intensities to preserve cross-sectional differences in R&D effort over time.

The knowledge accumulation equation (J1) resembles those in the R&D-based endogenous growth models in that there is an inter-temporal relationship between accumulated knowledge and current investment in knowledge acquisition.

J.4 The effect of R&D in the levels relationship

Panel models were first estimated as ln(MFP) models with the knowledge stocks specified as ln(K), and common coefficients imposed across the panel units. Testing indicated the knowledge stocks were stationary. Given non-stationary data, and if tests had rejected the presence of a unit root in the residuals of the model, then the specified relationship could have been interpreted as a co-integrating regression. Various estimation strategies were employed.

Basic static models including MFP, own-industry R&D, inter-industry R&D and foreign R&D were estimated. They did not provide support for co-integration. Given lags in R&D, the models may have been misspecified in that they were not 'dynamically complete'. A dynamically complete model is a model where enough lags of the explanatory variables and dependent variable have been included such that further lags do not matter for explaining the dependent variable (Wooldridge 2002, p. 382). Dynamic completeness is a very strong assumption for static and FDL models. If a model is dynamically complete, there will be no serial correlation. Finite distributed lag (FDL) versions of the models were then tested, but the results were also very highly serially correlated. ARDL specifications also did not provide a workable model. In the market sector time series models, FDL and ARDL estimation improved model results.

Additional controls and sources of growth were added to the models. All of the models were still subject to very strong serial correlation. Visual inspection of the residuals, the Wooldridge (2002) test for serial correlation in the errors of a linear panel data regression, and a battery of panel unit root tests, all indicated the presence of non-stationary errors.

The presence of unit roots in the residuals of the models indicated that the models probably did not form co-integrating regressions. However, a possible alternative source of the problem was the procedure of pooling the subdivisions and imposing a common coefficient.

Estimates for individual manufacturing subdivisions

Both basic and extended models did not produce reliable estimates of the effect of R&D when common coefficients were imposed on the manufacturing subdivisions. An alternative approach is to view the subdivisions as eight individual time series.

Estimates for individual manufacturing subdivisions using seemingly unrelated regression equations (SURE) show very significant variation across subdivisions in the magnitude of coefficients, their statistical significance, and even in the sign of coefficients (table J.3).

The estimated elasticities for own-industry R&D (rown15) range from very large, negative and statistically significant, to very large, positive and statistically significant. Chand et al. (1998) estimated an even wider range of elasticities in a first differenced production function framework for a combined private and public R&D variable.

The implied rates of return are very large (both positive and negative) which calls into question whether the R&D variable is proxying for a larger phenomenon. For example, while attempts have been made to control for changes in human capital, the education variable is the index used in the market sector regressions, which probably provides a poor measure for individual industries. Industry-specific measures were also constructed, but they cover a much shorter time frame.

Foreign R&D has a positive sign and is economically very significant in five of the eight industries ('rfrbi_etmio'). For these regressions, the foreign stocks were constructed building-up from industry level data. Both an inter-industry weight and a country weight were applied to create the potential spillover pool.

The inter-industry weight for the foreign R&D stock was based on Australian input-output table relationships and the country weight on import shares of Elaborately Transformed Manufactures (ETMs) (_etmio). Inter-industry weights based on socio-economic objectives (SEO) proximity also performed well when used with ETM import shares. The weight given to a particular foreign industry's R&D in forming the spillover pool depends both on the relationship between the foreign industry and the domestic industry for which the pool is being constructed (based on input-output relationships), and the relationship between Australia and the foreign country (based on the importance of that country to Australia in terms of a source of ETMs).

Australian inter-industry R&D (Rext15_s) is positive and significant in only two industries, while it is negative and significant in three industries. The inter-industry spillover pools were constructed using SEO weights, except for Petroleum, coal, chemicals & associated products where weights were based on trade relationships contained in *Australian System of National Accounts* (ASNA) input-output tables.

The estimates on general government infrastructure are positive, statistically significant and economically large in six of the eight industries. The sign on communications capital is generally positive.

Table J.3 R&D and the level of MFP, dependent variable equals ln(MFP)

Model MPS1. All variables in logs. Estimated using SURE, 1974-75 to 2000-01.

	OM	*FBT*	*TCF*	*PPRM*	*PCCAP*	*BMP*	*SSMP*	*TE*
ANZSIC[a] =	*23,26, 283-6,29*	*21*	*22*	*24*	*25*	*271-3*	*274-6*	*281-2*
Trend		-0.010	0.016	0.028***	-0.044***	-0.033***		0.104***
		(0.006)	(0.010)	(0.004)	(0.008)	(0.008)		(0.012)
Cycle (∆value added)	0.346***	0.299**	0.409***	0.199**	0.449***	0.487***	0.283***	0.224***
	(0.091)	(0.121)	(0.080)	(0.091)	(0.075)	(0.054)	(0.044)	(0.055)
Rown15 (t-1)			0.085*	0.192***		0.278***	-0.219***	0.319***
			(0.051)	(0.069)		(0.031)	(0.041)	(0.089)
Rfrbi_etmio (t)	0.218***	0.210**	0.345**			1.748***		1.096***
	(0.053)	(0.089)	(0.176)			(0.189)		(0.210)
Rext15_s (t)			-0.420***	-0.407***	0.149***		0.112***	-1.193***
			(0.127)	(0.052)	(0.057)		(0.029)	(0.137)
I3usage2s	0.288**	0.399***	0.295**	0.337***	0.286**		0.286***	
	(0.253)	(0.090)	(0.117)	(0.109)	(0.123)		(0.055)	
ci5iousage	0.035	0.016		-0.044***			0.037**	0.051***
	(0.022)	(0.012)		(0.015)			(0.017)	(0.014)
ITshare					0.154***			-0.258***
					(0.021)			(0.053)
edums		0.416***	0.505***		0.316***			
		(0.093)	(0.137)		(0.093)			
tiopenetm	0.253***			-0.151**		0.176***		
	(0.092)			(0.071)		(0.054)		
era	-0.091***	-0.009	-0.088***		-0.058**	0.050**	-0.050***	-0.054*
	(0.032)	(0.017)	(0.023)		(0.026)	(0.024)	(0.012)	(0.029)
centbrg		-0.022**	-0.049***		-0.031***	0.021**	-0.052***	0.038**
		(0.011)	(0.016)		(0.010)	(0.010)	(0.010)	(0.015)
dubai						0.026	-0.016*	0.097***
						(0.018)	(0.010)	(0.018)
Constant	2.622**	0.339	1.107	4.013***	3.213***	-4.930***	4.218***	0.699
	(1.223)	(0.718)	(0.759)	(0.859)	(0.643)	(0.894)	(0.328)	(0.693)
Test statistics								
No. of obs.	27	27	27	27	27	27	27	27
R^2	0.850	0.945	0.951	0.914	0.974	0.996	0.930	0.989
Chi2	176.2	558.7	665.6	294.7	1257.7	6133.1	452.8	2619.3
ADF[b]	-4.120	-5.118	-3.099	-4.880	-4.427	-4.798	-4.152	-6.604
	(0.001)	(0.000)	(0.027)	(0.000)	(0.000)	(0.000)	(0.001)	(0.000)
DF GLS [c]	-3.682	-5.075	-3.174	-4.962	-4.188	-3.536	-4.820	-6.418
	(-2.368)	(-2.455)	(-2.368)	(-2.455)	(-2.455)	(-3.195)	(-2.455)	(-3.386)
KPSS [d]	0.059	0.051	0.078	0.056	0.068	0.033	0.078	0.051

* Significant at 10 per cent. ** Significant at 5 per cent. *** Significant at 1 per cent. [a] For details of industry classification see table A.2. [b] Augmented Dickey-Fuller (ADF) unit root test of residuals. MacKinnon approximate p-value in brackets. A small p-value rejects the null of a nonstationary series. Lag length selection was based on a test down procedure, with initial testing using the mean squared error of the regression (RMSE), Akaike's Information Criterion (AIC), Amemiya's Prediction Criterion, and Schwarz's Information Criterion (SC). [c] Dickey-Fuller generalised least squares unit root test. Test is of a nonstationary I(1) process against a level stationary process (trend stationary for BMP and TE industries). 5 per cent critical value in brackets. A statistic smaller than the critical value rejects the null. [d] Kwiatowski, Phillips, Schmidt, and Shin (KPSS) 1992 unit root test. Null is that residuals are level stationary. 5 per cent critical value is 0.463. A statistic greater than critical value rejects the null. Maximum lag length was based on test default using Schwert (1989).

Source: Commission estimates.

The coefficient on effective rates of assistance is negative and significant in five of the eight industries and centralised bargaining is negative and significant in four of the eight industries. The decrease in effective rates of assistance is associated with an increase in the level of MFP. This was also found in Chand et al. (1998) and other Australian studies based on the Gretton and Fisher dataset. The decline in the extent to which wage outcomes are centrally determined also appears to have had a positive influence on the level of MFP, except in Basic metal products and Transport equipment.

Robustness of the results

Visual inspection of the residuals and formal unit root tests for each of the subdivisions indicated that the residuals were stationary. When the models were estimated independently for each subdivision, the Durbin-Watson statistic was greater than two for each industry. For a few of the industries, error variances did increase over time.

Using SURE estimation rather than ordinary least squares (OLS) on the individual subdivisions produced more statistically significant results. There was some evidence that restricting the last observation of the sample to 1998-99 rather than 2000-01 improved model results as, for some subdivisions, 1999-00 stood out as having a much greater difference between predicted and observed values. However, dropping the final two years of the sample did not produce better model results for most subdivisions when interaction terms were tested for chapter 9.

A large range of sensitivity tests were undertaken. The following tests did not provide better statistical significance overall or more frequently produce properly signed coefficients (relative to expectations): lower depreciation rates on industry-own R&D; industry-specific deflation of industry R&D expenditures using industry output implicit price deflators (IPDs) rather than the GDP(IPD) deflator for all industries; lag structures for industry-own and foreign R&D of (t)-(t) and (t-2)-(t-3) rather than (t-1)-(t); replacement of the inter-industry trade weighted measure with a measure including inter-industry and non-business R&D and weighted by socio-economic objective; use of nominal rates of assistance rather than effective rates of assistance; use of the QALI index rather than use the variable ‘edums’; basing the own-industry R&D stock on R&D expenditures performed and financed by the industry rather than on performed only; dropping the cycle variable; and estimating each subdivision as an independent OLS equation.

J.5 Growth in MFP and the level of R&D intensity

The models in this section investigate the relationship between growth in MFP and the level of R&D intensity. Results in table J.4 are for intensities specified as the knowledge stock over output. Model MP13 is specified differently and is a fully first differenced model, meaning that the knowledge stocks are specified as growth in ln(K), rather than as intensities.

The level of the knowledge stock as a proportion of output has a positive, but not statistically significant, partial effect on MFP growth in each of the models presented. The effect of foreign business R&D is positive and statistically significant in four of the five models in which it is included. The potential spillover pool was created using country weights based on import shares (_td) and inter-industry weights based on SEO proximity (_seo) (see appendix C for background on inter-industry weights and appendix F for country weights). Where statistically significant, the bottom of the 95 per cent confidence interval lies well above zero. Foreign gross R&D (GRD) — which does not vary by industry — is not statistically significant (model MP11). Inter-industry R&D has a negative and statistically significant effect in each of the intensity models.

The mean growth rate in MFP for the panel of manufacturing industries is 1.17 per cent per year. Models MP9-MP11 imply that a one per cent increase in the potential R&D spillover pool to Australia would increase the growth rate to about 1.25 per cent per year, with a two standard deviation confidence interval of roughly 1.19 to 1.31 per cent per year.

General government infrastructure has a large positive and highly statistically significant effect on the growth rate of MFP. This represents a 'free input' effect. Communications capital is also positive. The variable QALI represents changes in formal education and skills. It is economically large, positive, and statistically significant. It is sometimes argued that estimates of the return to R&D are likely to be biased upwards because controls have not been included for increases in human capital and skills not specifically related to, but correlated with, business R&D. In these models, the lack of significance on the own-industry R&D coefficient is not related to the inclusion of QALI. Dropping it only improves the statistical significance of own-industry R&D marginally, while the precision of the estimates for foreign and inter-industry R&D deteriorate slightly.

The coefficients on changes in nominal rates of assistance and centralised wage determination are consistently negative, but not statistically significant in the MFP growth models.

Table J.4 **Growth in MFP and the knowledge stock as a proportion of output, panel estimates**

Dependent variable = ∆ln(MFP). Models MP8 to MP12 use R&D specified as ln(K/Y). For Model MP13, all variables first differenced. All variables in logs.

Estimation =	*Pooled OLS*	*Fixed effects (FE)*	*FGLS*[b]	*FGLS*[b]	*PCSE*[c]	*Differenced PCSE*[c]
Model =	*MP8*	*MP9*	*MP10*	*MP11*	*MP12*	*MP13*
Cycle (∆value added)	0.226***	0.199***	0.212***	0.238***	0.188***	0.189***
	(0.051)	(0.047)	(0.041)	(0.040)	(0.056)	(0.045)
Own-industry R&D (t-1)	0.011	0.002	0.007	0.007	0.008	-0.004
	(0.011)	(0.011)	(0.009)	(0.011)	(0.013)	(0.044)
Foreign BRD (_tdseo) (t)	0.058	0.083**	0.082***		0.080**	0.432***
	(0.046)	(0.035)	(0.030)		(0.032)	(0.075)
Inter-industry R&D (_t) (t)	-0.077***	-0.082***	-0.085***	-0.057***	-0.077***	-0.028
	(0.029)	(0.023)	(0.020)	(0.017)	(0.022)	(0.078)
Foreign GRD (_td) (t)				0.073		
				(0.049)		
∆ci8iousage	0.023*	0.025**	0.024**	0.021**	0.030**	0.021*
	(0.012)	(0.012)	(0.011)	(0.011)	(0.013)	(0.012)
∆I8usage2	0.367***	0.426***	0.408***	0.324***	0.437***	0.437***
	(0.094)	(0.085)	(0.073)	(0.066)	(0.091)	(0.075)
∆QALI	0.140	0.380**	0.403***	0.390***	0.382*	0.393***
	(0.129)	(0.155)	(0.131)	(0.135)	(0.231)	(0.152)
∆nrao	-0.016	-0.017	-0.018	-0.018	-0.017	-0.007
	(0.019)	(0.020)	(0.017)	(0.017)	(0.021)	(0.020)
∆centbrg	-0.010	-0.011	-0.011*	-0.009	-0.012	
	(0.006)	(0.007)	(0.006)	(0.006)	(0.010)	
Constant	-0.373*	-0.397*** [a]	-0.477***	-0.227***	-0.445***	-0.009
	(0.200)	(0.139)	(0.136)	(0.081)	(0.143)	(0.012)
Shift1982			0.023***	0.017**	0.021**	
			(0.008)	(0.008)	(0.011)	
Shift8589		-0.022***	-0.023***	-0.021***	-0.025**	-0.029***
		(0.008)	(0.007)	(0.007)	(0.011)	(0.010)
Shift1989	0.222**	0.021**				
	(0.011)	(0.009)				
Shift1995	0.015**	0.011	0.014**	0.013*		
	(0.008)	(0.008)	(0.007)	(0.007)		
Industry dummies	Yes		Yes	Yes	Yes	Yes

(continued on next page)

Table J.4 **(continued)**

Estimation =	*Pooled OLS*	*Fixed effects (FE)*	*FGLS*[b]	*FGLS*[b]	*PCSE*[c]	*Differenced PCSE*[c]
Model =	*MP8*	*MP9*	*MP10*	*MP11*	*MP12*	*MP13*
Test statistics						
No. of observations	208	208	208	208	208	208
- per group	26	26	26	26	26	26
White Test for heteroskedasticity	185.0 (0.070)					
F-stat/Wald	10.2	15.1	244.1	229.6	180.2	172.0
R^2	0.481	0.491			0.502	0.471
Log Likelihood			445.1	443.2		
Levin, Lin, Chu[d]	-14.0 (0.000)	-14.1 (0.000)				
Ipshin[e]	-4.797 (0.000)	-4.640 (0.000)				
Hadrilm[f]	0.548 (0.292)	0.450 (0.326)				

* Significant at 10 per cent. ** Significant at 5 per cent. *** Significant at 1 per cent. [a] The fixed effects transformation eliminates the intercept and any other variables which are constant over time. The reported intercept is the average value of the fixed effects. [b] Estimation using feasible generalised least-squares method (FGLS) assumes an AR(1) error structure and is suited to the dimensions of the dataset — a small number of cross-sectional units combined with a larger number of observations over time. Different types of error structures can be specified. Testing and model fit favoured the specification of a panel-specific AR(1) term, combined with correcting for panel-level heteroskedasticity (differences in error variances across units), and correlation in errors across panel units. [c] Panel corrected standard errors (PCSE) estimation. [d] Levin, Lin and Chu (2002) unit root test. Test statistic coefficient and p-value presented. A small p-value (in brackets) rejects the null of I(1) behaviour. Various lag lengths tested. [e] Im, Pesaran and Shin (2003) t-test for unit roots in heterogeneous panels. Based on the mean of the individual Dickey-Fuller t-statistics of each unit in the panel. Test assumes that all series are non-stationary under the null hypothesis. The alternative hypothesis is that the series are level stationary. T-bar presented with p-value in brackets. [f] Hadri (2000) panel unit root test for stationarity in heterogeneous panel data. The Lagrange Multiplier statistic tests the null that all eight units are stationary processes. Assumed heteroskedastic disturbances across units. Z-tau statistic presented with p-value in brackets.

Source: Commission estimates.

Robustness of the results

The Wooldridge (2002) test for serial correlation in linear panel data was undertaken for the pooled OLS model. It gave a test statistic of 1.3 and a p-value of 0.30. The null of *no* serial correlation was not rejected at a confidence level of 10 per cent or greater. The unit root tests indicated that residuals were stationary. The Hadri test did not reject the null that the residuals of all eight subdivisions were stationary.

