TASMAN
ASIA
PACIFIC

BENCHMARKING THE PRODUCTIVITY OF AUSTRALIA'S BLACK COAL INDUSTRY

TASMAN ASIA PACIFIC Pty Ltd

June 1998

Tasman Asia Pacific Pty Ltd
PO Box 137
LYNEHAM ACT 2602

Telephone (02) 6247 0866
Facsimile (02) 6247 0876
e-mail canberra@tasman.com.au

Tasman Asia Pacific Pty Ltd specialises in the quantitative analysis of policy issues, performance measurement and the provision of management advice to industry and government both in Australia and overseas.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

No. Title

LIST OF FIGURES (CONTINUED)

No. Title

LIST OF BOXES

No. Title

EXECUTIVE SUMMARY

In October 1997 the Industry Commission contracted Tasman Asia Pacific to undertake a benchmarking study of the productivity performance of Australia's black coal mines. Tasman's brief was to benchmark mines in Australia's black coal industry against world best practice coal mines and best practice Australian metalliferous mines. The Commission will use this benchmarking in its current inquiry into the international competitiveness of the Australian black coal industry.

This report builds on earlier benchmarking work undertaken by Tasman. It benchmarks 44 separate mine operations in 1996 and 1997 — 22 truck and shovel, 13 dragline and 9 longwall operations.

Data used in this benchmarking study is based on information collected from a Tasman survey. The Australian mines invited to participate in the study were selected from a Barlow Jonker (1997) database. This database provides labour productivity and mine cost data separately for dragline, truck and shovel and longwall operations. Mines selected provided a representative coverage of mines exhibiting high, medium and low labour productivity. Tasman also aimed for representative coverage according to company ownership, location and mine technology. The black coal mines selected in the United States included a number that were nominated by industry experts as better practice operations as well as mines that were affiliates of Australian mining companies. Responses were received from 20 Australian black coal mines, eight United States coal mines and four Australian metalliferous mines. Black coal production from the responding Australian coal mines is equal to nearly 40 per cent of Australia's raw black coal production.

Tasman's benchmarking is based on total factor productivity measures (which measures total output relative to *all* inputs used) and supported by partial productivity measures to identify the drivers of productivity differences between mines.

The benchmarking analysis focuses on the main components of the mining process. However, it does not cover all mines inputs nor does it cover development work (eg setting up mine offices, developing access roads). The main items excluded from all three mining technologies are washeries, mine overheads, many maintenance activities and some materials used in production.

These elements have been excluded because:

- the data is often not supplied on a consistent basis by mines (eg mine office overheads and materials);
- the data vary considerably from year to year (eg due to the extent of major equipment overhauls in maintenance activities); and
- differences in inputs largely reflect geological or environmental factors (eg the yield of coal impacts on washeries input).

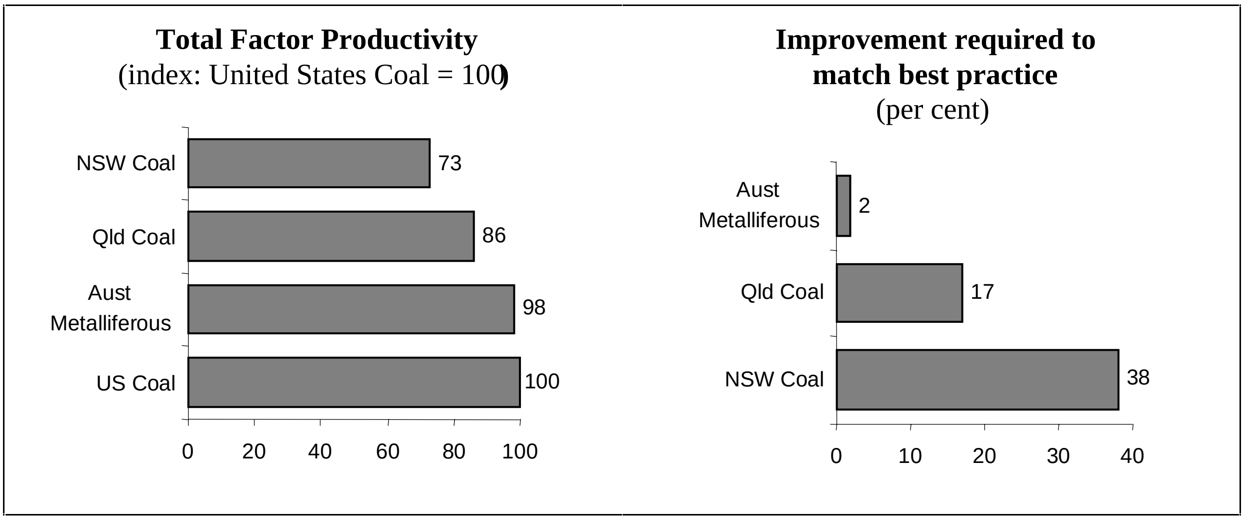
The analysis presented in this report has benefited from comments received from participants at the January 1998 and June 1998 benchmarking workshops that were conducted by the Productivity Commission in the course of its public inquiry process.

TRUCK AND SHOVEL PRODUCTIVITY BENCHMARKS

Truck and shovel mines remove both overburden and coal or other minerals primarily with trucks and shovels.

Tasman's benchmarking results indicate that in 1996–1997, the total factor productivity of the participating NSW and Queensland truck and shovel coal operations was, on average, well below best practice (Figure 1).

Figure 1: **Total factor productivity of truck and shovel operations**



Source: Survey undertaken by Tasman Asia Pacific (1998).

To match the best practice productivity levels of United States coal mines, participating NSW and Queensland coal mines needed, on average, to increase their productivity by 38 and 17 per cent respectively. Average productivity increases of 35 and 14 per cent, respectively, were required for these mines to match the average productivity of the Australian metalliferous mines covered by the survey. As a whole, the Australian coal mines in our sample needed to increase productivity by about 30 per cent to match the performance of the United States coal mines and Australian metalliferous mines.

A number of factors influenced these productivity outcomes. Geological conditions, such as thinner and more numerous coal seams in the NSW mine category explain some of the measured productivity gap. Of much more importance, however, were over-staffing, over-capitalisation of equipment and poor work practices. These were reflected in low relative labour and truck productivity in our sample of NSW and Queensland coal mines. For example, labour and truck productivity both needed to increase by around 70 per cent in the NSW coal mines to match the performance of our sample of United States coal mines. Queensland coal mines in our survey sample, on average, needed a corresponding 40 per cent increase.

Table 1: **Resourcing and work practices of typical best practice and moderately performing Australian truck and shovel coal mines**

	Best practice mine	*Moderately performing mine*
Total productivity	100	60
Resource levels		
Staffing levels: ratio of labour hours worked to equipment hours worked	1.5	2.1
Work time in shifts: time excluding leaving and joining shifts, meal and other breaks (per cent)	92	85
Utilisation of truck fleet: hours operated as a percentage of total available hours	45	40
Utilisation of major digging equipment: hours operated as a percentage of total available hours	50	40
Work practices		
Hot seat changes	✓	✓
Meal breaks in the field	✓	✗
Staggered meal breaks	✓	✗
Operators move between equipment within shifts	✓	rarely
Haulage equipment fuelled in breaks	✓	✗
Clean-up equipment does not impede production	✓	✗

Source: Survey undertaken by Tasman Asia Pacific (1998).

However, a number of Australian truck and shovel operations are at the frontier of efficient operation — achieving productivity levels more than 50 per cent higher than many other Australia mines. Table 1 and Table 2 outline differences in key characteristics of the frontier and moderately performing Australian truck and shovel operations included in our sample. These characteristics indicate ways for the poorer performing mines to improve efficiency.

Table 1 indicates that over-staffing and over-capitalisation are common causes of lower productivity. Often the moderate performing mines have more equipment than they need — resulting in low equipment utilisation and productivity and requiring additional staff. In such mines, excess staff are also often apparent in areas such as operating non-core equipment (eg water and lube trucks) and in general duties.

Work practices are more efficient in the high performing mines in the sample. For example, staff in efficient mines use effective hot-seat changes, take meal breaks on machines, stagger meal breaks to ensure that core equipment continues to operate, move between pieces of equipment within shifts where necessary, fuel haulage equipment during breaks and ensure clean-up equipment does not impede production. Generally the poorer performing mines in the sample implement only a few of these good practices.

Table 2: **Key attributes of typical best practice and moderately performing Australian truck and shovel coal mines**

	Best practice mine	*Moderately performing mine*
Efficient truck loading practices: incidence of double-sided or other efficient truck loading method (per cent)	>50	0
Spotting time of trucks under shovels (seconds)	35	65
Truck loads per shovel per 8-hour shift	185	135
Industrial disputes: days lost per thousand hours worked	0	20
Safety: lost time injuries per million man hours	20	50

Source: Survey undertaken by Tasman Asia Pacific (1998).

Highly productive truck and shovel operations often use efficient shovel techniques such as double-sided loading of trucks. This was supported by our survey findings, albeit based on a relatively small sample of mines (Table 2). While double-sided loading imposes an extra dimension of care to maintain safety standards it allows substantially more excavation per shift and improves truck productivity. For example, based on our sample, spotting times under trucks (the time from assigning away the previous truck to dumping the first load in the next truck) are often around 35 seconds with double-sided loading compared to 65 seconds with single-sided loading. This 30 second per truck lost digging and transportation time is significant given the frequency of truck loading.

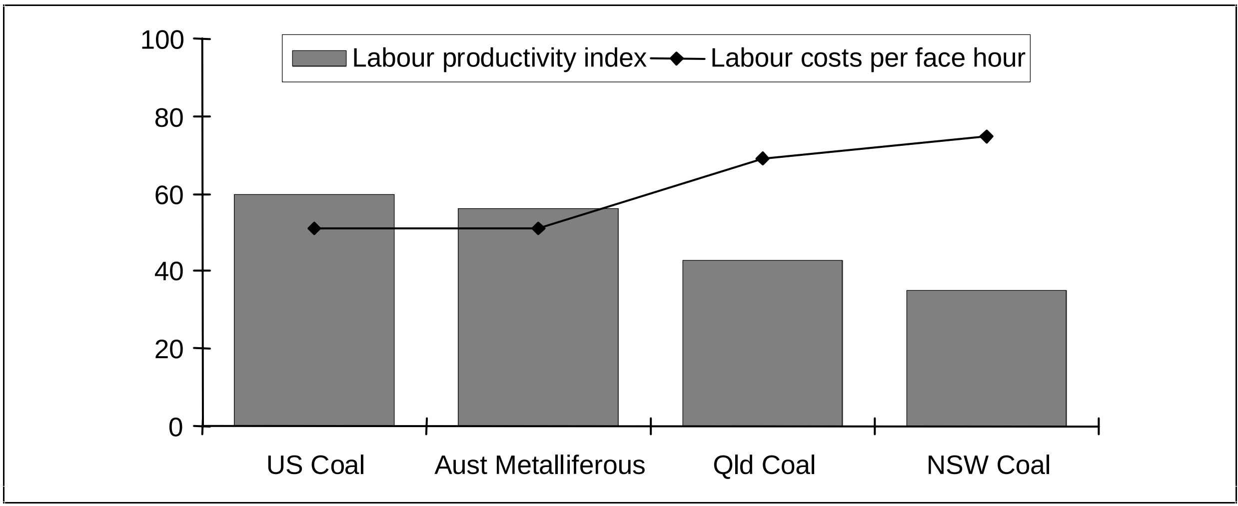
Better performing mines in the survey sample invariably have fewer industrial disputes and also seem to have a better safety record.

PRODUCTIVITY AND COST OF TRUCK AND SHOVEL OPERATIONS

Our analysis of mines in the sample showed that the cost of material extraction and transport to stockpiles in NSW and Queensland truck and shovel operations was around 50 per cent higher than the United States coal mines and 30 per cent higher than the Australian metalliferous mines. Most of this was due to low productivity while about 30 per cent of the cost difference between the United States and NSW mines was due to high unit costs — especially of labour.

As shown in Figure 2, the average cost per face hour worked in the sample mines was considerably higher in the NSW and Queensland coal mine categories than in the Australian metalliferous and United States coal mine categories. These higher labour costs are in sharp contrast to the poor labour productivity achieved in these mines.

Figure 2: **Labour productivity and cost in truck and shovel operations**
(index: United States Coal = 60 and $A costs)

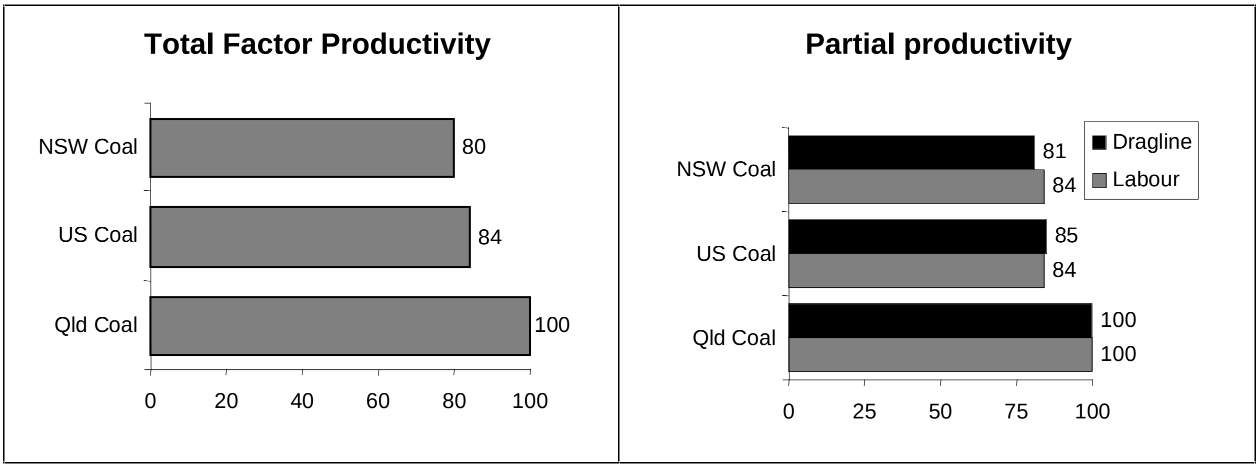


Source: Survey undertaken by Tasman Asia Pacific (1998).

DRAGLINE BENCHMARKS

Tasman's estimates of dragline productivity focused on overburden removal in 13 open cut black coal mines located in NSW, Queensland and the United States. The results of this benchmarking see Queensland mines in the sample as the most efficient performers in 1996–1997 (Figure 3). NSW and United States producers in the sample needed to improve total productivity by an average of 25 and 19 per cent, respectively, to equal the Queensland mines' performance. On average, the productivity of the participating Australian dragline operations was about 13 per cent higher than the United States operations.

Figure 3: **Total factor productivity and key partial productivity of dragline operations** (index: Queensland = 100)



Source: Survey undertaken by Tasman Asia Pacific (1998).

High dragline and labour productivity helped the sample of Queensland mines achieve this best practice result. Several factors contributed to the observed differences in productivity, across the sample, including:

- high dragline capacity utilisation coupled with operational efficiency of draglines in Queensland mines;
- low dragline operational productivity in New South Wales mines; and
- low blasting requirements in Queensland mines due to the geology of the overburden.

Table 3 shows that the Queensland mine category achieved the highest operational efficiency, achieving 47 full dragline bucket equivalents per hour. This compared to 44 in the United States mines category and only 37 for sample mines included in the NSW category. The sample mines in the NSW category were not making effective use of their relatively large draglines. The main problem related to the average number of swings per hour. It appears that a number of these NSW mines achieved high dragline bucket factors.

Table 3: **Productivity performance of dragline operations**

	Dragline output per hour (bcms)	*Bucket factor* (per cent)	*Swings per hour* (number)	*Bucket capacity* (loose cubic metres)	*Equivalent dragline bucketfuls* (number per hour)
Queensland coal	1 901	92	51	41	47
United States coal	2 074	88	50	47	44
NSW coal	1 910	95	39	51	37

Source: Survey undertaken by Tasman Asia Pacific (1998).

Based on our sample, labour productivity in Queensland dragline operations exceeded that in NSW and United States mines by about 20 per cent. Much of this difference stemmed from the greater operational efficiency of the Queensland draglines and fewer staff being required for drilling and blasting activities. Work practices appeared to be generally good throughout the Australian and United States dragline mines.

Despite the good productivity performance of many of the Australian dragline operations in the sample, they achieved cost levels well above their United States counterparts. For example, total costs of removing overburden in participating Queensland mines were 23 per cent higher than in participating United States mines, even though productivity was 19 per cent higher in the Queensland mines — which helps to reduce costs. The higher input costs in the Australian sample mines were largely due to the high cost of labour and explosives.

While the number of responses was relatively small, our analysis suggests that a number of Australian open-cut mines that have problems with over-staffing and inefficient work practices in their truck and shovel operations are able to achieve much higher relative productivity in their less labour-intensive dragline operations.

LONGWALL OPERATIONS

We have compared the performance of seven Australian longwall mines against two United States mines. Due to the fewer number of participating mines, these findings may not be as representative of the relative performance of the Australian industry as were the results of the truck and shovel and dragline surveys. This benchmarking analysis focuses on longwall operations, and excludes development work.

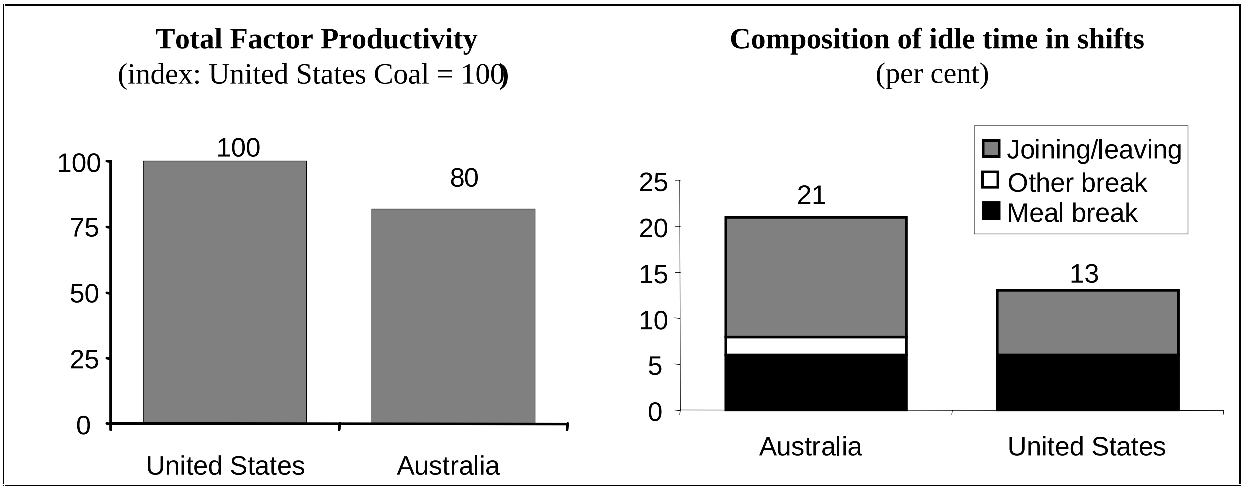
Our total factor productivity analysis indicates that the Australian longwall mines studied achieved productivity levels, on average, 20 per cent behind that achieved by longwall operations in the United States (Figure 4). Alternatively, the participating Australian longwall mines needed to improve productivity by an average of around 25 per cent to match the performance of the participating United States mines.

This lesser productivity performance mainly stemmed from:

- higher idle times in shifts in the participating Australian longwall mines;
- low utilisation of shearers in these Australian longwall mines; and
- geological differences.

The relatively high idle time in longwall shifts in the participating Australian mines was mainly due to longer times in joining and leaving shifts (Figure 4). Together with extra crib breaks, this reduced labour productivity in these Australian longwalls by about 10 per cent compared to the two United States mines. Other causes of lower labour productivity in these Australian longwalls related to operating conditions, installed equipment and, most likely, an element of over-staffing.

Figure 4: **Total factor productivity and extent of idle time in shifts of Australian and United States longwall mines**



Source: Survey undertaken by Tasman Asia Pacific (1998).

Low shearer productivity in our sample mines resulted from lower utilisation in Australian longwalls. Some of this was due to planning — with spare capacity brought in to allow quicker longwall transitions. This was successful to a point, although there was evidence that a number of participating Australian mines took much longer to achieve target production on new longwalls than the United States mines. There was also apparent over-capitalisation of face-conveyor capacity in a few of the participating Australian longwall mines.

Longwall production costs were higher in the seven Australian mines, on average, than in their United States counterparts. Most of this reflected the productivity differential, although labour costs were also higher in these Australian mines compared to the United States mines.

While the sample of longwalls was small, it was again evident that Australian mines can attain or approach world's best practice productivity performance. One of the Australian mines was only about 10 per cent below the best practice United States mine, which is an acknowledged efficient operator. This was over a period that was not particularly favourable for the Australian mine.

MAJOR FINDINGS

The results of Tasman's black coal mine benchmarking indicate a very mixed productivity performance by Australian black coal mines in our sample. In each of three main technologies examined — truck and shovel, dragline and longwall — Australia can boast a number of mines that are at or very close to world best practice performance levels. Based on our sample, the problem for the Australian coal industry is the large number of moderate and poorly performing mines. However, this suggests that the better practice Australian mines often provide excellent benchmarks for the many, less-efficient Australian mines.

This is especially the case for Australia's truck and shovel mines, which needed to improve productivity by an average of around 30 per cent to match better practice United States coal mines and Australian metalliferous mines. A large proportion of Australian truck and shovel operations in our sample needed to improve total productivity by over 50 per cent to match their "best practice" neighbours. The poor productivity mines typically suffered from over-staffing, over-capitalisation and poor work practices.

