5-year Productivity Inquiry: Whole-of-economy modelling

Inquiry report – *volume 9*
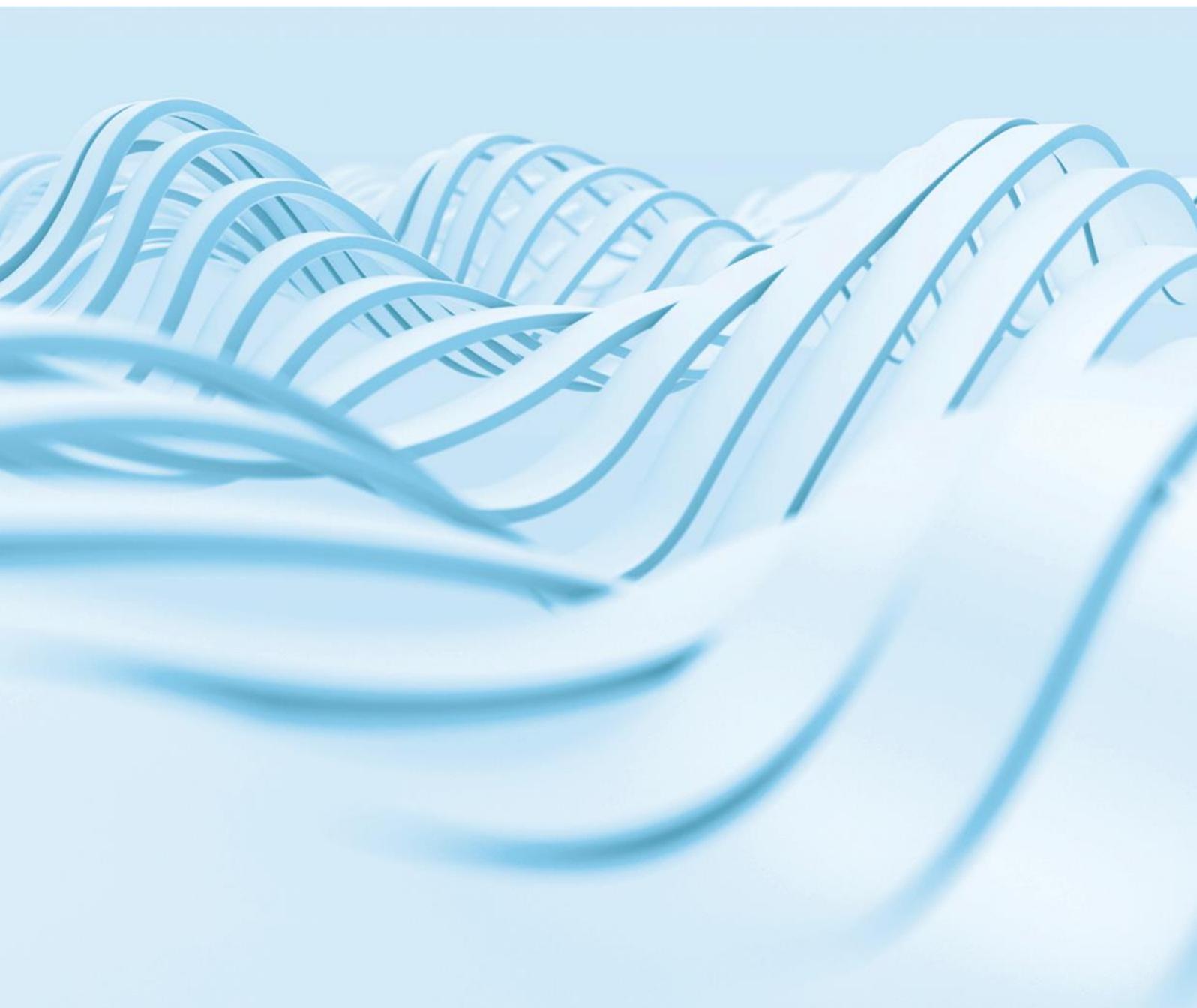
The Productivity Commission acknowledges the Traditional Owners of Country throughout Australia and their continuing connection to land, waters and community. We pay our respects to their Cultures, Country and Elders past and present.

The Productivity Commission

The Productivity Commission is the Australian Government's independent research and advisory body on a range of economic, social and environmental issues affecting the welfare of Australians. Its role, expressed most simply, is to help governments make better policies, in the long term interest of the Australian community.

The Commission's independence is underpinned by an Act of Parliament. Its processes and outputs are open to public scrutiny and are driven by concern for the wellbeing of the community as a whole.

Further information on the Productivity Commission can be obtained from the Commission's website (www.pc.gov.au).

Contents

The Commission's report is divided into 9 volumes: an overview document (volume 1) that presents our policy agenda, and inquiry content volumes (volumes 2–9) that explain in greater detail the reforms that make up the policy agenda, including a modelling appendix. The full report is available from www.pc.gov.au.

Preface

The Commission used a purpose-built computable general equilibrium (CGE) model to illustrate the whole-of-economy effects of stylised representations of some proposed reforms.[1] While the simulations are stylised, the value in using the model is its insights on:

• how productivity improvements can flow through the economy's structure, and what the changes are in underlying economic variables that are driving overall movements in aggregate outputs such as GDP, gross national income, prices, wages and use of labour
• measures relating to the impact of reforms on consumer wellbeing (in monetary terms, for example, equivalent variation) and inequality (for example, the Gini coefficient)
• the differential impacts of reforms across various groups in the economy, at both the individual level (by age, education and gender groups) and the business level (by industry).

However, there are questions that the model is not well placed to answer. CGE models trace the impacts of particular shocks over the short or long run but have limited ability to capture the broader aspects of a shock that are not explicitly defined in the model, such as uncertain spillover effects. If all or many of the inquiry's recommendations were implemented, the capacity of the economy to innovate and harness new opportunities would improve, further lifting long-run growth. These broader impacts can be illustrated using other methods, such as the simple growth accounting framework that demonstrates the power of exponential productivity growth on economic growth and living standards outlined in this inquiry's companion volume *Keys to Growth*.

This volume first covers the details of the CGE model structure and its limitations (chapter 1), data sources and parameters (chapter 2), and an outline of the simulations run for the Productivity Inquiry (chapter 3). The key results from each simulation are presented in the appendices of the relevant companion volumes of this inquiry. A summary of sensitivity testing results is presented in chapter 4, and simple representations of the model equations in chapter 5.

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[1] Consultations, including a workshop in November 2022, were held to receive feedback on the development of the model and simulation results. The model and results contained in a draft version of this volume were also reviewed by LY Cao, with the review report attached at the end of this volume. The feedback received through these methods was greatly appreciated and the Commission thanks participants for their time and engagement.

1. Model structure

The CGE model for the Productivity Inquiry is a static model of the Australian economy with multiple industries in the production sector and different individual groups within the household sector, which reflect different combinations of age groups, sexes and education levels. The model structure draws on some elements from the PCNational model (used for example in PC 2022, pp. 42–45) and the illustrative CGE model used by Hosoe, Gasawa and Hashimoto (2010), but contains greater heterogeneity.

The model's industries use labour and capital in their production process, where different types of labour are provided by the different individual groups in the household sector. The government comprises another sector of the economy, as does investment. The Australian economy interacts with the rest of the world through the flow of exports and imports, capital income and investment. Figure 1.1 shows a simple representation of the model structure, including the interlinkages between parts of the economy. The number of industries, and types of labour and individual groups in this figure are illustrative only.

Furthermore, in a CGE model, one price (the 'numeraire') must be determined outside of the model[2] — in this model, the household consumption price index is chosen as the numeraire. All model prices are expressed relative to the numeraire.

More detailed descriptions of the model structure by each major entity or activity, including choices around which variables are determined within the model and which are given outside of the model ('closure' assumptions), are covered below. Box 1.1 summarises the main closure assumptions in the model, and chapter 5 covers equations illustrating relationships in the model.[3]

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[2] This is due to Walras' law which implies that if all but one market clears, then the last market also clears and its market clearing constraint is redundant.

[3] The model was built using the GAMS software and the equations formulated as mixed complementarity problems. This formulation allows for explicit pairing between an economic variable and its equation either as an equality or inequality constraint (Abrell 2017; Murphy, Pierru and Smeers 2016). For example, a wage floor was implemented in some sensitivity testing simulations (chapter 4) as an inequality constraint, with unemployment as its paired variable.

Figure 1.1 – Simple illustration of model structure[a]

Producers

Use labour and capital

Use domestic and imported commodities

Sell domestic and exported commodities

| Industry 1 | Industry 2 | Industry 3 |

Rest of world

Buys exports

Sells imports

Provides capital
Receives capital income

Provides savings for investment

Government

Taxes and subsidises production, sales, household income, foreign capital income

Consumes domestic and imported commodities

Individual groups within household sector

Provide labour and capital
Receive labour and capital income

Provide savings for investment

Consume domestic and imported commodities

Enjoy non-work activity

| Individual group 1 / Labour type 1 | Individual group 2 / Labour type 2 | Individual group 3 / Labour type 3 |

Investment

Uses domestic and imported commodities to produce capital

a. Arrows indicate value flows originating from one sector and flowing to another sector. For example, the grey arrow linking producers to individual groups indicate payments flowing to individual groups for use of labour and capital, and to producers for purchases of commodities.

Box 1.1 – Summary of closure assumptions

Closure refers to the choice of variables that are determined within the model (endogenous variables) and those that are given outside of the model (exogenous variables). Key closure assumptions in the main model simulations are listed below. Some of these assumptions are changed in sensitivity testing analysis (chapter 4).

- The rate of return to capital (defined as the rental price of capital relative to the price of investment) is exogenous. Capital is mobile across any industry, and the size of the capital stock is determined through demand from the production sector, given the rental price. This implies a long-run assumption in which the size of the capital stock is flexible.
- Investment is determined through its relationship with the capital stock — if the capital stock increases, more investment is required to maintain that capital stock. Domestic saving and the domestic capital stock endogenously adjust to meet the level of investment and capital required.
- The quantity of foreign investment and the foreign capital stock are exogenous. This assumes that the availability of foreign investment and foreign ownership of capital are limited, and not affected by domestic variables or policies. It also means that the current account deficit (which equals foreign investment inflows) is fixed relative to the price of investment, and movements in the balance of trade are also limited.
- The international prices of imported commodities are exogenous. This implies that Australia takes world prices of imports as given. The total quantity of imports is determined through demand from users at given prices.
- Foreign demands for Australian commodities are based on fixed downward sloping demand curves. This assumes that Australian exporters have some market power in the world market.
- Government expenditure is determined through its relationship with GDP — the size of government spending grows linearly with GDP. Government spending is assumed to have no effect on the model's productivity parameters.
- Government tax rates are exogenous, except for household income tax rates that endogenously adjust to balance the government budget. The amount of household income tax enters as a lump sum into individual group decision making processes in a non-distortionary way.
- Each individual group has a fixed time endowment that can be allocated between labour and leisure. Wage rates are determined through market clearing of individual group labour supply decisions (via a utility maximisation process) and industry labour demand decisions (via a cost minimisation process). Any type of labour supplied can be used across any industry (that is, labour is perfectly mobile).