The Hausman test did not reject the null of no correlation between the fixed effects and the explanatory variables (the p-value of the test equalled fourteen per cent) (box J.2). However, as the test's p-value was close to ten per cent, fixed effects estimation was chosen.

Testing indicated that the errors of models MP8 and MP9 were not homoskedastic. This is likely due to the presence of error variances which are specific to the cross-sectional unit. Feasible generalized least-squares (FGLS) and panel corrected standard errors (PCSE) estimation was used to correct for heteroskedastic errors (models MP10-MP12). In models MP10 and MP11, an assumption of panel-specific AR(1) errors provided better results. In model MP12, the specified error structure included cross-unit correlation in the errors of the model.

If time dummies are used rather than the cycle variable, then the coefficients on the R&D variables maintain their signs and significance levels, the coefficient on general government increases significantly, and QALI drops from the model (possibly due to collinearity).

Models based on growth in MFP and the level of R&D intensity, specified as per the standard rate of return framework, performed poorly.

Box J.2 **The choice between estimation strategies**

Panel data regression techniques take into account various biases and other disturbances in the regression analysis that ordinary least squares (OLS) does not. These biases may arise from systematic variation between firms and/or across all units over time. An important advantage of panel data analysis is that it controls for unobservable or unspecified differences between units. A panel model can be represented as:

$$\dot{y}_{it} = \alpha + \beta x_{it} + u_{it} \qquad \text{(J2)}$$

where α is the common intercept across units and can be interpreted as unidentified technical change, x_{it} are explanatory variables, and u_{it} is the error term. The error term can be broken into three components: a unit-specific fixed effect (a_i); a time period effect (λ_t); and the pure random error (v_{it}).

The assumptions of correlation between the error terms and the explanatory variables determine the appropriate estimator for equation (J2). If it is assumed that either the a_i or the λ_t are correlated with the x_{it}, then fixed effects estimation is chosen as the fixed effects transformation removes the unobserved effects and/or time constant effects prior to estimation of the model. Any time constant variables are also removed unless they are interacted with the x_{it}. The fixed effects estimator is then estimated using pooled OLS.

If it can be assumed that the unobserved effect a_i and all the x_{it} are not correlated, then random effects estimation can be used. The random effects transformation does not eliminate the unobserved a_i from the model, and it allows incorporation of explanatory variables which are constant over time. Generalised least squares estimation (GLS) can be used to address any resulting serial correlation.

Feasible Generalised Least Squares and Panel Corrected Standard Errors methods can also be used in the panel context. These methods allow specification of the error structure of the model, for example, whether errors are correlated across panels or independent, whether variances are homoskedastic, and whether a common AR(1) or panel-specific AR(1) process is assumed. Pooling the units and using OLS to estimate a first differenced regression can also be useful in the presence of non-stationary data.

If the fixed effects are serially uncorrelated, then fixed effects estimation is more efficient than first differencing. However, if unobserved factors which change over time are serially correlated, then first differencing is preferred. Inference with the fixed effects estimator is potentially more sensitive to non-normality, heteroskedasticity, and serial correlation in the idiosyncratic errors. Serial correlation will result when there are strong unit root processes, which is more of a problem when the number of time period observations is large relative to the number of cross-sectional units, as in the Gretton and Fisher (1997) dataset. However, fixed effects estimation is less sensitive to violation of the strict exogeneity assumption, which is an issue with the ‘simultaneity’ of R&D.

Source: Wooldridge (2003).

J.6 A comparison of inter-industry R&D spillover mechanisms

Four different inter-industry potential spillover pools were created for each of the eight manufacturing industries: an unweighted stock; a stock weighted by ASNA input-output table relationships; a stock weighted by the technological proximity of each industry's R&D activity decomposed by Socio-Economic Objective; and a SEO technological proximity measure, which includes the proximity of higher education and government-performed R&D.

For aggregate Australian manufacturing, inter-industry external effects have a net negative effect on manufacturing MFP and the effect appears to be predominantly transmitted by embodiment in traded goods and services (table J.5). The unweighted and weighted by SEO inter-industry spillover pools performed poorly relative to the inter-industry stocks weighted by trade relationships. Their inclusion also severely impacted on the results for industry-own R&D and foreign R&D. The SEO weighted inter-industry pool which included higher education and government-performed R&D also did not produce satisfactory model results.

The data's preference for input-output weighted spillover pools for detecting inter-industry external effects contrasts with the results from the sensitivity testing of alternative foreign knowledge stock weighting schemes based on foreign industry-level data (see chapter 9). In those results, the SEO proximity measure fit the data better when aggregating foreign R&D expenditures from the industry level.

This appears to suggest that the dominant mechanism for knowledge transfer across industries in Australia, at least to manufacturing, is embodiment in trade relationships, but the impact on manufacturing productivity is negative.

Table J.5 **Tests of alternative inter-industry potential spillover pools**

	Unweighted	*ASNA Input-output relationships*	*Proximity by socio-economic objective*	*SEO with Higher education & Government*
Model MP8 (OLS) -				
Ry15 (t-1)	-0.003	0.010	0.008	-0.004
	(0.014)	(0.011)	(0.013)	(0.010)
Rfrybi_tdseo (t)	-0.034	0.057	0.005	-0.053*
	(0.035)	(0.046)	(0.034)	(0.030)
Ryext15_[x] (t)	-0.001	-0.074***	-0.042	0.030
	(0.029)	(0.029)	(0.027)	(0.043)
AIC*N (BIC)	-809(-33)	-821(-44)	-812(-35)	-810(-34)
Model MP9 (FE) -				
Ry15 (t-1)	0.002	0.002	0.006	-0.012
	(0.013)	(0.011)	(0.012)	(0.010)
Rfrybi_tdseo (t)	0.032	0.083**	0.061	-0.007
	(0.040)	(0.035)	(0.037)	(0.037)
Ryext15_[x] (t)	-0.055	-0.082***	-0.079***	-0.020
	(0.035)	(0.023)	(0.030)	(0.044)
F-test (10,190)	13.5	15.1	14.2	13.1
R^2(within)	0.463	0.491	0.475	0.456
Model MP12 (PCSE) -				
Ry15 (t-1)	-0.001	0.008	0.005	-0.011
	(0.014)	(0.013)	(0.013)	(0.012)
Rfrybi_tdseo (t)	0.010	0.080**	0.035	-0.010
	(0.042)	(0.032)	(0.038)	(0.042)
Ryext15_[x] (t)	-0.028	-0.077***	-0.047*	-0.015
	(0.030)	(0.022)	(0.026)	(0.041)
R^2	0.472	0.502	0.480	0.469
Wald	166.0	180.2	166.6	164.7

Source: Commission estimates.

J.7 Are results dependent on the MFP framework?

Given the weakness of some aspects of the MFP modelling, and the fragility of signs on R&D coefficients in the market sector and some industry models, labour productivity models were also estimated (table J.6). If robust estimates were found when estimating production functions in labour intensive form, it might help indicate the sources of weakness in MFP results. In particular, labour productivity models were estimated to ensure the consistency of the sign of coefficients on own-industry R&D, foreign business R&D and inter-industry R&D.

Models MLP1 to MLP3 are motivated by the Howitt long-run relationship outlined in chapter 4. In that model, a steady R&D intensity is consistent with constant growth in output per person (hours worked in these models). A rising R&D intensity would lead to an increase in the growth rate. Model MLP3 pools the subdivisions and estimates with standard OLS. Model MLP4 is a fully first differenced model, where the R&D variables are measured as the change in the knowledge stock per hour worked rather than being specified as intensities. Model MLP5 is the same model as MLP4, but with a different lag structure. Model MLP6 uses a patent indicator rather than a foreign knowledge stock and also includes a quadratic term for industry-own R&D.

The measured effect of the R&D variables on manufacturing labour productivity is significantly different to the results of the MFP models, especially for models MLP1 to MLP3. In the MFP growth models, industry-own R&D was positively signed but not significant. In the labour productivity growth models, the coefficient on industry-own R&D is sensitive to model specification and estimation. It is statistically significant and positive in some models, but negative in others. Re-estimating MLP1 and MLP2 with different lag structures on the R&D variables did not alter these results.

In model MLP6, the quadratic term is jointly significant at greater than five per cent. Evaluated at the mean of the sample, the coefficient on industry-own R&D is 0.006 with a standard error of 0.003 and a p-value of 0.024.

Where negative, the interpretation is that the positive effects of spillovers within-industry, combined with the private excess return (under the expectation that it is positive), is being offset by external effects which lower the industry's output per hour worked. These effects might be negative duplication externalities or creative destruction effects. Various other issues in interpreting a negative coefficient on own-R&D are discussed in chapter 10.

Foreign R&D is negative in the R&D intensity models, but positively signed in the pooled first differenced equations (models MLP4 and MLP5). In the MFP growth models earlier, foreign business R&D had a positive effect across all specifications, more like the strong, positive effect in the patent model below (MLP6).

The external effects of inter-industry R&D are either insignificant or positive in the labour productivity models, whereas, they were negative and significant in all the MFP growth models. These results hold under different foreign and inter-industry weighting schemes.

Table J.6 **Growth in labour productivity**

Model =	*MLP1*	*MLP2*	*MLP3*	*MLP4*	*MLP5*	*MLP6*
	Fixed Effects(FE)	*Random Effects(RE)*	*Pooled OLS*	*Pooled first difference*	*Pooled first difference*	*Random Effects*
Lag structure =	*Own=(t-1) For.=(t) Ext.=(t)*	*Own=(t-1) For.=(t) Ext.=(t)*	*Own=(t-1) For.=(t) Ext.=(t)*	*Own=(t-1) For.=(t) Ext.=(t)*	*Own=(t-2) For.=(t-3) Ext.=(t-2)*	*Own=(t-1) For.=(t-1) Ext.=(t)*
R&D spec. =	*ln(K/ (Y*hrs))*	*ln(K/ (Y*hrs))*	*ln(K/ (Y*hrs))*	*Δln(K/hrs)*	*Δln(K/hrs)*	*ln(K/ (Y*hrs))*
Cycle (ΔΔ real value added)	0.389*** (0.036)	0.371*** (0.037)	0.371*** (0.041)	0.469*** (0.032)	0.415*** (0.042)	0.413*** (0.039)
Δksrvhr	0.415*** (0.044)	0.441*** (0.043)	0.441*** (0.061)	0.188*** (0.060)	0.526*** (0.065)	0.427*** (0.045)
Own-industry R&D	-0.026* (0.014)	0.009*** (0.003)	0.009*** (0.003)	-0.171*** (0.035)	-0.081* (0.048)	0.076 (0.088)
Own-industry R&D squared						0.002 (0.003)
Foreign stock (‘tdio’ weights)	-0.071*** (0.017)	-0.008*** (0.003)	-0.008* (0.004)	0.281*** (0.084)	0.043 (0.040)	
ΔUSPTO patents (“_ti” weights)						0.339*** (0.078)
Inter-industry R&D stock (‘t’ weights)	0.073*** (0.023)	0.005 (0.005)	0.005** (0.005)	0.181** (0.059)	0.125* (0.066)	0.000 (0.003)
ΔQALI / Δedums	0.242* (0.142)	0.214 (0.143)	0.214 (0.144)	0.412*** (0.133)	0.393** (0.159)	0.220** (0.086)
Δnrao	-0.033 (0.020)	-0.009 (0.020)	-0.009 (0.017)	-0.051*** (0.015)	-0.023 (0.018)	0.016 (0.022)
Δcentbrg	-0.015** (0.007)	-0.005 (0.007)	-0.005 (0.007)	-0.012*** (0.006)	-0.014* (0.010)	-0.019* (0.011)
Δdubai	0.013 (0.008)	0.020** (0.008)	0.020** (0.009)			0.019* (0.011)
Shift8589					-0.011 (0.008)	
Constant	-0.283** (0.115)	0.118** (0.047)	0.118** (0.049)	-0.021*** (0.008)	-0.021** (0.010)	0.606 (0.638)
Industry dummies				Yes	Yes	

(continued on next page)

Table J.6 **(continued)**

Model =	*MLP1*	*MLP2*	*MLP3*	*MLP4*	*MLP5*	*MLP6*
	Fixed Effects(FE)	*Random Effects(RE)*	*Pooled OLS*	*Pooled first difference*	*Pooled first difference*	*Random Effects*
Lag structure =	*Own=(t-1) For.=(t) Ext.=(t)*	*Own=(t-1) For.=(t) Ext.=(t)*	*Own=(t-1) For.=(t) Ext.=(t)*	*Own=(t-1) For.=(t) Ext.=(t)*	*Own=(t-2) For.=(t-3) Ext.=(t-2)*	*Own=(t-1) For.=(t-1) Ext.=(t)*
R&D spec. =	*ln(K/ (Y*hrs))*	*ln(K/ (Y*hrs))*	*ln(K/ (Y*hrs))*	*Δln(K/hrs)*	*Δln(K/hrs)*	*ln(K/ (Y*hrs))*
Test statistics						
# of obs.	224	224	224	216	192	192
R^2 ('within' for FE/RE models)	0.473	0.427	0.440	0.614	0.533	0.543
F-test	20.7		14.7	22.9	9.9	
AIC*n(BIC)				-880(-125)	-730(-62)	
Wald / Log Likelihood		167.9	432.1			222.8
Likelihood Ratio			134.9			
Levinlin[a]	-12.3 (0.000)	-12.0 (0.000)	-12.0 (0.000)	-9.7 (0.000)	-10.5 (0.000)	-10.9 (0.000)
Ipshin[a]	-4.2 (0.000)	-4.1 (0.000)	-4.1 (0.000)	-3.4 (0.000)	-3. 6 (0.000)	-3.8 (0.000)
Hadrilm[a]	1.3 (0.100)	2.3 (0.011)	2.3 (0.011)	4.5 (0.000)	1.4 (0.080)	2.6 (0.004)

* Significant at 10 per cent. ** Significant at 5 per cent. *** Significant at 1 per cent. [a] See table J.4 for a description of the tests.

Source: Commission estimates.

Robustness of the results

The Hausman test performed on the fixed and random effects models of MLP1 and MLP2 did not reject the random effects assumption of no correlation between the fixed effects and the explanatory variables. The unit root tests indicate that the residuals are stationary. The Hadri test indicates that the residuals are not stationary for all eight subdivisions in model MLP3.

In model MLP5, if foreign R&D is dropped, then the coefficient on capital per hour increases from 0.188 to 0.315. However, in model MLP6, dropping foreign does not bring the coefficient on capital services down from 0.526.

Potential causes of the conflicting stories

Problems with the data

Chand et al. (1998) used the same dataset (Gretton and Fisher 1997) to investigate the effects of industry protection on industry productivity growth. In estimating production functions, their initial results did not produce coefficients on labour and capital which were roughly equal to their respective factor income shares in ASNA. Suspecting measurement error in the capital measures and hours worked data, a procedure was undertaken that iteratively adjusted the capital and labour data until reasonable coefficient estimates were obtained in OLS regressions.

The problem of poorly estimated coefficients on capital and labour was also found in this study when estimating production functions. However, the adjustment procedure was not undertaken in this project. In the labour productivity growth models, the coefficient on the capital to labour ratio is reasonably well estimated in the intensity models. This suggests that the data may not need to be 'massaged'. Or, it may be that the ratios of output to hours worked and capital to labour are less affected by the measurement errors than are their levels. As any adjustments to level of capital and labour inputs will impact on the construction of MFP indexes, the MFP models may suffer from mismeasurement.

Embodied technological change and comparative labour productivity and MFP performance in manufacturing

The differently signed coefficients may be related to the role of capital deepening and the embodiment of knowledge in new capital. Labour productivity growth in manufacturing has been generally much stronger than growth in MFP (table J.7) — which is equivalent to saying that capital deepening plays an important role in growth in output per hour worked.

Manufacturing labour productivity recorded very strong growth rates over the 1990s. The major reason for this was the increase in measured capital intensity. An increase in intensity may partly reflect the influence of technical change embodied in physical capital. Productivity Commission (2003, p. 180) noted that the labour productivity gains in manufacturing during the 1980s and 1990s may have been in part due to technical change in the global production of capital equipment, which allowed the manufacturing sector to acquire an effectively greater stock of capital.

Table J.7 **Difference between labour productivity growth and MFP growth manufacturing industries and market sector[a], various periods**

Per cent

	1969-70 to 1973-74	*1973-74 to 1984-85*	*1984-85 to 1993-94*	*1993-94 to 2000-01*	*1969-70 to 2000-01*
Manufacturing subdivisions[b]					
Food, beverages & tobacco	1.6	2.2	1.3	1.7	**1.7**
Textiles, clothing, footwear & leather	1.8	1.3	2.2	0.9	**1.5**
Printing, publishing & recorded media	0.3	1.3	2.5	1.9	**1.6**
Petroleum, coal, chemicals etc.	0.0	1.4	1.9	1.0	**1.2**
Basic metal products	3.2	3.9	2.2	1.5	**2.8**
Structural & sheet metal products	1.9	1.7	0.4	-0.2	**1.0**
Transport equipment	1.2	1.0	3.2	0.8	**1.6**
Rest of manufacturing	1.7	1.4	1.9	1.4	**1.6**
Average for the above	1.5	1.8	1.9	1.1	1.6
Market sector	**1.3**	**1.3**	**0.9**	**1.4**	**1.2**

[a] Labour productivity average annual growth less MFP average annual growth rate for selected periods. Also see the notes for table 3.4. [b] For details of industry classification see table A.2.

Sources: Commission estimates based on unpublished ABS data; ABS (*Australian System of National Accounts*, Cat. no. 5204.0); Updated estimates from Gretton and Fisher (1997) in PC (2003).