Despite the smaller sample, a similar story emerged from the analysis of longwall mines. The analysis suggests that Australia has outstanding longwall mines but also many moderate performers. To approach best practice, the poorer performing Australian longwall mines need to decrease the extent of idle time in shifts, increase equipment utilisation and decrease the time taken to achieve full production on new longwalls.

In contrast, Queensland's dragline operations, as a sample group, were identified as best practice, operating at productivity levels around 20 to 25 per cent higher than similar mines in the United States and NSW samples. This good productivity performance was consistently achieved in the Queensland operations and appeared due to good engineering, management and labour practices.

In summary, the sample of mines included in the benchmarking study, suggests that the performance of mines in the Australian black coal industry is mixed. The varying levels of performance are now mainly due to problems at the company or mine level rather than industry level.

1. INTRODUCTION

1.1 STUDY BACKGROUND

In July 1997, the Treasurer requested that the Industry Commission inquire into the international competitiveness of the Australian black coal industry. Part 3(a) of the terms of reference for the inquiry requested that the Commission report on:

> Sound, objectively determined benchmarks of productivity performance for Australian black coal mines, best practice in comparable international black coal mines and best practice in analogous Australian metalliferous mines, identifying the reasons for differences in productivity performance between the specified groups. Components investigated should include management, labour, machine performance and mine geology.

Tasman Asia Pacific (Tasman) has considerable experience in benchmarking the coal industry both domestically and internationally. Tasman staff have undertaken a number of coal benchmarking studies including Swan Consultants (Canberra) (1994) and Tasman Asia Pacific (1997).

This benchmarking report addresses the requirements of Part 3(a) of the terms of reference for the Productivity Commission's Coal Inquiry.

The analysis presented in this report has benefited from comments received from participants at the January 1998 and June 1998 benchmarking workshops that were conducted by the Productivity Commission in the course of its public inquiry process.

1.2 THE AUSTRALIAN BLACK COAL INDUSTRY — A SNAPSHOT

The black coal industry plays a significant role in the Australian economy. The industry is a major contributor to Australia's gross domestic product, exports and employment.

New South Wales and Queensland are Australia's major producers of black coal. Approximately 95 per cent of Australia's saleable coal is extracted from mines in these two states. The industry employs over 20,000 people. Australia's black coal is currently mined by both underground and open cut methods. Underground mining methods are chosen when the coal seams are covered by extensive amounts of overburden. Longwall mining is the major removal technology used underground. Two alternative methods are used in open cut mining, these are truck and shovel, and dragline. The removal method used in open cut mines is generally determined by the extent of overburden and inter-burden between the coal seams being mined.

The electricity generation industry is the major domestic user of black coal — consuming just under 80 per cent of the 56 million tonnes used domestically. Thus, indirectly, coal is an important input for all Australian industries. The iron and steel industry is another major domestic user. In 1995–96, 138 million tonnes of black coal were exported. These exports generated $7.8 million of export income. Black coal is Australia's largest single export commodity. It represents around eight per cent of total exports. Japan is the largest single destination of these exports.

Australia produces around five per cent of the world's total production of black coal. However, it is the largest producer of black coal for export — one-third of all black coal export tonnes are from Australia.

Currently, the United States, South Africa and Canada are Australia's main competitor countries. However, in recent years a number of Asian countries, such as China and Indonesia, have become more competitive in the world market. Unless the industry can find ways of improving its viability, increased international competition will put downward pressure on Australia's returns from black coal. Productivity improvements are one way of improving viability.

1.3 MINING TECHNOLOGIES

Coal is recovered using both open cut and underground technologies.

The process of recovering coal in an open cut mine involves several processes. Topsoil and vegetation are sometimes removed with bulldozers and scrapers exposing the material overlaying the coal seam. This is known as the overburden.

Overburden can be removed in one of three ways. First, cast blasting can be used to "throw" a portion of it into a previously mined strip. Second, draglines can be used to remove the overburden and place it on the spoil pile. Depending on pit configuration, this can involve handling the overburden more than once. Thus, overburden removed is typically classified into "prime" overburden and re-handled overburden. Finally, shovels and trucks can be used to remove overburden and interburden.

Once the overburden is removed the coal seam may be blasted and the coal recovered using a truck and shovel operation.

Underground coal mining operations use two technologies — longwall operations and bord and pillar. In underground longwall mines a shaft is sunk from the mine surface to the coal seam. This shaft must have a gradient low enough to allow miners and machines to access the coal face.

In longwall mines, once the coal seam is reached a shaft is driven either side of the coal seam which is to be mined. The coal face is then created by joining the shafts. All these tunnels are supported by roof bolts. Once the coal face has been created the longwall equipment is put in place. Moveable hydraulic chocks are put in place along the coal face. These chocks support the roof while mining takes place. The coal is cut by a shearer which is placed in front of the roof supports. Once the coal is cut, the shearer loads the coal onto an armoured face conveyor. The armoured face conveyor removes the mined coal from the coal face and places it in the stage loader. The stage loader then places the coal on a gate conveyor which transports the coal to the trunk conveyor. The trunk conveyor transports the coal to the surface.

As the coal face is mined, the equipment in the longwall is advanced. This leaves the previously mined area unsupported and the rock which previously overlaid the coal collapses, filling the void. Longwalls can differ in dimensions but typically the coal seams mined can be between one to three metres thick. The coal can be mined in blocks of over a kilometre in length and they can be several hundred metres wide.

Because the technologies used to mine the coal are so vastly different, the productivity analysis was conducted for each mining technology included in the analysis.

1.4 OUTLINE OF THE REPORT

This report uses total factor productivity and partial productivity indicators to compare the performance of coal/ore and overburden removal. It benchmarks open-cut and underground mines. In the open cut side of the industry two removal methods have been benchmarked — truck and shovel, and dragline. The longwall mining technique has been benchmarked in the underground mines. In addition to presenting productivity benchmarks, the report also discusses the main reasons for any identified productivity differences. The following chapter outlines the methodology used in this analysis. Chapters 3 and 4, respectively, present the findings for the two open-cut methods, truck and shovel and dragline. Chapter 5 presents the longwall benchmarking analysis.

2. BENCHMARKING METHODOLOGY

A large amount of data is required to produce sound and objectively determined benchmarks of black coal mine productivity performance. Much of this data is commercially sensitive and not publicly available. Tasman developed a questionnaire and sought the required data from individual mines. A separate questionnaire was produced for each of the three mine technologies investigated.

In addition to operating and financial data, the questionnaires sought information about geological characteristics of mines. The questionnaires collected information on factors such as rock hardness and seam thickness. These factors affect explosives requirements and the digging and loading components of the mining cycle. The collection of this data has allowed Tasman to take into account how many geological characteristics can effect mine performance. While not all geological differences are accounted for, these generally have relatively minor influences on total productivity compared to factors under the control of management such as staffing levels, work practices and equipment capacity and usage.

2.1 SELECTING MINES FOR BENCHMARKING

One of the prime objectives of the study is to make the sample of Australian coal operations as representative as possible of the productivity of the industry. To achieve this we selected mines on the basis of analysis of a detailed database of Australian coal operations provided by Barlow Jonker (1997). This database provides labour productivity and mine cost data separately for dragline, truck and shovel and longwall operations.

Using the Barlow Jonker database, we selected mines to provide a representative coverage of mines exhibiting:

- high labour productivity;
- medium labour productivity; and
- low labour productivity.

On request of Tasman, the Barlow Jonker database defined labour productivity as total movements of coal and overburden per mine employee. Mine employees were defined to exclude maintenance, office and washeries staff. As explained later, these operations are usually excluded from our analysis, as they are difficult to benchmark accurately. We stratified the sample by labour productivity performance as this was considered to be more reliable than the cost estimates which were more significantly affected by mine operating conditions as well as input prices.

In selecting the Australian mines to be invited to participate in the study, we also aimed for a representative coverage according to company ownership, location and mine technology.

The international mines invited to participate in the study were all in the United States. Many other countries that were nominated as having efficient mines had wage rates much lower than those in Australia so were not suitable comparisons for a total productivity analysis. This was mainly because these low-wage countries had much larger relative work forces and different operating practices. These countries included Indonesia, South Africa and Chile.

The black coal mines selected in the United States included a number that were nominated by industry experts as better practice mines. However, this was not universally the case as we also needed to choose mines that were affiliates of Australian mining companies to increase the prospects of receiving data. The rationale for selecting better practice international comparisons rather than average international comparisons is to show the scope for improvement in the Australian industry and ways of achieving that improvement. This is the primary objective of benchmarking.

We also included a number of domestic metalliferous mines as their mining techniques are comparable to the truck and shovel operations at black coal mines. These included better practice Australian metalliferous mines. We excluded one metalliferous mine that responded as it had abnormally low equipment utilisation in that year. We did not exclude any other responding mines.

To achieve a broad sample, we requested data for 52 separate mine operations. Many of the open-cut mines were asked to provide data on both truck and shovel and dragline operations. Taking this into account, we asked for information from 35 separate mines.

We received survey responses from 44 mine operations as shown in Table 2.1. These returns have been provided by 32 separate mines (ie 12 mines provided information on both truck and shovel and dragline operations). In total, our survey presently covers about 38 per cent of total run-of-mine coal produced in Australia. Our truck and shovel sample represents about 45 per cent of total run-of-mine coal produced in Australian open-cut mines. Similarly, the seven participating Australian longwall mines produced around 27 per cent of all Australian raw longwall coal in 1996/97.

Table 2.1: **Characteristics of mine operations responding to the survey**

Mine type and location	*NSW*	*Queensland*	*WA*	*United States*	*Total*
Truck and shovel coal	6	6	0	6	18
Truck and shovel metalliferous	0	0	4	0	4
Dragline	3	5	0	5	13
Longwall	5	2	0	2	9
Total	14	13	4	13	44

Source: Survey undertaken by Tasman Asia Pacific (1998).

A similar number of responses were received from NSW, Queensland and United States mine operations.

Twenty-two of the 44 mine operations included in this analysis use truck and shovel technologies. Another thirteen cover dragline operations. Twelve of the thirteen mines that provided data on dragline operations also provided data on their truck and shovel operations. Nine longwall mines provided data for benchmarking.

It appears that for the open-cut operations we have achieved our objective of obtaining a representative coverage of Australian productivity performance. However, the lower response means that we are unsure whether this is the case for the longwall industry.

2.2 PRODUCTIVITY PERFORMANCE MEASURES

The analysis in this report uses total factor productivity and partial productivity measures. As the name suggests, total factor productivity takes into account a broad range of mine outputs and inputs to provide an overall measure of relative mine performance. Partial productivity measures are then used to validate the total factor productivity analysis and to explain reasons for differences in total productivity between mines.

Appendix 1 provides a technical explanation of the productivity analysis used in this study.

The benchmarking analysis focuses on the main components of the mining process. However, it does not cover all mines inputs nor does it cover development work (eg setting up mine offices, developing access roads). The main items excluded from all three mining technologies are washeries, mine overheads, many maintenance activities and some materials used in production.

These elements have been excluded because:

- the data is often not supplied on a consistent basis by mines (eg mine office overheads and materials);
- the data vary considerably from year to year (eg due to the extent of major equipment overhauls in maintenance activities); and
- differences in inputs largely reflect geological or environmental factors (eg the yield of coal impacts on washeries input).

However, in many cases the relative productivity of mine operations is consistent throughout the various activities it undertakes. For example, an efficient truck and shovel operation typically has lean staffing levels, good work practices and high equipment utilisation and thus achieves high productivity in the mining activities we have measured. Such operations typically apply the same principles to the activities we have not covered in our analysis. For example they also have efficient maintenance, site office and washeries activities. On this basis, it is likely that our analysis is often representative of the broader efficiency of mine operations.

3. OPEN CUT TRUCK AND SHOVEL OPERATIONS

This chapter reports the productivity benchmarking results for 22 coal and metalliferous mines which use truck and shovel mining technologies. These mines remove both overburden and coal or minerals with trucks and shovels. Many of these mines use front-end loaders and excavators as well as, or in place of, shovels.

3.1 THE CHARACTERISTICS OF THE BENCHMARKED OPERATIONS

Although the technologies for extraction and removal are similar for truck and shovel coal and metalliferous mines, they use different removal techniques. Coal mines remove coal and overburden (waste) separately while metalliferous mines remove waste and ore together. Metalliferous mines subsequently crush the rock and extract the ore. Thus for coal mines, the extent of overburden removed and the number and thickness of coal seams have an important influence on costs per tonne of coal removed. The latter two factors also affect productivity. For example, a mine that is working a large number of thin seams requires more extensive use of bulldozers and, in general, front-end loaders than a mine working fewer thick seams.

The key geological characteristics of the 22 participating truck and shovel mines are summarised in Table 3.1

Table 3.1: **Key geological characteristics of participating mines with truck and shovel operations**

	Australia metalliferous	*United States coal*	*Queensland coal*	*NSW coal*
Number of seams (average)	nr	1.7	3.5	8.0
Seam thickness (metres)	nr	39.0	9.2	1.9
Powder factor: kg explosives per tonne moved	0.19	0.22	0.20	0.20
Proportion of coal and ore in total material excavated (%)	27	40	30	10
Average size: million tonnes of coal and waste moved	53	29	26	48
Average size: million tonnes of coal/ore moved	14	11	8	5

nr No response.

Source: Survey undertaken by Tasman Asia Pacific (1998).

The table illustrates that, on average, the NSW coal mines face the most difficult conditions of the four coal mining locations examined in the sample. NSW mines generally operate on multiple, thin seams whereas the United States mines generally have very few, broad seams. On average, the NSW mines operated eight seams of about two metres thickness while the United States mines had one or two seams of about 40 metres thickness. The Queensland coal mines generally had three to four seams, averaging about nine metres thick.

The similarity of powder factors (ie kilograms of explosives used per tonne of overburden and coal/ore removed) suggests that there was little difference in the average overburden hardness encountered by the four mine categories. However, powder factors are also influenced by other variables. For example, differences in the average energy per kilogram of explosives and the amount of shatter required for shovel operations.

The NSW mines had to remove more waste, on average, to uncover coal deposits. While this does not have a major influence on productivity as measured in this study, it does impact on costs per unit of coal produced. Thus, NSW mines would need to be relatively efficient to achieve rates of return on capital of the other mine categories. Our analysis will show that, on average, this is not the case.

Productivity is a physical measure. It measures the volume of output produced per unit of the volume of inputs used. To calculate the productivity of truck and shovel operations the level of output produced must be compared to the level of inputs used to produce these outputs. The following section details the output and input indexes for the mines in the four truck and shovel operation categories. Appendix 2 presents more detailed information on the approach and data used by Tasman to estimate these aggregate output and input levels. These indexes are used in the total factor productivity calculations reported in Section 3.3.

3.2 MINE OUTPUTS AND INPUTS

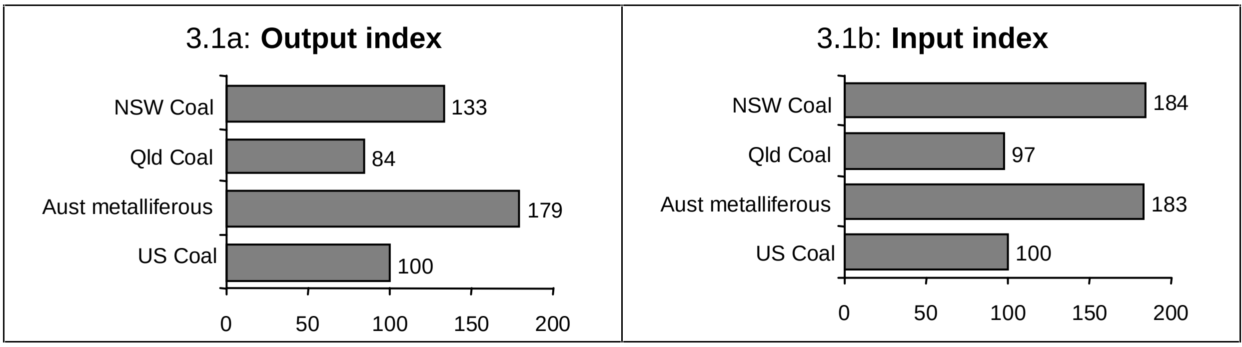
Truck and shovel mining operations involve two broad functions or physical outputs. These outputs are:

1. the excavation of minerals and waste (such as overburden); and
2. the transportation of minerals and waste to stockpiles and processing plants.

Tasman has developed an output measure which incorporates these physical outputs (Appendix 2). Figure 3.1a presents the average mine output index for the four mine categories. The index shows that Australian metalliferous operations had the highest average physical output. The average physical output of the United States and Queensland coal operations was considerably lower.

Productivity analysis also requires information on inputs. Inputs from the sample mines were broken down into 11 categories (Appendix 2). As might be expected, equipment and labour inputs comprised the largest shares of the costs of excavating and moving materials by truck and shovel technologies within mines. Figure 3.1b, shows that, on average, the sample mines in the NSW coal mine category had the highest level of input use of the four mine categories. However, the average level of inputs used by the sample mines in the Australian metalliferous mine category was only marginally lower. In contrast, participating United States and Queensland coal operations had, on average, a more moderate level of input use.

Figure 3.1: **Average output and input — truck and shovel mines**
(index: United States Coal = 100)



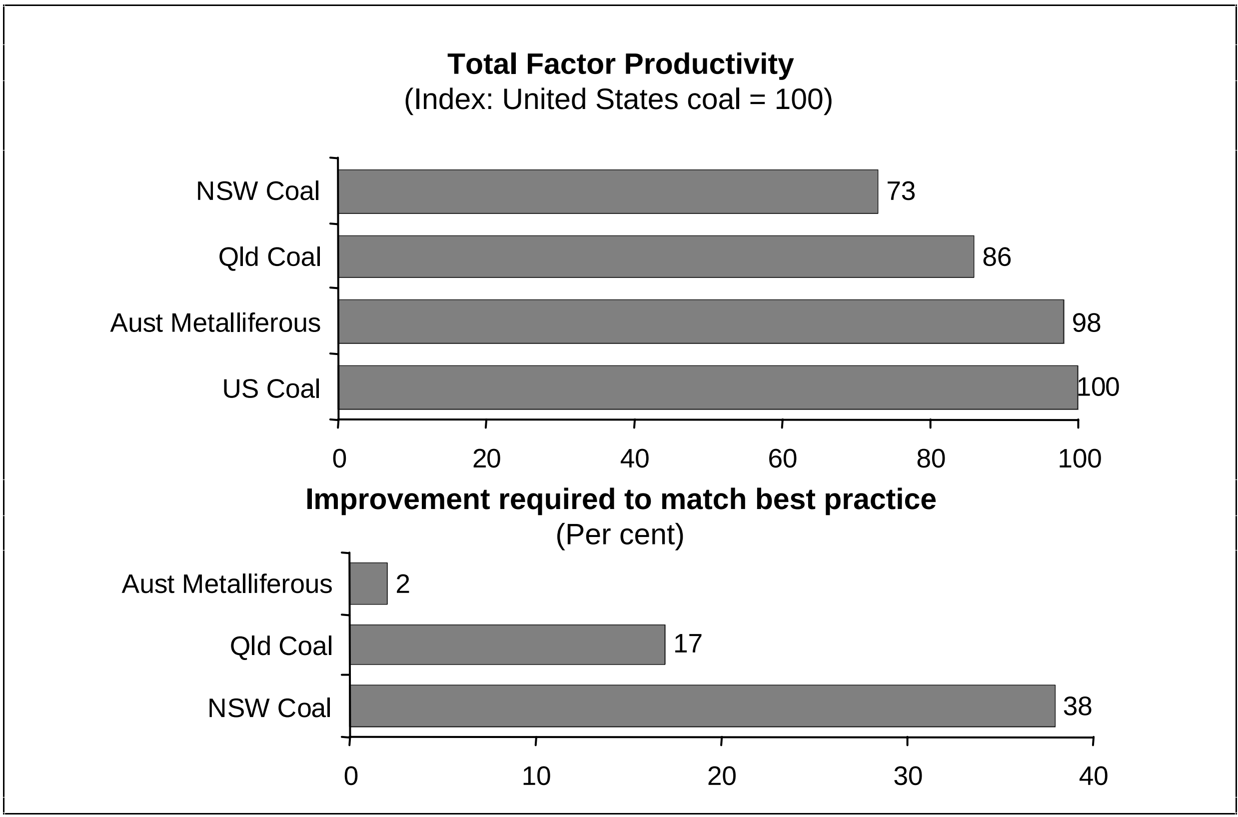
Source: Survey undertaken by Tasman Asia Pacific (1998).

Section 3.3 reports productivity estimates Tasman has derived from these output and input data.

3.3 TRUCK AND SHOVEL OPERATIONS — TOTAL PRODUCTIVITY BENCHMARKS

The total factor productivity of each mine category can be found by dividing the index of total outputs reported in Figure 3.1a by the index of input use reported in Figure 3.1b. This productivity measure is also expressed as an index with the best mine category given a value of 100. Figure 3.2 reports the results of these calculations. The Figure also indicates the extent of the productivity improvement required by the various mine categories to match best practice United States coal mines.

Figure 3.2: **Total factor productivity of truck and shovel operations**



Source: Survey undertaken by Tasman Asia Pacific (1998).

The total factor productivity results for the sample mines show that the average Australian black coal productivity performance was well below that of better practice United States coal mines. As a whole, the Australian coal mines in the sample need to increase productivity by about 30 per cent to match the performance of the United States coal mines.