1.1 Individual group decision process

The household sector is split into individual groups to enable analysis of reforms that may affect different groups in different ways. For example, these groups can represent individuals that are likely to be affected differently by proposed reforms to schooling and tertiary education (chapter 3). Simulated shocks to the productivity of industries can also have differential effects on these groups depending on the composition of labour used by the industries. Individuals are grouped according to their combinations of:

- age group — 15-24, 25-34, 35-44, 45-54, 55-64, 65+
- gender — male, female
- highest education level — 'Up to Year 12 or Cert I/II', 'VET Cert III/IV or Diploma', 'Bachelor degree or higher' (or school-, VET- and university-educated for simplicity).

Figure 1.2 illustrates the nested decision process for individual groups to consume commodities (goods and services) and supply labour. Individual groups seek to maximise their utility, which is a constant elasticity of substitution (CES) function of 'leisure' (any time not spent in work) and a 'composite' consumption good (a bundle of commodities they consume), subject to their budget constraint and a time constraint.[4] The budget constraint comprises labour and capital income, less saving and income taxes, to fund consumption. Saving and income taxes enter the budget constraint in a non-distortionary way as lump sum values. The time constraint allocates a fixed time endowment between leisure and hours worked.

Individual groups also choose how much of each household composite (of domestic and imported commodities) they consume, by minimising their expenditure to meet a given quantity of the composite consumption good (determined from the above utility maximisation problem), via a CES function.

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[4] The model includes the option of a wage floor, which can drive a wedge between hours actually worked and available labour, creating unemployment endogenously. A wage floor can illustrate the effects of wages that are sticky downwards, for example due to long-term contracts or labour market rigidities. The wage floor is used to test the sensitivity of some modelled scenario results. It is implemented via an intermediate household decision, where individual cohorts first choose how much they would like to work, given prevailing wages and prices. If there is a binding wage floor, labour supply will exceed labour demand, inducing unemployment.

Figure 1.2 – Individual group decision process[a,b]
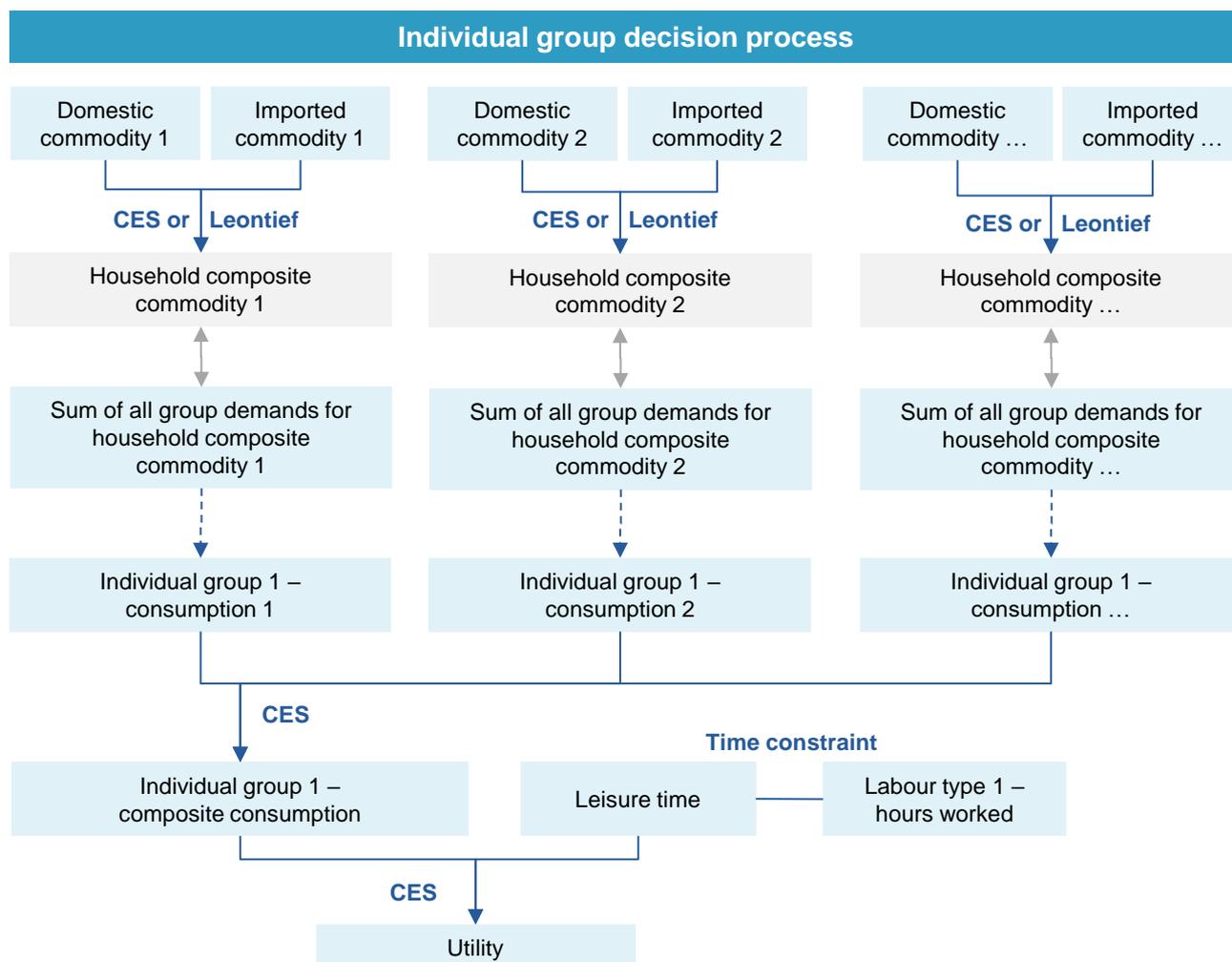
a. Blue text describes relationships between different components of this diagram. Grey shading indicates a component that is subject to product taxes. Dashed arrows indicate that only some components of a sum are detailed in the diagram. Grey arrows indicate that market clearing conditions balance demand and supply. **b.** A CES relationship was used to create composites of domestic and imported commodities, and a Leontief relationship was used where there were no imports of a commodity in the database.

1.2 Industry production processes

The model has 17 industries on the production side (listed below), based on the main industries of interest for the inquiry's simulations (for example, 'school education' and 'technical, vocational and tertiary education' were separated due to separate reforms simulated for school education and higher education). Some industries were also separately identified due to their more distinctive production or expenditure structures (for example, construction is heavily used by the investment sector):

1. Agriculture, forestry and fishing
2. Mining

3. Advanced manufacturing[5]
4. Other manufacturing
5. Construction
6. Transport and wholesale
7. Retail trade
8. Hospitality
9. Technology and telecommunications[6]
10. Financial services
11. Professional, scientific and technical services
12. School education
13. Technical, vocational and tertiary education
14. Health and social services
15. Public administration
16. Other services[7]
17. Ownership of dwellings.

Figure 1.3 illustrates the nested production process for a given industry. Inputs are used to create outputs at each stage of the process via a cost minimisation decision for given levels of output, subject to assumed CES, constant elasticity of transformation (CET) and Leontief production functions.

The two factors of production used are capital and labour, the quantity of which are both flexible. Capital inputs and each labour type input are also perfectly mobile; that is, they can be used across any industry (there are no industry-specific labour types or capital). However, each industry has their own production functions to determine the composition of labour types and composition of labour and capital used.[8]

Alongside these factors of production, producers in each industry use intermediate inputs to produce industry outputs. Both domestic and imported commodities are combined to form composites of intermediate inputs.

Across the production functions for creating composite labour, composite factors (value added, combining labour and capital), and industry output, there were productivity parameters included to allow adjustments to labour-augmenting technical change, multifactor productivity, and input-neutral technical change respectively. These parameters were adjusted in various model simulations (chapter 3).

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[5] Industries that comprise 'advanced manufacturing' were identified with reference to industries listed in a study of Australian advanced manufacturing (DIIS and IP Australia 2017, pp. 85–86). These include industries covered under 'basic chemical manufacturing', 'cleaning compound and toilet preparation manufacturing', 'transport equipment manufacturing' and 'machinery and equipment manufacturing'.

[6] 'Technology and telecommunications' includes 'internet service providers, internet publishing and broadcasting, websearch portals and data processing', 'telecommunication services' and 'computer systems design and related services'.

[7] 'Other services' include energy and utilities, rental and real estate services, administrative and support services, arts and recreation, repair and maintenance, and personal services. These services were grouped together for the model because they were not separately considered to be key industries of interest for the simulation scenarios.

[8] There are two CES processes for creating composite labour for each industry. The first involves combining age-sex labour combinations to create a composite labour by education level. The second involves combining each education-level labour composite into a single industry composite labour. Note that while producers are not actually able to discriminate in their hiring choices by age group or sex, assuming imperfect substitution of labour by age group and sex in the model provides a simple way of reflecting differences that exist due to people's preferences for working in certain industries.