However, these benefits may not appear in the MFP figures, to the extent that the ABS has taken into account these technical changes in inputs as a quality adjustment to the price of plant and equipment inputs:

> In the low inflation era of the 1990s, absolute equipment prices have actually fallen (in quality adjusted terms). Thus, increased capital productivity of equipment at market prices is translated into lower prices at a given productivity, increasing measured capital inputs. As Australian manufacturing is not a large producer of the relevant capital goods, there is no significant corresponding increase in quality-adjusted outputs. Accordingly, the gains to labour productivity are ascribed to greater capital inputs in a MFP growth accounting framework, and MFP may not be much affected. (PC 2003, p. 180)

If the embodiment and quality adjustment story is economically significant, then both MFP and labour productivity models will understate the contribution of foreign R&D to Australian manufacturing, if an important transfer mechanism of the benefits of that R&D is the exports of capital equipment to Australia. In the MFP models, growth in MFP will be less as the gains from technological change are appropriately attributed to capital inputs. However, the effect of R&D obtained from MFP models will be understated as MFP will be only a partial measure of technological change. In the labour productivity models, the capital inputs measure has been increased to reflect the improved quality of capital inputs, and it is also in the regression, so the effect of foreign R&D will be biased downwards.

The other source of difference between the model results might be the assumptions which underlie the construction of MFP indexes within a growth accounting framework (see chapter 4). In particular, MFP estimates are less reliable at lower levels of aggregation.

J.8 Is there evidence of scale or non-linear effects in manufacturing R&D?

The effect of R&D on productivity at the market sector level showed some evidence of a non-linear partial effect of R&D on MFP possibly related to scale or concentration effects. The effects are hard to pin-down, given the overall imprecision of estimates, but, if valid, are likely part of the broad story of structural change in the Australian economy and supporting policy reforms. These changes very likely had impacts on the structural relationships between R&D and productivity because they affected the 'pay-offs' to innovation — the relationship between the inputs to innovation, the outputs of innovation and the economic value of those outputs.

The presence of these effects would be one reason why parameters appear to be unstable and difficult to estimate precisely. This section explores whether manufacturing is the source of the effects in the more highly aggregated market sector level data.

A quadratic term for manufacturing own-industry R&D intensity, specified as the knowledge stock over output, was entered into each of the MFP growth models MP8 to MP12. The quadratic term was not statistically significant in any of the models.

The SURE model for the individual manufacturing subdivisions was re-estimated with a quadratic term on own-industry R&D (table J.8). The quadratic term is statistically significant in four of the eight industries at 10 per cent or greater. The sign on the term is negative in three of the four models indicating a declining partial effect of own-industry R&D. When the combined terms are evaluated at the mean of the sample, three of the coefficients are significant at 10 per cent or more. When evaluated at each year, the resulting profile of the total effect coefficient in each of the models is far too volatile to be sensible.

The quadratic models generally do not produce better overall model fit. There does not appear to be the same sort of non-linear effect in manufacturing subdivision data as some of the market sector models exhibit.

Table J.8 **R&D and the level of MFP, manufacturing subdivisions**[a]

Dependent variable = ln(MFP). All variables in logs. Estimated using SURE.

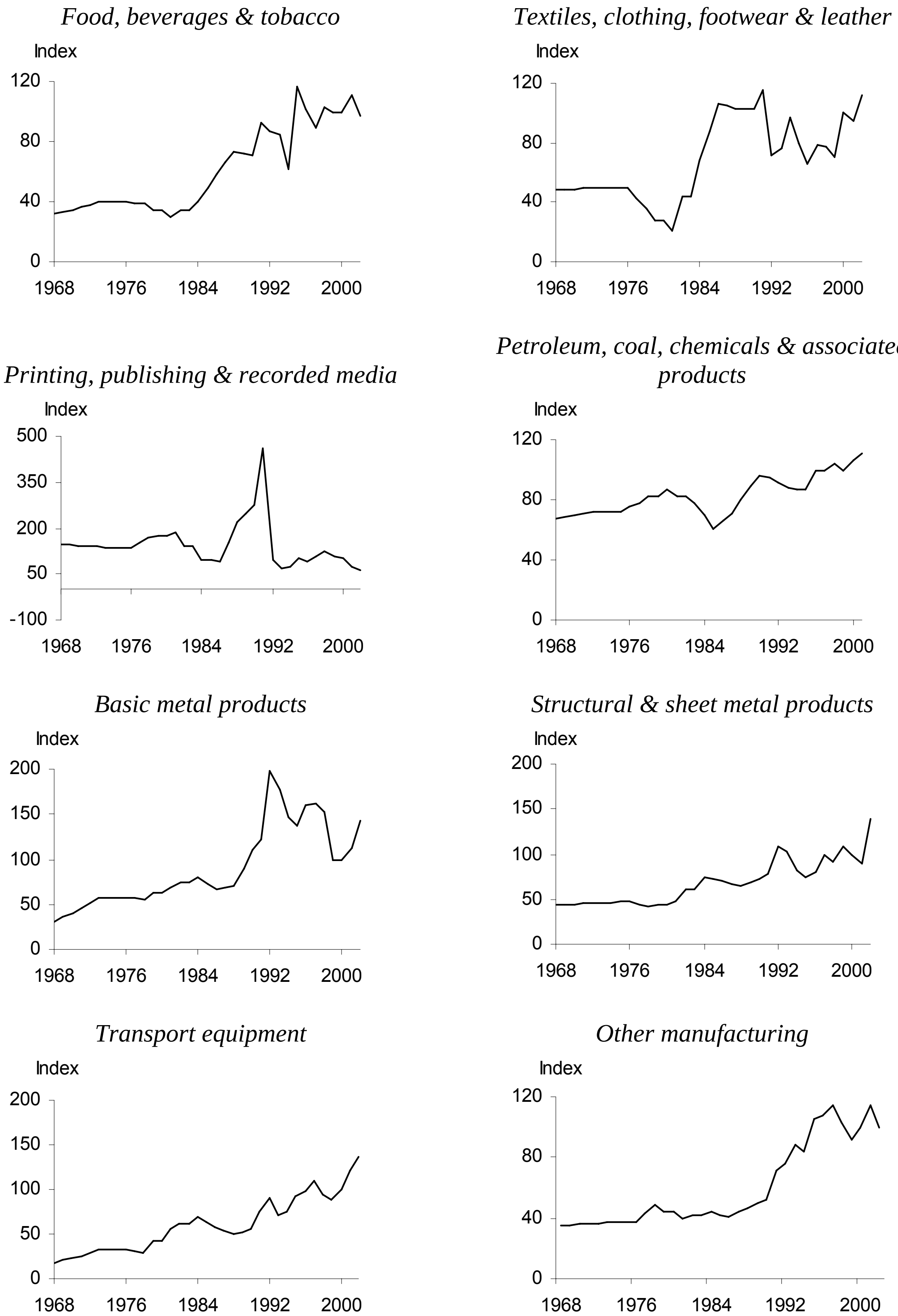
	OM	*FBT*	*TCF*	*PPRM*	*PCCAP*	*BMP*	*SSMP*	*TE*
Industry	*23,26, 283-6,29*	*21*	*22*	*24*	*25*	*271-3*	*274-6*	*281-2*
Rown15 (t-1)	-0.885	-0.718	0.388	10.885**	-0.800	1.560*	-2.167*	4.518***
	(0.645)	(0.694)	(1.068)	(5.218)	(0.737)	(0.820)	(1.113)	(0.776)
Rown15sq (t-1)	0.090	0.071	-0.045	-1.161**	0.093	-0.176*	0.233*	-0.518***
	(0.081)	(0.074)	(0.141)	(0.578)	(0.091)	(0.100)	(0.134)	(0.095)
Evaluated @ sample means	-0.199***	-0.190	0.015	0.106	-0.058	0.182*	-0.161	0.570***
	(0.077)	(0.165)	(0.109)	(0.177)	(0.111)	(0.096)	(0.101)	(0.109)
Rfrbi_ etmseo (t)	0.747***	-0.424	0.352	-0.864***	0.509***	1.225***	0.105	-0.048
	(0.141)	(0.271)	(0.299)	(0.233)	(0.162)	(0.359)	(0.176)	(0.196)
Rext15 (t)	0.004	0.202	-0.157	0.074	0.384***	0.211	0.167*	-1.641***
	(0.158)	(0.175)	(0.124)	(0.197)	(0.111)	(0.160)	(0.095)	(0.224)
Test statistics								
R^2	0.928	0.949	0.957	0.933	0.977	0.991	0.938	0.992
Chi^2	452.1	576.2	743.4	412.5	1350.4	3163.9	533.5	3598.1

* Significant at 10%. ** Significant at 5%. *** Significant at 1%. [a] For details of industry classification see table A.2.

Source: Commission estimates.

R&D expenditure per R&D performing firm has increased in each of the manufacturing subdivisions (figure J.3). Some industries experienced steady increases while average expenditure increased rapidly in others. Only Printing, publishing & recorded media experienced a decline in average expenditure. It also experienced a very rapid increase from the mid-1980s up until 1992, followed by an equally sharp decline.

Figure J.3 **R&D expenditure per R&D performing enterprise, 1968-69 to 2002-03[a]**



Financial years beginning 1 July of year specified. [a] For details of industry classification see table A.2.

Data sources: ABS (*Research and Experimental Development, Businesses, Australia*, Cat. no. 8104.0); ABS unpublished data.

The effect of including R&D expenditure per R&D performing enterprise (rdperfirm) as a separate explanatory variable in the panel ln(MFP) models is to raise the primary coefficient on own-industry R&D and increase its statistical significance from not significant at 10 per cent to statistically significant at 5 per cent or more (table J.9). In addition, the estimate on R&D per enterprise is also significant at 5 per cent or greater. The log likelihoods for the models are roughly the same as the models without rdperfirm.

Table J.9 **The impact of including R&D expenditure per R&D performing enterprise**

Dependent variable = ln(MFP). All variables in logs.

Estimation =	*FGLS: i.i.d. errors*	*FGLS: hetero. plus correlated errors*	*PCSE: hetero. plus correlated errors*
Model =	*MPS3*	*MPS4*	*MPS5*
Cycle (∆value added)	0.318***	0.257***	0.318***
	(0.046)	(0.035)	(0.054)
Rown15 (t-1)	0.090***	0.060**	0.090**
	(0.032)	(0.027)	(0.039)
rdperfirm	0.032**	0.023**	0.032**
	(0.013)	(0.010)	(0.016)
Rfrbi_etmseo	0.219***	0.198***	0.219***
	(0.067)	(0.051)	(0.078)
Rext15_t	-0.076	-0.062	-0.076
	(0.052)	(0.043)	(0.064)
ci8iousage	0.031**	0.019**	0.031**
	(0.013)	(0.009)	(0.014)
I8usage2	0.175***	0.279***	0.175***
	(0.058)	(0.038)	(0.057)
tiopenetm	0.054	0.054	0.054
	(0.037)	(0.046)	(0.055)
era	0.052***	0.029**	0.052***
	(0.015)	(0.012)	(0.018)
Constant	2.024***	1.880***	2.024***
	(0.424)	(0.092)	(0.421)
Shift1989	0.016	0.017	0.016
	(0.014)	(0.016)	(0.020)
Industry dummies	Yes	Yes	Yes
Test statistics			
No. of observations	216	216	216
- per group	27	27	27
R^2 (within)			
Log Likelihood	417.5	473.9	

* Significant at 10%. ** Significant at 5%. *** Significant at 1%.

Source: Commission estimates.

While these tests suggest that the scale or concentration of R&D might have an ‘additional’ effect on MFP, and that taking this into account helps get better estimates on the primary R&D variable, the panel ln(MFP) models still produce highly serially correlated residuals. Therefore, the results should not be considered robust.

The inclusion of R&D per enterprise does not improve the estimates for manufacturing subdivisions (table J.10). The biggest changes in model test statistics are for Petroleum, coal, chemicals & associated products and Basic metal products. Without rdperfirm, foreign R&D is positive, large and highly statistically significant at 1 per cent or greater in both these industries. With rdperfirm, the coefficients on foreign R&D are not statistically significant and, for Basic metal products, even change signs. For Basic metal products, the coefficient on own-industry business R&D changes from 0.177 and significant at 10 per cent to -0.878 and significant at 1 per cent.

Table J.10 **The effect of R&D per enterprise in manufacturing subdivisions**[a]

Dependent variable = ln(MFP). All variables in logs. Estimated using SURE.

	OM	*FBT*	*TCF*	*PPRM*	*PCCAP*	*BMP*	*SSMP*	*TE*
Industry	*23,26, 283-6,29*	*21*	*22*	*24*	*25*	*271-3*	*274-6*	*281-2*
Rown15 (t-1)	-0.141*	-0.139	0.039	0.329***	-0.029	-0.878***	-0.334***	0.286
	(0.084)	(0.117)	(0.077)	(0.095)	(0.117)	(0.174)	(0.104)	(0.215)
Rdperfirm (t-1)	-0.020	-0.008	0.009	0.008	-0.144**	0.300***	0.078**	-0.025
	(0.036)	(0.025)	(0.016)	(0.011)	(0.058)	(0.047)	(0.033)	(0.051)
Rfrbi_ etmseo (t)	0.779***	-0.451**	0.230	-0.710***	0.066	-0.390	0.410**	0.630***
	(0.146)	(0.222)	(0.249)	(0.256)	(0.213)	(0.276)	(0.178)	(0.241)
Rext15 (t)	-0.147	0.060	-0.207	-0.143	0.012	1.628***	0.304***	-0.673*
	(0.133)	(0.102)	(0.140)	(0.108)	(0.149)	(0.247)	(0.116)	(0.345)
Test statistics								
R^2	0.930	0.950	0.957	0.933	0.983	0.995	00944	0.985
Chi^2	458.6	600.1	741.0	388.5	1844.3	5331.2	564.4	1956.2

* Significant at 10%. ** Significant at 5%. *** Significant at 1%. **a** For details of industry classification, see table A.2.

Source: Commission estimates.

R&D expenditure per R&D performing enterprise in the panel MFP growth models is not statistically significant and inclusion weakens the economic magnitude of the primary coefficient, and further weakens its statistical significance (table J.11).

Table J.11 **Growth in MFP and the knowledge stock as a proportion of output, panel estimates**

Dependent variable = Δln(MFP). All variables in logs. Intensities measured as ln(K/Y).

Estimation =	*Pooled OLS*	*Fixed effects*	*FGLS*	*FGLS*	*FGLS*
Model =	*MPS8*	*MPS9*	*MPS10*	*MPS11*	*MPS12*
Cycle (Δvalue added)	0.202*** (0.049)	0.202*** (0.045)	0.215*** (0.041)	0.230*** (0.041)	0.230*** (0.042)
Ry15 (t-1)	0.021* (0.012)	0.021* (0.011)	0.019* (0.010)	0.004 (0.011)	0.019* (0.010)
Δrdperfirm	0.007 (0.010)	0.007 (0.012)	0.014 (0.012)	0.014 (0.012)	0.015 (0.012)
Rfrybi_etmseo (t)	0.065** (0.033)	0.065** (0.028)	0.052** (0.023)		0.050** (0.023)
Ryext15_t (t)	-0.081*** (0.030)	-0.081*** (0.025)	-0.067*** (0.020)	-0.018 (0.015)	-0.068*** (0.020)
Ryfrg15_td				-0.033 (0.044)	
Δci8iousage	0.026** (0.011)	0.026** (0.012)	0.029** (0.011)	0.027** (0.011)	0.026** (0.011)
ΔI8usage2	0.403*** (0.091)	0.403*** (0.079)	0.383*** (0.069)	0.336*** (0.065)	0.363*** (0.070)
Δtiopenetm	0.016 (0.031)	0.016 (0.031)	0.022 (0.028)	0.014 (0.012)	0.010 (0.029)
Δnrao	-0.010 (0.020)	-0.010 (0.020)	-0.014 (0.017)	-0.011 (0.016)	-0.012 (0.017)
ΔQALI					0.151 (0.121)
Constant	0.220 (0.154)	0.311** (0.153)	0.173 (0.109)	-0.011 (0.066)	0.152 (0.111)
Shift1989	0.020* (0.011)	0.020** (0.009)	0.018* (0.008)	0.012 (0.008)	0.021** (0.008)
Test statistics					
Industry dummies	Yes		Yes	Yes	Yes
No. of observations	208	208	208	208	208
- per group	26	26	26	26	8
R^2	0.476	0.464			
Log Likelihood			437.7	436.7	438.5

* Significant at 10%. ** Significant at 5%. *** Significant at 1%.

Source: Commission estimates.

Overall, if the evidence of non-linear and/or scale effects at the level of the market sector is valid, then the tests in this section indicate that manufacturing is unlikely to be the source of the effects. Testing of a quadratic functional form on own-industry R&D, and testing for a separate partial effect of the concentration or scale of R&D with R&D expenditure per R&D performing enterprise, did not produce improved model results.

J.9 Summary discussion

The pooling of manufacturing subdivisions and estimation using panel estimators leads to misspecified ln(MFP) models. The problem lies with imposing a constant coefficient for each explanatory variable across subdivisions, when the levels relationship between the explanatory variables and productivity differs by subdivision.

However, allowing the coefficients to vary by subdivision, either by estimating with SURE or by estimating separate OLS regressions for each subdivision, does produce results that are more reliable. There is still a concern that the results may be spurious given that the data are non-stationary. The SURE models included a trend term in the test down procedure which reduces this risk if the underlying data generating process is a trend stationary process.

Partly to address non-stationarity and partly to investigate alternative long-run relationships, MFP growth models were also estimated. Where the relationship was between growth in MFP and the level of the industry's knowledge stock as a proportion of its output, the sign on own-industry R&D was positive, but not statistically significant in any model. Foreign business R&D (BRD) was estimated to have a large positive impact, while the impact of inter-industry R&D was negative. With all variables first differenced (model MP13), own-industry R&D was not significant, foreign BRD had a positive and economically large impact, and inter-industry R&D was negative, but not statistically significant. Communications capital, general government infrastructure, and education and skills all had a positive effect on MFP growth.