However, as reported in Figure 3.2, the difference in performance of the sample mines was more marked in NSW:

- NSW coal mines needed to increase productivity by 38 per cent on average to match United States coal mines; and
- Queensland coal mines needed to increase productivity by 17 per cent on average to match United States coal mines.

The estimates also reveal that the productivity performance of the Australian coal mines in the sample was well below Australian metalliferous mines. Once again the performance of NSW coal mines in the sample was below Queensland's coal mines productivity:

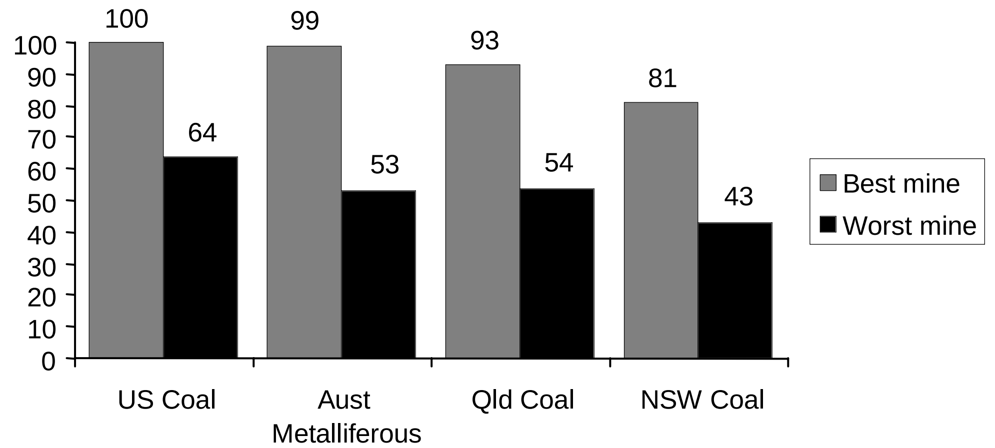
- NSW coal mines needed to increase productivity by 35 per cent on average to match Australian metalliferous mines; and
- Queensland coal mines needed to increase productivity by 14 per cent on average to match Australian metalliferous mines.

As a group, the NSW coal mines in the sample needed to increase productivity by an average of 18 per cent to match the Queensland coal mine sample. However, as the following section shows there is considerable variation of productivity performance within all mine categories, particularly NSW and Queensland coal producers.

3.3.1 Variation in productivity within mine categories

The data reported in the previous section is based on average results for each mine category. This approach facilitates reporting of the results and protects the identity of individual participating mines. However, there is considerable variation in the productivity performance within mine categories. This is illustrated in Figure 3.3, which shows the highest and lowest total factor productivity scores of mines in the NSW, Queensland and United States black coal samples and the Australian metalliferous sample.

Figure 3.3: **Variation in total productivity within truck and shovel mine categories** (index: best mine = 100)



Source: Survey undertaken by Tasman Asia Pacific (1998).

Some of the major observations from this analysis of sample mines are that:

- each of the four categories had considerable variation between best and worst productivity performers;
- the NSW coal category has the greatest variation in productivity performance and the United States coal category the least; and
- the best performer in all categories is close to the best individual performing mine.

As discussed in Chapter 2, we deliberately selected representative Australian coal mines. That is, we selected an equal number of expected high, moderate and low efficiency Australian mines so that the total productivity analysis would indicate the average scope for productivity improvement across the industry. Metalliferous mines in the sample were generally expected to be high performers although they showed considerable variation in practice. United States coal mines participating in this analysis included known high performers and as a group, would be expected to represent above the United States industry average.

Thus, based on this sample, it is arguable that the Australian coal industry needs to increase its productivity by around 30 per cent on average to match the Australian metalliferous industry. However, the gap between average Australian and United States truck and shovel coal performance would be somewhat less than 30 per cent.

The main value of benchmarking is to indicate an achievable target for productivity improvement and demonstrate ways to achieve that target. Figure 3.3 shows that a number of Australian mines in the sample have achieved close to world best practice performance and thus provide excellent benchmarks for similar Australian operations.

To further illustrate this point, Table 3.2 reports the best practice (or frontier) mines from each sample category and compares their total factor productivity scores with the average performance of the remaining mines. This shows that the scope for productivity improvement of many mines is very large. Most notably, many mines in the NSW sample needed to improve productivity by around 70 per cent to match the performance of their NSW peers. In this instance, the best performing NSW mines had the most difficult mining conditions of all participating mines.

Table 3.2: **Scope for productivity improvement using local participating mines as benchmarks**

	United States Coal	*Australia Metalliferous*	*Queensland Coal*	*NSW Coal*
TFP scores of frontier mines	100	99	93	81
Average TFP scores of other mines in category	77	68	63	47
Scope for improvement of other mines in category (%)	31	46	47	74

Source: Survey undertaken by Tasman Asia Pacific (1998).

Thus, domestic comparisons alone are sufficient to indicate an industry which can benefit greatly by more operators achieving the productivity levels of the relatively efficient operators.

3.4 FACTORS CONTRIBUTING TO PRODUCTIVITY DIFFERENCES

A range of factors could contribute to the productivity differences discussed above. We now examine these factors by looking at partial productivity and other measures of mine performance. Partial productivity measures are calculated by dividing the output index by the physical inputs used in each input category. To aid analysis and presentation, these partial productivity indicators have been indexed so that United States coal mines equal 100 for each input class (Table 3.3).

Table 3.3: **Partial productivity indicators of truck and shovel operations** (index: United States coal = 100)

	United States coal	*Australia metalliferous*	*Queensland coal*	*NSW coal*	*Average share of costs (%)*
Labour	100	93	71	59	38
Trucks	100	80	70	60	17
Explosives	100	116	104	89	13
Diesel	100	87	91	92	11
Shovels	100	146	146	118	7
Dozers	100	126	80	108	4
Loaders	100	44	44	23	3
Other equipment	100	116	49	64	3
Electricity	100	115	276	142	2
Contracting out	100	nr	nr	83	1
Drills	100	90	99	91	1

na Not applicable as negligible contracting out indicated in survey forms.
Source: Survey undertaken by Tasman Asia Pacific (1998).

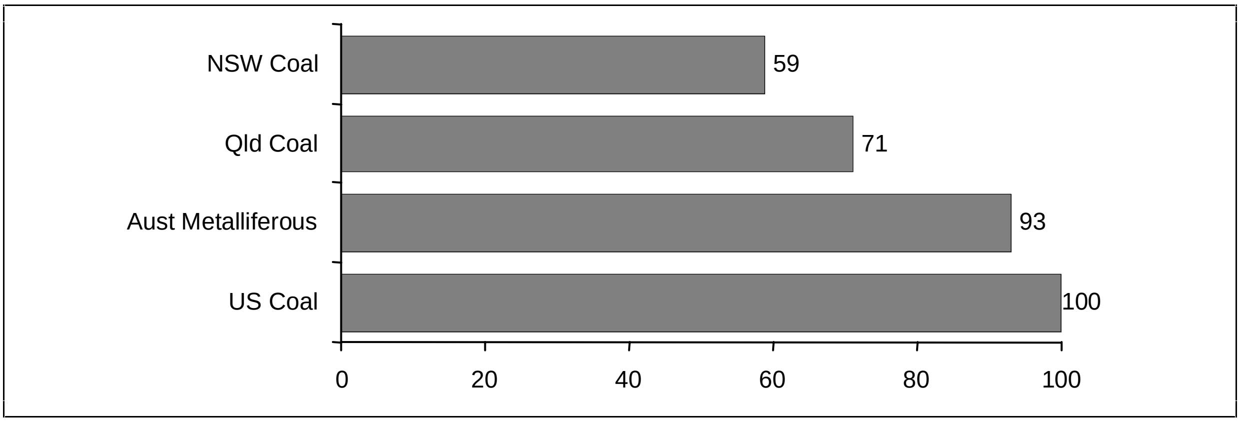
The main cost items are labour, trucking, explosives and diesel. Excavation costs — the combination of shovel, loader and excavator costs — are also significant. Differences in the productivity of these major items explain most of the differences in overall productivity between mine categories.

Indeed it can be readily seen that the main problems for the Australian truck and shovel coal operators in the sample involve labour productivity and truck productivity. These are considered in the following section, along with excavation equipment (shovel, loader and excavator) performance.

3.4.1 Efficiency of the labour force

Labour is a major input to coal and metalliferous mines. Labour averaged 38 per cent of total costs (excluding materials and overheads) across all mines in the survey (Table 3.3). Because of its significant share of costs, labour inputs (hours worked) obtained a high weighting in the calculation of total factor productivity. Thus, labour inputs have a major influence on both the productivity and cost of mine operations.

Figure 3.4: **Labour productivity of truck and shovel mines[a]**
(index: United States coal = 100)



a Labour productivity equals output index divided by total hours worked.
Source: Survey undertaken by Tasman Asia Pacific (1998).

Figure 3.4, above, summarises labour productivity performance for the sample mines in the four mine categories. As reported in Table 3.3, this measure was calculated by dividing the output index by the number of labour hours worked. United States coal mines under this partial measure can be considered as best practice, as this category has the highest labour productivity. Figure 3.4 also shows that NSW and Queensland black coal mines in the sample typically had relatively poor labour productivity. Based on these estimates, NSW coal mines, on average, needed a 70 per cent increase in labour productivity to match United States coal mines. Similarly, Queensland coal mines needed an average increase in labour productivity of around 40 per cent to match the labour productivity of the best practice United States coal mines.

Figure 3.4 also shows that the sample of Australian coal mines had much lower labour productivity than the mines in the Australian metalliferous category. On average the sample mines in the NSW and Queensland coal mine categories needed to increase labour productivity by 57 per cent and 30 per cent, respectively, to match Australian metalliferous mines.

Given these productivity gaps it follows that, on average, the sample coal mines in NSW category had a much poorer labour productivity performance than coal mines in the Queensland category. Mines in the NSW coal category needed to increase labour productivity by 21 per cent, on average, to match sample mines in the Queensland coal category. However, as noted earlier, there is considerable variation of productivity performance within the four mine categories, particularly the NSW coal category.

The main influences on labour productivity include:

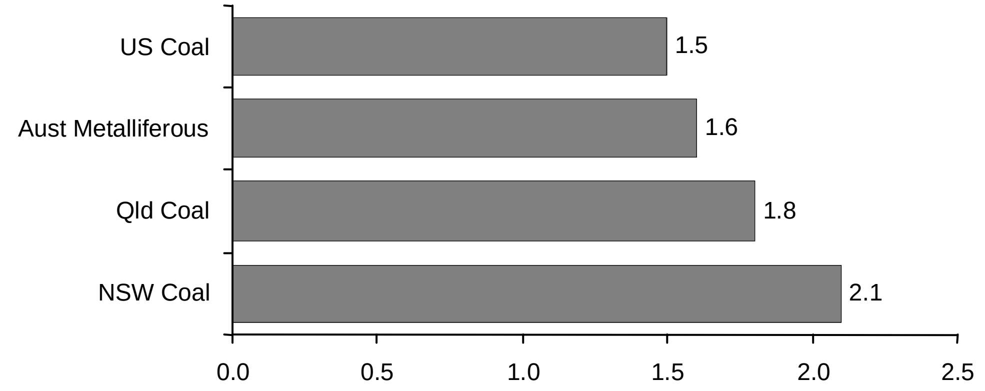
- staffing levels;
- the amount of idle time in shifts;
- equipment operating practices; and
- labour practices.

These factors are examined in detail in the next section.

- *Influence of staffing levels on labour productivity*

Based on the sample, over-staffing appears to be a major cause of poor labour productivity in Australia's black coal mines truck and shovel operations. Compared to the sample mines in the Australian metalliferous category and the United States coal mine category, there are too many workers per individual piece of equipment operated in the participating Australian coal mines. This can be seen from Figure 3.5, which shows the level of mine staff relative to the operating hours of truck and shovel equipment. In this context, labour includes all equipment operators, supervisors, shot-firers, cleaners and staff on general duties. But it excludes maintenance and administrative staff.

Figure 3.5: **Staffing of equipment in truck and shovel mines[a]**



a Ratio equals average hours worked divided by equipment hours operated.
Source: Survey undertaken by Tasman Asia Pacific (1998).

On average participating NSW black coal mines had 2.1 employees for every piece of equipment operated, representing around 40 per cent more employees than used by Australian metalliferous mines. Similarly, participating mines in the Queensland coal mine category employed 1.8 employees for every piece of equipment operated. As noted above, the ratios reported here should not be interpreted strictly as the number of operators per machine. For example, a proportion of the 2.1 operators per piece of equipment in the NSW mines involves non-equipment workers such as supervisors, cleaners and shot-firers. The extent of equipment idle time (ie hours equipment is manned but not operating) also affects this ratio.

There appears to be a strong negative correlation between over-staffing and productivity in the sample mines. The mine categories with the highest overall productivity — the United States black coal mines and Australian metalliferous mines — had the lowest average staffing per machine hour operated. Further, the sample mines with the worst overall performance — NSW and Queensland black coal mine categories — had the highest average staffing per machine hour operated.

To examine how over-staffing occurs, both in terms of too many workers per average piece of equipment and associated with over-capitalisation of equipment, Box 3.1 compares a likely staffing profile of an efficient Australian "frontier' mine in the sample, with that of a less efficient mine, such as many of the sample mines in the NSW category. The staffing assumes three eight-hour shifts per day, five days per week (for coal operations) moving around 30 million tonnes of coal and waste per year.

Box 3.1: **Truck and shovel staffing profile: Australian "frontier" and moderately performing mines**

	Australian Frontier mine	*Moderately performing mine*
Equipment crew		
Trucks	10	13
Shovels	2	3
Loader/excavators	2	2
Dozers	3	4
Drills	2	2
Other equipment:		
• graders	1	2
• water trucks	1	2
• fuel trucks	1	1
• other	1	1
Non-equipment workers		
Supervisors	1	1
Shot-firers	1	2
Bath house cleaners	0	1
General duties staff	0	2
Average workers per shift		
(total of equipment and non-equip. staff per shift)	23	35
Average hours per shift		
(including extra time paid for travel)	8	8
No. of shifts per year	251	251
Number of days mine operated per week	5	5

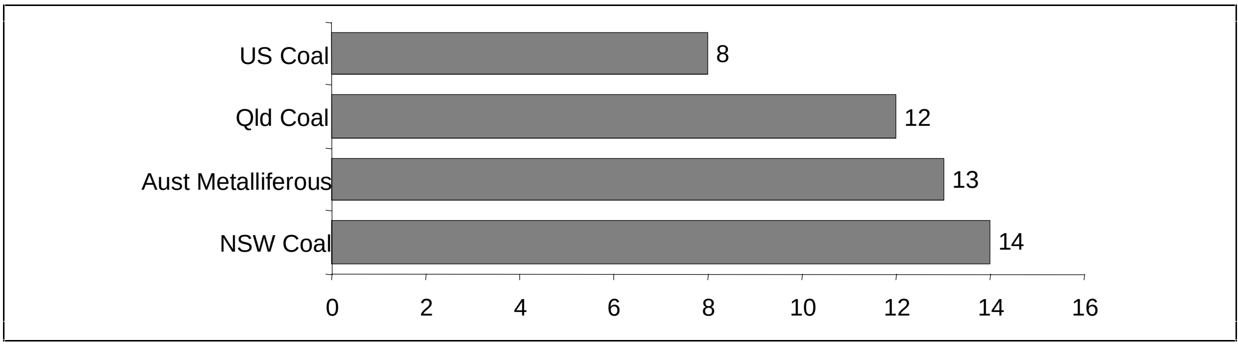
In the less productive mines, over-staffing is often observed throughout the various truck and shovel activities but is particularly evident in the truck fleet (more trucks than needed to do the job), operating other equipment (often due to lack of flexibility in moving between equipment within shifts) and in general duties roles. Box 3.1 shows that to move about 30 million tonnes of material, the less productive mine has 50 per cent higher staffing than the best practice mine. This is equivalent to 50 per cent higher labour productivity in the best practice mine.

- *Other influences on labour productivity*

The amount of work-at-face time in an average shift is another factor that can contribute to labour productivity differentials between mine categories. Time is scheduled for joining, leaving, meal breaks and sometimes other breaks. The greater the extent of this idle time, the lower the amount of actual work time and the lower the productivity of labour.

Figure 3.6 shows that the United States mines in the sample had an extremely low amount of idle time, or high amount of work time, per average shift compared to the sample mines in the other mine categories examined. This helps explain some of the difference in labour productivity performance compared to the United States black coal mine category. The United States mines invariably had just a 30 minute meal break and were reasonably efficient in leaving and joining shifts. A number of the Australian sample mines had additional breaks within shifts that added to the idle time.

Figure 3.6: **Composition of idle time in shifts at truck and shovel mines** (per cent of total shift time)



Source: Survey undertaken by Tasman Asia Pacific (1998).

It is usually more productive for shift changes to take place in the field (ie "hot seat changes") rather than at centralised mustering points. Our survey data (Table 3.4) indicates that the sample Australian coal mines have a higher incidence of hot seat changes than the United States mines and the Australian metalliferous mines.

However, based on our sample, Australian mines do not appear to take as many breaks at their machines as do the United States mines. This has a two-fold impact on productivity. Firstly, taking breaks on machines saves travel time to central meal areas. Secondly, trucks can remain evenly spaced in the cycle — whereas centralised meal breaks create a congestion of trucking on resumption that impedes productivity.

Table 3.4: **Key labour operating practices in truck and shovel operations**

	Australia metalliferous	*United States coal*	*Queensland coal*	*NSW coal*
Common shift type	12 hour – 7 day	12 hour – 7 day	8 hour – 5 day	8 hour – 5 day
Hot seat change (%)	25	33	83	50
Meals in the field (%)	0	50	17	33
Staggered meal breaks	Never	Often	Mixed	Rarely

Operate multiple equipment	Often	Often	Often	Mixed
Haulage equipment fuelled in break	No response	Sometimes	Rarely	Rarely
Clean-up operations not impeding production	Sometimes	Often	Rarely	Rarely

Source: Survey undertaken by Tasman Asia Pacific (1998).

Further, Australian coal mines do not appear to stagger meal breaks as often as United States coal mines. Staggering meal breaks allows major pieces of equipment such as shovels, and some trucks, to continue to operate throughout the shift. Staggering meal breaks requires staff to operate multiple pieces of equipment within shifts. Operating multiple pieces of equipment also occurs for other purposes and is common in nearly all participating mines. The only exceptions were a few NSW coal mines in the sample.

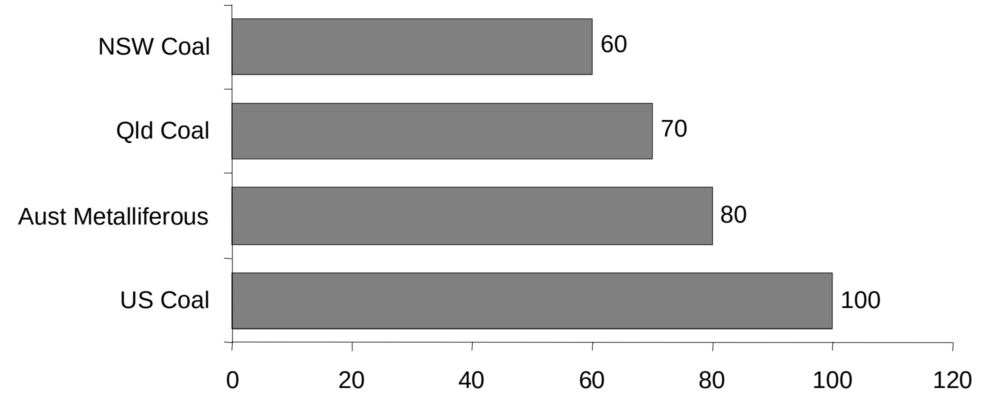
The use of clean-up equipment in Australian coal mines surveyed also appears to halt production more often than in United States coal mines and Australian metalliferous mines. The United States coal mines and Australian metalliferous mines nearly always ensure that the clean-up of ore and waste does not interfere with the core excavation and transportation tasks at the mine. However, shovels and trucks in Australian coal mines often must wait for equipment to tidy up coal and waste spills. Again this impairs production both directly in idle waiting time and indirectly in reconfiguring efficient truck cycling.

In summary, the analysis of this sample of mines suggests that compared to domestic metalliferous mines and United States black coal mines, labour productivity in truck and shovel operations is very poor in NSW and Queensland black coal mines. This poor labour productivity is a contributor to the low total productivity of truck and shovel operations in NSW and Queensland black coal mines. Over-staffing appears to be an important contributor to these results. There are a number of other labour practices that can be tightened up in many Australian coal mines that would improve productivity. These include a greater incidence of breaks at machines rather than at central locations, a greater transfer between machines, particularly to allow core equipment to operate as much as possible within shifts, and ensuring clean-up equipment does not disrupt production.

3.4.2 Efficiency of truck operations

Truck costs comprise a large share of total costs (excluding overheads and materials) averaging nearly 20 per cent for all mines examined. Thus, low truck productivity has a substantial negative impact on total productivity.