Figure 1.3 – Industry production processes[a,b,c]
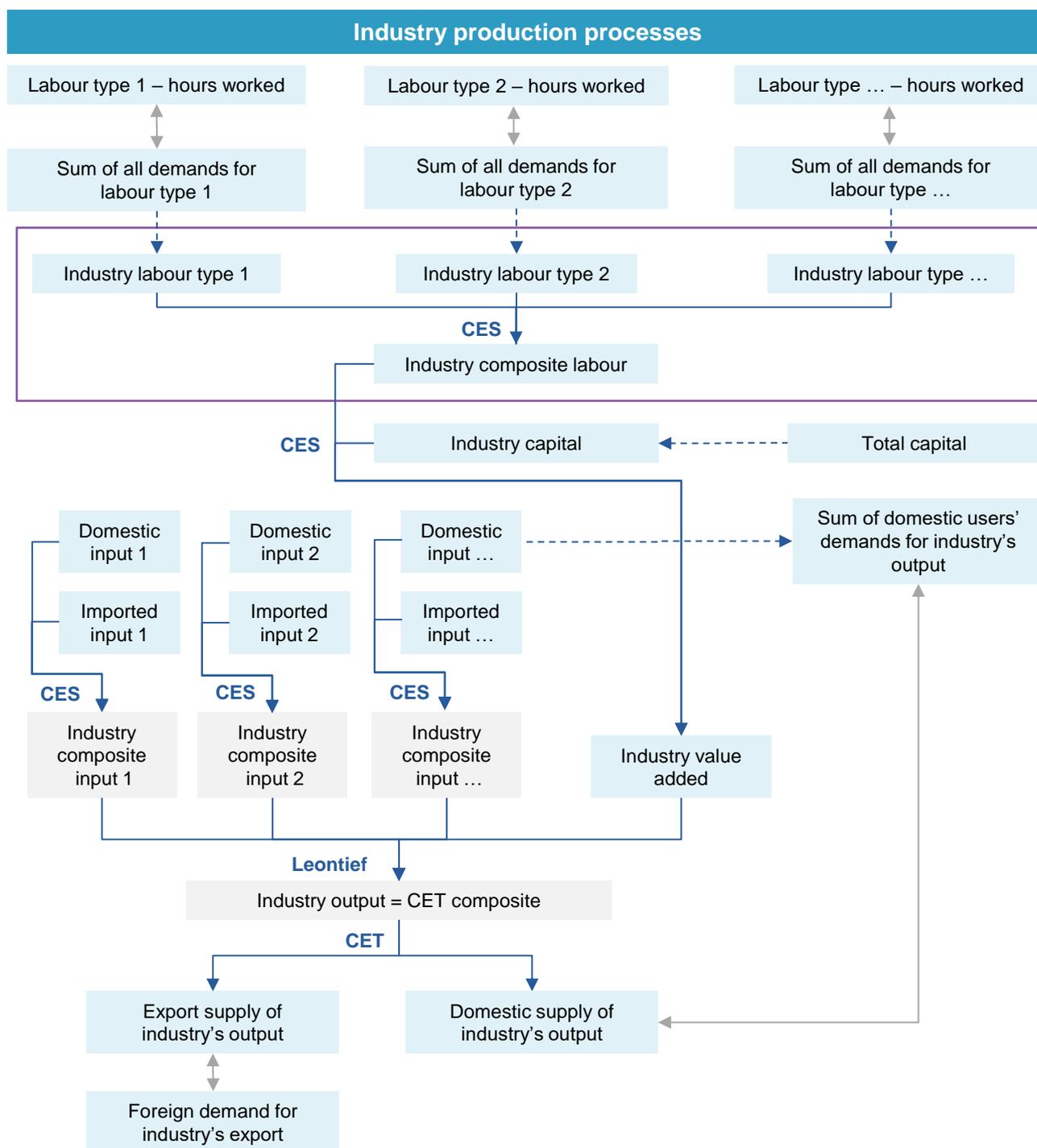
a. Blue text describes relationships between different diagram components. Grey shading indicates a taxed component (either a product tax or production tax). Dashed arrows indicate that only some components of a sum are detailed. Grey arrows indicate that market clearing conditions balance demand and supply. b. The purple box is a simplified representation of the creation of composite labour in each industry. In the model, there are two CES nests in this process. The first involves combining age-sex labour combinations to create a composite labour by education level for each industry. The second involves combining each education-level labour composite into a single industry composite labour. c. The 'ownership of dwellings' industry does not employ labour in the data, so is only produced using capital and intermediate inputs.

Producers also make choices about whether industry outputs are exported or used domestically via a CET function. Given the relatively broad industries used in the model, this decision could arise because the composition of more granular commodities (not separately modelled) exported by an industry may be different from the composition of granular commodities sold domestically.

1.3   Government decision process

Figure 1.4 illustrates the government decision process. There is one government entity, which purchases composite commodities (made up of domestic and imported commodities) according to a Cobb-Douglas consumption function, subject to its budget constraint. The government budget constraint comprises net tax revenues (less subsidies) from production (including industry-specific taxes levied on the value of production, and taxes levied on sales with rates that differ by the commodity and the buyer of that commodity), household income taxes and foreign capital income taxes. The Cobb-Douglas relationship implies that expenditure shares are constant — that is, the government allocates a fixed share of its total expenditure to consumption of each commodity. The total nominal value of government consumption is also assumed to be a fixed share of nominal GDP, so grows with GDP growth.

Government tax rates are fixed, except for household tax payments, so revenue largely moves in line with the various tax bases. Household tax payments adjust to balance the government budget constraint. Each individual group's tax rate scales according to the total value of tax the government requires under the simulation relative to the base scenario.

Figure 1.4 – Government decision process[a,b]
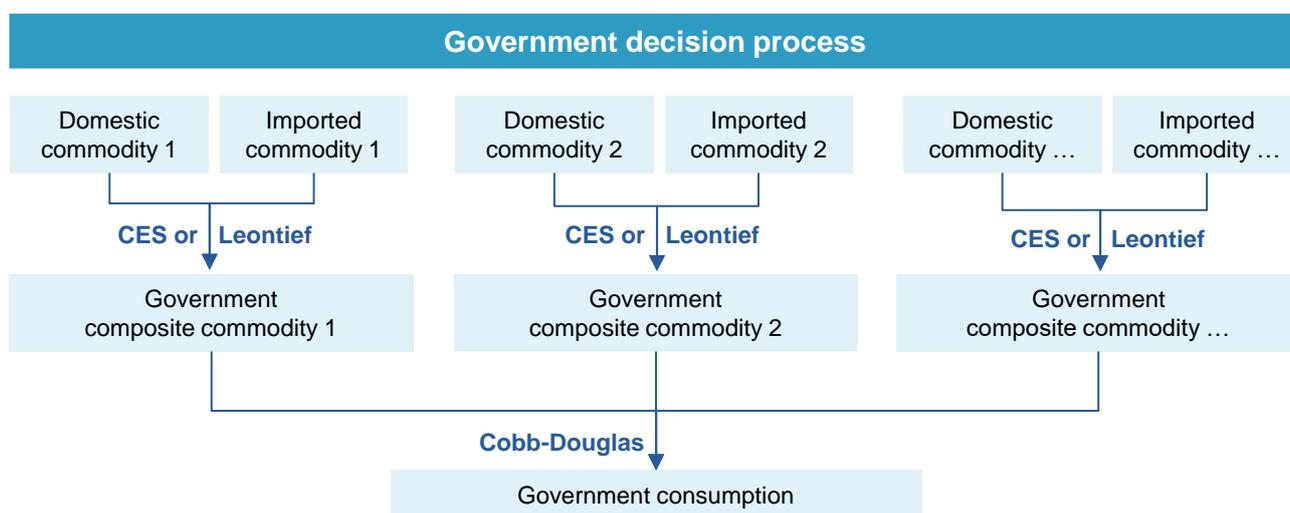
a. Blue text describes relationships between different diagram components. **b.** A CES relationship was used to create composites of domestic and imported commodities, and a Leontief relationship was used where there were no imports of a commodity in the database.

1.4   Investment and capital processes

The size of the capital stock is assumed to be variable, while the rate of return to capital (defined as the price of capital relative to the price of investment) is fixed. It is also assumed that investment and capital relationships are in steady state, and that the ratio of real investment (new capital) to real capital (the capital stock) is fixed — that is, a fixed quantity of investment is required to keep the capital stock constant due to capital depreciation.

Figure 1.5 illustrates the investment process. The investment sector uses domestic and imported commodities to produce composite inputs, which it then uses in fixed shares to invest in capital (via a Leontief function).

Capital is owned by domestic and foreign investors, and savings from individual groups and foreign investors are used to fund investment activity. Real foreign investment and the capital stock owned by foreigners are assumed to be fixed. This means that only savings by domestic investors adjust to meet the value of investment activity, and similarly for the capital stock. Each individual group's saving rate and capital to saving ratio scale according to the total value of domestic saving and capital required under the simulation relative to the base scenario.

Figure 1.5 – Investment process[a,b]
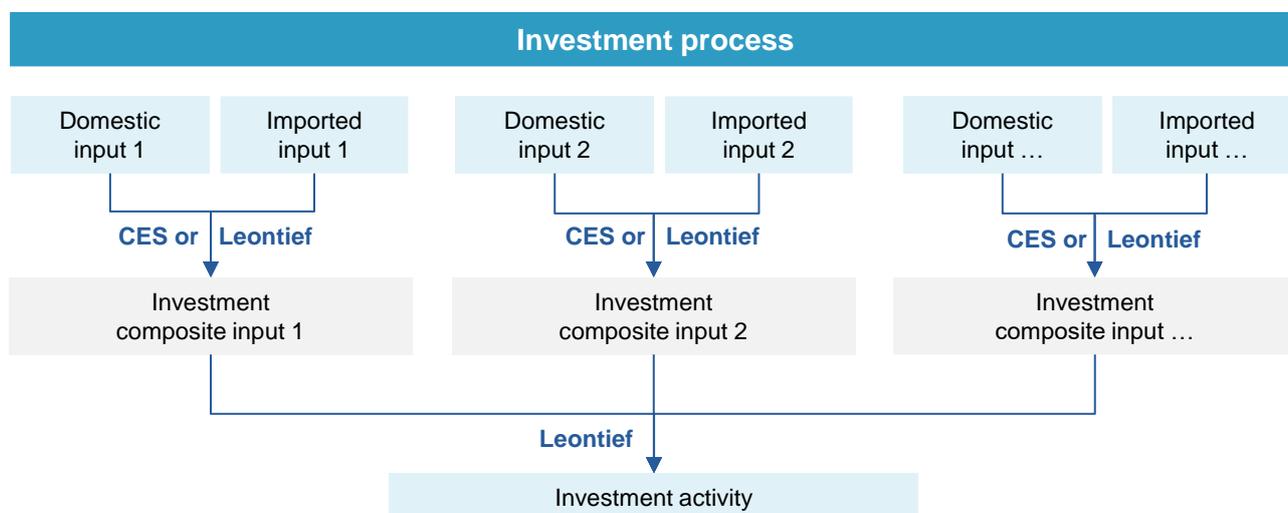
a. Blue text describes relationships between different diagram components. Grey shading indicates a component that is subject to product taxes. **b.** A CES relationship was used to create composites of domestic and imported commodities, and a Leontief relationship was used where there were no imports of a commodity in the database.

1.5   The rest of the world

Australia interacts with the rest of the world via trade in commodities, foreign investment and supply of foreign capital. Foreign supplies of imported commodities are assumed to be perfectly elastic at a given international price. The exchange rate changes relative to the household consumption price index. Total Australian demand for an imported commodity is the sum of demands from household, production, government and investment sectors. Foreign demands for Australian commodities are based on downward sloping demand curves. Total outflows from Australia to the rest of the world equal total inflows.