Rather than supporting these results, the results from the labour productivity growth models added greater uncertainty as to the true effects of own-industry, foreign and inter-industry R&D. When the specified relationship is between growth in labour productivity and the level of the industry's knowledge stock as a proportion of its output per hour worked, the estimated sign on the coefficient for own-industry R&D is sensitive to estimation strategy.

Inter-industry stocks weighted by trade relationships performed better than those that were unweighted or were weighted by the technological proximity measure based on the similarity of R&D expenditures from a decomposition of R&D

expenditure by Socio-Economic Objective. The SEO weighted inter-industry stock which included higher education and government-performed R&D did not produce significant results.

The models in this chapter do not produce a strong and consistent story of the partial effect of own-industry, inter-industry or foreign business R&D on Australian manufacturing productivity. MFP and labour productivity growth models can produce oppositely signed estimates of the effect of R&D. This may be because of the assumptions which are adopted in constructing MFP estimates using the growth accounting approach. It is also very likely due to the process of the embodiment of technological change in capital inputs and how that is measured in the Australian System of National Accounts.

Estimates by subdivision show that the economic magnitude of the effects of R&D is likely to vary dramatically across industries. However, the sheer magnitude of some of the estimated effects are of concern, and the width of the confidence intervals do not give precise estimates.

K Sensitivity testing of the returns

K.1 Returns to total versus own-financed business R&D

The knowledge stocks used in the regressions in chapters 6 to 10 are based on R&D expenditure data collected on an intramural basis. This means that measured business R&D activity includes own-financed R&D, R&D financed by governments but performed by businesses, R&D performed by a business but financed by other businesses, and R&D financed from overseas sources.

Overseas studies have found differences in the estimated returns to R&D for R&D performed by businesses for themselves versus R&D they undertake for others (for example, under contracts to government). To check whether Australian returns show a similar pattern, a number of models were re-estimated based on R&D stocks that excluded R&D performed by businesses but financed by government, other businesses and overseas sources (table K.1).

The estimated elasticities for own-financed stocks are not markedly different in most models. The own-financed point estimates fall well within the 95 per cent confidence interval of the estimates based on all sources of finance.

Table K.1 **Sensitivity of estimated elasticities to the use of own-financed business R&D**

Model[a]	*FDL BL3s*	*ARDL(1,3) BL4*	*Y5*	*Y5 with USPTO*	*Total manu.*	*Mining*	*Wholesale & retail trade*
Dep. variable =	*ln(MFP)*	*ln(MFP)*	*Δln(MFP)*	*Δln(MFP)*	*ln(MFP)*	*ln(MFP)*	*ln(MFP)*
R&D variable =	*ln(k)*	*ln(k)*	*ln(ΔK/Y)*	*ln(ΔK/Y)*	*ln(k)*	*ln(k)*	*ln(k)*
Total BRD coefficient	0.041[b] (0.026)	0.021[b] (0.033)	0.018** (0.008)	-0.007*** (0.002)	0.041** (0.018)	0.074** (0.035)	0.060** (0.020)
Performed and own-financed coefficient	0.056* (0.027)	0.037 (0.035)	0.024* (0.011)	-0.006** (0.002)	0.038** (0.017)	0.077** (0.035)	0.055** (0.019)

[a] Full results of these models are in chapters 6 (BL3s, BL4), 7 (Y5, Y5USPTO) and 8 (industry models). [b] Joint F-test on lags significant at greater than 5 per cent, but evaluation at long-run is not significant.

Source: Commission estimates.

K.2 Sensitivity of results to the assumed rate of decay

Section 4.2 discusses how the 'depreciation' of knowledge is conceptually different to the depreciation of physical capital. It also surveys studies which have attempted to estimate the rate of decay in appropriable revenue (table 4.4). Almost all studies of the effect of R&D on output or productivity assume a rate of decay. Are estimated elasticities sensitive to these assumptions?

Hall and Mairesse (1995) found that estimates of the elasticity of productivity with respect to R&D, estimated within a production function framework, were insensitive to the choice of depreciation rate. The industry level models were re-estimated assuming rates of decay of 5, 10 and 15 per cent to test whether this result also held on Australian industry-level data (table K.2). For Manufacturing, the estimated elasticity declines as the rate of decay increases as a higher rate of decay means that the knowledge stock which can affect output is smaller. However, the marginal product remains unchanged. In Mining and Wholesale & retail trade, the marginal product of R&D increases as the assumed rate of decay increases.

Table K.2 **Elasticity and sensitivity of return to assumed rate of decay[a]**

Model	*Manufacturing*	*Mining*	*Wholesale & retail trade*
Assumed rate of decay			
5 per cent	0.086 (36%)	0.121 (131%)	0.073 (382%)
10 per cent	0.049 (33%)	0.092 (191%)	0.063 (416%)
15 per cent	0.038 (35%)	0.077 (201%)	0.055 (438%)

a Implied rate of return in brackets.

Source: Commission estimates.

Where the rate of decay used in the construction of the knowledge stocks is greater than the true rate of decay, this will tend to result in an upward bias in the measured return to R&D.

One way to overcome this arbitrariness in the estimated rates of return is to empirically determine the rate of decay on the same data used to estimate the models. However, given the small samples in both the aggregate and industry-level datasets, attempts to estimate the rate directly were not successful. With a small sample, only a limited number of R&D investment lags can be included in the regression equations, and the coefficients on the R&D investment lags are non-linear, which make robust estimation of the decay rate difficult.

Hall and Mairesse (1995, p. 276) commented, ‘Disentangling the appropriate depreciation rate with the available data using the production function approach may be an impossible dream’.

Various market sector models were also re-estimated with a large range of decay rates. Stocks based on a changing assumed decay rate were also tested. In the static multifactor productivity model (model L1), the coefficient on Australian business R&D (BRD) is slightly better estimated the lower the assumed rate of decay (table K.3). In model L3, the only statistically significant estimate for Australian business R&D is for the 5 per cent rate of decay.

The slight preference for a lower rate of decay in the MFP models was not apparent in the MFP growth models. Overall, the choice of decay rate is not driving the pattern of results in the models of this paper. Where estimated returns are high, they are high with various rates. Where they are unexpectedly negative or insignificant, alternative rates of decay do not materially change the results.[1]

Table K.3 **Sensitivity of the elasticity estimate in aggregate models to the assumed rate of decay**

Foreign gross R&D rate of decay held at 15 per cent.

	Model L1	*Bayesian information criteria*	*Model L3*	*Bayesian information criteria*
5 per cent	0.150*** (0.043)	-151	0.140* (0.072)	-125
10 per cent	0.099*** (0.032)	-150	0.087 (0.057)	-123
15 per cent	0.077*** (0.028)	-148	0.042 (0.042)	-120
20 per cent	0.065** (0.025)	-147	0.009 (0.031)	-119
30 per cent	0.054** (0.023)	-145	-0.003 (0.024)	-119
7.5 to 15 per cent	0.086*** (0.031)	-149	0.059 (0.053)	-121
15 to 30 per cent	0.068** (0.027)	-148	0.012 (0.027)	-119

*** Statistically significant from zero at 1 per cent. ** 5 per cent. * 10 per cent.

Source: Commission estimates.

[1] See van Pottelsberghe (1997, pp. 480–52) for a discussion of the sensitivity of estimates of the return to R&D to the assumption of the rate of decay or obsolescence, including the relative robustness of estimates obtained from estimation of elasticities versus direct estimation of the return.

K.3 Double counting and expensing bias

Expenditure on R&D capital and labour are used to form the R&D capital stock. These costs are often not netted out from the traditional measures of capital and labour, thus they are 'double-counted' when the traditional measures (included in the measure of MFP) and R&D capital stock are used to estimate the returns to R&D.

The obvious approach to solving this problem is to net out the capital and labour used for R&D from the traditional measures, and then derive the estimates accordingly. But this is not always possible due to data constraints. Another way to get around this problem is to interpret the estimated returns to R&D under double-counting as the returns above and beyond the normal remuneration to traditional capital.

This excess returns interpretation is quite popular in many empirical studies on R&D. However, it has been demonstrated by Schankerman (1981) that the double-counting bias can potentially be offset by another bias, which arises from the mismeasurement of value added. The latter bias is called the expensing bias, since R&D is treated as an intermediate expense rather than as a capital asset, and this bias could be either positive or negative. Schankerman demonstrates that because of the existence of the expensing bias, the excess returns interpretation is conceptually incorrect, but it appears to be valid empirically based on an example using the data from Griliches (1980).[2]

Following the approach by Schankerman, this section focuses on the effects of double counting and expensing biases on econometric model specification and the estimated rate of returns to R&D. The results are derived from the log-level specification based on MFP, which is used frequently for the econometric estimation in this study. They are consistent with Schankerman's results, but there are some notable differences. Also, it is argued that since the current price measure of value-added is a sum of labour and capital income, the correction to the expensing bias may not be as clear-cut as indicated in Schankerman's paper.

Measured value added

The expensing bias derived by Schankerman is the result of mismeasurement of value added. He states that ' … since current R&D is typically expensed (subtracted

[2] The empirical validity of the excess returns interpretation is based on the finding by Schankerman that the average excess returns bias of -0.10, using the large micro data set from Griliches (1980), is roughly equal to the net rate of return to traditional capital.

from gross product as an intermediate input), measured value added is too small by that amount' (Schankerman 1981, p. 455). He adds the amount of R&D expenditure back to the measured value added, and then derives the term that captures the expensing bias.

At the industry-level, some of the volume measures of value added are derived from the double-deflation procedure under the framework of national accounts (ABS 2000). It partly involves the subtraction of the value of intermediate inputs from the value of gross output. Focusing on the quantity terms and denoting value added by *Y*, gross output by *GO* and intermediate inputs by *IM*, (with the prime (') denoting the measured variable for the 'true' variable), the accounting identity linking gross output and value added is

$$Y' = GO' - IM'$$

There are several ways to look at the measured gross output. One could argue that gross output is in fact measured correctly, but the measured intermediate inputs are incorrect because they include R&D expenditure. Once R&D expenditure is re-allocated to be part of measured value added, the resulting value added will be the correct one. This seems to be the basis for Schankerman's adding back solution.

However, one can also argue that there are also problems with measured gross output as a result of improper treatment of R&D in the system of national accounts. Thus, rather than using the assumption that gross output is measured correctly in the presence of R&D, attention is focused on the measured value added directly. Since the current price measure of value added is equal to the value of measured capital and labour income (assuming no net taxes, or they have been allocated to capital and labour), the 'true' value added should then also *exclude* R&D capital and labour. This is opposite to Schankerman's adding back correction.

While this argument is not intended to discredit the importance of the expensing bias as analysed in Schankerman's paper, it does highlight the fact that the problem of treating R&D investment expenditure as intermediate inputs may not be resolved simply by reclassifying them as part of value added. It requires more complex work both at conceptual and practical levels to bring about changes to the current framework of national accounts. For a recent exploratory study on this issue at the economy-wide level in the United States, see Fraumeni and Okubo (2004). Given the importance of the expensing bias, the following analysis of the effects of mismeasurement is based on the second argument about the measured value added.

The effects of mismeasurement

The Cobb-Douglas production function of chapter 4 is used to illustrate the effects of the biases due to double counting and expensing of R&D. To simplify, the control variables and time are omitted, although the inclusion of these variables does not change the conclusions. The simplified version of this production function is

$$Y = K^{\alpha} L^{\beta} R^{\gamma} \tag{K0}$$

where Y is value added measure of output, K, traditional capital, L labour, and R represents R&D capital stock. The coefficients are output elasticities with respect to the relevant inputs. As usual, taking log on both sides and using the definition of MFP gives

$$\ln MFP = \ln Y - \alpha \ln K - \beta \ln L = \gamma \ln R \tag{K1}$$

Now suppose capital and labour are measured inclusive of the primary inputs used for R&D and traditional factors

$$\begin{aligned} K' &= K + K_R \\ L' &= L + L_R \end{aligned} \tag{K2}$$

where, as before, a prime denotes a measured variable, K_R and L_R represent R&D capital and labour. The measured productivity under growth accounting is

$$\ln MFP' = \ln Y' - \alpha' \ln K' - \beta' \ln L' \tag{K3}$$

Note that the measured factor shares in (K3) are also biased by double-counting. They are assumed to be $\alpha' = \alpha(1+s)$ and $\beta' = \beta(1+\delta)$, where $s = K_R / K$ and $\mu = L_R / L$. One of the assumptions used to derive MFP is constant returns to scale, thus $\alpha' + \beta' = 1$. This implies that $\alpha + \beta < 1$.

If the second argument about the measured gross value added, as discussed above, is used, this gives

$$Y' = Y + I_R \tag{K4}$$

Using (K2) and (K4), the measured variables (in log) can be expressed as

$$\begin{aligned} \ln K' &= \ln K + \ln(1 + K_R / K) \approx \ln K + s \\ \ln L' &= \ln L + \ln(1 + L_R / L) \approx \ln L + \mu \\ \ln Y' &= \ln Y + \ln(1 + I_R / Y) \approx \ln Y + \theta \end{aligned} \tag{K5}$$

where $\theta = I_R / Y$ is the R&D intensity measured in flows. The approximate equality in (K5) uses the fact that the shares as defined above are small. Substituting the measured variables in (K5) for those in (K3) and using (K1), the relationship is

$$\ln MFP' = \gamma \ln R - \alpha s \ln K' - \beta\mu \ln L' + \theta - (\alpha s + \beta\mu) \qquad \text{(K6)}$$

Assuming that s, μ are constant coefficients, the last term in the right hand side of (K6) becomes part of the intercept in a regression equation.

By ignoring the mismeasurement due to double-counting and expensing of R&D, the output elasticity of R&D γ can be estimated in the MFP based regression equation without including variables $\ln K'$, $\ln L'$ and θ as in (K6). To derive the effects of the biases on the estimated elasticity and the return to R&D, the formula for omission of relevant variables is used. The bias for γ from the mis-specified equation is

$$E(\hat{\gamma}) - \gamma = -\alpha s B_{K'R} - \beta\mu B_{L'R} + B_{\theta R} \qquad \text{(K7)}$$

where the 'hat' indicates an estimated coefficient; and the *B*s represent coefficients in auxiliary regressions of the omitted variables on $\ln R$. Multiplying (K7) by Y / R and noting that rate of return to R&D, $\pi = \gamma(Y / R)$, gives

$$E(\hat{\pi}) - \pi = -[(\alpha s B_{K'R} + \beta\mu B_{L'R})(Y / R)] + B_{\theta R}(Y / R) \qquad \text{(K8)}$$

The terms in the square bracket represent the excess returns bias. It is a downward bias, as it is most likely that $B_{K'R} > 0$ and $B_{L'R} > 0$. The last term in (K8) represents the expensing bias, and it may be either positive or negative, and it can also be zero if *R* is uncorrelated with θ. Thus, the total bias may also be positive or negative and will depend on sample characteristics. Note that here the assumption of (K4) is adopted rather than Schankerman's adding back correction. The resulting difference is only in the sign associated with θ in (K6), (K7) and (K8), while the ambiguity about the direction of the total bias remains.

The effects on the estimates

The implication of the above discussions for the econometric estimation carried out in this study is very clear. Because the R&D capital and labour are not netted out from the measured primary inputs due to data constraints, it may be more appropriate to use equation (K6). It includes the additional terms $\ln K'$, $\ln L'$ and θ that are absent from the conventional R&D and productivity equations as shown in chapter 4. The estimation results based on (K6), including a set of control variables, are presented in chapter 8. The table K.4 summarises the results and also shows those estimates from the specification without adjusting for the measurement biases.

Table K.4 **Comparing the results from the specification adjusted for the measurement biases with those from the unadjusted specification**

	Manufacturing	*Mining*	*Wholesale & retail trade*	*Agriculture*
Elasticity of R&D				
Unadjusted	0.038	0.077	0.055	
Adjusted	0.055	0.061	0.055	
Rate of return				
Unadjusted	35%	201%	438%	32%
Adjusted	50%	159%	438%	24%

a The results from the specification without adjusting for the measurement biases are based on table 8.2 in chapter 8, while those from the adjusted specification are based on table 8.5. The rate of return is derived using the average ratio of output to capital. See chapter 8 for details.

Source: Commission estimates

By using the specification adjusted for double-counting, the estimated output elasticity with respect to R&D has increased from 0.038 to 0.055 in Manufacturing and, as a result, the derived rate of return has also increased from 35 to 50 per cent in this industry. In contrast to Manufacturing, the rates of return have decreased both in Mining, from 201 to 159 per cent, and in Agriculture, from 32 to 24 per cent, because of the use of the adjusted specification. However, there is no change for Wholesale & retail trade.

Direct adjustment for double counting

The capital services and labour input indexes used in the construction of MFP were directly adjusted as described in chapter 4. A wide selection of models were tested with the adjusted MFP index. The adjustment had almost no effect on the sign, magnitude or statistical significance of the estimated elasticity for Australian BRD (table K.5).

Industry Commission (1995) found that adjusting for double counting made little difference at the aggregate level:

> … when the net and gross capital and labour data are plotted against each other, the net and gross graphs are virtually indistinguishable. This appears to explain why the correction for double counting makes little difference for Australian estimates in practice. (appendix QB.25)

Table K.5 **Sensitivity of market sector elasticities to 'double counting'**

Hetereoskedastic robust standard errors in brackets

Model	*L3*	*L4USPTO*	*Y3USPTO*	*Y4 (without constant)*	*Y5*	*Y5USPTO*	*S4FDL (without constant)*
Dep. var. =	*ln(MFP)*	*ln(MFP)*	*Δln(MFP)*	*Δln(MFP)*	*Δln(MFP)*	*Δln(MFP)*	*Δln(MFP)*
R&D var. =	*ln(k)*	*ln(k)*	*ln(k)*	*ln(k/y)*	*ln(Δk/y)*	*ln(k)*	*ln(Δk/y)*
Unadjusted Australian business R&D (t-1)	0.042 (0.042)	0.003 (0.014)	0.027** (0.011)	0.013* (0.006)	0.018** (0.008)	-0.007*** (0.002)	-0.007*** (0.001)
Adjusted for double counting	0.048 (0.042)	0.014 (0.014)	0.027** (0.011)	0.014** (0.006)	0.019** (0.008)	-0.006*** (0.002)	-0.007*** (0.001)

Source: Commission estimates.