Figure 3.7: **Truck productivity[a]** (index: United States Coal = 100)

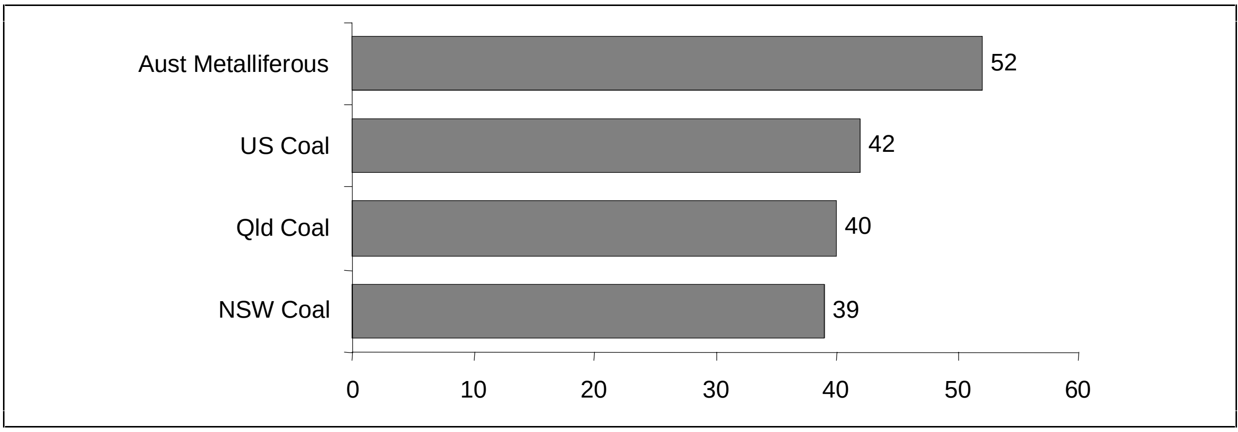


a Truck productivity equals output index divided by total truck capacity, standardised to make US coal = 100.
Source: Survey undertaken by Tasman Asia Pacific (1998).

The partial productivity measures reported in Figure 3.7 for the sample mines indicate that the truck productivity of NSW and Queensland black coal mines was well below that achieved in United States coal mines and domestic metalliferous mines. This productivity difference was particularly large in sample mines in NSW and to a lesser extent in Queensland. The mines in the NSW coal mine category achieved only 60 per cent of the truck productivity of the participating United States coal mines. The sample mines in the Queensland coal mine category achieved 70 per cent of the truck productivity of the United States coal mines.

Low truck productivity in sample NSW mines was partially due to low truck utilisation (Figure 3.8). For example, the utilisation of trucks in Australian metalliferous mines was around 30 per cent greater, on average, than in the NSW coal mine category.

Figure 3.8: **Truck utilisation in truck and shovel mines[a]**



a Hours worked as a percentage of available hours.
Source: Survey undertaken by Tasman Asia Pacific (1998).

The capacity utilisation of trucks is given by the following formula:

$$Truck\ utilisation = \frac{Average\ truck\ hours\ of\ operation}{8{,}760}$$

Low truck productivity in sample NSW and Queensland black coal mines has required excessive numbers of trucks to fulfil the trucking task. This over-trucking represents a significant over-capitalisation in Australian (especially NSW) black coal mines in the sample, and additional employment costs to operate this excessive number of poorly utilised trucks.

Table 3.5: **Inherent truck productivity**

	Truck productivity (1)	*Truck utilisation (per cent) (2)*	*Operating productivity (3)=100*(1)/(2)*	*Indexed operating productivity (4)=(3) indexed*
Australia metalliferous	80	52	154	64
United States coal	100	42	241	100
Queensland Coal	70	40	172	72
NSW Coal	60	39	153	64

Source: Survey undertaken by Tasman Asia Pacific (1998).

Truck productivity can be broken down between truck utilisation (proportion of hours trucks are operated per year) and the inherent operating productivity (productivity per hour operated). Table 3.5 above shows that the inherent operating productivity of truck operations at the participating Australian coal mines was much lower than the average participating United States coal mines. Indeed, our sample indicates that the operating productivity of the

United States truck fleets was 39 and 56 per cent higher than the Queensland and NSW truck fleets respectively. It is somewhat surprising that, on an hour-operated basis, the productivity of participating Australian metalliferous mines' truck fleets was no higher than those of the average participating NSW coal mines.

The greater operating productivity of the participating United States mines was partly due to higher average truck travel speeds (Table 3.6). Average truck speed is calculated by "average kilometres travelled per truck operating hour". The participating mines in the NSW coal mine category had the lowest average travel speed of participating mines in all mine categories over the total truck cycle distance (ie out and back), although this was partly due to the shorter average travel distances. Mines with relatively short-distance hauls may achieve slower average truck speeds than mines with longer hauls — mainly due to a greater proportion of a truck's time being spent queuing, dumping and manoeuvring slowly in the loading and dumping areas. Other factors that may affect average travel speeds include the gradient of the terrain, the quality of roads, climatic conditions, the specification and standard of the truck fleet and workforce behaviour.

Table 3.6: **Key truck haul statistics for truck and shovel mines**

	Distance (km)	*Speed*[a] (km/hr)	*Total cycle time* (minutes)	*Trips per hour* (number)
US coal	8.5	31	16	3.7
Aust metalliferous	8.2	27	18	3.3
Qld coal	7.1	27	16	3.7
NSW coal	4.8	19	15	3.9

a Average travel speed = number of kilometres travelled per truck operating hour.
Source: Survey undertaken by Tasman Asia Pacific (1998).

Most mines achieve truck factors close to 100 per cent. That is, trucks are filled very close to their maximum rated capacity on every haul. This was the case for participating NSW and United States coal mines and the Australian metalliferous mine. These mines achieved average truck factors of between 97 and 100 per cent. However, the average truck factor for the Queensland mines in the sample was only 91 per cent. This was largely due to loading constraints at a few mines such as tyres not being able to cope with maximum loads on long hauls.

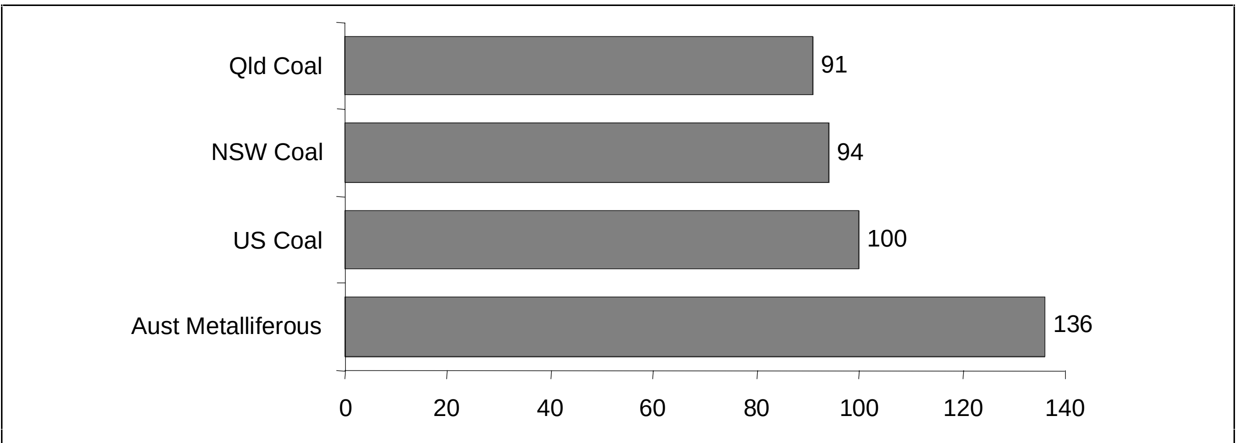
Work practices and other operating factors can also bear significantly on average operating speeds and thus truck productivity. As mentioned in the previous section, these include a greater incidence of meal breaks in the field rather than at central locations and less disruption to truck cycles from clean-up equipment. Another factor influencing truck productivity is shovel-loading practices. This is discussed in the next section.

3.4.3 Efficiency of excavation equipment

Open cut black coal and metalliferous mines use a variety of excavation tools to dig coal or ore and overburden. These tools include electric shovels, hydraulic shovels, front-end loaders and excavators. The same excavation tools, while similar across mines, are not always used for the same purpose. For example, shovels are often used in metalliferous mines to remove ore but are mainly used to remove overburden from coal mines. Loaders are used in metalliferous mines and coal mines to load mined minerals, but are also used for digging in coal mines, particularly when there are multiple coal seams that require more careful digging of overburden. However, geology is not the sole dictator of the tool used. In some cases where digging conditions are similar, one mine may use a shovel where another may use a loader.

For these reasons, Tasman has combined shovels, loaders and excavators in its analysis of the partial productivity of excavation equipment. This is achieved by dividing total movements by the capacity of shovels, loaders and excavators combined. The ensuing excavation equipment productivity results are presented in Figure 3.9.

Figure 3.9: **Excavation equipment productivity**[a]
(index: United States Coal = 100)

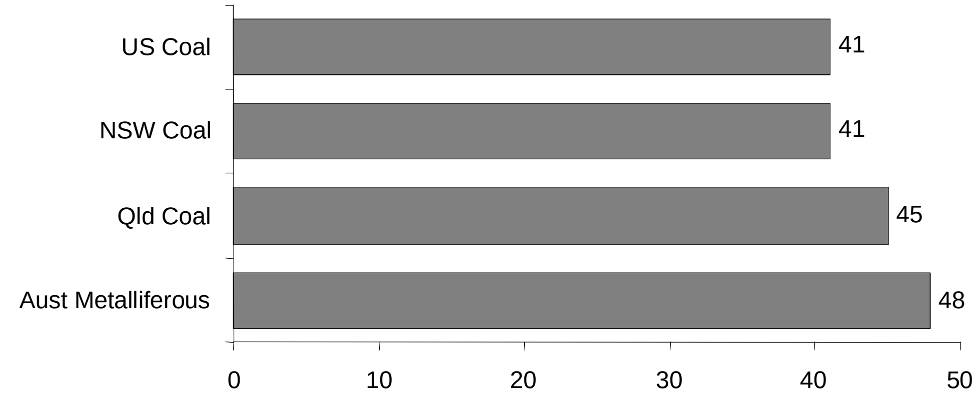


a Excavation equipment productivity equals output index divided by total shovel, loader and excavator capacity.
Source: Survey undertaken by Tasman Asia Pacific (1998).

These sample data indicate that Australian metalliferous mines are, on average, clearly the most efficient in their use of excavation equipment. The other mine categories have reasonably similar productivity of all excavation equipment. However, Queensland coal mines exhibited the lowest productivity of excavation equipment as a whole.

The good excavation equipment productivity for the Australian metalliferous mines was partially due to high utilisation levels (Figure 3.10). Similarly, participating Queensland coal mines had very good utilisation rates for their excavation equipment, contributing to their overall partial productivity measure for excavation equipment. Conversely, participating NSW and United States coal mines had the lowest utilisation rates.

Figure 3.10: **Utilisation of excavation equipment in truck and shovel mines[a]**



a Hours worked as a percentage of available hours.
Source: Survey undertaken by Tasman Asia Pacific (1998).

While high utilisation explains some of the difference in excavation equipment productivity between mines, there were also substantial differences in the inherent (or per-hour operated) productivity of the excavation fleets in the various mine categories surveyed. Table 3.7 shows that the same rankings are apparent in inherent productivity as in total excavation equipment productivity. However, the Queensland mines sampled are relatively unproductive on an hour-worked basis, needing to increase performance by nearly 40 per cent to achieve the average performance of the participating Australian metalliferous mines.

Some of the productivity shortfalls of excavation equipment can be explained by geological conditions. For example, the number and thickness of coal seams appeared to contribute to relatively poor productivity of excavation equipment in the Queensland black coal mines. NSW mines in the sample performed quite well in this regard given the multiple, thin seams common to most of its mines. It appears that many of the NSW coal mines surveyed over-truck their shovels while the converse was true for the participating United States coal mines.

Table 3.7: **Inherent excavation productivity**

	Excavation equipment productivity (see Fig 3.9) (1)	*Excavation equipment utilisation (see Fig 3.10) (per cent) (2)*	*Operating productivity (3)=100*(1)/(2)*	*Indexed operating productivity (4)=(3) indexed*
Australia metalliferous	136	48	282	115
United States coal	100	41	246	100
NSW Coal	94	41	229	93
Queensland Coal	91	45	204	83

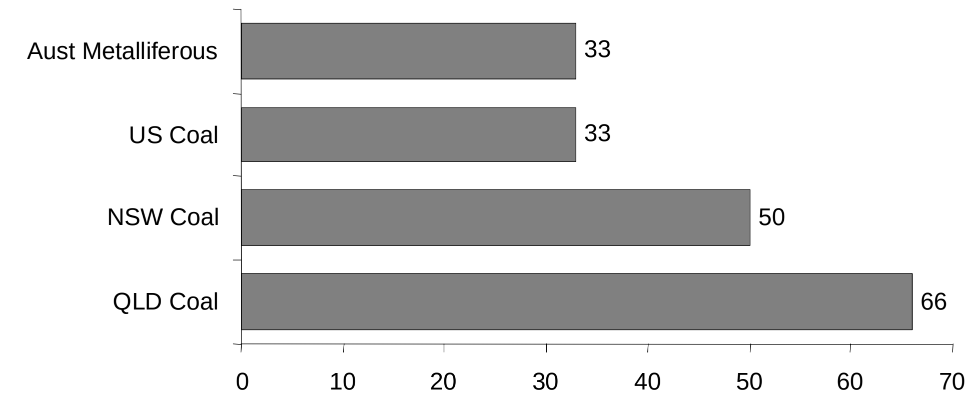
Source: Survey undertaken by Tasman Asia Pacific (1998).

Loading methods also have a major influence on digging equipment productivity. It is generally accepted that double-sided loading is a very efficient loading technique as it reduces the amount of time a shovel has to wait for a truck to position itself. With double-sided loading, shovels swing from rock face to trucks and back continually throughout a shift. Lost time is mostly due to repositioning the shovel on the face. Double-sided loading is not always possible, especially if the rock face is too narrow to fit the manoeuvring of trucks on both sides. In such cases, modified drive-by loading may sometimes be used. In this case trucks do not fully reverse into the face, instead they use a more side-on approach which allows quicker total entry and exit times. Another specialist loading method sometimes used is rear loading.

The standard loading technique in Australian coal mines is single-sided loading. This involves trucks waiting for the previous truck to be assigned away from a shovel, reversing into the face, being loaded and then leaving. This is a less productive method as shovels (and sometimes other trucks) must wait for the positioning process to be completed. Double-sided loading is more dangerous than single-sided loading as it is possible for the shovel to swing around and hit the other truck. However, many mines around the world are apparently able to use this method safely. Our evidence is that more productive mines are generally safer. More productive mines usually use some type of specialist loading technique.

Figure 3.11 shows that Australian coal mines in the sample are much more reliant on single-sided loading methods than the United States coal mines or the Australian metalliferous mines. Our survey data shows that only about one-third of United States coal mines and Australian metalliferous mines rely almost exclusively on single-sided loading whereas about 50 per cent of NSW coal mines and 66 per cent of Queensland coal mines rely on this method.

Figure 3.11: **Percentage of participating mines predominantly using single-sided loading techniques**



Source: Survey undertaken by Tasman Asia Pacific (1998).

As indicated by Table 3.8, the metalliferous mines sampled used a number of specialist loading methods including rear loading. The United States coal mines extensively used both double-sided loading and modified drive-by techniques. Queensland coal producers mainly used single-sided loading while the NSW mines either relied almost exclusively on single-sided loading or almost exclusively on double-sided loading. Not surprisingly, there appears to be a very strong relationship between the use of double-sided or modified drive-by loading and total productivity scores. Most of the productive mines employ these techniques.

Table 3.8: **Shovel loading practices of participating mines**

	Common loading methods
Australia metalliferous	Mixed — includes specialised methods
United States Coal	Much double-sided and modified drive-by loading
NSW Coal	Two extremes — either solely single sided or mainly double sided
Queensland Coal	Mixed but mainly single sided

Source: Survey undertaken by Tasman Asia Pacific (1998).

It appears that the relatively low incidence of double-sided loading in Australia is partly due to physical conditions and partly because management and staff have not been able to agree on how to manage the safety risks of implementing double-sided loading.

We also collected data on excavation equipment performance, including:

- truck spotting time (time between assigning previous truck away to dumping first bucket load in current truck);
- shovel factor (average proportion of rated bucket capacity filled per shovel load); and
- number of truck loads per shift.

There were not enough responses to these questions to provide meaningful averages across the four mine categories. However, it is possible to distinguish the achievements of good performers compared to other mines (Table 3.9). This comparison assumes the use of a common shovel of around 30 to 35 metres loose cubic metres capacity, and common 200 tonne rated capacity trucks.

Table 3.9: **Shovel loading performance**

	Shovel swing factor (seconds)	*Truck spotting time (seconds)*	*Truck loads per shift*
Frontier mine	35	35	185
Moderate performing mine	35	65	135

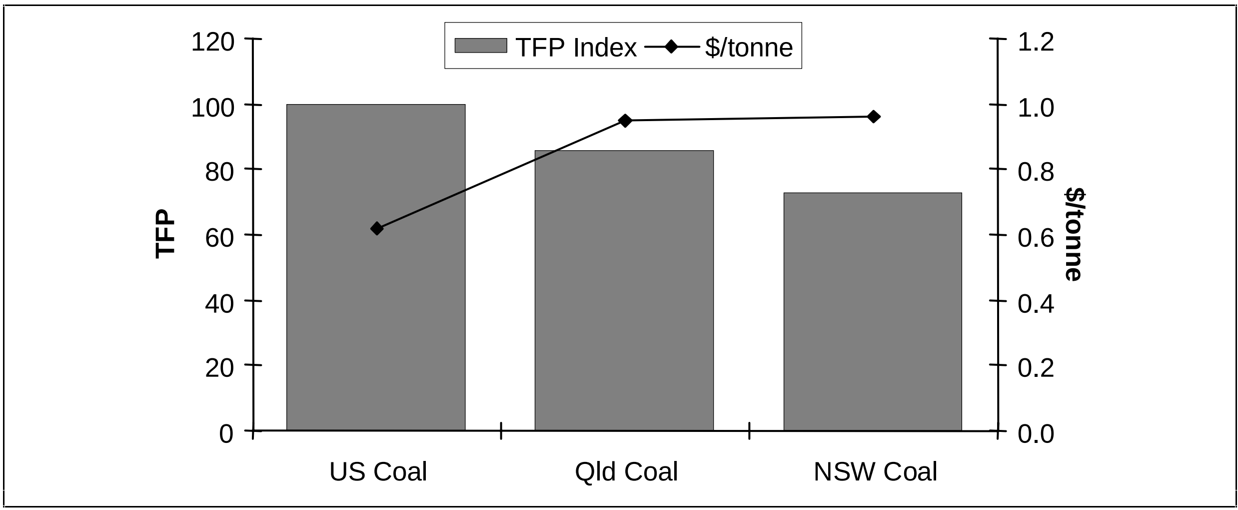
Source: Survey undertaken by Tasman Asia Pacific (1998).

All mines surveyed have very similar swing times on the shovels. However, the better mines in the sample, that use more efficient loading techniques, have truck spotting times around half those of the less efficient shovel operators. That is, the elapsed time between assigning away the previous truck and dumping the first load in the new truck is around 35 seconds when using double-sided loading (ie the same as the swing time) but around 65 seconds for some mines using single-sided loading techniques. As a result of this efficiency and fewer disruptions to production within shifts, the better performing shovels can average around 185 truck loads per shift compared to around 135 truck loads in the less efficient mines.

3.5 THE LINK BETWEEN PRODUCTIVITY AND COST

Lower costs, improved competitiveness and expanded coal exports are the expected outcomes of improved productivity in the Australian coal industry. As shown in Figure 3.12, the productivity advantages enjoyed by United States mines surveyed contribute significantly to their much lower unit costs (ie costs per tonne of material moved). Notice however, that the cost difference between the participating United States and NSW mines is much greater than the difference in productivity. In total, about 30 per cent of the cost difference between these mines was due to high unit costs.

Figure 3.12: **Total factor productivity and cost per tonne, truck and shovel operations: Australian and United States coal operations** (index: United States Coal = 100, cost $A)



Source: Survey undertaken by Tasman Asia Pacific (1998).

Table 3.10 presents more detail on sampled mine's relative cost to mine and move a tonne of excavated material — coal/ore, overburden, interburden and other waste. The table also highlights the cost impost currently faced by the sample mines in the Australian black coal mine categories. Clearly, there is a need to improve productivity and/or reduce input prices if Australian coal producers are to approach the cost levels of United States coal producers. However, it is important to keep the scope of these costs in context. Firstly, they relate to material extraction and movement within the mine, so exclude some mine processes that are difficult to measure accurately, such as washeries. They also exclude maintenance, overheads and some materials costs. They refer to costs per total movements (ie including overburden) rather than per tonne of saleable coal or ore produced. Finally, they do not include ex-mine costs such as rail, port and shipping costs. The costs covered are those related to the input categories listed in Box A2.3.

Costs for United States mines have been converted to Australian currency using purchasing power parity estimates (OECD 1998). These equate to an exchange rate of about 76 US cents to the Australian dollar in 1996 and 1997. We have used purchasing power parity estimates as these best eliminate differences in price levels between countries. It is often argued that the alternative, official exchange rates, do not adequately reflect the comparative purchasing power of local currencies in their own markets (OECD 1998).