1.6   Model structure limitations

The model structure means that it is not able to produce detailed results of some aspects of the economy. For example, it is not able to comment on effects across more granular industry groupings (than the 17 that have been explicitly defined in the model), different states or regions of Australia, different types of capital, occupations, or dynamic effects over time. The measure of hours worked also does not differentiate between changes due to more people gaining employment or existing workers working more hours.

Other simplifying assumptions may also have an effect on model results. For example, the main model assumptions do not contain 'fixed factors'; that is, factors that are assumed to be in fixed supply (such as

land, which is especially important for agriculture and mining). Inclusion of a fixed factor would involve assuming some portion of payments currently allocated to capital or labour are instead allocated to the fixed factor. Allocating some share of capital to land as a fixed factor would mean that the production sector has more limited scope to expand, and some aggregate effects in the economy may be smaller than seen under the current model, because land cannot grow via investment. Some of the effects of constraining factors of production are examined as part of sensitivity testing (chapter 4).

In addition, it is assumed that the rate of return to capital, foreign capital and real foreign investment are fixed in the model. It is possible that some policy reforms that improve productivity could increase rates of return and induce greater foreign investment. These dynamics are not examined in this model.

Capital and investment are also assumed to be in steady state, with investment being equal to depreciation. However, data on capital and investment for a particular year might not reflect a steady state economy — due to mismatches between the timing of investment decisions and depreciation, or because investment and the capital stock are growing over time. The model and use of data for calibrating parameters (chapter 2) does not account for this possibility. Therefore the size of the investment sector (and use of inputs used to create investment) may differ from an actual steady state economy.

Furthermore, an attribute of the CES function, which is used in individual group decisions to consume commodities, is that expenditure elasticities are unitary — a 1% increase in income or expenditure is associated with a 1% increase in demand for commodities. Past research suggests that this is unlikely to be the case; for example, people may dedicate some amount of expenditure to a bundle of necessities first, irrespective of income, before choosing to spend their remaining income on other goods and services (Gharibnavaz and Verikios 2018). The CES functional form means that, for industries that supply commodities for which demand usually rises with increasing income levels, simulated growth may be lower than it otherwise would be.

Given model structure limitations, along with the stylised way in which simulated shocks have been implemented (chapter 3), the simulation results should not be interpreted as being the absolute effects of reform. Nevertheless, the model structure provides a tractable means of illustrating some whole-of-economy effects of the stylised scenarios.

2. Data sources and parameters

The initial values of the model's variables (of prices and quantities for example) and the estimation of parameters (such as share parameters in Cobb-Douglas functions) require a database that reflects the Australian economy. The values, prices and quantities in the database are then used to solve for unknown model parameters through a process known as 'calibration'. As model databases usually contain data on *values* of production and expenditure (equal to prices multiplied by quantities), rather than prices or quantities separately, it is conventional to assume that prices are normalised to be one. This allows quantities to be estimated as values divided by prices. Where there are indirect taxes, tax-exclusive prices are normalised to be one, and then adjusted by applicable tax rates to estimate 'purchaser prices', in order to determine quantities. This convention has been applied in the calibration process for most parameters in this model.

In some functions, there are more unknown parameters to solve for than there are available data on prices and quantities. Consequently, some model parameters have to be assumed to allow the other model parameters to be calibrated — for CES functions, usually the elasticity of substitution is assumed or drawn from the literature.

This chapter describes the data used to form the model's database, and the elasticities assumed in the model.

2.1 The social accounting matrix

An aggregate social accounting matrix (SAM) was developed to form the backbone of the model's database.[9] This contains aggregate flows between the model industries, commodities, capital and labour, the household sector, government sector, investment sector, and the rest of the world. This was supplemented by an Input-Output (IO) table that contains more detail on use of domestic and imported commodities and product taxes.

The ABS National Accounts IO tables were the main data source for the model's SAM. The tables contain data that 'provide detailed information about the supply and use of products in the Australian economy, and the structure of and inter-relationships between Australian industries' (ABS 2021a). This data is categorised into 114 'Input Output Industry Groups', which were then aggregated to the model's 17 industries.

Data from 2018-19 was used because production activity in the more recent 2019-20 data may reflect the impacts of COVID in 2020. For consistency, 2018-19 sources of data were used for other values in the model's database where available. 2018-19 data was not available for some sources needed to estimate variables by individual group (described below), in which case data from the closest year to 2018-19 was used, and adjusted for the 2019 population.

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[9] A SAM records data on transactions (inflows and outflows) between economic agents in an economy. It is a square matrix where each row and column represents an activity, commodity, factor or institutional sector. Each cell shows the payment from the column account to the row account. The SAM must be balanced — that is, all inflows must equal outflows for a particular account. The structure of the SAM (that is, the economic agents included and the flows between them) must also concord with the CGE model's structure and equations.

The value of foreign capital income was informed by data in the Balance of Payments (ABS 2021b). For other cells in the aggregate SAM where the values were not given in the ABS IO tables (such as household income tax payments and savings), values were calculated as the remainder of the row or column total to ensure the SAM was a balanced matrix.

As described in chapter 1, the model's household sector is split into individual groups or labour types — for example, income and expenditure differ by individual group — which is not reflected in the aggregate SAM. Additional data sources were used to reflect this heterogeneity in the model database (described below). The heterogeneity was achieved by calculating *shares* attributable to labour types and individual groups, which were then used to apportion the values in the SAM. The sums across labour types and individual groups must equal the corresponding cells in the aggregate SAM, to ensure that the SAM remains balanced.

2.2 Expenditure, factor incomes, and income tax by individual group

Expenditure by individual group

Each individual group within the model consumes a proportion of total household consumption of commodities. Data from the 2015-16 Household Expenditure Survey (HES) (ABS 2017) was used to estimate these proportions.

To estimate person-level expenditure, household expenditure was apportioned to each person over 15 years old in the household according to their contribution of disposable income to the household. This was necessary as the expenditure data in the HES is collected at a household level, but the model's individual groups are based on person-level characteristics.

The amount of expenditure on each industry in the model was estimated by mapping HES expenditure classifications (which use the Household Expenditure Classification) to the 17 model industries. This was done using concordances and information in IO tables on production of commodities by industry. Negative expenditures in the HES, arising for example from sales of cars and dwellings, were also removed as the inclusion of these sales is inconsistent with the definition of expenditure in the model.

The person-level expenditures by industry were then used to calculate the proportion of expenditure by each individual group in the household sector of the model (adjusted to the 2019 population). These proportions were applied to aggregate household expenditure by industry in the SAM to estimate the expenditure for each individual group.

Labour and capital income, and income tax by individual group

The amounts of labour income received by each individual group working in each industry, as well as capital income received and income tax paid by each group in the model, are based on proportions calculated using data from the 2017-18 Survey of Income and Housing (SIH) (ABS 2019b).

The method used to calculate the proportions for each variable in the model was essentially the same, but different variables from the SIH were used. For example, for income tax paid, the aggregate weighted income tax paid and the share of the total paid by each group was calculated and adjusted to the 2019 population. These proportions were then applied to aggregate household income tax in the SAM to estimate the amount of tax paid by each group. A similar process was undertaken to estimate labour and capital income for each group in the model.

2.3   Normalised hours

Normalised time endowment

Each individual group in the model has an exogenous time endowment, representing the total amount of time they can choose to allocate between work and leisure activities. These time endowments were normalised to a value of 1 per person in the group's population. Individual group populations were based on Australian demographic statistics on the Estimated Residential Population at June 2019 (ABS 2019a). Normalising total time per person to 1 means that changes to population size can be easily interpreted in terms of numbers of people, and it allows wage rates (calibrated from normalised hours worked below) to be more easily compared across individual groups because they are in terms of the same time units.

Normalised hours worked

A range of values have been used in the literature to represent the ratio of hours worked to total time available (usually at the population level rather than at an individual group level). Parameters range from about 0.3 to 0.9 in different models (based on Boeters and Savard 2013, p. 1654; Dixon and Nassios 2019, p. 7; Hinson, Wende and Womack 2020, p. 24; Turnovsky 2002, p. 1774), which do not usually imply a total of 24 hours per day or a standard work week of 40 hours. Values are sometimes chosen to achieve plausible labour supply elasticities. Boeters and Savard (2013, p. 1653) argue that the ratio should be such that the income elasticity of labour supply is within an empirically plausible range.

The parametrisation of hours worked in this model assumes a ratio of total hours worked to total time available in the population of 0.5. That is, half of potential time available is spent working, while the other half is spent on leisure activities. This determines total normalised hours worked across the *population*.

Normalised hours worked at the *individual group* level was then determined using estimates from the 2017-18 SIH (ABS 2019b) on the share of total hours worked attributed to each group (adjusted to the 2019 population). These shares were applied to *population* normalised hours worked in order to calculate normalised hours worked for each *group*.

Using this method, the ratio of hours worked to total time varies greatly across individual groups, ranging up to about 0.9 for some prime working age groups, and down to about 0.1 for retirement age groups. The implied income elasticities of labour supply[10] also vary greatly across groups, with an aggregate elasticity of about -0.5. This is larger in magnitude than the plausible value suggested in the literature of about -0.1, though is similar to plausible values suggested for lone parents (Boeters and Savard 2013, p. 1654; Giesecke et al. 2021, p. 5934). An alternative approach to determining the ratio of hours worked to total time, that achieves a more plausible income elasticity of labour supply, is discussed below.

The implied wage elasticities of labour supply differ across individual groups as well, with labour supply responses tending to be higher for women and for less educated groups, and an aggregate elasticity of about 0.2. These patterns across sex and education level are consistent with the literature, and the aggregate elasticity is within ranges in other studies of about 0.1 to 0.3 on average across men and women (based on estimates cited in Dandie and Mercante (2007, pp. 37–39) and Dixon and Nassios (2019, pp. 9–

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[10] Note that the income elasticity of labour supply is not the same as the wage elasticity of labour supply, which is discussed subsequently. The income elasticity of labour supply is calculated as the change in labour supply with respect to a change in non-labour income by an amount that would increase total disposable income (from labour and non-labour sources) by 1% if labour supply did not react (Boeters and Savard 2013, p. 1653).

10)), but is higher than the elasticities of slightly less than 0.1 that were calibrated in an Australian CGE study (Dixon and Nassios 2019, p. 9).

In the calibration process, using data on normalised hours worked (a quantity variable) means that wage rates (a price variable) are estimated by dividing labour income values by normalised hours worked for each individual group, rather than being normalised to one like other prices. Calibrated wage rates per normalised hour were higher for men and more highly educated groups, consistent with actual data on the Australian economy.