L Controlling for the effects of the business cycle

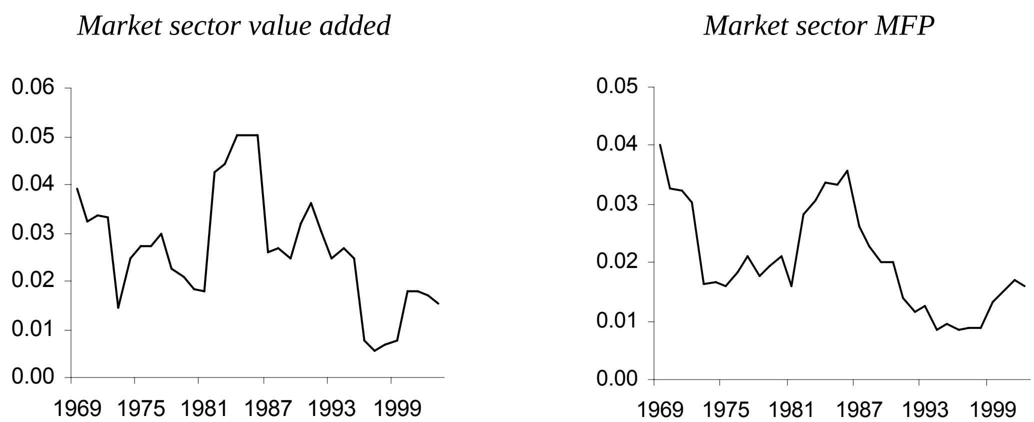
Results in chapter 6 for the basic multifactor productivity (MFP) models highlighted the sensitivity of the results to the inclusion of a control variable for the business cycle. In those models, the control variable was the growth in value added for the market sector. This appendix discusses alternatives ways of controlling for the effects of the cycle on productivity measures. Results are not only sensitive to the inclusion of a cycle variable, but are sensitive to the choice of cycle variable.

L.1 Trends in output and MFP volatility

Over the last thirty years, the amplitude of business cycle fluctuations has declined significantly across almost all OECD countries with the standard deviation of the output gap falling by roughly 30 per cent (Cotis and Coppel 2005). Output and MFP volatility in the Australian market sector has similarly declined (figure L.1).

Figure L.1 **A decline in output and MFP volatility, 1969 to 2002**

Standard deviation of annual growth over 5-year backward-looking windows



Data source: ABS (*Australian System of National Accounts,* Cat. no. 5204.0) .

The causes of the decline was recently investigated in a number of papers presented at the Reserve Bank of Australia's 2005 conference, *The Changing Nature of the*

Business Cycle. Kent et al. (2005) group the possible causes under the following headings.

- *Monetary and fiscal policy reforms*: the use of monetary and fiscal policies as stabilisation tools. Monetary policy reforms include greater central bank independence and the adoption of regimes that are stricter on inflation. Fiscal policies include discretionary fiscal policies (for example, deliberate changes in government spending and taxes to change aggregate demand) and non-discretionary policies (for example, automatic stabilisers such as income tax, unemployment compensation and welfare programs).
- *Change in the composition and behaviour of GDP components*: improvements in inventory management techniques, changes in the nature of demand (for example, increased stability of consumption) and a shift in composition from a more volatile manufacturing sector towards the services sector.
- *Product and labour market reforms*: aggregate output volatility could fall if reforms encourage more efficient reallocation of resources across sectors and across firms in response to sector- and firm-specific shocks.
  - Labour market reforms can reduce hiring and firing costs, including through more flexible work arrangements, and increase wage flexibility. Stronger market signals prompt labour to be allocated to its most productive use.
  - Product market reforms, such as a decreased regulation, may lead to price signals that better reflect profitable opportunities.

Some studies find that a decline in the magnitude of economic shocks explains the reduction in output volatility. However, the magnitude of the shocks themselves may have been affected by policy reforms:

> Studies that have used structural models to identify various demand and supply shocks find that most of the decline in output volatility is due to a decline in the magnitude of shocks, with a limited role for structural reforms and monetary policy. In comparison, our atheoretical approach accounts for the possibility that smaller shocks may themselves be the result of structural changes. (Kent et al. 2005, p. 170)

Based on a panel of OECD countries, the authors conclude that:

> We find that less product market regulation and stricter monetary policy regimes have played a role in reducing output volatility, with our estimates robust to a number of alternative specifications … However, in the presence of time dummies, indirect measures of labour market regulations (days lost to labour disputes) and of monetary policy effectiveness (inflation volatility) are significant … Other indirect measures of market reforms, such as trade openness and credit to GDP, are generally not statistically significant explanators of output volatility … The finding of a significant role for increased efficacy of monetary policy and less regulated markets in explaining the trend decline in output volatility across a wide range of developed economies has

an important implication for future output volatility. Namely, while any decline in global shocks that has been driven solely by good fortune cannot (by definition) continue indefinitely, the benefit of significant structural reforms is likely to limit the extent of any future rise in output volatility. (Kent et al. 2005, pp. 169–70)

L.2 The pro-cyclical nature of productivity measures

Difficulties in adequately measuring short-term variations in the utilisation of capital and labour inputs results in productivity measures being pro-cyclical:

> … productivity growth tends to accelerate during periods of economic expansion and decelerate during periods of recession. One explanation given earlier was one of measurement: while variations in volume output tend to be relatively accurately reflected in economic statistics, variations in the rate of utilisation of inputs are at best partially picked up in data series. In particular, the rate of utilisation of capital equipment, *i.e.* the measurement of machine hours, is rarely accomplished. Labour input, if measured by hours actually worked, is better suited to reflect the changing rte of utilisation of manpower, but remains an imperfect measure. Consequently, a higher rate of capacity utilisation in periods of expansion is accompanied by output measures that may show rapid growth whereas input measures may remain stable or grow less rapidly. The result is a rise in measured productivity growth. The converse holds for periods of recession. (OECD 2001, p. 119)

In addition to the measurement difficulties in controlling for changes in utilisation, the underlying methods to the measurement of productivity are not suited to accurately reflecting short-term movements associated with the business cycle:

> However, even if capacity utilisation were accurately measured, the standard productivity model is not easily fitted to the realities of the business cycle. Because much of the economic and index number theory relies on long-term, equilibrium relationships, with little or no unforeseen events for economic actors, the economic model of productivity measurement is easier to implement and to interpret during periods of continued, and moderate expansion than during rapidly changing phases of the business cycle. This has implications for the interpretation of productivity measures. In particular, it means that year-to-year changes in productivity growth should not be interpreted *prima facie* as shifts in disembodied technology. For this purpose it is preferable to examine productivity growth patterns over longer periods of time – and best between years that mark the same position in the business cycle. (OECD 2001, p. 119)

For these reasons, the ABS notes:

> … MFP estimates are probably most useful when computed as average growth rates between growth-cycle peaks, which are determined as peak deviations of the market sector MFP index from its long-term trend. In this way, most of the effects of variations in capacity utilisation and much of the random error are removed. (ABS 2000, chapter 27)

L.3 Alternative controls for the business cycle

There are a range of different methods used to control for the effects of the business cycle in modelling. Simple measures which are collinear with movements in output may be used, such as the CPI index, the unemployment rate, or bond yields. However, while there is a pro-cyclical element in these measures, they are also affected by structural shifts (for example, rising real rates of interest and bond yields from the 1970s followed by declines through the 1990s). They may also lead or lag the business cycle. Therefore, their use may not adequately 'soak-up' the effects of the cycle, thereby impacting on estimation and interpretation of the variables of interest.

Sentiment-based measures, such as the ACCI-Westpac capacity utilisation measure, can also be used. It is a subjective measure based on survey respondent's views as to the capacity utilisation they are working at (above, at, or below normal capacity).

Output gap measures provide more sophisticated methods for controlling the effects of the business cycle. The output gap is defined as growth in actual less potential output. When the economy is growing faster than its long-run potential, the measure is positive. It is negative when economic growth is slower than its potential. The different methods for measuring 'potential' output and the output gap include the following.

- *The linear time trend method:* regress output on a linear time trend and use the residuals from the regression as a measure of whether growth is above or below its potential.
- *Univariate filtering:* the linear trend method assumes that potential output grows at a constant rate which may be false, particularly in the presence of significant structural reforms. Various de-trending methods can be used, which result in a non-constant 'potential' growth rate, including the univariate Hodrick-Prescott (H-P) method or the Henderson filters used by the ABS for trend estimates. These are univariate methods because potential output is obtained using the information in the real output data only.
- *Multivariate filtering:* this method augments a filter, such as the H-P filter, with additional economic or structural information on the stage of the business cycle, possibly including information on the relationships between inflation, the non-accelerating inflationary level of output, the non-accelerating inflation rate of unemployment and capacity utilisation.

– One example is the Philips curve method which uses information from the Philips curve relationship to improve estimates of the output gap.[1]

- *Unobservable components model:* given that potential output and the gap are unknown, this method is based on statistical techniques that can decompose a time series into unobservable components.
- *Production function method:* this method estimates the output gap as actual output less potential output calculated on the basis of an aggregate production function. This method is used by the OECD in its cross-country work.

There can be significant differences in the output gap measures at a point in time, although patterns over time appear broadly similar (figure L.2). However, there are important differences. Gruen et al. (2002) compare their preferred Philips curve specification with gap estimates from the linear time trend and univariate approaches. The linear time trend estimates are rejected because longer term growth rates have not been stable.

> … the growth rate of actual and potential output has been subject to significant, long-lived, changes over the four decades from the early 1960s to 2001. (p. 21)

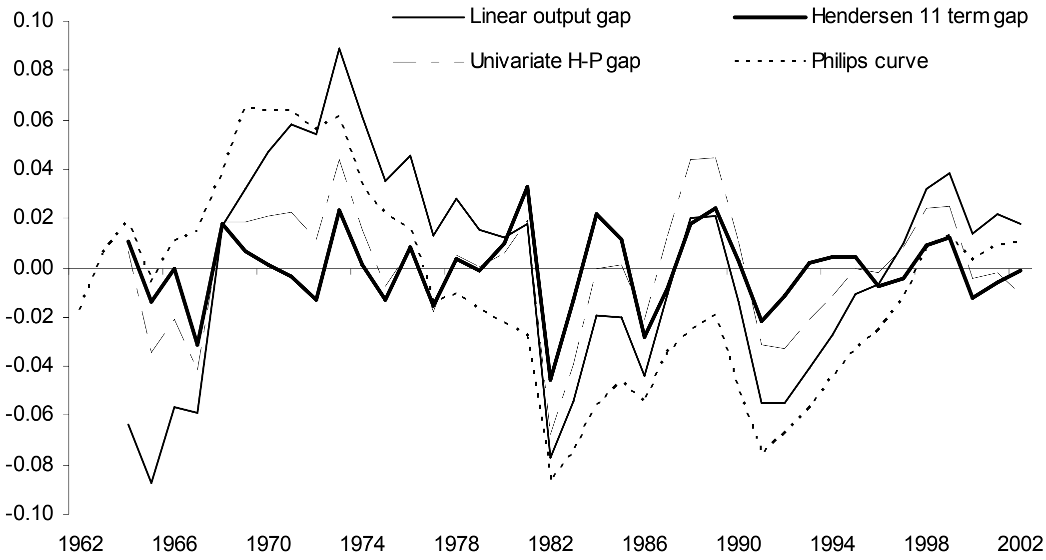
H-P filter gaps are also rejected.

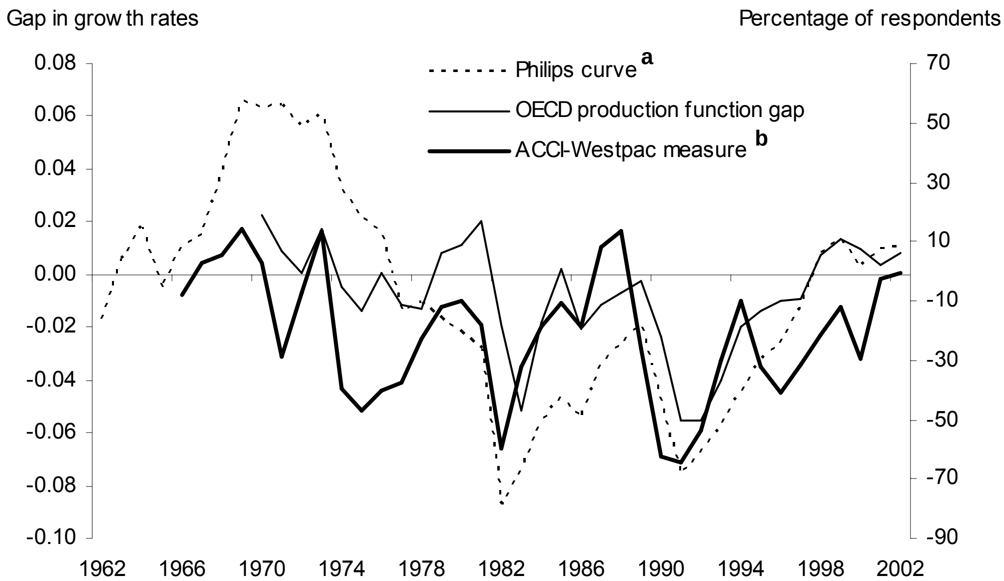
> … inflation experience over the four decades from 1960 to 2001 would be particularly hard to understand on the basis of output gaps derived from the H-P filter. The average values of the final H-P filter output gaps in the four decades of the 1960s, 1970s, 1980s and 1990s, are, in percentage points, -0.1, 0.1, 0.2, and -0.1, a pattern of capacity utilisation that clearly gives no hint about the longer-run inflation developments over this time.[15] (p. 24)
>
> [15] The corresponding average final output gaps using our preferred Phillips curve method in the four decades are 0.7, 2.6, -3.6 and -2.9. These decadal averages sit much more comfortably with the observed inflation outcomes — with strongly rising inflation and inflation expectations in the 1970s, and the opposite in the 1980s and 1990s.

[1] See de Brouwer (1998) for a discussion of the linear time trend, univariate H-P method, multivariate H-P method, unobserved components model, and production function method. The Philips curve method is discussed in Gruen et al. (2002) and Robinson et al. (2003).

Figure L.2 **Alternative output gap measures, 1962-63 to 2002-03**

Gap is growth in actual output less growth in measure of potential output





Financial years beginning 1 July of year specified. [a] The Philips curve measure was provided by the Reserve Bank of Australia. The measure is described in an RBA discussion paper by Gruen et al. (2002). It was updated with more recent data using the exact median inflation equation published in the discussion paper for the 'final vintage' of data considered (refer table 1 of the discussion paper). Incorporating the updated data, the specification produces coefficient estimates and t-statistics with very similar values to those reported in table 2. [b] There is a break in the ACCI-Westpac measure in 1987-88 as the capacity utilisation question was changed.

Data sources: ABS (*Australian System of National Accounts*, Cat. no. 5204.0); Reserve Bank of Australia; OECD Economic Outlook database; Commission estimates.

The bi-variate correlation coefficients of the cycle variables with ln(MFP) can range widely. The coefficients against MFP and labour productivity growth show greater consistency (table L.1).

Table L.1 **Bi-variate correlation between productivity and alternative business cycle controls, 1968-69 to 2002-03[a]**

For ln(MFP) models, cycle variables are first differenced. For productivity growth models, cycle variables are second differenced.

Model	*Market sector output*	*ACCI-Westpac*	*Linear gap*	*Univariate H-P gap*	*Hendersen 11 term gap*	*Philips curve gap*	*OECD output gap*
Ln(MFP)	-0.027	0.122	-0.027	0.079	0.112	0.104	0.274
Δln(MFP)	0.789	0.321	0.790	0.796	0.800	0.682	0.672
Δln(Labour Productivity)	0.680	0.278	0.680	0.689	0.713	0.568	0.530

a The correlation coefficient between two variables *X* and *Y* is defined as equal to the covariance of *X* and *Y* over the product of the standard deviations of *X* and *Y*. The covariance of *X* and *Y* is $E[(X - u_x)(Y - u_y)]$, where *u* is the mean of the variable. A correlation coefficient of -1 and +1 implies a perfect linear relationship.

Source: Commission estimates.

L.4 Sensitivity of the results to the choice of control variable

The following tables show the results of sensitivity testing various models to the choice of control for the business cycle.

The choice of business cycle control in a basic finite distributed lag (FDL) model does not have a large influence on the economic magnitudes of the estimates (table L.2). However, the statistical significance of the estimates on the stock of Australian business R&D (BRD) does vary.

The extended models tends to show greater sensitivity to the choice of control with the signs of coefficients on the R&D variables changing in some cases, and statistical significance varying across the alternative measures (table L.3, L.4, and L.5).