Table 3.10: **Cost per tonne of mineral and waste removed, truck and shovel mine categories**

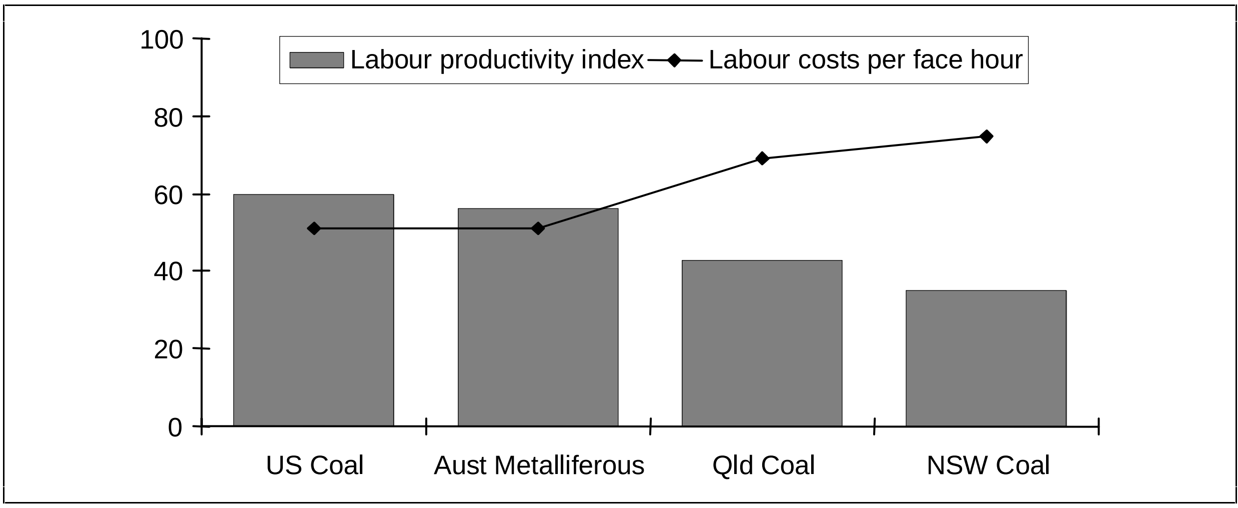
	Cost per tonne of mineral and waste removed ($A)	*Amount NSW coal costs exceed other mines' costs* (per cent)	*Amount Queensland coal costs exceed other mines' costs* (per cent)
United States coal	0.62	55	48
Australia metalliferous	0.71	35	29
Queensland coal	0.92	4	na
NSW coal	0.96	na	–4

na not applicable.
Source: Survey undertaken by Tasman Asia Pacific (1998).

3.5.1 High unit labour costs contribute to the high costs of operation

Workers in the surveyed NSW and Queensland black coal mines are paid significantly more than their counterparts in the sample domestic metalliferous mines and United States coal mines. These higher labour costs are in sharp contrast to the low productivity achieved in these mines. As shown in Figure 3.13, the average labour cost per face hour worked was considerably higher in the NSW and Queensland coal mine categories than in the Australian metalliferous and United States coal mine categories. The labour cost per face hour worked is calculated by summing the labour cost per hour at shift (including base wage, overtime, bonuses and on-costs) and the cost of leave taken for every hour worked then dividing this sum by the proportion of productive work time per hour (ie non-idle time).

Figure 3.13: **Labour productivity and cost in truck and shovel operations** (index: United States Coal = 60 and $A costs)



Source: Survey undertaken by Tasman Asia Pacific (1998).

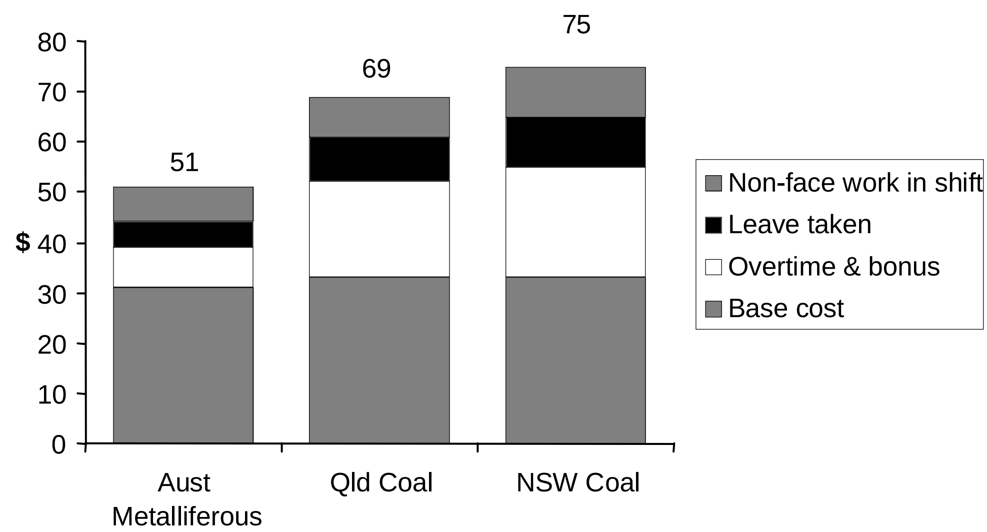
The disparity between labour productivity and labour cost per face hour was particularly wide in the sample mines in the NSW coal mine category. Labour costs per face hour were, on average, 50 per cent higher in these NSW black coal mines than in the sample United States coal and Australian metalliferous mines. Conversely, the labour productivity of these United States coal and Australian metalliferous mines, as measured by the Output Index divided by labour hour worked, was nearly 60 per cent higher than the average for the NSW coal mines.

On a mine-by-mine basis, our sample did not indicate a clear relationship between labour costs per face hour worked and labour productivity in Australian black coal mines. Similarly, we did not find a clear relationship between labour costs per shift hour worked and labour productivity in Australian black coal mines Thus, there was no strong evidence of a broad linkage of pay to productivity in the Australian coal industry. Despite the substantial difference between average labour costs per face hour worked in surveyed Australian black coal mines and domestic metalliferous mines, the base rates of pay were fairly similar across these mine categories. Figure 3.14 shows that, compared to domestic metalliferous mines, the sample mines in the Queensland and NSW categories had higher earnings from overtime and bonuses, took more leave and worked fewer face hours per shift. For example, the higher labour cost in the NSW black coal mines surveyed were due to:

- high earnings from overtime and bonuses in NSW (comprising 60 per cent of the cost differential);

- greater leave taken per hour worked in NSW (nearly 20 per cent); and
- less face work per shift in NSW (15 per cent).

Figure 3.14: **Breakdown of labour cost per face hour worked, truck and shovel operations** ($ per hour)



Source: Survey undertaken by Tasman (1998).

High costs associated with overtime in sampled NSW coal mines generally stem from the relatively short ordinary time hours (35 hour week) and high overtime premiums. The leave taken in these mines includes five to six weeks annual leave and generous long service leave arrangements. These long service leave arrangements apply after eight years of service even if service with the company in non-continuous.

3.6 OTHER FACTORS

This section examines three other factors that affect the productivity of truck and shovel operations, namely:

- the incidence of industrial disputes;
- safety; and
- equipment maintenance.

3.6.1 Incidence of industrial disputes

The Australian coal industry has a very high level of industrial disputation. A report by the National Institute of Labour Studies (1997) indicated that the rate of industrial disputation in coal mines was 45 times the rate of other Australian industry in 1996. Our survey results are consistent with these findings for the coal industry (Table 3.11). For example, we found that there were around 8,200 days of industrial disputes per thousand employees in the Australian coal industry. This was similar to the 7,700 respective days reported in NILS (1997).

Table 3.11: **Incidence of industrial disputation** (average per mine)

	Number of disputes	*Man hours lost per dispute*	*Hours lost in dispute per thousand hours worked*	*Days lost per thousand employees*
Australia metalliferous	0.3	80	0.2	48
United States coal	0.0	0	0.0	0
NSW Coal	6.7	4,748	34.0	7,512
Queensland Coal	9.3	15,700	42.0	8,943

Source: Survey undertaken by Tasman Asia Pacific (1998).

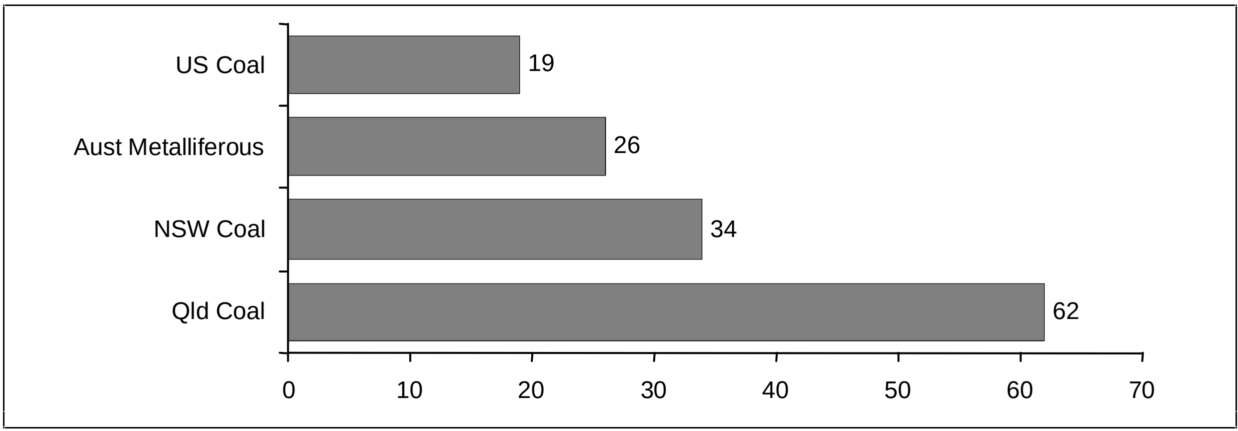
There is a great disparity in the incidence of industrial disputation in the Australian coal industry compared to the United States coal industry and Australian metalliferous mines. Our survey data shows that none of the United States mines had any industrial disputes at all in 1996–97 while the Australian metalliferous mines had an extremely low level.

There appears to be a strong inverse relationship between productivity and the level of industrial disputation. All the better performing mines in our sample had a lower level of disputation while many of the lower productivity mines had many, extended disputes.

3.6.2 Safety

Worker safety is a major concern for the coal industry. While longwall mines are more dangerous than open-cut operations, there is still a relatively high injury rate compared to most other occupations. Our survey results provide a broad indication of the relative safety record within the four mine categories (Figure 3.15). The figure reports lost time injuries per million person hours worked. Lost time injuries are defined to be injuries that prevent a worker from attending the next scheduled shift.

Figure 3.15: **Open-cut mine safety:** (lost time injuries per million person hours)



Source: Survey undertaken by Tasman Asia Pacific (1998).

Figure 3.15 indicates that the participating Australian mines, especially those in Queensland, had a higher injury rate than in participating United States coal mines and Australian metalliferous mines. While this data can only be interpreted very broadly, it suggests that, if anything, there is a positive relationship between productivity and safety. That is, that the more productive mines have better safety records.

3.6.3 Equipment maintenance

The total factor productivity analysis undertaken for participating truck and shovel operations does not include maintenance activities. We excluded maintenance activities because previous data we have collected has proven to be inconsistent between mines. As maintenance is a fairly major cost item for these operations, this can introduce a significant error into the total productivity estimates. While maintenance costs are recorded much more accurately in most mines now compared to three to five years ago, there are still problems associated with the 'lumpy' nature of maintenance work and related expenditures. For example, major engine and other overhauls or refurbishments are often recorded in maintenance systems on an operating rather than capital basis. That is, major maintenance work is reported in the year it occurs rather than distributed (or amortised) over a longer period. Thus, reported maintenance costs of equipment that have undergone major overhaul are much larger than maintenance costs in normal years — making consistent analysis very difficult.

To highlight the importance of maintenance costs in the operation of major equipment in truck and shovel equipment, Tables 3.12 and 3.13 indicate the total cost for participating mines of operating typical mid-size shovels and trucks. These are broken down to capital costs, maintenance (spares, maintenance labour and other maintenance), operator labour and power.

Table 3.12: **Typical costs of operating shovels** (A$'000)

Cost item	*Australia metalliferous*	*United States coal*	*Queensland coal*	*NSW coal*
Capital cost	800	800	800	800
Spares	600	500	300	230
Maintenance labour	300	200	400	250
Other maintenance	150	0	200	370
Operator labour	230	180	415	350
Power	200	180	140	130
Total	2,280	1,830	2,255	2,130

Source: Survey undertaken by Tasman Asia Pacific (1998).

Table 3.12 indicates that maintenance costs represent about 40 per cent of the cost of operating mid-size shovels in truck and shovel mines. This is similar in magnitude to capital costs. Labour costs represent about 15 per cent of total costs and power costs the remaining five per cent. Maintenance labour typically represents about one-third to one-half of total maintenance costs and is a greater cost item than operator labour.

Given the variation in maintenance costs reported, often related to the different types of maintenance undertaken (eg major overhauls versus routine services), it was not possible to identify any difference in maintenance efficiency between mines or the relationship between maintenance activities and productivity.

Survey data presented in Table 3.13 indicates that maintenance cost shares are typically lower for trucks than shovels — representing about 30 per cent of total costs. Capital costs often comprise about 40 per cent of costs, operator labour around 20 per cent and diesel 10 per cent. More than twice as much is often spent on operator labour compared to maintenance labour. Again, it was not possible to identify any difference in maintenance efficiency between mines or the relationship between maintenance activities and productivity.

Table 3.13: **Typical costs of operating trucks** (A$'000)

Cost item	*Australia metalliferous*	*United States coal*	*Queensland coal*	*NSW coal*
Capital cost	300	300	300	300
Spares	130	170	110	120
Maintenance labour	40	70	60	90
Other maintenance	0	0	90	60
Operator labour	120	120	180	200
Diesel	100	125	90	65
Total	690	785	830	835

Source: Survey undertaken by Tasman Asia Pacific (1998).

3.7 ATTRIBUTES OF FRONTIER VERSUS MODERATELY PERFORMING MINES

Section 3.3.1 reported that a number of Australian truck and shovel coal operations which participated in this benchmarking study are at or close to world's best practice and that these operations provide meaningful benchmarks for the many lesser performing Australian coal operations.

This section compares attributes of such frontier Australian truck and shovel mines compared to moderately performing Australian operations. As such, it indicates ways for the poorer performing mines to improve efficiency. It also provides some mid-level performance targets (Box 3.2).

Efficient mines use their resources intensively. This is especially the case for the labour force and trucking and shovel fleets. It is generally believed that better performing mines over-truck. However, our analysis suggested that the more productive mines generally have high productivity of excavation equipment as well as trucks. Over-staffing and over-capitalisation are common causes of lower productivity. Often the moderate performing mines in the sample have more equipment than they need (especially trucks) — requiring additional staff. In such mines, excess staff are also often apparent in areas such as operating non-core equipment and in general duties.

Box 3.2: **Key attributes of Australian frontier and moderately performing mines**

	Best practice mine	*Moderately performing mine*
Total productivity	100	60
Resource levels		
Staffing levels: ratio of labour hours worked to equipment hours worked	1.5	2.1
Work time in shifts: time excluding leaving and joining shifts, meal and other breaks (per cent)	92	85
Utilisation of truck fleet:	45	40
Utilisation of major digging equipment	50	40
Work practices		
Hot seat changes	✓	✓
Meal breaks in the field	✓	✗
Staggered meal breaks	✓	✗
Operators move between equipment within shifts	✓	Rarely
Haulage equipment fuelled in breaks	✓	✗
Clean-up equipment does not impede production	✓	✗
Other indicators		
Efficient truck loading practices: incidence of double-sided or some other efficient truck loading method (per cent)	>50	0
Spotting time of trucks under shovels (seconds)	35	65
Truck loads per shovel per 8-hour shift	185	135
Industrial disputes: days lost per thousand hours worked	0	20
Safety: lost time injuries per million man hours	20	50

Source: Survey undertaken by Tasman Asia Pacific (1998).

Work practices are also more efficient in the high performing mines in the sample. For example, staff in efficient mines use effective hot-seat changes, take meal breaks on machines, stagger meal breaks to ensure that core equipment continues to operate, move between pieces of equipment within shifts where necessary, fuel haulage equipment during breaks and ensure clean-up equipment does not impede production. Generally the poorer performing mines implement only a few of these good practices.

Highly productive truck and shovel operations usually use efficient shovel techniques such as double-sided loading of trucks. While this imposes an extra dimension of care to maintain safety standards it allows substantially more excavation per shift and improves truck productivity. For example, limited responses to our sample suggested that spotting times under trucks are often around 35 seconds with double-sided loading compared to 65 seconds with single-sided loading. This 30 second per truck lost digging and transportation time is significant given the frequency of truck loading (eg 30 seconds times 135 trucks per shovel per shift times 750 shifts per year times three shovels equals 2,500 lost production hours per year).

As noted earlier, the better performing mines in the sample invariably have fewer industrial disputes and also seem to have a better safety record.

3.8 SUMMARY OF TRUCK AND SHOVEL ANALYSIS

The analysis presented above shows that the productivity of the surveyed NSW and Queensland truck and shovel coal mines in 1996–97 was well below that of domestic metalliferous mines and United States coal mines. For example, to match the productivity of the United States coal mines, the mines in the NSW and Queensland coal mine categories would, on average, have needed to increase their productivity by 38 and 17 per cent, respectively. Similarly, these mines needed to increase productivity by an average of 35 and 14 per cent, respectively, to match the productivity of the Australian metalliferous mine category.

Several factors contributed to this difference in productivity. These included:

- excessive labour inputs in NSW and Queensland coal mines;
- low truck utilisation in NSW and Queensland coal mines;
- less productive shovel loading practices in many NSW and Queensland coal mines;
- inefficient work practices; and
- geological differences.

From our analysis of sampled mines it appears that low labour and truck productivity in NSW and Queensland coal mines, compared to United States coal mines and domestic metalliferous mines, were the major causes of this total factor productivity difference. Relatively low productivity of excavation equipment also contributed to these differentials compared to domestic metalliferous mines.

Over-staffing was a major contributor to the poor labour productivity in the participating mines in the NSW and Queensland black coal mine categories. This stemmed from both excessive numbers of equipment (eg over-capitalisation of the truck fleet) and too many operators of non-core equipment and in general duties. Many good work practices are not as widespread in the Australian coal mines surveyed as they are in participating United States coal mines and domestic metalliferous mines.

Low truck productivity in these NSW and Queensland black coal operations stemmed from reasonably low utilisation together with poorer work and truck loading practices. The latter involved a greater reliance on single-sided loading rather than more efficient methods such as double-sided or modified drive-by loading.

A number of NSW and Queensland truck and shovel coal operations surveyed are at or close to world's best practice and can provide meaningful benchmarks for the many lesser performing Australian coal operations. Comparison of such domestic 'frontier' mines with lesser performing Australian operations clearly shows the scope for general improvement of the Australian industry from utilising resources more intensively, improving work practices and improving the industrial relations climate.

4 DRAGLINE OPERATIONS

Draglines are used solely for removing overburden to uncover coal seams. This chapter benchmarks the removal of overburden using draglines. It reports productivity performance results for 13 Australian and United States open cut coal mines which use dragline mining equipment as the primary overburden removal method.

4.1 KEY CHARACTERISTICS OF THE BENCHMARKED MINES

The dragline operations analysed, comprised five coal mines from Queensland, three from NSW and five from the United States. All but one of these mines also provided data on truck and shovel operations. As with the truck and shovel operations, results are aggregated by location (ie for Queensland, NSW and United States coal mines).

Table 4.1 summarises the key characteristics of the participating mines. It shows that the average size of mines varied between the mining categories examined. In particular, the Queensland mines moved much more overburden than the United States mines. Our analysis does not indicate much correlation exists between productivity and size of operations, although some of the smaller operations had relatively low productivity.

Table 4.1: **Characteristics of dragline operations: average per mine**

	Prime overburden moved (million bcm)	*Re-handled overburden moved (million bcm)*	*Total overburden moved (million bcm)*	*Re-handle factor (re-handled/ prime over burden per cent)*	*Powder factor (kg explosives per bcm)*
Queensland coal	27	10	37	0.38	0.26
United States coal	14	6	20	0.45	0.38
NSW coal	20	5	25	0.27	0.38

Source: Survey undertaken by Tasman Asia Pacific (1998).

The three mine categories also varied in the proportion of re-handled overburden. For example, participating mines in the United States category had an average re-handle factor nearly double that of the NSW mine category. Re-handling overburden can either help or hinder the productivity of a dragline, depending on the circumstances. In some instances, productivity will decrease because of the need for the dragline to move to re-handle the overburden. Thus a dragline with a high re-handle factor may spend a greater proportion of its time re-positioning and creating work-benches rather than digging. However, draglines with low re-handle factors may also spend significant amounts of time building work-benches. Further, re-handling may increase the productivity of a dragline by "short-swinging".

The high proportion of sandstone and other dense materials in the NSW mines overburden disadvantages these mines. These materials require greater amounts of blasting to achieve a satisfactory degree of shatter for digging by the dragline. This higher level of blasting is reflected in the high average powder factor of the NSW mines compared to the Queensland operations. The United States mines in the study also had a relatively high powder factor.