Normalised time and hours worked for sensitivity testing

An alternative approach to determining the ratio of hours worked to total time was also examined, with discussions of simulations using this approach covered in the sensitivity testing chapter (chapter 4). Under this approach, a ratio of hours worked to total time was assumed in order to produce income elasticities of labour supply closer to the range suggested in the literature. It was also assumed that women had larger labour supply responses than men, and that school-educated groups had larger responses than more highly educated groups.[11] Total time available to each cohort was determined by applying the assumed ratios to the individual group-level normalised hours worked from the previous approach.

Using this method, income elasticities of labour supply ranged from about -0.08 for more educated men to -0.15 for less educated women, with an aggregate elasticity of about -0.10, which is similar to that suggested in the literature, noted above. Elasticities of labour supply with respect to wages were relatively low, with an aggregate elasticity of about 0.02 (which corresponds more closely to elasticities for married men in the literature cited above).

Normalised unemployed hours for sensitivity testing

The primary model simulations assume that there is no unemployment, and that labour markets fully clear. The existence of unemployment was assumed in some sensitivity testing simulations (chapter 4). In these simulations, an initial value of normalised unemployed hours was required for each individual group. Detailed Labour Force Survey data for 2018-19 (ABS 2022a) was used to estimate these values. Available information on unemployment by age-sex-education group was used to inform how hours sought (available only by age and sex) might be distributed across different education levels. To then calculate *normalised* unemployed hours, the ratio of hours worked to hours sought was estimated for each group, and applied to normalised hours worked.

2.4   Other individual group values

The value of saving by each individual group was calculated as a remainder from individual group income and expenditures. For some individual groups (typically younger and female groups), the value was negative, likely because they tend to be living in households where higher income earners supplement their proportional household spending. The interpretation in the model is such that some 'saving' by positive-saving groups is transferred to negative-saving groups so that the latter groups can consume more. The sum of individual group savings equals household savings in the aggregate SAM.

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[11] As cited in Giesecke et al. (2021, p. 5934), past research suggests that income elasticities of labour supply for married women are more negative than for married men, and elasticities for lone parents are more negative than for couple families. Lone parents have also been found to have lower levels of education on average (ABS 2007).

An initial quantity of utility is also required for each individual group. Utility is a conceptual construct, and is not observable in data. Initial utility was normalised to be 1 per person in each group, which implies that each person's utility is equally important to begin with. Changes in utility values were converted to equivalent variation estimates (expressed in monetary terms) for ease of interpretation in the analysis of simulations (chapter 3).

2.5   Elasticities

Table 2.1 outlines the elasticities used in the model, including the values used in the base model and those used in sensitivity testing (chapter 4). The elasticities were informed by the literature and existing models where possible, and tested at a technical workshop with external CGE modellers. Elasticities for which there was greatest uncertainty were sensitivity tested.

Table 2.1 – Assumed elasticities

Parameter	Base value	Sensitivity testing	Comments and sources
Individual groups in household sector			
CES elasticity of substitution between consumption and leisure	1.1	None	Base value based on Dixon and Nassios (2019). Background research included: Agbahey, Siddig and Grethe (2020); Boeters and Savard (2013); Fox (2002); Qi (2014)
CES elasticity of substitution between composite consumption commodities	0.5	0.3 to 0.7	Hinson, Wende and Womack (2020); Murphy (2018)
Industry production			
CES elasticity of substitution between (composite) labour and capital	0.5	0.3 to 0.9	Base value based on Hinson, Wende and Womack (2020). Background research included: PCNational model (unpublished); Bullen et al. (2021); Cheong and Sonnenschein (2012); Gechert et al. (2019); Kopecna, Scasny and Recka (2020); KPMG Econtech (2010); Independent Economics (2015); Murphy (2018); Sanchez (2004)
CES elasticity of substitution between different types of labour	4 (by age-sex) 3 (by education)	2.0 to 6.0 (by age-sex) 1.5 to 5.0 (by education)	Values based on feedback from modelling workshop participants. Background research included: Autor (2018); Blankenau and Cassou (2011); Cheong and Sonnenschein (2012); De Giorgi (2013); Ghosh (2018); Guisinger (2020); Havranek et al. (2020); Jerzmanowski and Tamura (2020); KPMG

Parameter	Base value	Sensitivity testing	Comments and sources
			Econtech (2010); Merette (2007); Murphy (2018)
Trade			
CES elasticity of substitution between domestic and imported commodities — for household, production, government and investment sectors	1.12 (agriculture, forestry and fishing) 3.42 (mining) 2.12 (advanced manufacturing) 2.69 (other manufacturing) 0.25 (transport and wholesale) 0.30 (hospitality; technology and telecommunications; professional, scientific and technical services; other services) 0 (all other industries)	None	Values based on KPMG Econtech (2010) and feedback from modelling workshop participants. Background research included: PCNational model (unpublished); Cheong and Sonnenschein (2012); Clements, Mariano and Verikios (2020); Delahaye and Milot (2020); Go (1994); Hinson, Wende and Womack (2020); Sanchez (2004); Independent Economics (2015); Hertel and van der Mensbrugghe (2019); Verikios et al. (2021)
CET elasticity of transformation between exports and domestic commodities	2.5	None	Value based on feedback from modelling workshop participants. Background research included: Cheong and Sonnenschein (2012); Go (1994); Independent Economics (2015); KPMG Econtech (2010); Verikios et al. (2021); Warr and Lapiz (1994)
Price elasticity of export demand	-3 for industries where Australia has more price-setting power (agriculture, forestry and fishing; mining; advanced manufacturing; transport and wholesale; hospitality; school education; technical, vocational and tertiary education) -4 for other industries	None	Values based on feedback from modelling workshop participants. Background research included: Adams, Dixon and Horridge (2015); Hinson, Wende and Womack (2020); Independent Economics (2015); KPMG Econtech (2010); Verikios et al. (2021)

3. Simulations and output variables

3.1 Summary of simulations

This chapter provides a summary of the simulations run for the Productivity Inquiry. The modelling shows how stylised representations of select reforms could flow through the economy given the defined relationships between the various sectors of the economy in the model.

Table 3.1 lists the modelled scenarios, while the key results from each simulation are presented in the appendices of the relevant companion volumes of this inquiry. Shocks were dimensioned based on estimates from the literature where possible and were tailored for the specific scenarios modelled. Sensitivity testing was undertaken given the significant uncertainty in potential shock sizes and the relevance of the literature. Depending on the nature of the scenario, productivity shocks were implemented as an improvement in either:

- the input-neutral technical change parameter, which results in all production inputs (labour, capital and intermediate inputs) being used more productively such that more output can be produced using the same level of input
- the multifactor productivity parameter, which results in labour and capital being used more productively
- the labour-augmenting technical change parameter, which results in labour being used more productively.

The scenarios do not include modelling of the costs of implementing reforms (which could include, for example, changes in the use of intermediate inputs, changes to fiscal budgets, adjustment costs). These costs are also highly uncertain and depend on the specifics of the implementation process. Costs and other considerations in reform implementation are discussed in other volumes of this inquiry.

The results from one scenario should not be directly compared with another, as there are significantly different levels of confidence in the size of the potential reform impact and/or the ability to represent the reform in the model.

Table 3.1 – Summary of simulations

Report volume	Scenario description	Shocked parameter	Size of shock	Sensitivity testing values	Rationale
Innovation for the 98%, appendix A	[1] Increasing productivity through better diffusion of new business models, technologies, management capabilities, and data use	[1a] Input-neutral technical change parameters were increased for each industry (excluding 'ownership of dwellings') in 16 separate simulations	1%	None	Assumed for illustrative purposes only.
		[1b] Input-neutral technical change parameters were increased for the above industries in a single simulation	1%	0.5 to 1.5%	
Australia's data and digital dividend, appendix B	[2] Increasing productivity in regional and remote areas through better access to digital infrastructure, leading to more uptake of technology and data tools	Multifactor productivity parameters were increased for the 'mining' and 'agriculture, forestry and fishing' industries	0.5%	0.2 to 1%	A meta-analysis suggests that a 10% increase in use of information and communication technologies (ICT) is associated with a 0.5% increase in output (Cardona, Kretschmer and Strobel 2013, pp. 118–119). For illustrative purposes in this shock, it was assumed that the improvement in digital infrastructure in regional and remote areas would lead to such an increase in ICT use. The 'mining' and 'agriculture, forestry and fishing' industries were shocked, as they have much higher shares of labour (as a proxy for output) in outer regional and remote areas, based on analysis using 2016 Census data (ABS 2016b).

Report volume	Scenario description	Shocked parameter	Size of shock	Sensitivity testing values	Rationale
From learning to growth, appendix B	[3] Changing the composition of labour towards more highly-educated workers (to better meet labour market needs/shortages)	Among 15-24 year old groups, there was a change in population composition by education level	10% increase in number of university-educated people 4% fall in number of VET-educated people Decrease in school-educated so that 15-24 year old population is unchanged	8 to 12% increase in number of university-educated	Assumed for illustrative purposes only, with reference to projections of employment growth by skill level (NSC 2022).
From learning to growth, appendix B	[4] Increasing the productivity of skilled workers by improving tertiary education quality – long run and very long run simulations	[4a] Improvements will take time as people go through the education system and enter the workforce, and will likely affect younger workers first. In this long run simulation, labour-augmenting technical change parameters were increased for university-educated labour aged 15-24 and 25-34	2%	1 to 4%	Based on a study (Braga, Paccagnella and Pellizzari 2016, p. 803) that found that a professor who is one standard deviation better increased students' earnings by about 5.4%, or about 5.5% of average earnings. The shock size was chosen to reflect that improvements in professor quality across the tertiary education industry would likely be less than one standard deviation.
		[4b] In the very long run, all university-educated workers will have been educated in the improved system. In this simulation, labour-augmenting technical change parameters were increased for all university-educated labour groups	2%	1 to 4%	
From learning to	[5] Increasing labour productivity of the school industry by better use of curriculum resources to save	[5a] The short run benefit was modelled by increasing the labour-augmenting technical change parameter in the 'school education'	3%	2 to 4%	The short run benefit was based on research that estimated that teachers would save about 3 hours per week from a centralised resources (Hunter,