Table L.2 **Basic MFP model BL3s FDL with alternative business cycle controls[a]**

10 per cent rate of decay assumed

Dep. Var. = ln(MFP)	*Market sector output*	*Linear gap*	*Univariate H-P gap*	*Hendersen 11 term gap*	*Philips curve gap*	*OECD output gap*
Control for business cycle (t)	0.340*** (0.077)	0.340*** (0.078)	0.352*** (0.079)	0.346*** (0.092)	0.514*** (0.111)	0.464*** (0.109)
Aus. BRD stock (t-1)	0.041 (0.026)	0.041 (0.026)	0.049* (0.026)	0.045 (0.027)	0.048* (0.027)	0.058** (0.025)
Foreign BRD stock import share weighted (t)	0.220*** (0.041)	0.220*** (0.041)	0.210*** (0.041)	0.222*** (0.043)	0.210*** (0.038)	0.201*** (0.037)
Constant	3.449*** (0.065)	3.459*** (0.067)	3.465*** (0.068)	3.440*** (0.068)	3.465*** (0.060)	3.455*** (0.059)
R^2	0.993	0.993	0.994	0.993	0.993	0.992
Durbin-Watson[b]	2.190	2.189	2.188	2.065	2.264	2.450
White test χ^2(p) for heteroskedasticity[c]	31 (0.415)	31 (0.415)	31 (0.415)	31 (0.415)	31 (0.415)	31 (0.415)
AIC*n/(BIC)	-198(-121)	-198(-121)	-199(-123)	-196(-120)	-197(-121)	-191(-114)

* Significant at 10 per cent. ** Significant at 5 per cent. *** Significant at 1 per cent. [a] Heteroskedastic standard errors in brackets. Coefficient, t-statistic and statistical significance is for the long-run effect. [b] Test for serial correlation using Durbin-Watson 'd' statistic. [c] White's general test for heteroskedasticity.

Source: Commission estimates.

Table L.3 **Sensitivity of extended ln(MFP) models to alternative business cycle controls**

Assumed rate of decay of 15 per cent

Dep. Var. = ln(MFP)	*Market sector output*	*Linear gap*	*Univariate H-P gap*	*Hendersen 11 term gap*	*Philips curve gap*	*OECD output gap*
Model L4, quadratic, with USPTO patents granted -						
Aus. BRD stock (t-1) at full sample mean	0.003 (0.014)	0.003 (0.014)	0.011 (0.014)	-0.018 (0.014)	0.010 (0.017)	0.042 (0.028)
USPTO patents granted (t)	0.039*** (0.009)	0.039*** (0.009)	0.045** (0.017)	0.045** (0.017)	0.047** (0.022)	-0.036 (0.023)
Model L6, gross expenditure FDL -						
Aus. BRD stock	0.017 (0.016)	0.021 (0.020)	0.025 (0.021)	0.054** (0.019)	0.0101 (0.025)	0.033 (0.042)
Foreign GRD[a] stock	0.509* (0.279)	0.508* (0.279)	0.522* (0.282)	0.822** (0.280)	0.597 (0.390)	-0.103 (0.676)

[a] Gross R&D.

Source: Commission estimates.

Table L.4 **Sensitivity of extended growth in MFP models to alternative business cycle controls**

Assumed rate of decay of 15 per cent

Dep. Var. = Δln(MFP)	*Market sector output*	*Linear gap*	*Univariate H-P gap*	*Hendersen 11 term gap*	*Philips curve gap*	*OECD output gap*
Model Y4 FDL ln(K/Y), with intercept dropped -						
Aus. BRD stock	0.013** (0.006)	0.012* (0.006)	0.012* (0.006)	0.012* (0.006)	0.003 (0.007)	0.003 (0.007)
Foreign GRD stock	0.041* (0.022)	0.040 (0.022)	0.040 (0.023)	0.034 (0.022)	0.003 (0.029)	0.002 (0.30)
Model Y5 ln(ΔK/Y) -						
Aus. BRD stock (t-1)	0.018** (0.008)	0.018** (0.008)	0.018** (0.008)	0.013 (0.009)	0.024*** (0.008)	0.015* (0.008)
Foreign GRD stock (t)	0.014* (0.007)	0.014* (0.007)	0.014* (0.007)	0.011 (0.008)	0.019 (0.012)	0.004 (0.011)

Source: Commission estimates.

Table L.5 **Sensitivity of system growth in labour productivity models to alternative business cycle controls**

Assumed rate of decay of 15 per cent

Dep. Var. = Δln(LP)	*Market sector output*	*Linear gap*	*Univariate H-P gap*	*Hendersen 11 term gap*	*Philips curve gap*	*OECD output gap*
*Model S3LP ln(K/(Y*hrs)) -*						
Aus. BRD intensity (t-1)	0.025 (0.016)	0.025 (0.016)	0.023 (0.015)	0.009 (0.017)	0.019 (0.028)	-0.014 (0.010)
Foreign GRD intensity[a] (t-2)	0.065** (0.028)	0.065** (0.028)	0.069** (0.028)	0.055* (0.032)	0.028 (0.052)	-0.102 (0.067)
*Model S4LP ln(ΔK/(Y*hrs)) -*						
Aus. BRD intensity (t-2)	-0.005 (0.003)	-0.005 (0.003)	-0.005* (0.003)	-0.008* (0.003)	-0.003 (0.005)	-0.006 (0.008)
Foreign GRD intensity[a] (t-4)	0.028*** (0.010)	0.028*** (0.010)	0.029*** (0.010)	0.030*** (0.011)	0.037** (0.015)	0.055** (0.026)

[a] Foreign gross R&D Elaborately Transformed manufactures (ETM) weighted.

Source: Commission estimates.

M Differentiating between transitional dynamics and permanent impacts

Autoregressive distributed lag (ARDL) econometric models provide a useful framework for analysing economic systems that may not always be in a long-run equilibrium state. The standard form of an ARDL(m,n) model is:

$$y_t = \sum_{i=1}^{m} \alpha_i y_{t-i} + \sum_{i=0}^{n} \beta_i x_{t-i} + \varepsilon_t \qquad \text{(M1)}$$

A permanent shock to x will typically result in both temporary impacts along the transition path to a new equilibrium and a permanent long-run impact. In order to estimate the true long-run impact, it is necessary to incorporate enough lags of both the dependent variable and independent variable to completely account for the transition dynamics.

Determining exactly how many lags should be incorporated is a difficult problem. In an ideal world, a large number of lags would be incorporated initially and then any that are neither statistically nor economically significant could be eliminated. However, when only a limited number of observations are available, the number of lags that can be incorporated is necessarily limited. This problem is further exacerbated by the strong multi-collinearity between the R&D capital stock in the current period and past periods. This multi-collinearity problem occurs for both the domestic R&D capital stock and the foreign R&D capital stock.

The usefulness of the ARDL models is that they potentially allow the short-run impacts of a shock, which are largely dictated by the transition from one equilibrium to another, to be separated from the long-run impact of the shock (box M.1).

It can take a relatively long time to reach a new equilibrium after a shock, even if the underlying model does not incorporate many lags. The ARDL(1,3) model that was estimated in chapter 6 provides an example of this. The estimated model was:

$$\begin{aligned} MFP_t \quad = \quad & 2.65 + 0.26 MFP_{t-1} - 0.48 K_t^A + 0.98 K_{t-1}^A - 0.9 K_{t-2}^A + 0.042 K_{t-3}^A \\ & + 0.06 K_t^F + 1.24 K_{t-1}^F - 2.84 K_{t-2}^F + 1.7 K_{t-3}^F \end{aligned} \qquad \text{(M2)}$$

where K^A is the stock of Australian business R&D (BRD) and K^F is the stock of foreign business R&D.

The long run equilibrium for this model is characterised by:

$$MFP = 3.58 + 0.03K^A + 0.22K^F \qquad \text{(M3)}$$

Box M.1 **Disentangling transitional dynamics from long-run impacts for an ARDL model**

The standard ARDL(m,n) model is given by equation (M1). It can be rearranged in a variety of ways to yield models that will provide direct estimates of both the transitional dynamics and the long-run impact of a shock (Wickens and Breusch 1988). Two particularly useful forms relate to the cases in which the long-run equilibria are either static or involve a steady state growth path.

If the long-run equilibria are thought to be static, so that they involve a stationary steady state, then Wickens and Breusch (1988) suggest that (M1) be rearranged to yield:

$$y_t = \sum_{i=1}^{m} \gamma_i (y_t - y_{t-i}) + \theta x_t + \sum_{i=1}^{n} \lambda_i (x_t - x_{t-1}) + u_t \qquad \text{(M4)}$$

where the parameters in equation (M4) can be expressed in terms of the parameters from the standard ARDL model as follows:

$$\theta = \frac{\sum_{i=0}^{n} \beta_i}{1 - \sum_{i=1}^{m} \alpha_i}, \quad \gamma_i = \frac{-\alpha_i}{1 - \sum_{i=1}^{m} \alpha_i}, \quad \lambda_i = \frac{-\beta_i}{1 - \sum_{i=1}^{m} \alpha_i} \quad \text{and} \quad u_t = \frac{\varepsilon_t}{1 - \sum_{i=1}^{m} \alpha_i} \qquad \text{(M5)}$$

In this case, the long-run equilibrium involves:

$$y = \theta x . \qquad \text{(M6)}$$

The marginal long-run impact of a permanent shock to x is given by θ, while the transitional dynamics are governed by the γ_i and λ_i terms.

If, on the other hand, the long-run equilibrium is thought to involve a steady state growth path, then Wickens and Breusch (1988) suggest rearranging (M1) to obtain:

$$y_t = \sum_{i=1}^{m} \phi_i \Delta^i y_t + \theta x_t + \sum_{i=1}^{n} \eta_i \Delta^i x_t \qquad \text{(M7)}$$

Note that (M7) can be further rearranged to yield:

$$y_t = \sum_{i=2}^{m} \phi_i \Delta^i y_t + \phi_1 \Delta y_t + \theta x_t + \phi_1 \Delta y_t + \eta_1 \Delta x_t + \sum_{i=2}^{n} \eta_i \Delta^i x_t \qquad \text{(M8)}$$

(continued on next page)

Box M.1 **(continued)**

Suppose that the y_t and x_t variables are in the form of natural logarithms, so that:

$$y_t = \ln Y_t \quad \text{and} \quad x_t = \ln X_t \qquad \text{(M9)}$$

Then:

$$\Delta y_t \approx g_Y \quad \text{and} \quad \Delta x_t \approx g_X \qquad \text{(M10)}$$

where g_Y is the steady state growth rate of Y and g_X is the steady state growth rate of X.

Note that if (M10) is substituted into (M8):

$$y_t = \sum_{i=2}^{m} \phi_i \Delta^i y_t + [(\phi_1 g_Y + \eta_1 g_X) + \theta x_t] + \eta_1 \Delta x_t + \sum_{i=2}^{n} \eta_i \Delta^i x_t \qquad \text{(M11)}$$

In this case, the long-run equilibrium is given by

$$y = (\phi_1 g_Y + \eta_1 g_X) + \theta x \qquad \text{(M12)}$$

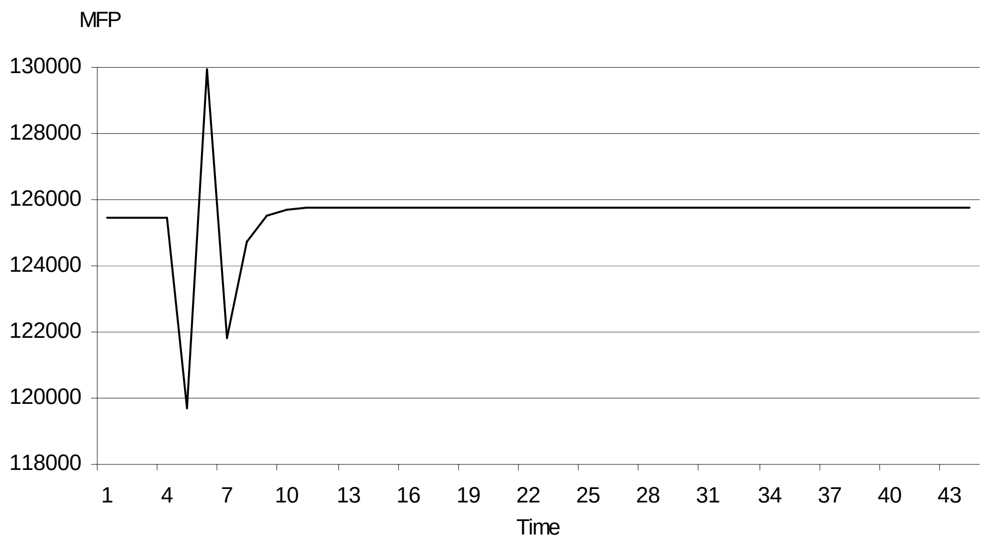
The marginal long-run impact of a permanent shock to x will depend on whether or not the shock to x alters the steady state growth rates of X and Y. If it does not alter these steady state growth paths, then the marginal long-run impact is once again given by θ. If the shock does alter these steady state growth rates, then the marginal long-run impact will be given by $\phi_1 \frac{\partial g_Y}{\partial X} + \eta_1 \frac{\partial g_X}{\partial X} + \theta$. In both cases, the transitional dynamics are governed by the ϕ_i and η_i terms for $i > 1$.

Source: Wickens and Breusch (1988).

Imagine that there is an initial equilibrium in which Australian BRD is equal to $8,047 million and the foreign BRD stock is equal to $579,126 million, both in terms of constant 2001-02 Australian dollars. This generates an MFP level for Australia of approximately 125,438. Suppose that the Australian BRD stock is permanently increased to $20,025 million, in terms of constant 2001-02 Australian dollars, while holding the foreign BRD stock constant. The long-run impact of this shock is to raise Australia's level of MFP to approximately 125,761. However, the transition to the new equilibrium following the shock takes 18 years. Furthermore, the level of MFP fluctuates dramatically during the early part of the transition, as can be seen in figure M.1.[1]

[1] The dramatic fluctuations of MFP during the early years of the transition phase are generated by the sign differences on the coefficients of the various Australian business R&D stock variables. This feature is not peculiar to this particular set of regression results. Rouvinen (2002) also obtains sign differences in an ARDL model of the relationship between productivity and R&D using a variety of estimation techniques.

Figure M.1 **The timepath of MFP following a shock to domestic BERD**



Data source: Commission estimates.

The values chosen for the various R&D stocks in this thought experiment were not entirely arbitrary. The initial value for Australian BRD is equal to the average stock over the period from 1968-69 to 1985-86, while the final value is equal to the average stock over the period from 1986-87 to 2002-03. Similarly, the value for foreign BRD is equal to the average stock for the period from 1968-69 to 2002-03.

An alternative approach to estimating the length of the transition period is to measure it for a particular model of an economy. This is the approach employed by Jones (1995a) and Chou (2003). Jones (1995a) uses an endogenous growth model to simulate the impact of a permanent increase in the R&D share of total employment from 1 per cent to 2 per cent. Using a variety of parameter values, he finds that the approximate half-life of the transition period for multifactor productivity growth ranges from 35 to 347 years. Chou (2003) conducts a similar thought experiment to Jones (1995a). Chou assumes a population growth rate of 1 per cent and an initial multifactor productivity growth rate of 0.82 per cent, which is the Australian average multifactor productivity growth rate between 1960 and 2000. This gives an exact half-life of the transition period for multifactor productivity growth ranging from 7 years to 448 years.

Given the very limited length of the time series data employed in this study, it is unlikely that the short-run and the long-run impacts of R&D on Australia's multifactor productivity growth have been completely disentangled. Even if the only shock to R&D occurred in the first period of the dataset, the transition phase could last for most of the period covered by the time series data. Indeed, the simulation results from Jones (1995a) and Chou (2003) appear to indicate that the transition phase might even take longer than the period of time covered by the time series data. Furthermore, it is highly unlikely that only one shock has occurred over the entire timeframe, yet alone that the only shock occurred in the first period of observations.

The inherent difficulty in disentangling long-run impacts from transitional dynamics in a limited dataset may account for some of the statistical difficulties that were encountered. It might also account for the unusual signs and magnitudes of some variables.

N Industry disaggregation of trend in R&D expenditure

Tables N.1, N.2 and N.3 provide a detailed breakdown of growth in R&D expenditure by industry.

Table N.1 **R&D expenditure for disaggregated IT industries, 1988-89 to 2001-02**
Constant 2002-03 dollars

Code	*Service industries*	*Exp. in 2001-02*	*Change from 1988-89*	*Trend growth 1988-89*[a]	*Trend growth 1992-93*[a]
		$m	$m	%	%
IT sectors					
461	Machinery & equipment wholesaling	280.9	107.3	4.4	4.4
783	Computer services	741.7	600.4	13.1	10.8
2841	Computer & business machine manufacturing[b]	51.0	24.0	6.0	5.4

[a] Covers the period up to 2001-02. [b] The industry, Computer & business machine manufacturing (Code 2841), is classified as Manufacturing, but is listed in this table with ANZSIC Code 461 and 783 as all three sectors are predominantly information technology related.

Sources: ABS (*Australian System of National Accounts*, Cat. no. 5204.0); unpublished ABS data; Commission estimates.