4.2 DRAGLINE TFP

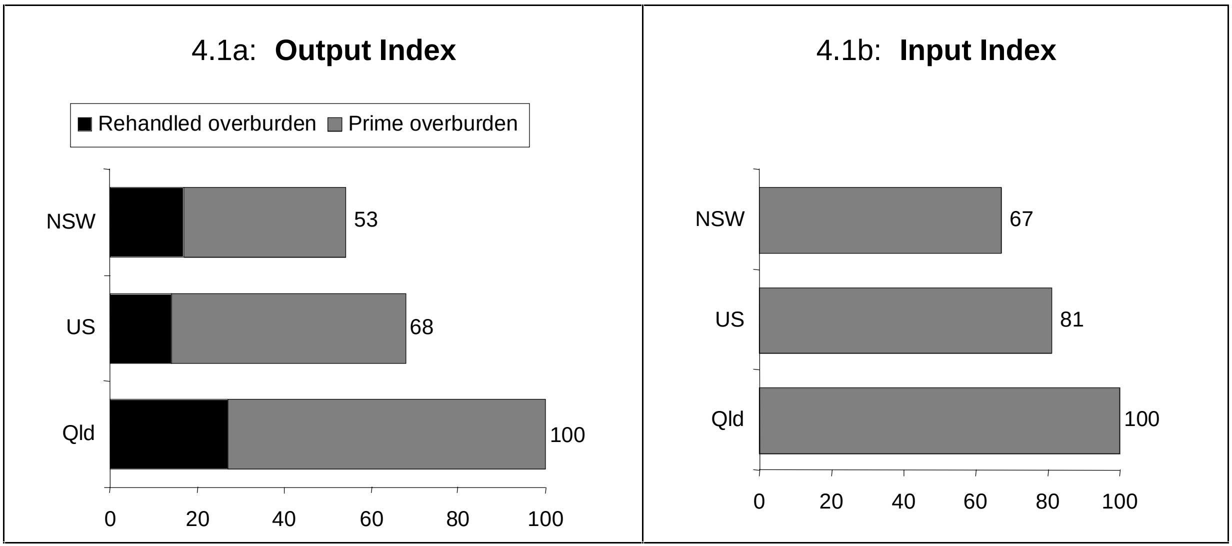
The calculation of a TFP index for our 13 dragline mines requires data on mine output and the inputs used to produce this output. This section provides information on the methods used by Tasman to estimate these data and presents TFP estimates for the three mine categories discussed above. The following section considers the factors which contribute to differences in the three mine categories' productivity.

4.2.1 Mine outputs and inputs

The sole purpose of dragline operations is to move overburden. Overburden removed is typically classified into "prime" overburden and re-handled overburden. For the purpose of calculating total productivity, Tasman has defined the dragline output to be the sum of prime and re-handled overburden expressed in banked cubic metres.

Following the methodology outlined in Appendix 3 (Box A3.1) and used in the benchmarking of truck and shovel operations, Tasman has calculated an output index from these quantities. This index has been derived by dividing the overburden moved in each mine by the overburden moved in Queensland, with each quotient then multiplied by 100. This method produces an output index with Queensland equal to 100. Figure 4.1 presents the resulting output index.

Figure 4.1: **Average output and input — dragline mines** (index: Queensland = 100)



Source: Survey undertaken by Tasman Asia Pacific (1998).

Dragline productivity analysis also requires information on inputs. Mine inputs were broken down into eight categories (Appendix 3). Dragline, explosives and labour inputs comprised the largest shares of the costs of excavating material by dragline technologies. Figure 4.1b, shows that, on average, the Queensland category had the highest level of input use of the three mine categories. The average level of inputs used by the United States mines was substantially higher than those used by NSW mines.

Section 4.3 reports productivity estimates Tasman has derived from these output and input data.

4.2.2 Dragline operations — total productivity benchmarks

Tasman has estimated the productivity of coal mine dragline operations by dividing mine output (total movements in banked cubic metres) by the index of input use derived in Section 4.2.1. These TFP estimates were then expressed as an index with the Queensland mines given a value of one hundred. Table 4.2 and Figure 4.2 present the results of this analysis for the three mine categories and summarise, in index form, the quantities of output and inputs used.

These estimates indicate that the participating mines making up the Queensland mine category had the highest total productivity of the three categories examined. The productivity performance of participating NSW mines in 1996–1997 was well below that of the Queensland mines. The mines making up the NSW coal mine category needed to increase productivity by an average of 25 per cent to match the Queensland mines.

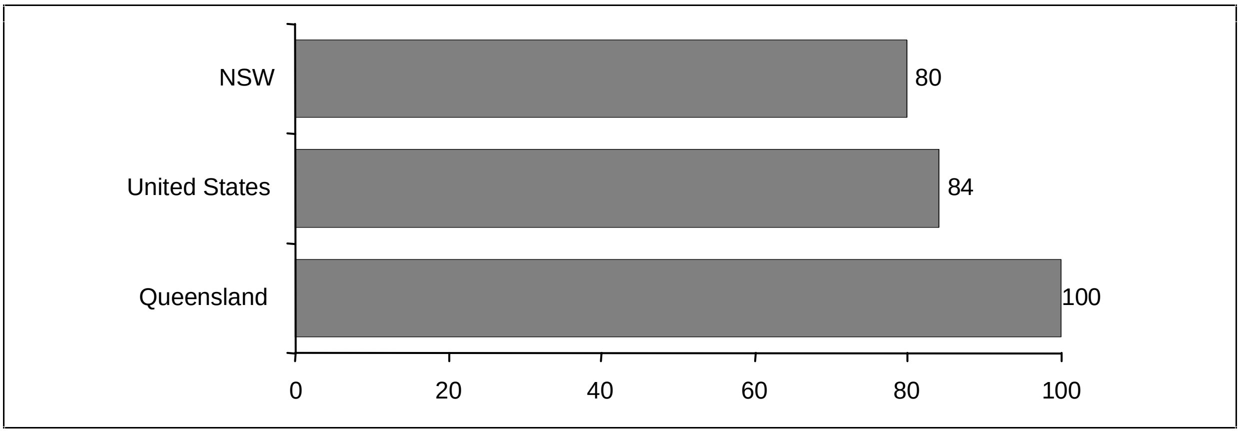
Table 4.2: **Total productivity of dragline operations** (index: Queensland = 100)

	Output (index: Queensland = 100)	*Input use* (index: Queensland = 100)	*Productivity index* (index: Queensland = 100)
Queensland	100	100	100
United States	68	81	84
NSW	53	67	80

Source: Survey undertaken by Tasman Asia Pacific (1998).

The productivity performance of the participating mines in the United States category was slightly superior to the performance of the NSW mine category. NSW coal mines needed to increase productivity by five per cent to match United States mines. On average, the productivity of the Australian dragline operations was around 13 per cent higher than the participating United States mines.

Figure 4.2: **Total productivity of dragline operations** (index: Queensland = 100)



Source: Survey undertaken by Tasman Asia Pacific (1998).

There was some variation in productivity performance within categories, particularly for mines in the Queensland and United States categories. Thus, although the reported averages reflect typical productivity performance in those regions, they also disguise variations between mines within regions. Because of the limited number of mines in these categories Tasman, for confidentiality reasons, has not presented details of the best and worst performers. However, the variations in dragline productivity performance were not as great as those reported for truck and shovel operations in Chapter 3. For example, there was around 30 per cent difference in productivity between the best and worst performing dragline operation in each of the three categories (Queensland, NSW and the United States).

As discussed earlier, many open-cut mines provided data on both their dragline and truck and shovel operations. Analysis of these mines shows that dragline operations of Australian mines were, in a relative sense, about 10 to 15 per cent more productive than truck and shovel operations at the same mine (Table 4.3). Conversely, dragline operations of United States coal mines were on average about 15 per cent relatively less productive than truck and shovel operations at the same mine.

Table 4.3: **Comparing the productivity of dragline and truck and shovel operations of mines**

	Dragline TFP (average TFP per mine)	*Truck & shovel TFP (average TFP per mine)*	*Difference in TFP (per cent)*
Queensland coal	91	80	14
United States coal	75	88	–15
NSW coal	67	60	11

Source: Survey undertaken by Tasman Asia Pacific (1998).

While the number of responses was relatively small, it does appear that a number of Australian open-cut mines that have problems with over-staffing and inefficient work practices in their truck and shovel operations are able to achieve much higher relative productivity in the less labour-intensive dragline operations. One possible explanation for this dichotomy in productivity performance is that some mines have a primary focus on dragline operations and thus achieve relatively greater efficiency in those operations. This is reinforced by our observation that a number of participating open-cut mines that do not have draglines, and thus focus solely on truck and shovel operations, are amongst the better performing truck and shovel mines.

4.3 FACTORS CONTRIBUTING TO DIFFERENCES IN DRAGLINE PRODUCTIVITY

An examination of a range of partial productivity measures helps identify broad reasons for the differences in observed total productivity. These partial measures can be calculated by dividing total overburden moved by draglines by the physical inputs used in each input category. Table 4.4 presents these measures in index form — Queensland mines equal 100 for each input class. The partial productivity measures are listed according to their importance in average cost shares. This focuses attention on the more important input categories — mainly draglines, explosives and labour.

Table 4.4: **Partial productivity indicators of dragline operations** (index: Queensland Coal = 100)

	Qld	*US*	*NSW*	*Average share of costs* (%)
Dragline productivity ('000 bcms per loose cubic metre of dragline capacity)	100	85	81	38
Explosives productivity ('000 bcms per kg explosives)	100	70	69	21
Labour productivity (bcms per labour hour worked)	100	84	84	21
Electricity productivity ('000 bcms per megawatt hour)	100	107	110	12
Dozer productivity ('000 bcms per kilowatt of dozer capacity)	100	95	120	4
Diesel productivity (bcms per litre of fuel used)	100	34	139	3
Drill productivity ('000 bcms per centimetre of drill capacity)	100	47	45	2
Other equipment productivity ('000 bcms per kilowatt of other equipment capacity)	100	57	15	<1

Source: Survey undertaken by Tasman Asia Pacific (1998).

This partial analysis indicates that participating Queensland mines ranked highly on all partial productivity indicators. However, for three partial indicators — electricity, dozers and diesel — the participating NSW mines' productivity exceeded Queensland's performance. These inputs form a reasonably small proportion of total dragline input costs.

The partial productivity analysis of the sample indicates that the Queensland mines' superior average performance was partially due to mine geology. For example, the material types in Queensland's overburden needed less blasting compared to those facing participating mines in NSW and the United States. As explosives are 20 per cent of the total input costs a geological advantage of this type is an important explanator of the observed total productivity differences.

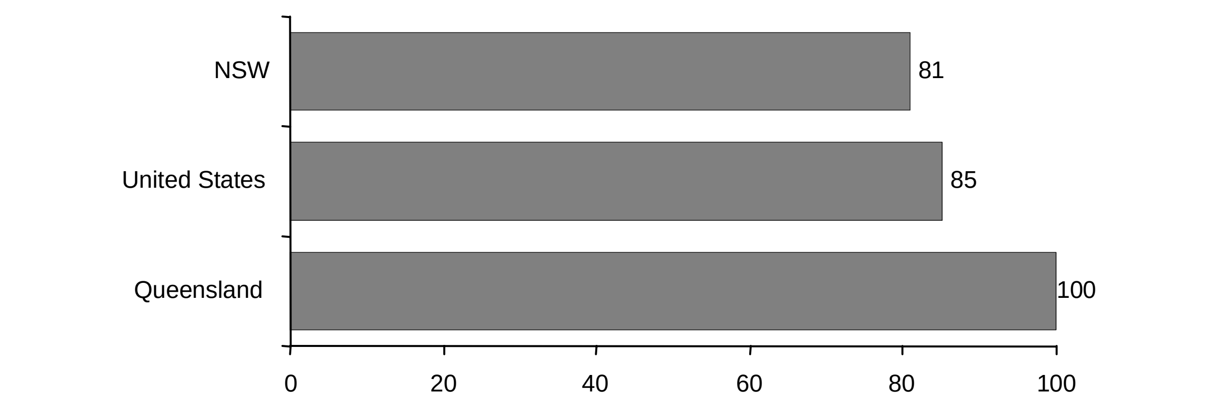
Other factors also contributed to Queensland's superior performance. The partial productivity indicators suggest that a significant portion of Queensland's productivity advantage results from better dragline and labour practices. The following sub-sections consider influences which impact on dragline and labour productivity.

4.3.1 Efficiency of dragline operations

Dragline capital costs comprise a large share of total costs (excluding overheads and materials) of dragline operations, averaging nearly 40 per cent for all mines examined. Thus, productivity of the draglines themselves has a major influence on total productivity.

The partial productivity measures reported in Figure 4.3 indicate that the productivity of draglines in Queensland mines was much higher than in the United States and NSW mines. The NSW mine category needed to increase dragline productivity by about 25 per cent to match that of the Queensland mine category. United States mines needed to increase dragline productivity a corresponding 17 per cent.

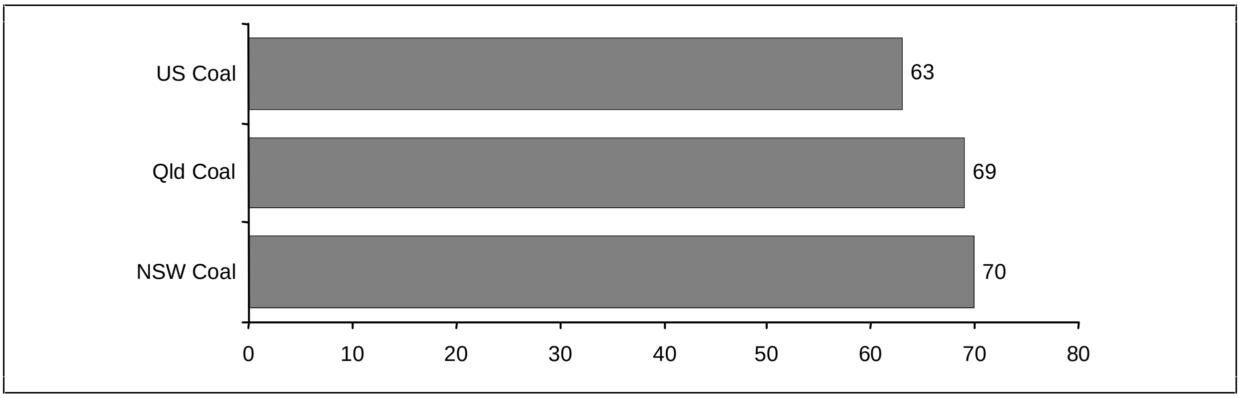
Figure 4.3: **Productivity of draglines[a]** (index: Queensland = 100)



a Dragline productivity equals output index divided by total dragline capacity.
Source: Survey undertaken by Tasman Asia Pacific (1998).

Analysis of the survey data indicates that low productivity of United States dragline operations relative to Queensland operations was partially due to lower dragline utilisation (Figure 4.4). This explained about half the observed difference in dragline productivity between these two categories.

Figure 4.4: **Dragline utilisation** (per cent)



a Hours worked as a percentage of available hours.
Source: Survey undertaken by Tasman Asia Pacific (1998).

However, the moderate dragline productivity of NSW mines was not due to relatively low utilisation. Rather it reflected lower operating productivity. Table 4.5 indicates that participating NSW mines only averaged 37 full bucket equivalents compared to 44 for the United States mines and 47 for the Queensland mines in the sample. Thus these NSW mines were not making effective use of their relatively large draglines. The main problem related to the number of swings per hour. It appears that a number of the NSW mines achieved high dragline bucket factors.

Table 4.5: **Productivity performance of dragline operations**[a]

	Dragline output per hour (bcms)	*Bucket factor (per cent)*	*Swings per hour (number)*	*Bucket capacity (loose cubic metres)*	*Full bucket equivalents (number per hour)*
Queensland coal	1,901	92	51	41	47
United States coal	2,074	88	50	47	44
NSW coal	1,910	95	39	51	37

a The total hourly output per dragline was estimated using the following formula:
*Output per hour = Total mine output / (dragline hours worked * number of draglines)*
Source: Survey undertaken by Tasman Asia Pacific (1998).

The participating Queensland mines had moderately higher operational efficiency (full bucket equivalents) than the United States mines surveyed. Together, with high utilisation, this explained the difference in dragline productivity between these mine categories (Table 4.6).

Table 4.6: **Capacity utilisation and improvements needed to match best practice dragline performance**

	Improvement needed to match Queensland dragline performance in:			
	Utilisation (%)	*Full bucket equivalents per hour* (%)	*Full bucket equivalents per year* (%)	*Dragline productivity* (%)
United States	10	7	17	17
NSW	–2	26	23	23

Source: Survey undertaken by Tasman Asia Pacific (1998).

Table 4.6 also shows that participating NSW mines needed to increase dragline productivity by 23 per cent to match Queensland productivity levels, on average. NSW mines had two per cent higher utilisation of draglines so needed to increase operational efficiency by about 26 per cent to match the Queensland mines in the sample.

Draglines accounted for about 40 per cent of costs for the NSW and other mine categories. Thus, the 23 per cent improvement in dragline productivity required by the participating NSW operators to match the average of participating Queensland operators would translate into around a ten per cent improvement in total factor productivity. This would have reduced the gap between the NSW and Queensland operators from around 25 to 15 per cent.

As with the truck and shovel analysis, maintenance costs have been excluded for the dragline analysis because they can be very misleading — especially when some mines include major overhauls and others do not. While there is a very large range in maintenance costs reported in our survey, Table 4.7 shows 'typical' values for the mine categories.

Table 4.7: **Typical costs of operating draglines** (A$'000)

Cost item	*Queensland*	*United States*	*NSW*
Capital cost	3,500	3,500	3,500
Spares	1,000	800	900
Maintenance labour	600	400	500
Other maintenance	700	600	1,000
Operator labour	1,300	1,000	1,100
Power	600	700	1,000
Total	7,700	7,000	8,000

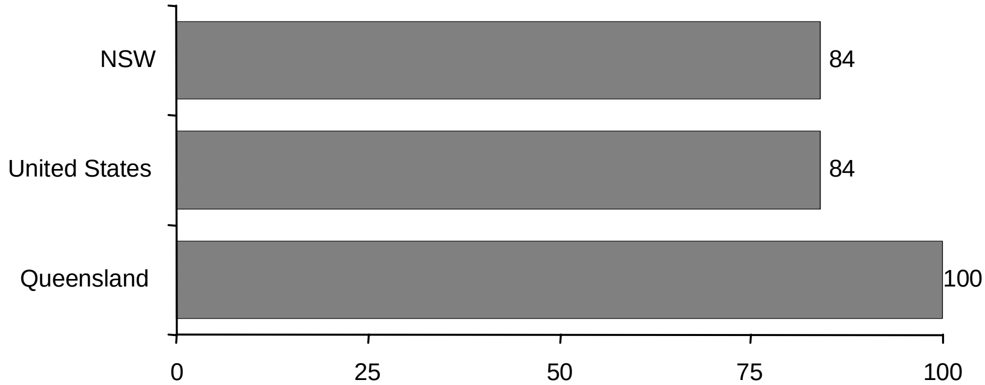
Source: Survey undertaken by Tasman Asia Pacific (1998).

Table 4.7 indicates that participating mines' maintenance costs typically represent about 30 per cent of total costs of operating draglines. Capital costs often comprise about 45 per cent of dragline costs, operator labour around 15 per cent and electricity 10 per cent. This indicates that while draglines are not labour intensive, they still have considerable operator wage cost. It was not possible to identify any difference in maintenance efficiency between mines or the relationship between maintenance activities and productivity.

4.3.2 Labour Productivity

Labour accounts for around 20 per cent of dragline input costs (excluding materials and overheads). On average, participating mines in the Queensland category had the highest labour productivity (Figure 4.5).

Figure 4.5: **Labour productivity in dragline operations** (index: Queensland = 100)



a Labour productivity equals output index divided by labour hours worked.
Source: Survey undertaken by Tasman Asia Pacific (1998).

The average labour productivity performances of the participating NSW and United States mines was very similar and needed to increase by about 20 per cent to match the best practice Queensland category. This moderate labour productivity performance comprised about one-quarter of the 25 per cent total productivity shortfall of the NSW mines compared to the Queensland mine category.

Table 4.8 shows the staffing of a typical, efficient Australian dragline operation using a single dragline. While over-staffing has not been identified as a major problem for Australian dragline mines, some mines have additional dozer, drill and general duties staff.

As reflected in the example in Table 4.8 below, virtually all dragline mines in the sample operate year-round (ie 24 hours per day, seven days per week, only having Christmas Day off). The participating Australian mines typically operate three eight-hour shifts per day whilst most of the United States dragline operations have two 12 hour shifts.

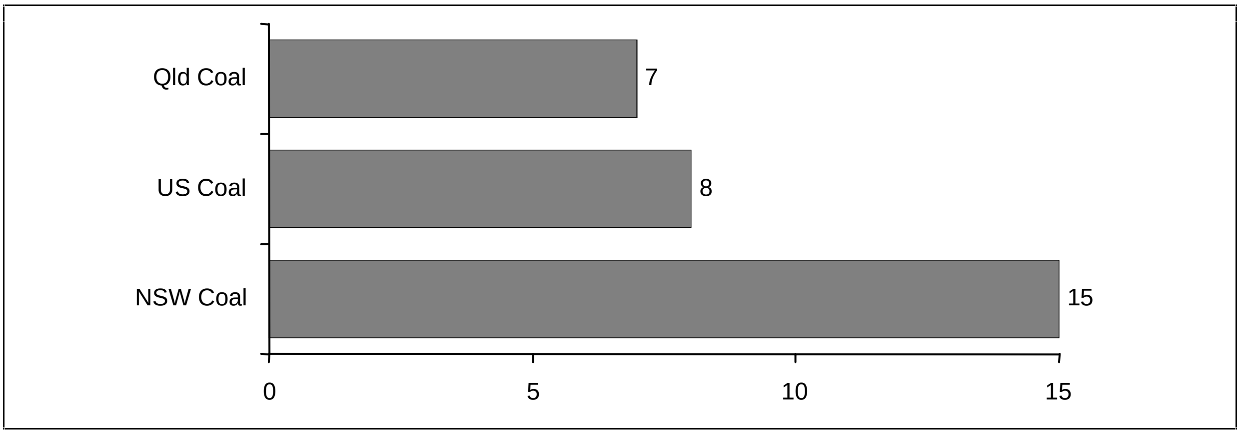
Most of the Australian and United States dragline operations sampled appeared to have good work practices in their dragline operations. For example, meal breaks were taken in the field and hot seat changes were employed on major equipment for virtually all dragline operations in Queensland, NSW and the United States. Further, there was usually no cost to production of meal breaks as staff staggered these breaks to continue operating draglines.