Report volume	Scenario description	Shocked parameter	Size of shock	Sensitivity testing values	Rationale
growth, **appendix B**	teachers' time and improve practices, as well as better integration of technology within classrooms – short run, long run and very long run simulations	industry. Labour use in the 'school education' industry was assumed to be fixed. The capital stock was also assumed to have had time to change (consistent with other model simulations)			Haywood and Parkinson 2022, p. 27). This was converted into a 3% increase in school labour productivity by assuming time gained would be spent on teaching (with teaching hours based on PC (2023, p. 11)) and have the same marginal productivity as other teaching hours. It was also adjusted for the fact that teachers comprise about 60% of the school workforce (ABS 2022b).
		[5b] In the long run, younger workers will be the initial group of school leavers benefiting from teaching improvements. This was simulated by increasing labour-augmenting technical change parameters of 15-24 year old workers. The continued impact of improved labour productivity of workers in the school industry was also included (from scenario 5a). Labour use in the 'school education' industry was assumed to be fixed.	3% for school industry 2% for 15-24 year old groups 5% for 15-24 year old groups in the school industry	2 to 4% for school industry 1 to 3% for 15-24 year old groups 3 to 7% for 15-24 year old groups in school industry	Longer run benefits were based on converting extra teaching time into higher test scores and then higher wages later in life. Based on the literature, it was estimated that 3 additional teaching hours raises test scores by 0.12-0.18 standard deviations (Lavy 2015, p. F399; Wedel 2021), and that each standard deviation increase raises future wages by 9-18% (Chetty et al. 2011, p. 1613; Currie and Thomas 2001, p. 116; Rose 2006; Vu and Yamada 2022; Watts 2020). Multiplying these numbers and taking the midpoint results in about 2% higher wages.
		[5c] In the very long run, all workers that have completed school will have done so in the improved system. Labour-augmenting technical change parameters of all workers were increased to simulate these effects. The continued impact of improved labour productivity of workers in the school industry was also included (from scenario 5a). Labour use in the 'school	5% for school industry 2% for all other workers	3 to 7% for school industry 1 to 3% for all other workers	

Report volume	Scenario description	Shocked parameter	Size of shock	Sensitivity testing values	Rationale
		education' industry was assumed to be fixed.			
A more productive labour market, **appendix A**	[6] Increasing labour productivity by reducing unnecessary occupational licensing restrictions and thus lowering barriers to labour mobility	Labour-augmenting technical change parameters were increased for the following industries as they are more likely to employ workers subject to occupational licensing requirements: • construction • transport and wholesale • professional, scientific and technical services • school education • health and social services	0.8%	0.3 to 1.6%	Based on a study (Bambalaite, Nicoletti and von Rueden 2020, p. 23) that found that a 1 unit reduction in an indicator measuring the stringency of occupational entry regulations improved labour productivity among 11 European countries by 1.6%. For the simulation, a 0.5 unit reduction in stringency was assumed, which translates to a 0.8% increase in labour productivity. Relevant industries were selected based on those that were more likely to have occupational licensing requirements.
A more productive labour market, **appendix A**	[7] Increasing the productivity of workers coming through permanent skilled migration by better matching the migration program to labour market needs	Labour-augmenting technical change parameters were increased for industries with a higher share of migrant workers	0.1% (construction; retail trade; hospitality; school education; public administration; other services) 0.2% (mining; other manufacturing; transport and wholesale; financial services; professional, scientific and technical	Scaled by 2% to 10%, instead of 5% improvement in labour productivity of migrants	For illustrative purposes, it was assumed that better matching of the migration program could increase the labour productivity of migrants by 5%. Census data of migrants (ABS 2016b, 2016a) was used to calculate the share of workers in each industry in 2016 who were primary applicants of permanent skilled visas, and who arrived in Australia between 2006

Report volume	Scenario description	Shocked parameter	Size of shock	Sensitivity testing values	Rationale
			services; health and social services) 0.3% (advanced manufacturing; technical, vocational and tertiary education) 0.6% (technology and telecommunications)		and 2016. Modelled shocks were based on multiplying the migrant shares by the labour productivity change.

3.2   Aggregate output variables

A range of aggregate outputs were calculated from the model results to analyse the overall effects of shocks. These outputs are at a whole-of-economy, industry and labour group (age, sex or education) level, and are summarised in tables 3.2 and 3.3 below. Detailed tables containing these results are available on the inquiry's webpage.

Table 3.2 – Whole-of-economy outputs

	Variable[a]
Output and expenditure	Nominal GDP
	Real GDP
	Real gross national income (GNI)
	Real consumption
	Real investment
	Real government expenditure
	Real exports
	Real imports
Prices[b]	GDP price deflator
	Consumption price deflator
	Investment price deflator
	Government price deflator
	Export price deflator
	Import price deflator
	Real consumer wage (relative to CPI)
	Real producer wage (relative to GDP price deflator)
	Real consumer capital rental rate
Factors of production	Capital stock
	Total hours worked
	Labour productivity
Household wellbeing	Equivalent variation ($ billion)
	Gini coefficient of inequality in consumption (percentage point change)
Trade	Current account deficit (percentage of GDP)
	Terms of trade

a. Measured in percentage change terms unless otherwise stated. **b.** Relative to the model's numeraire, which was the household consumption price index (chapter 1).

Table 3.3 – Output variables at industry and labour group levels[a,b]

Variables at an industry level	Variables at a labour group level
Nominal output	Equivalent variation ($ million)
Real output	Hours worked
Output price deflator[b]	Leisure hours
Labour hours used	Real labour income[b]
Capital used	Real capital income[b]
Real consumption of domestic commodities	Real savings[b]
Real investment of domestic commodities	Real income taxes[b]
Real government expenditure on domestic commodities	Real consumption[b]
Real exports by commodity	Average real consumer wage rate[b]
Real imports by commodity	Average wage gap (one labour group indexed to 100)
Domestic commodity price deflator[b]	Population (million)[c]
Export commodity price deflator[b]	
Import commodity price deflator[b]	

a. Measured in percentage change terms unless otherwise stated. **b.** Relative to the model's numeraire, which was the household consumption price index (chapter 1). **c.** Population composition changes only apply in simulation 3.

4. Sensitivity testing

Sensitivity testing was conducted to examine the extent to which some aggregate results would change with adjustments to uncertain assumptions. Sensitivity testing was undertaken to examine the effects of:

• high and low values of shock sizes (outlined in table 3.1)
• high and low values of select elasticities (outlined in table 2.1), specifically the:

  – CES elasticity of substitution between composite consumption commodities (identified as 'household consumption elasticity' in the charts illustrated below)
  – CES elasticity of substitution between composite labour and capital (industry factor elasticity)
  – CES elasticity of substitution between different types of labour (industry education labour elasticity, and industry age-sex labour elasticity)

• using an alternative method to determine total time endowments (and hence the initial split of time into labour and leisure) for each individual group in order to achieve income elasticities of labour supply that were closer to plausible values stated in the literature (as described in chapter 2)
• separately assuming that there are some constraints on factors of production, specifically that:

  – the capital stock is fixed
  – labour supply by each individual group is fixed
  – an initial portion of people are unemployed due to a wage floor; that is, wages are sticky downwards.[12]

The effects of these sensitivity tests on some key output variables (changes in real GDP, hours worked, real consumer wages, and EV) are illustrated for select model simulations in figure 4.1. The vertical grey line on the charts indicate the value of the variable under the original shock size and model assumptions. The points on the charts indicate the values under different sensitivity tests, with the horizontal lines highlighting the difference between these values and the values for the original shock. Sensitivity tests with the longest horizontal lines had the largest effect on results.

The sensitivity testing results illustrate that assumptions around some constraints on factors of production tended to have the largest effects on aggregate output variables.

When the **capital stock was fixed**, economic growth was significantly lower because of a lack of capital needed to support production and relatively high capital rental prices. For example, in simulation 1b it was assumed that all production inputs (labour, capital and intermediate inputs) could be used more efficiently across all industries excluding 'ownership of dwellings'. The assumption of a fixed capital stock led to a real GDP increase of only 1.8% instead of 3.3%. This could be thought of as representing the short-run effects of the shock; that is, the economic impact before the capital stock has had a chance to grow to its steady state level.

Assuming **unemployment and a wage floor** in the economy implies that wages were initially higher and production was lower than would be the case if labour markets cleared. This meant that households

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[12] Sensitivity tests in some simulations were not analysed, where it was likely that the model had not solved optimally.

inefficiently spent more time on leisure and consumed less than they would like at the given wages. The simulated shocks tended to increase the market-clearing wage level because they induced growth in the economy. This brought wages closer to (or led them to exceed) the wage floor and led to a reduction in unemployment (to zero for some labour types under some simulations). This also led to a relatively larger increase in production than was seen under original model assumptions. While these results are seen in this stylised model, it is noted that, in reality, unemployment is unlikely to fall to such an extent due to other factors that can affect it, such as structural and frictional factors.

Varying the **shock sizes** also had relatively large effects on the magnitude of changes in key output variables, although the direction of effects tended to be the same as under the original shock size. For example, in simulation 1b, the simulated change in real GDP was about 3.3% under the original assumed shock size of a 1% improvement in input-neutral technical efficiency. The real GDP increase ranged from 1.6 to 4.9% under the respective assumptions of a 0.5% and 1.5% improvement in input-neutral technical efficiency.

The sensitivity tests for the **alternative method of allocating labour and leisure**, and for the assumption of **fixed labour supplies**, tended to have smaller effects on output variables. This is because changes in hours worked in the simulated shocks were relatively small in general under original model assumptions due to various competing effects. On the household side, the effect of higher wages had income and substitution effects that worked in opposite directions (that is, people may want to substitute towards more work and consumption instead of leisure because of the higher wages, but they can also earn the same income by working less and enjoying more leisure instead). On the producer side, most of the industry-specific labour productivity shocks meant that industries required less labour to produce the same amount of output, but subsequent demand effects then increased the amount of labour required.

Changes to assumptions around **elasticities** also tended to have smaller effects on aggregate outputs, relative to the other sensitivity tests conducted.