Table N.2 **R&D expenditure for disaggregated manufacturing industries[a], 1988-89 to 2001-02**

Constant 2002-03 dollars

Code	*Manufacturing industries*	*Expenditure in 2001-02*	*Change from 1988-89*	*Trend rate of growth from 1988-89*[b]	*Share of cumulative expenditure*[c]
		$m	*$m*	*%*	*%*
Food, beverages & tobacco					
211	Meat & meat products	41.7	27.7	5.7	1.4
212	Dairy products	42.9	22.6	8.4	2.0
213	Fruit & vegetable processing	27.3	23.7	15.3	0.7
215	Flour mill & cereal food	22.9	13.1	8.9	1.2
216	Bakery products	14.0	9.9	5.9	0.4
214, 217, 219	Oil & fat; Other food; and Tobacco products	54.7	7.4	2.1	2.9
218	Beverages & malt	16.3	-3.7	3.4	0.6
Textiles, clothing, footwear & leather					
221	Textile fibre, yarn & woven fabric	6.3	-1.1	1.0	0.4
222, 223, 224	Textile products; Knitting mills; and Clothing	11.9	-5.8	-1.6	0.5
225, 226	Footwear; and Leather & leather products	4.9	2.6	9.9	0.2
Wood & paper products; Printing, publishing & recorded media					
231	Log sawmilling & timber dressing	3.1	1.1	1.8	0.2
232	Other wood products	2.4	-5.6	-0.4	0.5
233	Paper & paper products	78.7	48.5	10.3	4.2
241	Printing & services to printing	4.8	3.4	2.6	0.2
242	Publishing	5.8	4.5	18.4	0.1
243	Recorded media manufacturing & publishing	6.0	1.3	5.2	0.3
Petroleum, coal, chemical & associated products					
251, 252	Petroleum refining; and Petroleum & coal products	19.0	17.9	19.7	0.5
253	Basic chemical manufacturing	77.7	-3.6	-1.6	3.6
254, 255	Other chemical products; and Rubber products	293.9	154.2	5.4	10.8
256	Plastic products	36.9	21.3	2.8	1.4
Non-metallic mineral products					
262	Ceramic products	5.5	-2.2	-1.3	0.5
263	Cement, lime, plaster & concrete products	45.0	33.1	11.8	1.7
261, 264	Glass & glass products; and Non-metallic mineral products	22.1	11.3	3.7	0.3

(continued on next page)

Table N.2 **(continued)**

Code	*Manufacturing industries*	*Expenditure in 2001-02*	*Change from 1988-89*	*Trend rate of growth from 1988-89*[b]	*Share of cumulative expenditure*[c]
		$m	*$m*	*%*	*%*
Metal products					
271	Iron & steel	130.6	34.8	0.1	8.2
272, 273	Basic non-ferrous metal; and Non-ferrous basic metal products	71.3	42.3	5.2	4.6
274	Structural metal products	4.6	-0.1	-1.0	0.3
275	Sheet metal products	5.5	-2.2	-3.8	0.5
276	Fabricated metal products	29.2	7.0	4.1	1.4
Transport equipment					
281	Motor vehicle & parts	502.1	301.7	8.8	14.1
282	Other transport equipment	65.0	43.9	4.9	4.3
Photographic & scientific equipment					
283	Photographic & scientific equipment	236.1	178.5	9.4	5.7
Electronic equipment; Electrical equipment & appliances					
284	Electronic equipment	354.4	87.1	2.5	16.5
285	Electrical equipment & appliances	67.8	-15.2	-0.8	4.0
Industrial machinery & equipment					
286	Industrial machinery & equipment	131.5	55.0	4.1	5.1
Other manufacturing					
291, 292	Prefabricated building; and Furniture	8.0	2.8	3.1	0.4
294	Miscellaneous manufacturing	10.1	1.7	0.0	0.7
Total manufacturing		**2459.8**	**1118.9**	**4.6**	**100**

a See table A.3 for industry classification details. **b** Covers the period 1988-89 to 2001-02. **c** This is a cumulative share of the Divisional (Manufacturing industries) cumulative real expenditure for the period 1988-89 to 2001-02.

Sources: ABS (*Australian System of National Accounts*, Cat. no. 5204.0); unpublished ABS data; Commission estimates.

Table N.3 R&D expenditure for disaggregated service industries, 1988-89 to 2001-02

Constant 2002-03 dollars

Code	Service industries	Exp. in 2001-02	Change from 1988-89	Trend growth 1988-89[a]	Trend growth 1992-93[a]	Cont. from 1988-89[b]
		$m	$m	%	%	%
Wholesale & retail trade						
45	Basic material wholesaling	50.0	26.7	3.6	1.6	1.5
462	Motor vehicle wholesaling	5.2	2.7	5.7	6.0	0.2
47	Personal & household good wholesaling	78.5	64.3	18.2	17.6	3.7
51, 52, 57	Food retailing; Personal & household good retailing; and Accommodation, cafes & restaurants	11.9	4.7	0.9	6.6	0.3
53	Motor vehicle retailing & servicing	6.7	6.4	26.1	24.2	0.4
Finance & insurance						
73	Finance	134.9	41.9	1.1	4.7	2.4
74	Insurance	38.0	25.7	0.3	-2.9	1.5
75	Services to finance & insurance	57.2	33.3	15.1	19.6	1.9
Property and business services						
77	Property services	4.1	-6.7	-10.0	8.7	-0.4
78	Business services less Scientific research (7810) and Computer services (783)	330.7	169.7	5.5	1.9	9.8
7810	Scientific research	316.2	209.5	10.0	11.9	12.1
IT sectors						
461	Machinery & equipment wholesaling	280.9	107.3	4.4	4.4	6.2
783	Computer Services	741.7	600.4	13.1	10.8	34.6
2841	Computer & business machine manufacturing[c]	51.0	24.0	6.0	5.4	1.4
Other not elsewhere classified (n.e.c.)						
36	Electricity & gas supply	51.5	28.9	1.3	-3.8	1.7
37	Water supply, sewerage & drainage services	14.1	5.9	-5.4	-7.3	0.3
41	General construction	32.7	23.4	17.8	13.2	1.3
42	Construction trade services	12.1	9.9	12.8	8.8	0.6
61, 63	Road transport; and Water transport	2.2	-6.2	-9.2	7.3	-0.4
62, 64, 65, 67	Rail transport; Air & space transport; and Other transport plus Storage	13.3	6.0	7.5	3.3	0.3
66	Services to transport	4.3	-0.4	3.2	6.2	0.0
71	Communication services	399.6	282.7	6.8	13.6	16.3
84, 86	Education and Health services	19.0	12.5	3.5	10.2	0.7
93	Sport & recreation	51.4	47.8	20.8	33.0	2.8
91, 92, 95, 96	Motion picture, radio & television; Libraries, museums & arts; Personal services; and Other services	19.6	15.0	16.0	15.9	0.9
Total services		**2727.0**	**1735.5**	**6.5**	**4.3**	**100**

a Covers the period up to 2001-02 **b** This is a cumulative share of the Divisional (Total services) cumulative real expenditure for the period 1988-89 to 2001-02. **c** The industry, Computer & business machine manufacturing (Code 2841), is classified as Manufacturing, but is listed in this table with ANZSIC Code 461 and 783 as all three sectors are predominantly information technology related.

Sources: ABS (*Australian System of National Accounts*, Cat. no. 5204.0); unpublished ABS data; Commission estimates.

O A changing partial effect of R&D on productivity?

Most regressions in this study produce an average estimate of the effect of R&D holding other factors constant. A log-linear functional form is adopted where the partial effect of R&D on productivity is treated as constant. With a constant elasticity, the levels models suggest diminishing returns to R&D (table 11.2). However, there are *a priori* reasons and evidence (although mixed) to support changes in the effect of R&D.

O.1 Did the responsiveness of output to R&D change?

Testing and difficulties encountered in modelling the effect of R&D give rise to a strong suspicion that R&D elasticities have not been stable.

An expectation of breaks and changing parameters

While there are candidates for immediate break points (such as droughts), there are also major trends in both R&D and output that may have affected their relationship.

- *Starkly weaker investment in the 1970s*: on the best information available, the degree of weakness of R&D investment in the 1970s points to a significant deterioration in the private incentives to innovate (resulting in a reduction in business demand for R&D), or a significant substitution away from R&D in favour of other inputs into innovation.
- *Weak R&D investment in parallel with deteriorating economic performance*: economic performance also deteriorated sharply in the 1970s (see the discussion of output gap measures in appendix L and chapter 11).
- *A strong acceleration in the rate of R&D investment:* the pattern of investment indicates a rapid reversal in the attractiveness of R&D investment in the early to mid-1980s.
- *No clear pay-off from higher R&D investment:* chapter 5 presents charts that contrast the rate of R&D investment against the rate of productivity growth. Productivity performance appears unresponsive to changes in business R&D,

although there could be a substantial lagged effect, or the effect could be masked by other effects.

Testing for breaks and parameter instability in the R&D-productivity relationship

Some tests confirm parameter instability, but other tests are inconclusive. Part of the problem in many models is that the estimates of the effect of R&D are estimated imprecisely so that there can be substantial movement of point estimates within broad confidence intervals, but the movements do not necessarily confirm breaks.

- *Structural breaks in individual series*: unit root tests for immediate or gradual breaks in the productivity and R&D time series found that the order of integration of the series was sensitive to controlling for breaks in the mean or trend of variables (appendix E).
  - CUSUM tests for immediate and haphazard breaks in various models did not find strong evidence of breaks.
- *Recursive estimation*: the plotting of how coefficient estimates change over time, as the regression sample is successively shortened by sequentially dropping the earliest observations, often resulted in reasonably different point estimates of the partial effect of Australian business R&D (BRD) (appendix E). However, the imprecision of the estimates usually did not allow clear conclusions to be drawn.
- *Greater instability in the return to R&D*: estimating the rate of return directly from within the standard rate of return framework produced very fragile and poorly estimated returns at all levels of industry aggregation (except for Agriculture). This might indicate that rates of return have changed more than elasticities.

Slope shift terms indicate a reduction in the effect of R&D

Introducing slope shift terms for the effect of Australian business R&D in the levels models produced negatively signed shifts in the 1980s (chapter 6), but generally did not indicate the sort of magnitude in shifts that might be expected from descriptively analysing charts of the relationships.

An important exception was when the basic levels model was re-estimated as part of the two-equation systems (chapter 10). In this case, there were very significant shifts in the effect of Australian BRD around 1983-85, in both the levels and intensity models. The breaks indicate that the partial effect of Australian BRD on productivity was much lower after the mid-1980s.

A systematic change related to the level of R&D

Table O.1 summarises models in the paper that include productivity specified as a quadratic function of Australian business R&D, and models that have been re-estimated with a quadratic term.

The first three models test the hypothesis that the partial effect of business R&D on productivity depends, in part, on the level of R&D undertaken. A positive coefficient on the quadratic term means that the partial effect is increasing in the level of R&D activity.

The latter four models test the hypothesis that the partial effect of business R&D on multifactor productivity (MFP) or labour productivity growth depends in part on the level of R&D intensity. The first two intensity models specify intensity as the ratio of the knowledge stock over output. The second two intensity models specify intensity as the ratio of the change in the knowledge stock over output (that is, the rate of net accumulation of the stock as a proportion of output). A negative sign on the quadratic term would indicate that the rate of productivity growth is declining in the level of R&D intensity.

An increasing effect in the levels regressions

An increasing partial effect of business R&D on the level of MFP is found in the market sector. Evaluated at the mean of the period up until 1985, Australian business R&D is not statistically significant. Evaluated at the mean from 1986, both economic and statistical significance increase. This implies that the relationship between R&D and productivity was stronger from the mid-1980s and that the effect of R&D on productivity became stronger as the level of R&D activity increased.

However, similar evidence from the industry models was weak. Testing of the manufacturing panel models in appendix J indicated both positive and declining partial effects depending on the industry. If a changing partial effect at the level of the market sector or expanded market sector was related to inter-industry effects, then it might be expected that the more highly aggregated models would show stronger evidence of such effects, since more of the inter-industry effects are captured in the estimated elasticities.

Table O.1 **An increasing partial effect of R&D?**[a]

K is the knowledge stock and *R* is real R&D expenditure

Model -	*L4 USPTO*	*L6 FDL*	*S1*	*S3 FDL*	*S3LP Static*	*S4 FDL*	*S4LP Static*
Dep. Var.	*ln(MFP)*	*ln(MFP)*	*ln(MFP)*	*Δln(MFP)*	*Δln(LP)*	*Δln(MFP)*	*Δln(MFP)*
R&D var. -	*Ln(K)*	*Ln(R)*	*Ln(K)*	*ln(K/Y)*	*ln(K/ (Y*hrs))*	*ln(ΔK/Y)*	*ln(ΔK/ (Y*hrs))*
# of lags -		*Aus. = 1 For. = 3*		*Aus. = 2 For. = 2*		*Aus. = 1 For. = 3*	
Regression coefficients -							
BRD	-0.285***[b] (0.064)	-0.283[b]	-0.683***[b] (0.180)	-0.386[b]	-2.339**[b] (0.994)	-0.019[b]	-0.038***[b] (0.012)
BRD squared	0.039*** (0.009)	0.041	0.092*** (0.024)	-0.053	-0.075** (0.031)	-0.002	-0.001*** (0.000)
Foreign R&D[c]	0.051*** (0.017)	0.509*[b] (0.279)	0.486*** (0.164)	0.055** [b] (0.023)	0.064** (0.028)	0.024*** [b] (0.002)	0.027*** (0.009)
Evaluation of permanent total effect at -							
Mean up to 1985	-0.031* (0.015)	-0.042 (0.042)	-0.105** (0.045)	-0.950 (0.804)	0.056*** (0.016)	0.007*** (0.002)	-0.005* (0.003)
Mean of full sample	0.003 (0.014)	0.017 (0.016)	0.002 (0.036)	-0.012** (0.005)	0.014 (0.017)	0.003* (0.001)	-0.007** (0.003)
Mean after 1985	0.040** (0.018)	0.065** (0.028)	0.071* (0.040)	-0.034*** (0.008)	-0.011 (0.025)	0.000 (0.001)	-0.008** (0.003)

[a] Variables specified in log form and interpreted as elasticities. Full model results for models L4 and L6 FDL are presented in chapter 7, and other models in chapter 10. For the quadratic FDL models, standard errors and statistical significance not evaluated for the primary and quadratic terms individually. [b] Joint F-test of primary coefficient and its square, including all lags in FDL models, significant at 5 per cent or greater. [c] Foreign R&D represented by USPTO patents granted in model L4. In the other models, foreign knowledge stocks are weighted by ETM import shares and depreciated at 15 per cent.

Source: Commission estimates.

An increasing partial effect in the level of R&D may be related to within firm scale/scope economies in knowledge production. These could be traditional scale effects related to high fixed costs in R&D investment and declining average cost. Or, they could be related more to the characteristics of knowledge and increasing returns from ‘learning-by-learning’. A higher success rate might reflect learning or problem solving benefits from having more R&D personnel working together.

If the scale of firm activity had increased significantly, then other factors which might support an aggregate increasing partial effect include the following.

- *Risk and the organisation of knowledge production*: R&D investment can be characterised by high fixed costs and comparative uncertainty surrounding project outcomes. As the scale of R&D activity increases, R&D projects may be increasingly organised in a way which spreads the risks of investment and, at the same time, creates linkages with other businesses and institutions. These linkages help diffuse knowledge, either more widely or more rapidly (for example, joint ventures and strategic alliances).

- *Firm size specific spillover parameters*: smaller firms may be better at protecting their intellectual property (for example, because of lower mobility of R&D personnel). As average firm size and the level of R&D activity increases, relatively more of the knowledge generated from R&D may spillover to other firms. Another rationale for variance in the spillover parameter is that the scale of R&D activity is correlated with the propensity to be undertaking basic research. Basic research may have a larger 'spillover parameter' than other types of research.

However, there is no clear evidence of a significant change in the average scale of R&D activity. Average real expenditure per firm has more than doubled between 1976-77 and 2002-03 (chapter 3) but the average size of firm performing R&D (measured in person years devoted to R&D) has remained remarkably stable (appendix B). There has been a significant expansion in the number of firms performing R&D. Entry of firms into R&D activity has been more important than growth in average expenditure per firm as a source of growth in total business expenditure on R&D (appendix I). Entry has mostly been by small firms.

Over the long term, the number of firms engaged in R&D activity increased at 5 per cent a year, while real average expenditure increased at just over 3 per cent a year. R&D performing firms across industries (with the exception of Transport equipment) have used around 8 person-years of labour each year for a long time (appendix B). The concentration of R&D activity in most industries has declined, but this does not appear to have affected the intensity of R&D effort.

With more firms performing R&D, there may have been a broad-based increase in absorptive capacity across industries. On average, businesses may be better able to absorb spillovers from higher education, Government, and foreign R&D. In terms of an ability to absorb foreign spillovers, testing in chapter 9 provided inconclusive evidence.

Two other possible sources for the apparent increased partial effect are the following.

- *Increased inter-industry integration*: the knowledge obtained from R&D in one industry may have become more relevant to the productivity of other industries. However, results favoured a negative coefficient on the inter-industry stock of knowledge (appendix J), although there were some supporting results from labour productivity panel models.

- *Systematic unobserved effect correlated with R&D investment*: the pattern of R&D investment may be correlated with the source of the non-linear effect, rather than the partial effect of R&D depending on the scale of R&D activities as such. The pattern of investment in R&D contains information about shocks to the net benefits from undertaking R&D, the relative 'price' of R&D and demand responses. This implies an attribution problem and a bias in the measured return to R&D.

Profiles of the changing total effect

The total effect of Australian business R&D is evaluated at each year and plotted to show changes over time. For models L4 USPTO and L6 FDL, the total effect from 1974 to the early 1980s is negative, but it increases strongly thereafter (figure O.1). Both of these models specified in levels show the increasing partial effect of R&D as the level of R&D activity has increased. This illustrates that structural relationships may have changed over time, with the relationship between R&D and productivity stronger post the mid-1980s.