Table 4.8: **Number and composition of workers in typical shifts for an efficient Australian dragline operation**

	Morning shift	*Afternoon shift*	*Night shift*
Equipment crew			
Draglines	1	1	1
Dozers	2	2	2
Drills	1	1	
Non-equipment workers			
Supervisors	1		
Shot-firers	1	1	1
General duties staff			
Gardeners			
Other — dragline oiler	1	1	1
Average workers per shift	7	7	7
Average hours per shift (paid)	8.5	8.5	8.5
No. of shifts per year	364	364	364
Number of days mine operated per week	7		

The Queensland and United States mines surveyed generally had very low idle time, or high work time, in shifts (Figure 4.6).

Figure 4.6: **Percentage of idle time in shifts**



a Labour productivity equals output index divided by labour hours worked.
Source: Survey undertaken by Tasman Asia Pacific (1998).

Many of the Queensland dragline operations scheduled continuous shifts — that is, there were no breaks within the eight-hour shifts. Other mines in Queensland typically had 30 minute meal breaks and 15 minutes at shift change. The United States mines typically had similar breaks, but in 12 hour shifts. A few of the NSW mines had considerable additional breaks (to meal breaks) which substantially increased the extent of idle time in shifts.

Australian dragline workers in participating mines typically had more generous leave provisions than their United States counterparts. This increases the relative cost of labour in the Australian operations. Dragline staff in these Australian mines typically take one day's leave for every three days worked. The ratio in the United States mines is around double that (ie one day leave taken for every six days worked). Participating United States mines often have a formula whereby leave provisions are more generous the longer a worker is employed at a mine. However, many mine workers in the United States are paid leave for their birthday.

Work practice appeared to be generally good throughout the Australian and United States dragline mines surveyed. An influence on labour productivity in NSW and United States mines was the use of bulldozers. One United States mine used dozers very intensively (to reduce re-handle) while the NSW mines, on average, did not use dozers very extensively.

Much of the differences in labour productivity are due to differences in equipment productivity — with dozer operations affecting labour productivity as significantly as dragline operations. This is because of the relative labour intensity of dozers compared to draglines — at least when measured on the basis of output moved per unit of labour input. Thus the better labour productivity of participating Queensland dragline operations stems form a combination of higher dragline productivity, lesser use of dozers and fewer staff required for drilling and blasting.

4.4 THE LINK BETWEEN PRODUCTIVITY AND COST

Consistent with its poorer total factor productivity performance, NSW dragline operations exhibited high unit costs. For example, unit costs of NSW dragline operations were:

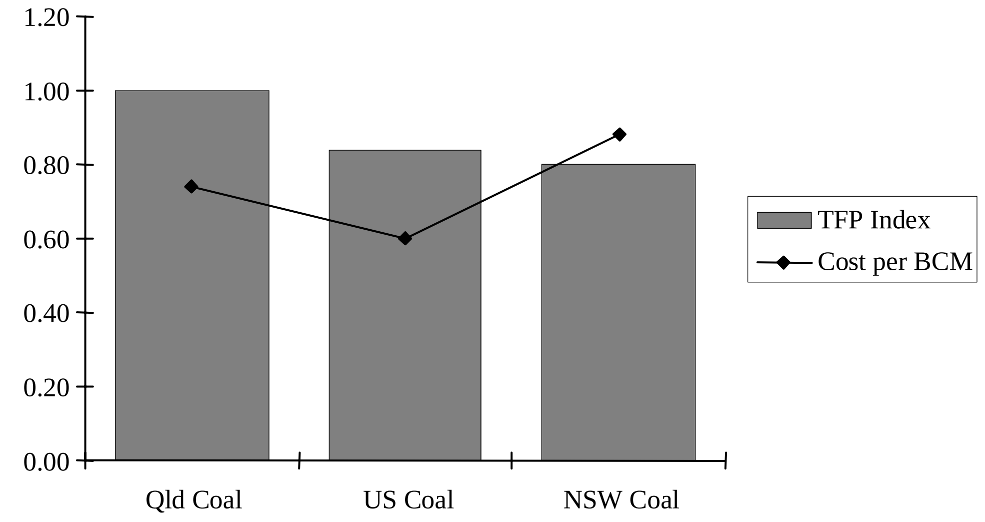
- 19 per cent higher than Queensland coal operations; and
- 47 per cent higher than United States coal operations.

Compared to Queensland dragline operations these higher costs can be explained almost entirely by differences in productivity. However, when compared to the United States operations, NSW dragline mines higher unit costs stem mainly from higher labour and explosives costs.

The costs we have reported are those relating to the inputs listed in Box A3.1. Again, costs for United States mines have been converted to Australian currency using purchasing power parity estimates (OECD 1998). These equate to an exchange rate of about 76 US cents to the Australian dollar in 1996 and 1997.

Despite their good productivity performance, many participating Queensland dragline operations achieved costs well above their United States counterparts. For example, the cost per banked cubic metre of overburden moved by the Queensland draglines was 23 per cent higher than in the United States mine category. This was despite a 19 per cent productivity advantage enjoyed by the Queensland operations (Figure 4.7).

Figure 4.7: **Total factor productivity and cost per BCM in dragline operations** (index: Queensland Coal = 100 and $A costs)



4.5 SUMMARY OF DRAGLINE ANALYSIS

Tasman's benchmarking of the productivity of NSW and Queensland black coal dragline operations with similar operations in the United States has found that the participating Queensland operations had the highest total factor productivity and can be considered as operating at best practice. Queensland mines recorded total productivity levels 19 and 25 per cent higher, on average, than the United States and NSW operations.

Several factors contributed to the difference in productivity, including:

- high dragline capacity utilisation coupled with operational efficiency in Queensland mines;
- low dragline operational efficiency in New South Wales mines; and
- low blasting requirements in Queensland mines due to the geology of the overburden.

Dragline productivity was a major influence on total factor productivity for the sampled mines. Dragline productivity was highest in the Queensland mines. These mines were best able to utilise dragline capacity when operating, and operated draglines more hours per year, on average, than United States mines in particular.

Based on our sample, labour productivity in Queensland dragline operations exceeded that in NSW and United States mines by about 20 per cent. Much of this difference stemmed from the greater operational efficiency of the Queensland draglines and fewer staff being required for drilling and blasting activities. Work practices appeared to be generally good throughout the Australian and United States dragline mines.

Despite their good productivity performance, many Australian dragline operations achieved cost levels above their United States counterparts. For example, total costs of removing overburden in Queensland mines were 23 per cent higher than in participating United States mines, even though productivity was 19 per cent higher in Queensland — which helps to reduce costs. The higher input costs in the Australian mines is largely attributable to the higher cost of labour and explosives.

5. LONGWALL MINING OPERATIONS

In very simple terms, a longwall is created by driving a shaft either side of the seam to be mined. The face is then created by joining the two shafts and the longwall equipment is installed. A shearer cuts the coal which is transported via conveyors and loaders to the surface and then to stockpiles.

This chapter benchmarks the removal of coal using longwall mining techniques. It reports productivity performance results for seven Australian and two United States collieries. However, given the small sample, the analysis should only be interpreted as a broad indication of the possible improvement in Australian longwall mines.

5.1 KEY CHARACTERISTICS OF THE BENCHMARKED LONGWALL MINES

Key mine characteristics were broadly similar between the Australian and United States mines (Table 5.1). The main difference between the mines was the longer average length of the United States longwalls. The United States mines also had slightly higher seams and mined more longwalls per year, on average. However, the United States collieries were mining at a greater depth underground than the average Australian operations.

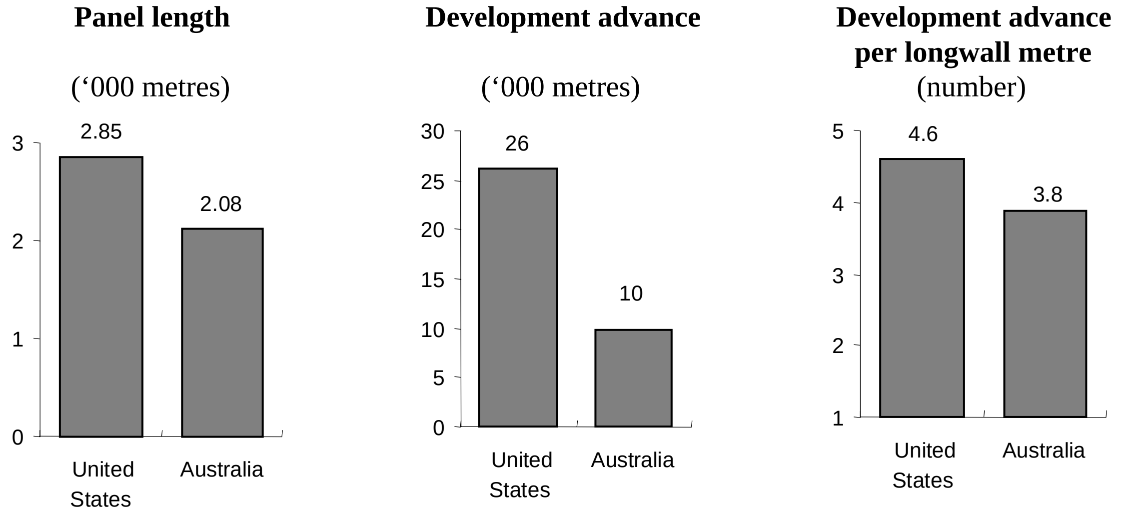
Table 5.1: **Characteristics of participating longwall mines**

Mine type and location	*Australia*	*United States*
Number of mines surveyed	7	2
ROM Coal ('000 tonnes)	1,972	3,930
Panel length (metres)	2,074	2,850
Seam height (metres)	2.5	3.1
Panels mined per year (number)	1.5	2.0
Depth underground (kilometres)	2.66	3.75

Source: Survey undertaken by Tasman Asia Pacific (1998).

While we focus on the longwall coal mining operations of the respondent mines, it is notable that the United States mines undertook slightly more development work than the participating Australian mines (Box 5.1).

Box 5.1: **Longwall and development production**



5.2 FRAMEWORK FOR MEASURING LONGWALL PRODUCTIVITY

In past work (Swan Consultants (Canberra) 1994), longwall operations were taken to include the development work as well as the coal mined from the longwall face. However, advice from mine engineers is that development work would be better treated as an input rather than as an output. Further advice is that the rate of development work is significantly influenced by geological conditions as it is therefore very difficult to benchmark accurately. For this reason, we have excluded development work associated with the construction of the longwall. Similarly, coal mined during development has been excluded from the analysis.

Modelling a longwall operation is also complicated by the time and cost involved in moving from one panel to another and in undertaking major maintenance. Ideally we would like to benchmark longwall operations which operate on only one face and which undertook no major maintenance operations.

However, the mines included in the analysis do not all operate on only one face. To allow valid benchmarks to be developed for longwall operations, the Tasman longwall survey form asks for data on the number of longwalls mined, the longwall move duration, etc. Where more than one longwall is mined, this information can be used to adjust the derived benchmarks for the number of longwalls mined.

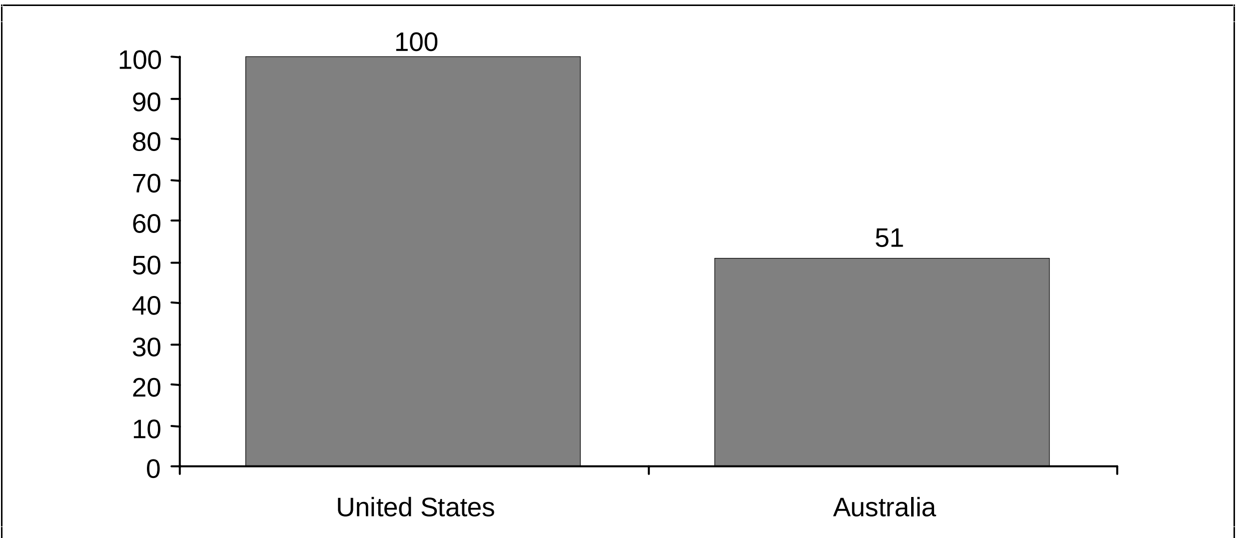
Thus, in order to ensure meaningful productivity results we have limited our analysis to the core mining operations of longwalls — namely shearing, roof support and transportation of the coal via the face conveyor to the stage loader. Labour associated with the operation and maintenance of this equipment is included, as are power and oils and other solubles.

Because the operating characteristics of the mines are broadly similar, and our analysis focuses on core longwall mining operations, our estimated productivity gaps are likely to reflect differences in management and work practices and thus indicate the potential for improvement in various mines.

5.3 LONGWALL OUTPUTS

Run-of-mine coal produced by the longwall is the sole output of the longwall productivity model. Similar to the open-cut models, we have calculated an output index from these quantities. This index has been derived by dividing the longwall coal in each category by the longwall coal produced in the United States, with each quotient then multiplied by 100. This method produces an output index with United States equal to 100. As shown in Figure 5.1, the United States mines have higher average output than the Australian mines.

Figure 5.1: **Average output of longwall mines** (index: United States Coal = 100)



Source: Survey undertaken by Tasman Asia Pacific (1998).

As mentioned above, we have not included coal produced during development as an output.

To calculate the productivity of longwall operations, the level of output produced must be compared to the level of inputs used to produce these outputs. An aggregate input measure for longwall operations is provided in the following section.

5.4 INPUTS USED IN LONGWALL OPERATIONS

Longwall inputs have been broken down into the nine categories shown in Box 5.2. All of these, except for contractors and consumables, have been specified in physical units. Contractors and consumables have been specified in constant dollars, adjusted for purchasing power rather than exchange rates for United States operations. As with the open cut operations, we have excluded overheads and materials because of difficulties in obtaining consistent data from mines. Maintenance labour was included as this was considered to be sufficiently reliable to warrant benchmarking comparison.

Box 5.2: **Longwall mines benchmark model**

Input	*Comments*	*Unit of measurement*
Labour	Includes all mine workers and maintenance workers but exclude office workers. Input calculated as the number of workers times typical hours worked per week times 52 weeks	Hours worked
Electricity	Electricity used by machinery operating the longwall and conveyors	Megawatt hours
Shearer & armoured face conveyor	Specific input in terms of engine capacity where available, otherwise in capacity of material moved	Kilowatts
Roof supports	Support capacity of the roof supports. Calculated as the number of supports times the capacity of the supports in tonnes	Tonnes
Contractors	Use dollar expenditure adjusted for purchasing power	Constant dollar
Consumables	Includes hydraulic fuels, solubles and other oils.	Constant dollar
Maintenance	Labour component of maintenance activities.	Hours worked

The cost, apart from capital inputs, of using each input was obtained from the survey forms. The cost of using capital equipment was calculated using the methodology outlined in

Appendix 2 (Box A2.1). The methodology requires data on the expected life of each piece of equipment and its replacement cost. The expected life of equipment was specified in terms of operating hours or years and is given in Table 5.2. For equipment where assets lives were specified in units other than years, the life in years was calculated by dividing the assumed working lives by the quantity of operations undertaken during the year. The replacement cost of each piece of equipment was then derived from the survey.

Table 5.2: **Assumed maximum working life for equipment in longwall mines**

Equipment type	*Assumed working life*
Longwall (shear, armoured face conveyor)	10 million tonnes
Roof supports	25 million tonnes
Conveyors	10 years

With the exception of capital input costs, the survey questionnaire sent to participating mines was the source of information on the inputs used by the three mine categories. In all cases the survey questionnaire specified the quantity of inputs in physical units. In many cases, mines employed several pieces of equipment of varying capacity. In these cases, Tasman assumed a linear relationship applied between the name plate capacity of the machine and its physical ability to work. Thus total capacity was found by multiplying the rated capacity of each machine times the number of machines in each capacity range and then summing these products.

Table 5.3 summarises the cost data derived from the survey and the capital cost calculations outlined above in terms of cost shares.

Table 5.3: **Cost shares in longwall operations: weighted average per mine** (per cent)

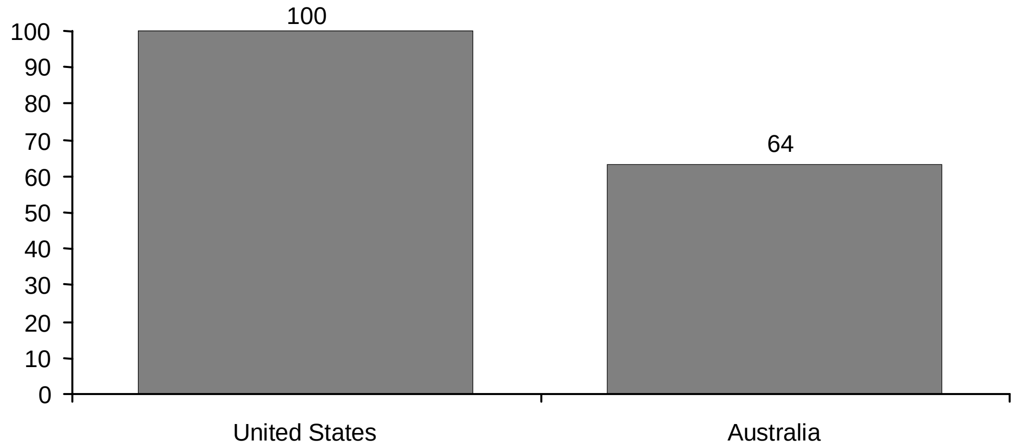
	Equipment	*Operator labour*	*Maintenance labour*	*Electricity*	*Oils*	*Total*
United States	45	29	14	9	3	100
Australia	38	37	17	6	3	100
Total	40	34	16	7	3	100

Source: Survey undertaken by Tasman Asia Pacific (1998).

The Australian longwall operations had lower equipment cost shares but higher labour cost shares than the United States mines. This mainly reflects higher staffing levels and unit costs in the Australian mines.

Following the methodology used in the truck and shovel analysis and outlined in Appendix 1 and Appendix 2, Tasman developed an aggregate longwall input index. The methodology weights together differences in inputs used in different mines where the weights used are input cost shares. Figure 5.2 presents information on the average level of input use by mine category.

Figure 5.2: **Average inputs used in longwall mines**
(index: United States = 100)



Source: Survey undertaken by Tasman Asia Pacific (1998).

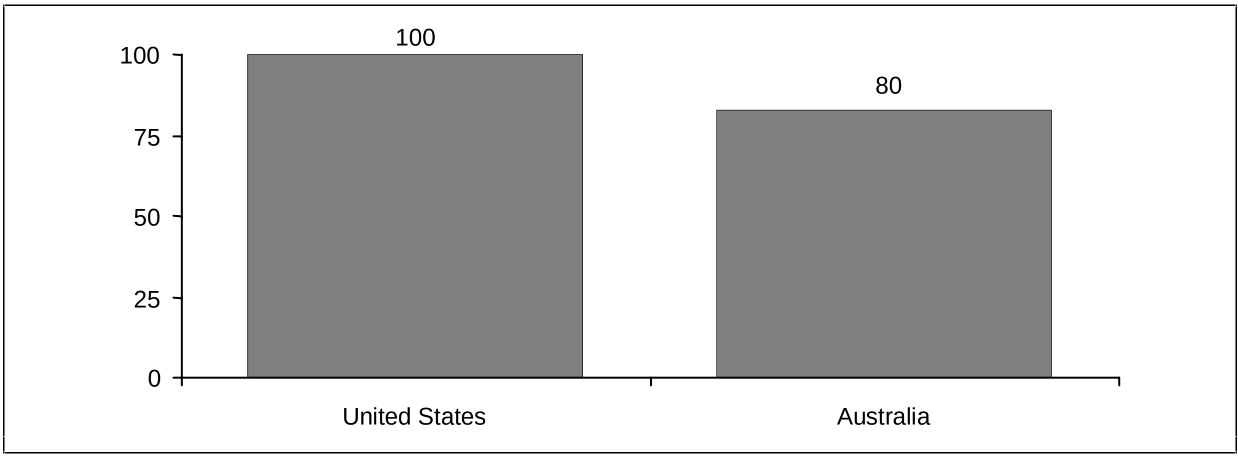
These data are used in conjunction with the output index data in the next section to estimate the total factor productivity of the two longwall mine categories.