Figure 4.1 – Select sensitivity testing results[a]

a. Simulation 1b — potential productivity benefits of diffusion
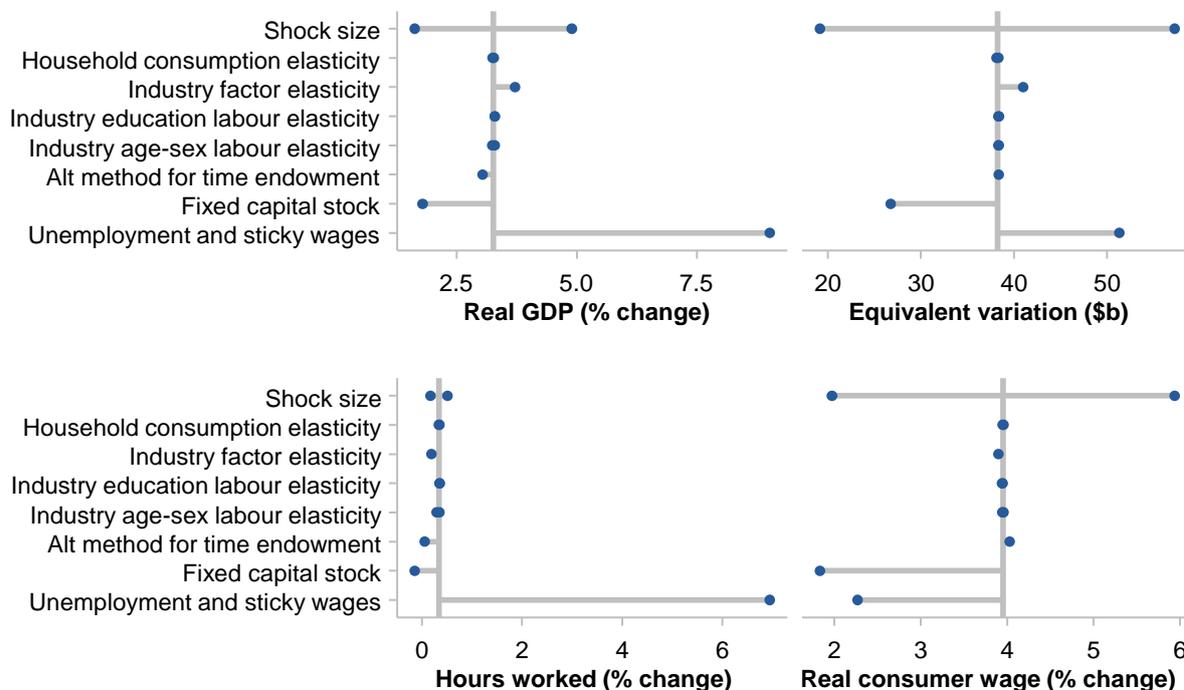
b. Simulation 6 — reducing unnecessary occupational licensing requirements
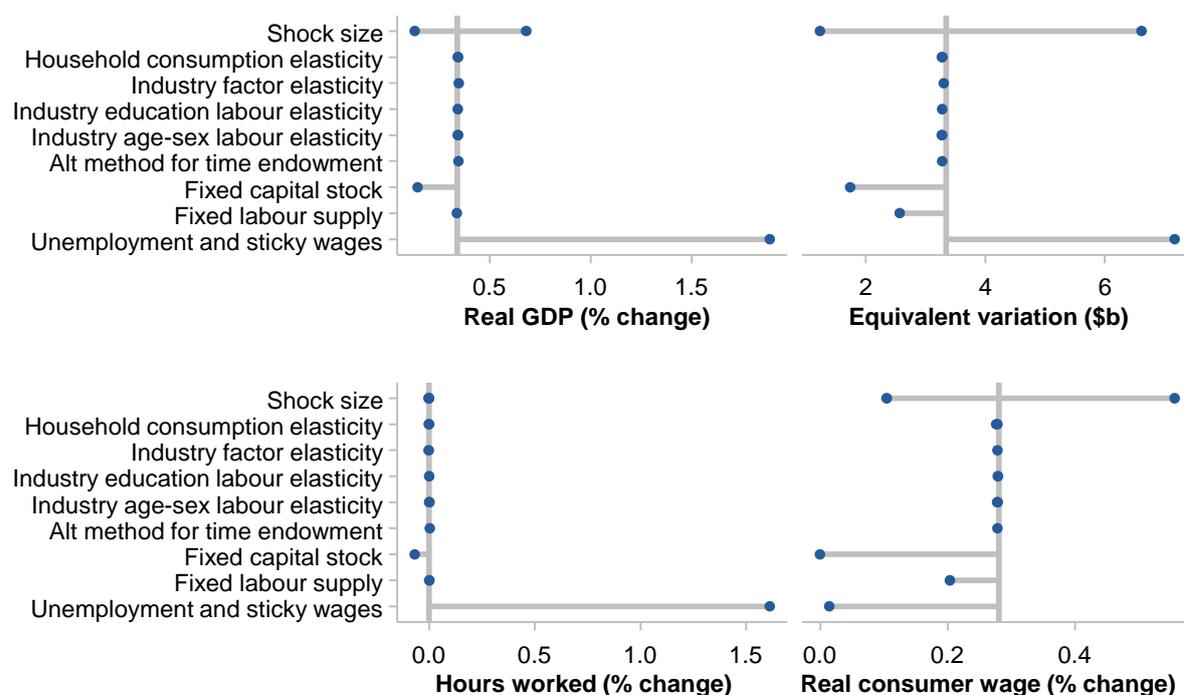
a. The vertical grey line indicates the value of the variable under the original shock size and model assumptions. The points indicate the values under different sensitivity tests, with the horizontal lines highlighting the difference between these values and the values for the original shock.

Source: Commission estimates.

5. Model equations

Simple representations of the key equations underlying the model are shown in table 5.1. These complement the high level diagrams showing the model structure in chapter 1. These equations are not in the same form as they have been included in the GAMS code, which were written as mixed complementarity problems with paired equations and variables.

Subscripts refer to various dimensions in the model:

- c — commodities or industries
- e — education level
- l — individual groups of different age group, sex and education level combinations
- s — source of commodity (domestic 'DOM' or imported 'IMP')
- u — user of domestic and imported commodities (industries, household sector 'HH', government sector 'GOV', investment sector 'INV').

Text colour refers to types of variables or parameters:

- black — endogenous variables
- blue — exogenous variables
- green — parameters (select parameters shown only).

When markets clear, demand quantities (denoted by Q^{DEM}) equal supply quantities (Q^{SUP}), and demand prices (purchaser prices, P^{DEM}) equal supply prices (basic prices, P^{SUP}) which are also equal to marginal costs. In some parts of the model, where there are taxes or price floors, demand and supply quantities and prices may not equal (noted in the table below).

Table 5.1 – Simple representations of model equations for key variables

Equation

Individual groups and labour supply in household sector

1. Desired quantity of composite consumption bundle per individual group, via utility maximisation

$$DesiredCompConsQ_l^{DEM} = CES\left(DesiredInc_l, GroupCompConsP_l^{DEM}, LabP_l^{SUP}\right)$$

2. Desired leisure per individual group, via utility maximisation

$$DesiredLeisQ_l^{DEM} = CES\left(DesiredInc_l, GroupCompConsP_l^{DEM}, LabP_l^{SUP}\right)$$

3. Labour available per individual group, via utility maximisation

$$LabAvailable_l = TimeEndow_l - DesiredLeisQ_l^{DEM}$$

4. Actual quantity of composite consumption bundle per individual group

$$GroupCompConsQ_l^{DEM} = CES\left(Inc_l, GroupCompConsP_l^{DEM}, LabP_l^{SUP}\right)$$

5. Actual time not in employment (leisure and unemployed hours) per individual group

$$GroupNonEmp_l = CES\left(Inc_l, GroupCompConsP_l^{DEM}, LabP_l^{SUP}\right)$$

6. Hours worked per individual group

$$LabQ_l^{SUP} = TimeEndow_l - GroupNonEmp_l$$

Equation

7. Unemployed hours per individual group

$$UnemployedHours_l = LabAvailable_l - LabQ_l^{SUP}$$

8. Minimum hourly wage by individual group

$$LabP_l^{SUP} \geq WageFloor_l$$

9. Income by individual group

$$DesiredInc_l = LabAvailable_l * LabP_l^{SUP} + GroupCapitalInc_l - GroupIncTax_l - GroupSaving_l$$

$$Inc_l = LabQ_l^{SUP} * LabP_l^{SUP} + GroupCapitalInc_l - GroupIncTax_l - GroupSaving_l$$

Demands for domestic and imported commodities, and composites of domestic and imported commodities, across each sector

10. Demand for domestic and imported commodities per user and commodity, to produce composite commodities of domestic and imported commodities, via expenditure minimisation

$$CommodityQ_{u,s,c}^{DEM} = \begin{cases} CES(CompCommQ_{u,c}^{SUP}, CommodityP_{s,c}) & where\ commodity\ is\ substitutable \\ Leontief(CompCommQ_{u,c}^{SUP}) & where\ commodity\ is\ not\ substitutable \end{cases}$$

11. Industry demand for industry composites per industry (c') and commodity (c), via expenditure minimisation

$$CompCommQ_{c',c}^{DEM} = Leontief(\varepsilon_{c'}^{OUTPUT}, IndOutputQ_{c'}^{SUP})$$

Where $\varepsilon_{c'}^{OUTPUT}$ is an input-neutral technical change parameter associated with the use of the industry composite factor of production and industry composite inputs made of domestic and imported commodities.

12. Individual group demand for household composites per individual group and commodity, via expenditure minimisation

$$GroupCompCommQ_{l,c}^{DEM} = CES(GroupCompConsQ_l^{SUP}, CompCommP_{HH,c}^{DEM})$$

$$CompCommQ_{HH,c}^{DEM} = \sum_l GroupCompCommQ_{l,c}^{DEM}$$

13. Government sector demand for government composites per commodity, via expenditure minimisation

$$CompCommQ_{GOV,c}^{DEM} = CobbDouglas(GovQ, CompCommP_{GOV,c}^{DEM})$$

14. Investment sector demand for investment composites per commodity, via expenditure minimisation

$$CompCommQ_{INV,c}^{DEM} = Leontief(InvQ)$$

15. Demand price of composite commodities by user

$$CompCommP_{u,c}^{DEM} = CompCommP_{u,c}^{SUP}(1 + CompCommTaxRate_{u,c})$$

16. Price of imported commodities

$$CommodityP_{IMP,c} = \frac{ImportWorldP_c}{ExchangeRate}$$

Demand for factors of production in production sector

17. Demand for labour hours per industry, via expenditure minimisation

$$IndLabQ_{c,l}^{DEM} = CES(\varepsilon_{c,l}^{LAB}, IndEducLabQ_{c,e}^{SUP}, LabP_l^{DEM})$$

$$Hours_l = \sum_c IndLabQ_{c,l}^{DEM}$$

Where $\varepsilon_{c,l}^{LAB}$ is a labour-augmenting technical change parameter associated with industry use of labour to produce industry-specific 'composite labour by education level'.

18. Demand for industry-specific 'composite labour by education level' per industry, via expenditure minimisation

$$IndEducLabQ_{c,e}^{DEM} = CES(IndCompLabQ_c^{SUP}, IndEducLabP_{c,e}^{DEM})$$

Equation

19. Demand for industry composite labour per industry, via expenditure minimisation

$$IndCompLabQ_c^{DEM} = CES(\alpha_c^{COMPFACTOR}, IndCompFactorQ_c^{SUP}, IndCompLabP_c^{DEM})$$

Where $\alpha_c^{COMPFACTOR}$ is a multifactor productivity parameter associated with the use of labour and capital to produce the industry composite factor of production (value added).