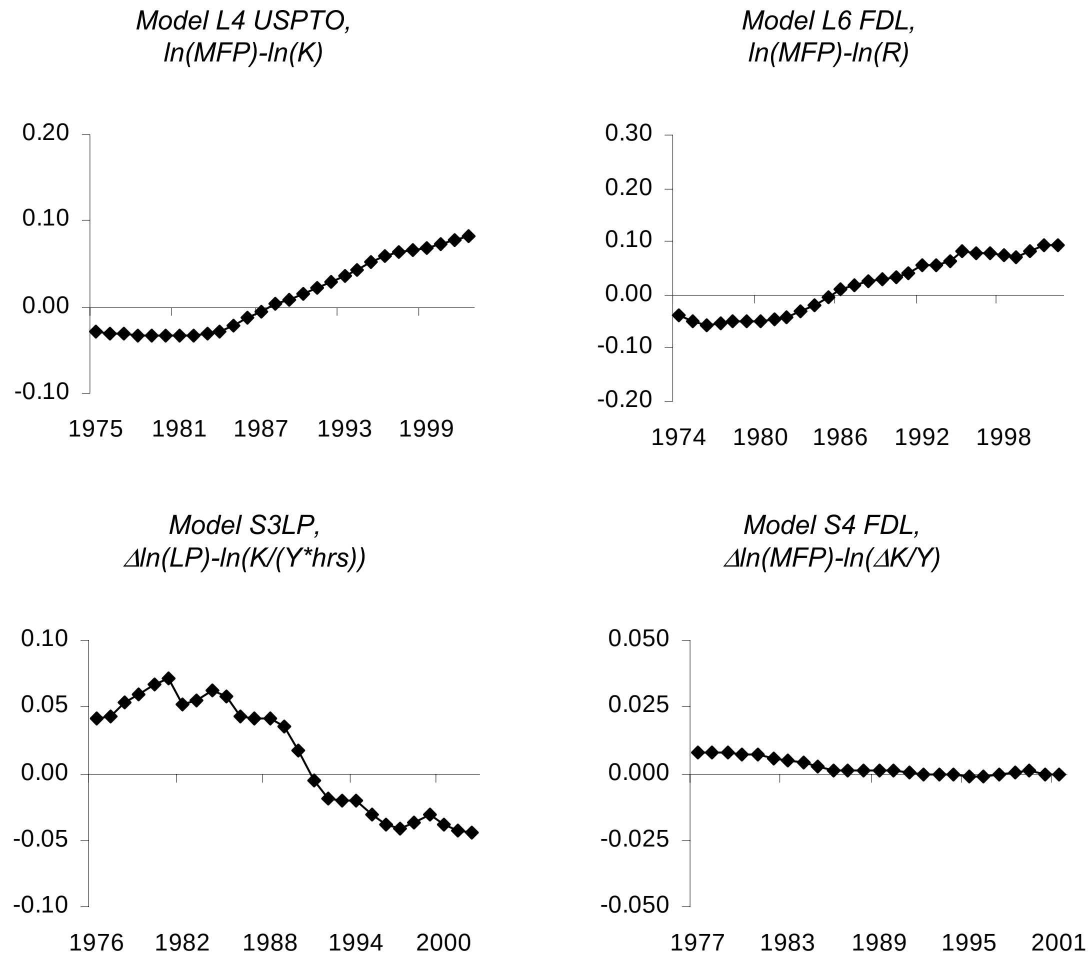
The regressions imply a negative effect of R&D in the 1970s and into the early 1980s — and, therefore, that the social return to R&D was below the private return. From the mid-1980s, the effect of R&D is increasingly positive suggesting that the social return is substantially above the private return.

One serious problem with these results is that the partial effect is not bounded. As more resources are devoted to R&D, the partial effect continues to increase to elasticities which are too large to be economically plausible. If the economy was in a state of transition from one steady state to another, an increasing partial effect might be observed, but the effect would tail-off and converge to some new level, which might include the original level.

Higher order polynomials of Australian BRD were tested in a range of models to see if a changing, but bounded effect could be obtained. While some cubic models were significant, they did not solve the problem.

Some models with dynamics have had difficulty estimating a permanent effect with any reasonable level of statistical significance. The two problems are likely related. Given the starkly different periods of R&D investment and significant changes in economic performance, much of the period under observation might be considered a transitionary period (see Chou (2003) who holds this view). If so, the economy may still be adjusting to the changes (see appendix M for a discussion of the implied length of adjustment).

Figure O.1 **The total effect of Australian business R&D**[a]



[a] Profile of coefficients constructed from evaluating Australian business R&D and its quadratic at each year.

Data source: Commission estimates.

A declining effect in the productivity growth regressions

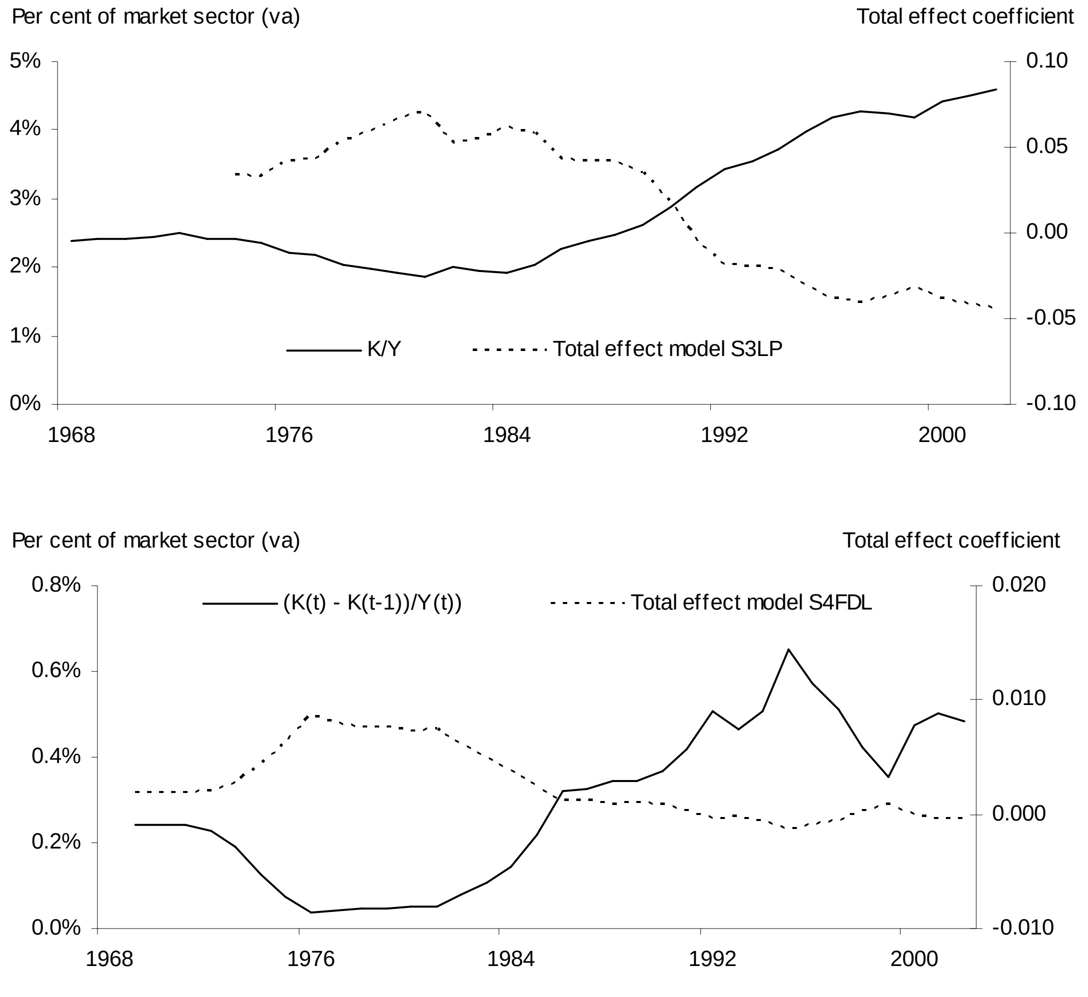
Productivity growth models for the market sector were re-estimated to test whether the effect of Australian business R&D intensity on productivity growth weakened as intensities increased. Intensity is measured as both the knowledge stock over output and change in the knowledge stock over output.

The increase in intensities can be viewed as a series of sequential shocks. All four productivity growth models point to a declining effect of R&D as intensities have increased (table O.1). For models S3LP and S4FDL, the declining coefficient of the partial effect of Australian BRD on productivity is plotted against the rising intensities (figure O.2). The total effect is positive early in the sample, but declines to a negative or insignificant effect.

The productivity growth models imply that the social return was significantly greater than the private return in the 1970s and into the early 1980s. However, as R&D intensities rose, the social return from additional R&D decreased. For the second half of the sample, the growth models do not provide evidence of a social return greater than the private return. This pattern of effects is preferred to the pattern in the quadratic levels models (discussed in chapter 11).

Figure O.2 **Rising intensity and declining effect on productivity growth**

Partial effect in upper panel is from regression of growth in labour productivity on R&D intensity defined as ln(K/Y). Partial effect in lower panel is from regression of MFP growth on R&D intensity defined as the change in the stock over output.



Data sources: Adjusted data from ABS (*Research and Experimental Development, Businesses, Australia,* Cat. no. 8104.0); ABS (*Australian System of National Accounts*, Cat. no. 5204.0); Commission estimates.

P An upper bound for the social rate of return to R&D

It is possible to generate an upper bound for the social (that is, private plus external) rate of return to R&D (see Revesz 2006 and Terleckyj 1974)

P.1 Basic framework

Taking equation (3) of chapter 4 (and dropping other inputs) yields.

$$\ln(MFP_t) = \alpha + \lambda t + \alpha \ln(K_t)\ . \tag{P1}$$

where:

- Y is aggregate output;
- A is a fixed and autonomous technology parameter;
- λ is the rate of exogenous technological change; and
- K is the knowledge (or R&D) capital stock.

Partially differentiating both sides of (P1) with respect to time yields:

$$\frac{\partial \ln(MFP_t)}{\partial t} = \lambda + \alpha \frac{\partial \ln(Z_t)}{\partial t}\ . \tag{P2}$$

Note that

$$\frac{\partial \ln(MFP_t)}{\partial t} = \frac{\partial \ln(MFP_t)}{\partial MFP_t}\frac{\partial MFP_t}{\partial t} = \frac{1}{MFP_t}\frac{\partial MFP_t}{\partial t} = \hat{MFP_t} \tag{P3}$$

and

$$\frac{\partial \ln(K_t)}{\partial t} = \frac{\partial \ln(K_t)}{\partial K_t}\frac{\partial K_t}{\partial t} = \frac{1}{K_t}\frac{\partial K_t}{\partial t} = \hat{K_t}\ . \tag{P4}$$

Substituting (P3) and (P4) into (P2) yields:

$$\hat{MFP}_t = \lambda + \alpha \hat{K}_t \ . \qquad \text{(P5)}$$

From equation (2) in chapter 4 the following can be obtained:

$$\alpha = \frac{\partial \ln(Y_t)}{\partial \ln(K_t)} = \frac{\partial \ln(Y_t)}{\partial Y_t}\frac{\partial Y_t}{\partial K_t}\frac{\partial K_t}{\partial \ln(K_t)} = \frac{1}{Y_t}\frac{\partial Y_t}{\partial K_t}\frac{1}{\left(\partial \ln(K_t) \big/ \partial K_t\right)}$$
$$= \frac{1}{Y_t}\frac{\partial Y_t}{\partial K_t}\frac{1}{\left(1 \big/ K_t\right)} = \frac{K_t}{Y_t}\frac{\partial Y_t}{\partial K_t} \qquad \text{(P6)}$$

Thus α may be interpreted as the knowledge-stock elasticity of output. Substituting (P6) into (P5) yields:

$$\hat{MFP}_t = \lambda + \frac{K_t}{Y_t}\frac{\partial Y_t}{\partial K_t}\frac{1}{K_t}\frac{\partial K_t}{\partial t}, \qquad \text{(P7)}$$

which, after some rearranging, becomes:

$$\hat{MFP}_t = \lambda + \frac{\partial Y_t}{\partial K_t}\left(\frac{1}{Y_t}\frac{\partial K_t}{\partial t}\right). \qquad \text{(P8)}$$

Suppose that the permanent inventory method is applied to R&D investment in order to approximate the knowledge stock. In general, this will mean that the change in the knowledge stock in any (infinitesimally short) period is given by:

$$\frac{\partial K_t}{\partial t} = R_t^{R\&D} - \delta K_t, \qquad \text{(P9)}$$

where R_t equals gross R&D expenditure or investment in period *t*.

Note that the impact of a one unit increase in R&D in the current period will typically diminish over time. However, this is not the case if the R&D stock does not depreciate.

Since placing an upper bound on the impact of an increase in R&D on technological change and hence output is of interest, it shall be assumed that the R&D stock does not depreciate. In this case, (P9) becomes:

$$\frac{\partial K_t}{\partial t} = R_t \ . \qquad \text{(P10)}$$

Substituting (P10) into (P8) yields:

$$\hat{MFP}_t = \lambda + \frac{\partial Y_t}{\partial K_t}\frac{R_t}{Y_t}. \quad \text{(P11)}$$

Finally, let:

$$\rho = \frac{\partial Y_t}{\partial Z_t}. \quad \text{(P12)}$$

Substituting (P12) into (P11) yields:

$$\hat{MFP}_t = \lambda + \rho\left(\frac{R_t}{Y_t}\right). \quad \text{(P13)}$$

Note that ρ in equation (P13) is commonly interpreted as the social rate of return to R&D. The reason for this is outlined below.

P.2 Internal rates of return

The estimate of ρ obtained from regressing the MFP growth rate on a constant term and R&D intensity is often interpreted as the social rate of return to R&D (see chapter 4).[1] The justification for this interpretation, which is based on internal rates of return, is set out in this section. It is assumed that output and R&D stocks are measured in constant price Australian dollars.

Suppose that an additional ΔK dollars is spent on R&D in the current period. In the absence of depreciation, this permanently increases the R&D stock by ΔK dollars over its business as usual time path. Imagine that this increase results in a constant stream of additional output in every future period. Suppose that the additional output in each period is equal to ΔY. If social time preferences can be represented by a constant discount factor $(\upsilon \in [0,1))$, then the present value of the stream of benefits that result from the R&D is:

$$PV(B) = \sum_{t=1}^{\infty} \upsilon^t \Delta Y = \left(\sum_{t=0}^{\infty} \upsilon^t \Delta Y\right) - \upsilon^0 \Delta Y = \frac{\Delta Y}{(1-\upsilon)} - \Delta Y = \frac{\upsilon \Delta Y}{(1-\upsilon)}. \quad \text{(P14)}$$

Suppose that r is the social rate of time preference that is equivalent to a social discount factor of υ. Then the relationship between r and υ is:

[1] Note that the social return includes both private returns and external returns.

$$\upsilon = \frac{1}{(1+r)}. \qquad \text{(P15)}$$

Substituting (P15) into (P14) yields:

$$PV(B) = \frac{\upsilon \Delta Y}{(1-\upsilon)} = \frac{\left(\Delta Y \big/ (1+r) \right)}{\left(1 - \left(1 \big/ (1+r) \right) \right)} = \frac{\left(\Delta Y \big/ (1+r) \right)}{\left(r \big/ (1+r) \right)} = \frac{\Delta Y}{(1+r)} \frac{(1+r)}{r} = \frac{\Delta Y}{r}. \qquad \text{(P16)}$$

The social rate of return for the proposed investment is estimated as the internal rate of return for the proposed investment. The internal rate of return is the social rate of time preference that would equate the present value of the benefits from the investment with the present value of the cost of the investment. Since the present value of the benefits is given by (P16) and the present value of the costs is simply ΔK dollars, this requires that:

$$\frac{\Delta Y}{r} = \Delta K. \qquad \text{(P17)}$$

Rearranging (P17) yields:

$$r = \frac{\Delta Y}{\Delta K}. \qquad \text{(P18)}$$

As the length of each time period becomes infinitesimally small, this becomes:

$$r = \frac{\partial Y}{\partial K}. \qquad \text{(P19)}$$

Note that this presentation differs slightly from that in Revesz (2006). In Revesz (2006), the benefits from the R&D investment are assumed to begin immediately rather than in the next period. As such, the formula in (P18) is only an approximation in the discrete-time version of his model. However, he also presents a continuous-time version of the model in which the formula in (P19) is the exact internal rate of return rather than an approximation of the internal rate of return.

P.3 The upper bound formula for zero depreciation

Note that (P18) can be rewritten as:

$$r = \frac{\Delta Y}{\Delta K}\left(\frac{1/Y}{1/Y}\right) = \frac{\Delta Y/Y}{\Delta K/Y} = \frac{\hat{Y}}{\Delta K/Y}. \qquad \text{(P20)}$$

Suppose that all of the growth in output is attributable to R&D. In the current model this requires four separate assumptions. First, the growth rate in employment must be zero. Second, the growth rate in the conventional capital stock must be zero. Third, the exogenous rate of technological change must be zero ($\lambda = 0$). Fourth, the rate of depreciation of R&D capital must be zero. The first two of these assumptions imply that the growth rate of output is equal to the growth rate of MFP. This allows (P20) to be rewritten as:

$$r = \frac{\hat{MFP}}{\Delta K/Y}. \qquad \text{(P21)}$$

The third assumption allows (P13) to be rewritten as:

$$\hat{MFP}_t = \gamma\left(\frac{R_t}{Y_t}\right). \qquad \text{(P22)}$$

Finally, the fourth assumption implies that

$$\Delta K = R. \qquad \text{(P23)}$$

Taken together, (P21), (P22) and (P23) allow the social return to R&D to be estimated as:

$$r = \frac{\hat{MFP}}{R/Y}. \qquad \text{(P24)}$$

Note that all four of these assumptions tend to overstate the impact that R&D has on the growth-rate of output. As such, they also tend to overstate the impact that R&D will have on the time path of output. Thus the estimate of the social rate of return to R&D provided by (P24) is likely to overstate the true rate of return.

Strictly speaking, the formula in (P24) only applies to a particular point in time. In reality, when it is applied as a rule of thumb, MFP growth rates and R&D investment intensities will be averaged over many periods. This will, at best, approximate the ‘average upper bound’. However, an average upper bound is not really an upper bound. It might be better to calculate the upper bound rate of return to R&D in every period and then use the upper bound of the upper bounds as the actual upper bound.

P.4 An application of the upper bound formula

Despite the caveat listed above, the application of upper bound formula in (P24) is illustrated by using the sample averages for market sector MFP growth rates and R&D investment intensities over the time period 1974-75 to 2002-03.

The average MFP growth rate was 0.009 and the average R&D investment intensity for the market sector was 0.007. As such the upper bound estimate for the social rate of return to R&D is 1.29 or 129 percent. A number of models break this upper bound (for example, model *S2* of chapter 10). This provides an additional reason for rejecting these models, in addition to the sensitivity of the models to seemingly modest alterations.

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