20. Demand for capital per industry, via expenditure minimisation

$$IndCapQ_c^{DEM} = CES(\alpha_c^{COMPFACTOR}, IndCompFactorQ_c^{SUP}, CapP)$$

$$CapQ = \sum_c IndCapQ_c^{DEM}$$

21. Demand for industry composite factor (value added in value terms), via expenditure minimisation

$$IndCompFactorQ_c^{DEM} = Leontief(\varepsilon_c^{OUTPUT}, IndOutputQ_c^{SUP})$$

Where ε_c^{OUTPUT} is an input-neutral technical change parameter associated with the use of the industry composite factor of production and industry composite inputs made of domestic and imported commodities.

Industry output, and production of domestic and exported commodities in production sector

22. Supply price of industry output

$$IndOutputP_c^{SUP} = (1 + ProductionTaxRate_c)$$
$$* \left(\beta_c^{OUTPUT.COMPFACTOR} \frac{IndCompFactorP_c^{DEM}}{\varepsilon_c^{OUTPUT}} + \sum_{c'} \beta_c^{OUTPUT.COMPCOMM} \frac{CompCommP_{c',c}^{DEM}}{\varepsilon_c^{OUTPUT}} \right)$$

Where β_c are Leontief parameters indicating units of input required per unit of output.

23. Supply of domestic and export commodities

$$DomCommodityQ_c^{SUP} = CET(OutputQ_c^{SUP}, CommodityP_{DOM,c}, ExpCommodityP_c^{SUP})$$

$$ExpCommodityQ_c^{SUP} = CET(OutputQ_c^{SUP}, CommodityP_{DOM,c}, ExpCommodityP_c^{SUP})$$

24. Demand for exported commodities

$$ExpCommodityQ_c^{DEM} = \left[\frac{(ExpCommodityP_c^{DEM} * ExchangeRate)}{\alpha_c^{EXP}} \right]^{\sigma_c^{EXP}}$$

Where σ_c^{EXP} is the price elasticity of demand and α_c^{EXP} is a scaling parameter.

25. Demand price of exported commodities

$$ExpCommodityP_c^{DEM} = ExpCommodityP_c^{SUP}(1 + ExpCommodityTaxRate_c)$$

Investment, capital and saving

26. Total investment and capital

$$InvQ = \alpha_{INVQ} CapQ$$

$$CapP = \alpha_{CAPP} InvP$$

Where α_{INVQ} is the fixed ratio of investment to capital quantities, and α_{CAPP} is the fixed ratio of capital to investment prices.

27. Domestic and foreign investment and capital

$$DomesticInvQ = InvQ - ForeignInvQ$$

$$DomesticCapQ = CapQ - ForeignCapQ$$

Equation

28. Saving per individual group

$$HHSavingScaleFactor = \frac{(DomesticInvQ * InvP)}{\sum_l \left(OrigGroupSavingRate_l * (LabQ_l^{SUP} * LabP_l^{SUP} + GroupCapitalInc_l) \right)}$$

$$GroupSaving_l = HHSavingScaleFactor * OrigGroupSavingRate_l * \left(LabQ_l^{SUP} * LabP_l^{SUP} + GroupCapitalInc_l \right)$$

29. Capital per individual group

$$HHCapInvScaleFactor = \frac{(DomesticCapQ * CapP)}{\sum_l (OrigGroupCapInvRatio_l * GroupSaving_l)}$$

$$GroupCapitalInc_l = HHCapInvScaleFactor * OrigGroupCapInvRatio_l * GroupSaving_l$$

Government activity

30. Total government expenditure

$$GovQ * GovP = \alpha_{GOV} NominalGDP$$

Where α_{GOV} is the fixed government share of nominal GDP.

31. Government budget balance

$$\begin{aligned}
GovQ * GovP = {} & HHIncTax + ForeignCapIncTaxRate * ForeignCapQ * CapP \\
& + \sum_c \left(ProductionTaxRate_c \frac{IndOutputQ_c^{SUP} * IndOutputP_c^{SUP}}{1 + ProductionTaxRate_c} \right) \\
& + \sum_c \sum_u \left(CompCommTaxRate_{u,c} \frac{CompCommQ_{u,c}^{DEM} * CompCommP_{u,c}^{DEM}}{1 + CompCommTaxRate_{u,c}} \right) \\
& + \sum_c \left(ExpCommodityTaxRate_c \frac{ExpCommodityQ_c^{DEM} * ExpCommodityP_c^{DEM}}{1 + ExpCommodityTaxRate_c} \right)
\end{aligned}$$

32. Income tax per individual group

$$HHTaxScaleFactor = \frac{HHIncTax}{\sum_l \left(OrigGroupTaxRate_l * (LabQ_l^{SUP} * LabP_l^{SUP} + GroupCapitalInc_l) \right)}$$

$$GroupIncTax_l = HHTaxScaleFactor * OrigGroupTaxRate_l * \left(LabQ_l^{SUP} * LabP_l^{SUP} + GroupCapitalInc_l \right)$$

Attachment A — Review of 'whole-of-economy modelling'

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I found the modelling appendix is well written and structured. It presents the CGE model developed by the Productivity Commission. The model is purposely built inhouse to suit the needs of the Commission's inquiry. The model is considered as a standard, static, national CGE model with connection to the rest of world through trade, investment and foreign ownership of capital. One feature I would like to highlight is that the model represents Australian households in detail. It includes households by age group, gender and education level. This enables a kind of microsimulation-type modelling to understand different effects of reforms on different household groups, for example, how economic benefits of a productivity reform are distributed across household groups (is the reform leading to improvement of equality or the opposite?). The model also includes endogenous labour supply through labour and leisure choices, which allows understanding of insights on labour supply responses across household groups under a set of stylised productivity reforms simulated in this inquiry.

I found the model is well documented in this appendix. The closure assumptions, nesting structures of each block, databases, parameterisation and calibration are all discussed in detail. Given the representation of multiple household groups in the model, additional sources (such as SIH and HES) of data to input-output tables are used to calibrate the household block. I found the household block is relatively complex but a very useful feature in this model, compared with some of other standard CGE models, since it introduces endogenous labour supply and potential unemployment through wage floor constraint for each household group.

The model is used to run a number of scenarios to gain insights of reforms. Each scenario represents a set of stylised productivity shocks for relevant sectors and/or household groups from hypothetical reforms. Overall, I found the model implementation of the channels of shocks is sensible, and the model results are largely as expected for each scenario, noting the closure assumptions and model parameters used. All results are well interpreted in the appendix.

My specific comments are listed below:

1. I would suggest also to report the model results on gross national income, since it captures foreign income transfers
2. For the aggregation of sectors used, i.e. 17 sectors, some justifications for the choice would be useful
3. For the primary factors in the model, note that land is not a separate factor. This can be considered as a limitation of the model, since land is an important input to Agriculture.
4. In relation with the model closure, suggest adding some reasons for keeping foreign investment fixed, when simulated domestic productivity increases
5. It would be useful to make it clear that an endogenous lump sum transfer to households is used to balance the government budget
6. Determining investment to keep capital stock constant implies the assumption of the capital stock being in a steady state. This has implications on domestic investment and savings required. Whether assuming a trend growth of capital stock would be more appropriate?
7. Model limitations may include: not dynamic and cannot simulate a time path of effects; land is not a separate primary factor (also see comment 3); both capital and labour are assumed perfectly mobile across sectors. If capital is immobile, for example, the gain would be smaller.

8. It would be interesting to know what the implied labour supply elasticity is with the assumed parameter of 0.5 for the ratio of total hours worked to the total time available
9. For the trade elasticities, a reference source could also include the GTAP database
10. For the CET elasticity between export and domestic market, depending on commodities, the number could be even higher. I tend to believe that a larger elasticity implies bigger effects.
11. That costs of implementing reforms are not included in the modelling can be added to the limitations of the modelling
12. The design for scenario 3a) and 3b) could be confusing, particularly in terms of comparison of results, whether 3b) is compared against the normal baseline or the 3a)
13. For scenario 5, the shocks are interpreted as in short-run, long-run and very long-run; while the model closure does not change accordingly – some explanations on the reasoning would be useful
14. For the table on Whole-of-economy outputs, it would be good to include a note that the prices are relative to the fixed numeraire which is CPI
15. In terms of reporting the results across sectors, are there any better metrics to measure the relative impacts between sectors, for example, change in GDP relative to change in the output of the shocked sector
16. Some interpretation of sector-specific impacts could be related to the capital intensity of the affected sector – as the intensity would drive the requirement for capital, given capital is flexible in this modelling
17. The interpretations of the results are mostly on labour. I'd suggest including the effects on capital as well in the interpretations.
18. In the first chart for the sim 2: what would be the reasons for the price drop for other manufacturing, and quantity drop for advanced manufacturing?
19. Interpretation for 3a) and 3b) could be made clearer (also see the comment 12 above).
20. The first chart in sim 5, based on the impacts on price and quantity, the implied price elasticity of demand for school education is greater than -1. Any estimate of this elasticity in the literature? Also, note in the second chart for sim 5 in relation with long run shocks, the implied elasticity for school education is much smaller (or much bigger in absolute value).
21. For sim 6, are the employment falls for older age groups due to the income effect as a result of higher wage?
22. I found the sensitivity test results are useful, which provide a range of possible estimates, depending on parameter values and closure assumptions. The directions of changes with the changes in parameters and closure assumptions are largely as expected with good interpretations provided in the appendix. But it seems there are too many charts. An additional test could include alternative assumption on the foreign investment.

In summary, my specific comments above are mainly related to closure setting, for example, is it appropriate to assume foreign capital stock and investment fixed in all of the productivity sims? In terms of interpretation of results – I was thinking some rules of thumb in understanding the impacts of productivity shocks. For example, the relative impact on GDP would depend on labour shares and GDP shares of a shocked sector. As capital is endogenous, the results would also depend on how much capital is increased. The other point is whether we could draw any guidance to understand the impact on quantity given the impact on price, from the perspective of price elasticity of demand (if there are any estimates of these elasticities in the literature) (i.e. related to the comment 20).

A final point I would like to mention that the modelling presented in the appendix has also taken inputs from the public modelling workshops in which I also participated – these inputs include, for example, the suggested parameter values to use in the modelling and model closure assumptions.

Abbreviations

ABS	Australian Bureau of Statistics
CES	Constant elasticity of substitution
CET	Constant elasticity of transformation
CGE	Computable general equilibrium
CPI	Consumer price index
EV	Equivalent variation
GAMS	General algebraic modelling system
GDP	Gross domestic product
GNI	Gross national income
GTAP	Global Trade Analysis Project
GVA	Gross value added
HES	Household Expenditure Survey
ICT	Information and communication technologies
IO	Input-output
SAM	Social accounting matrix
SIH	Survey of Income and Housing
VET	Vocational education and training

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