5.5 TOTAL PRODUCTIVITY OF LONGWALL OPERATIONS

We have estimated the total productivity of longwall operations by dividing mine output (total tonnes of coal removed at longwalls) by the index of input use derived in section 5.4. This productivity measure is also expressed as an index with the United States category given a value of 100. Figure 5.3 presents the results of this analysis for the two mine categories.

The total factor productivity results show that average productivity performance for the participating Australian black coal longwall mines was below the average of the two United States mines. These Australian longwall mines, as a whole, needed to increase productivity by about 25 per cent to match the performance of the two United States mines.

Figure 5.3: **Total productivity of longwall mines** (index: United States = 100)



Source: Survey undertaken by Tasman Asia Pacific (1998).

The productivity of the seven Australian mines varied considerably — from a TFP score of around to 50 to nearly 90. However, this indicates that one of the participating mines was close to best practice, around 10 per cent below the total productivity of the best United States mine. This United States mine is well recognised as being a world's best practice performer. This again shows that Australian mines can be at best practice — it is a matter of increasing the number of such exceptional performers.

We now examine factors that contributed to the productivity differences discussed above by looking at partial productivity and other measures of mine performance. As explained in Chapter 3, partial productivity measures are calculated by dividing the output index by the physical inputs used in each input category. To aid analysis and presentation, these partial productivity indicators have been indexed so that average of the two United States coal mines equal 100 for each input class (Table 5.4).

The main cost items are labour, hydraulic roof supports and maintenance labour. Differences in the productivity of these major items explain most of the differences in overall productivity between mine categories. Interestingly, the shearers themselves are a relatively small cost item. However, their effective operation is nevertheless crucial to achieving high longwall productivity.

Table 5.4 shows that low labour and shearer productivity are the main problems for the participating Australian longwall operators. These are discussed in the following section.

Table 5.4: **Partial productivity indicators of longwall operations**

(index: United States = 100)

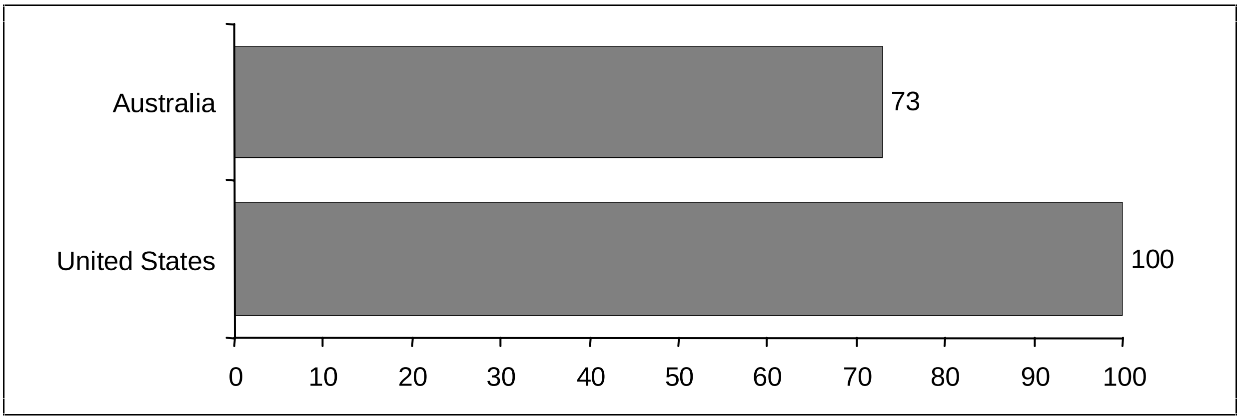
	United States	*Australia*	*Average share of costs (%)*
Labour (000 tonnes per hour worked)	100	73	34
Roof supports (000 tonnes per tonne of support capacity)	100	86	24
Maintenance (000 tonnes per maintenance hour worked)	100	99	16
Electricity (000 tonnes per mWh)	100	88	7
Shearers (000 tonnes per kW of shearer capacity)	100	52	7
Face conveyors (000 tonnes per kW of face conveyor capacity)	100	84	6
Oils (000 tonnes per oil $)	100	70	3
Stage loaders (000 tonnes per kW of stage loader capacity)	100	77	3

Source: Survey undertaken by Tasman Asia Pacific (1998).

5.5.1 Efficiency of the labour force

Labour is a major input to longwall mines, averaging 34 per cent of total measured costs across all mines in the survey (Table 5.4). Thus the efficiency of the labour force is a major determinant of both the productivity and cost of longwall operations.

Figure 5.4: **Labour productivity of longwall mines[a]** (index: United States = 100)

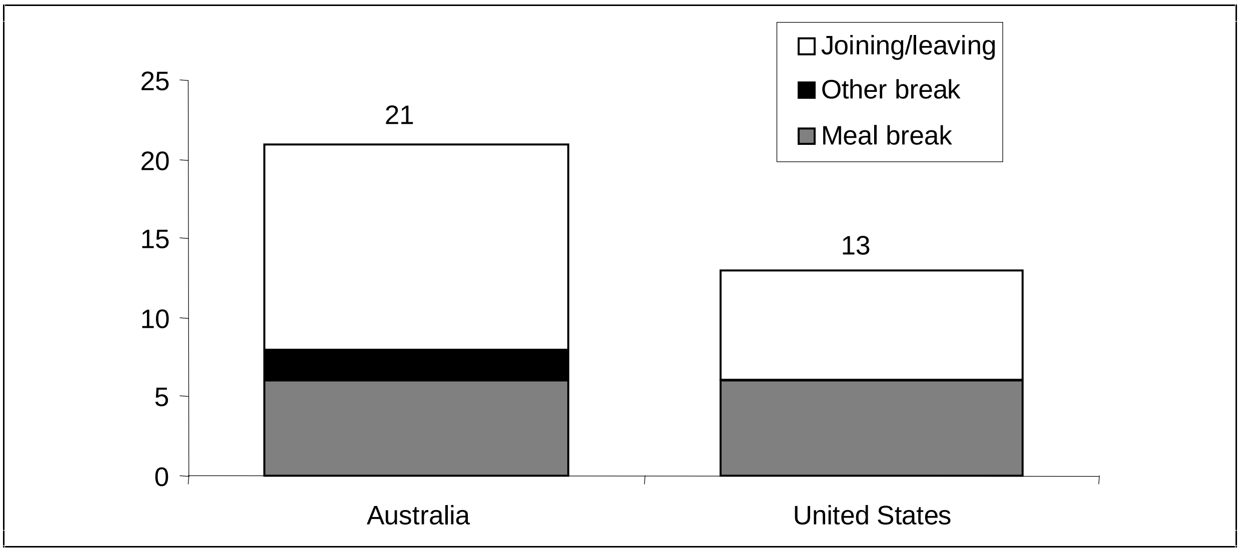


a Labour productivity equals output index divided by total hours worked.
Source: Survey undertaken by Tasman Asia Pacific (1998).

Figure 5.4 above, shows that the average labour productivity of the two United States mines was about 37 per cent higher than the average of the Australian mines surveyed. Again, there was considerable variation in the performance of the Australian and United States mines.

One reason for the lesser labour productivity among the Australian mines surveyed was a higher extent of idle time in shifts. As illustrated in Figure 5.5, around 21 per cent of the time in shifts at these Australian longwall mines comprised non-production activities such as meal breaks and joining and leaving shifts. Based on this sample of seven mines, a typical eight-hour shift in an Australian longwall mine would comprise a meal break of 30 minutes, another break of 10 minutes and around 60 minutes taken in joining and leaving shifts.

Figure 5.5: **Composition of idle time in shifts at longwall mines** (per cent of total shift time)



Source: Survey undertaken by Tasman Asia Pacific (1998).

The United States mines in the sample would also have a 30 minute meal break, but would typically not have another break and workers would be much quicker in joining and leaving shifts, taking an average of around 30 minutes compared to the 60 minutes in Australian mines. The distance travelled by employees from surface access point to mine face was very similar between the average participating United States and Australian mines so does not explain this large difference in joining and leaving time. Thus it would seem that either different work practice or employee transportation systems were the cause of this observed difference.

This results in around 60 minutes idle time in the United States mines or around 13 per cent of the total shift. This allows an extra 40 minutes production time in the United States mines, increasing labour productivity by about 10 per cent compared to the typical Australian longwalls. It is possible that the difference in working time may be larger than this estimate as some Australian mines are reasonably flexible in allowing crib breaks and do not measure them in detail.

However, there is still a significant amount of the labour productivity gap not explained by differences in working time. Part of this difference in operating labour productivity can be attributed to mine geology and engineering and the effectiveness of the mine equipment, particularly the shearer, face conveyor and stage loader.

Part of the difference may also be due to differences in work practices and possibly to over-manning. On the latter, it is unlikely that the best practice United States mine is over-manned as it has a significant contractor workforce paid on hourly rates. The mine has the flexibility to reduce labour input to match its workload. Australian mines do not have that degree of flexibility.

Labour cost

The direct financial cost of Australian longwall labour is similar to that in the United States mines. Our survey data indicates that employees in the seven Australian longwall mines are paid about $70 000 per annum, on average, with associated on-costs of around $30 000. They worked around 1,750 hours per year at a cost of about $57 per hour (Table 5.5).

Table 5.5: **Cost of labour in longwall operations: average per worker** ($A)

	Wage cost	*On-cost*	*Total labour cost*	*Average hours worked*	*Labour cost per hour worked*
United States	80,000	20,000	100,000	2,150	47
Australia	70,000	30,000	100,000	1,750	57

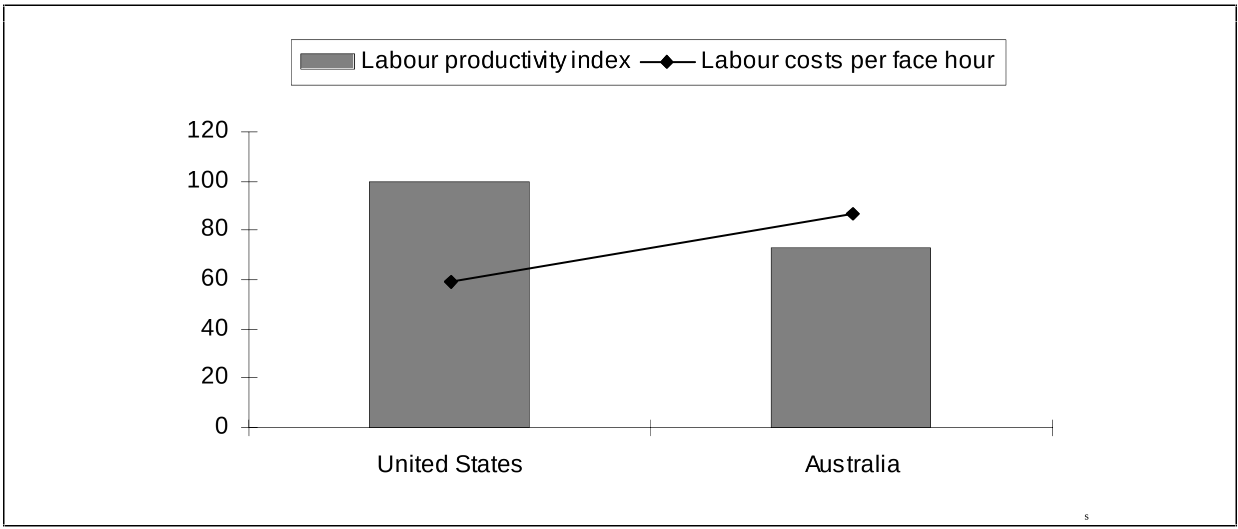
Source: Survey undertaken by Tasman Asia Pacific (1998).

In the two United States longwall mines, employees earned slightly more per annum, on average, but had lower associated on-costs. Their gross wage costs were also about $100,000 per annum. This is using purchasing power parity estimates which equate to an exchange rate of about 76 US cents to the Australian dollar in 1996 and 1997. However, the United States miners worked considerably more hours for their money, costing an average $A47 per hour.

This wage differential is increased when measured on the basis of cost per face hour worked. As mentioned above, the participating Australian longwall mines had around 21 per cent idle time in shifts or 79 per cent face hours worked compared to a corresponding 87 per cent in the two United States mines. Further, leave provisions were more generous in Australian mines. On average these Australian longwall miners took a day of leave for every 4.7 days worked whereas the ratio was double that for the United States workers (ie a days leave for every 9.3 days worked).

Figure 5.6 reports the resulting cost per face hour worked for the two mine categories, contrasting it with labour productivity achieved. As with the truck and shovel operations, there is an inverse relationship when comparing labour productivity and labour cost between Australian and United States longwall mines in the sample.

Figure 5.6: **Labour productivity and cost in dragline operations** (index: United States = 100 and $A costs)



Source: Survey undertaken by Tasman Asia Pacific (1998).

Figure 5.6 indicates that the cost per face hour worked was about $60 per hour in the two United States mines and $87 per hour in the seven Australian mines. However, this would be different if recent exchange rates (eg around 63 US cents to the Australian dollar) were selected as the unit of conversion instead of purchasing power parities. In this case, the estimated cost per face hour worked of United States longwall miners would be about $A75 per hour.

One feature of the remuneration of Australian longwall miners that provides an incentive for efficiency is the extent of production bonuses. Our survey indicated that, on average, these bonuses accounted for 23 per cent of the total wage of Australian longwall miners covered by the study. This was significantly higher than in the participating United States mines, where bonuses only represented about five per cent of total wages. However, it is worth noting that there was a large proportion of contract staff in the leading United States longwall mine.

- *Industrial relations and safety*

As we found for truck and shovel operations, the more productive longwall mines appear to have better industrial relations and safety records. Similarly, the United States longwalls had fewer strikes and less accidents, on average, than the participating Australian mines. However, caution should be taken when interpreting these results given the small sample size and the sporadic nature of disputes. Table 5.6 shows that, like its participating open-cut mines, the United States longwalls had no days lost to industrial disputes in the survey period. The Australian longwalls had an average of 3.7 disputes but, on average, they had less disputes than Australian open-cut mines.

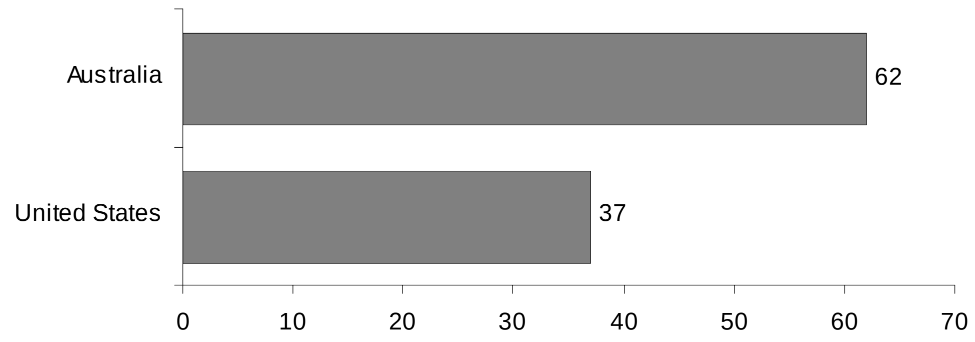
Table 5.6: **Incidence of industrial disputation in longwall mines** (average per mine)

	Number of disputes	*Man hours lost per dispute*	*Hours lost in dispute per thousand hours worked*	*Days lost per thousand employees*
United States	0.0	0	0	0
Australia	3.7	3 718	10	2 100

Source: Survey undertaken by Tasman Asia Pacific (1998).

Similarly, Figure 5.7 shows that these more efficient United States longwall mines had a better safety record than the seven participating mines in the Australian longwall category.

Figure 5.7: **Longwall mine safety** (lost time injuries per million man hours)



Source: Survey undertaken by Tasman Asia Pacific (1998).

However, the most efficient Australian longwall mine had a similar safety record to the two United States mines. Again, lost time injuries are defined to be injuries that prevent a worker from attending the next scheduled shift. Longwall mines generally had a higher incidence of lost time injuries than the open-cut mines in the sample.

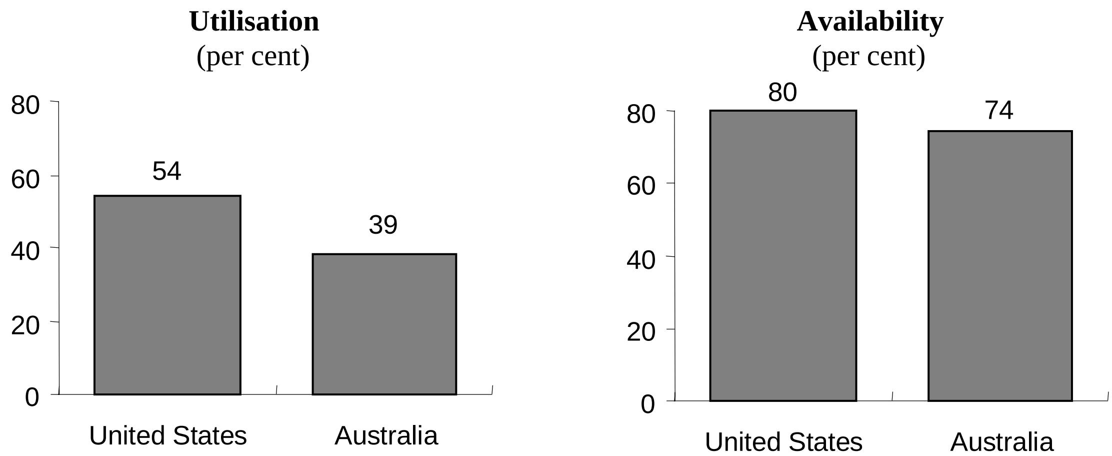
5.5.2 Equipment productivity

As outlined in Table 5.4, the productivity of shearers in the participating Australian mines was only around half of that achieved by the two United States longwall mines. This was largely due to lower average utilisation of the shearers, in the Australian mines. Box 5.3 shows that the Australian longwalls only operated their shearers 39 per cent of all available hours, or about 3 400 hours per year. The United States mines achieved much higher capacity utilisation of their shearers, operating them around 54 per cent of total hours.

The Australian mines in the sample did not schedule their shearers for as much work as the two United States mines, expecting them to be working 74 per cent of total hours compared to 80 per cent for the United States mines. This mainly reflects the use of spare shearer capacity in a few Australian mines to allow for a speedier transition between longwalls.

This relatively rapid transition between longwalls was achieved in the Australian mines. On average, they spent about 420 hours in moving the longwall compared to about 460 hours in the United States mines. However, the longwall bolt-up was typically much longer in the Australian mines, taking an average 160 hours compared to 70 hours in the United States mines. This warrants further examination as an avenue of possible productivity improvement in Australian longwall mines.

Box 5.3: Utilisation[a] and availability[b] of shearers



a Hours worked as a percentage of total hours in year.
b Hours worked as a percentage of scheduled work hours.
Source: Survey undertaken by Tasman Asia Pacific (1998).

Our data shows that the Australian mines in the sample took considerably longer to achieve targeted production in new longwalls than the two United States mines. The United States longwalls reported that production targets were achieved within 70 hours on a new longwall while it took around 210 hours in the Australian mines, on average. However, this high average figure for the Australian mines was mainly due to extreme problems faced by four of the mines.

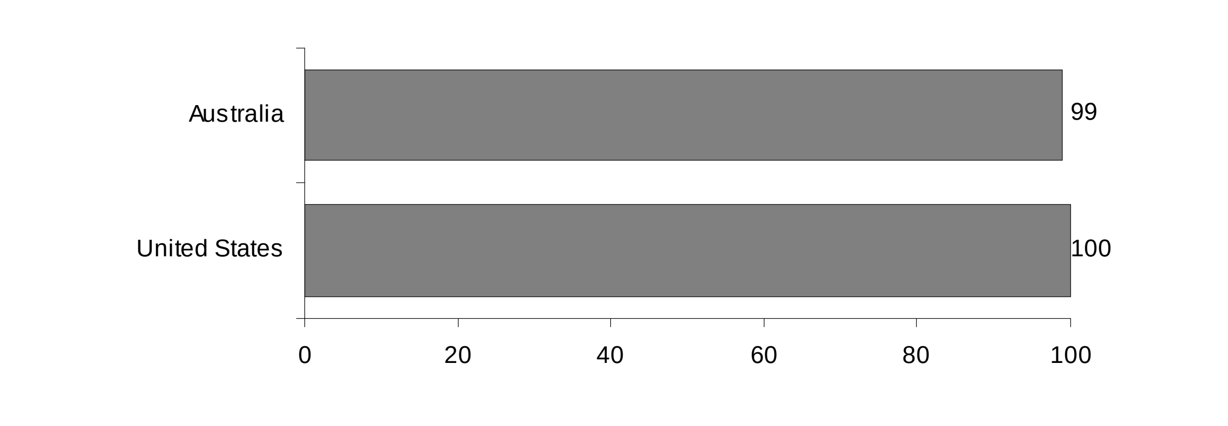
The participating Australian mines also achieved lower productivity of their face conveyors and stage loaders. As indicated by Table 5.5, the Australian longwall mine category had to increase the productivity of its face conveyors by about 20 per cent to match the average performance of the United States mines. This shortfall stemmed mainly from two mines that had apparently overcapitalised on the capacity of the face conveyor, given its actual throughput.

5.5.3 Maintenance

We have included maintenance labour in the productivity analysis as most of the longwall mines have a maintenance workforce mainly involved in routine and preventative maintenance. We have excluded the cost of spares for equipment maintenance as the incidence of these can vary greatly between mines, depending mainly on the extent of major overhauls or refurbishments of longwall equipment.

As outlined in Figure 5.8, the productivity of Australian maintenance labour in the sample was about the same as in the sampled United States longwall mines. This stemmed mainly from two of the Australian longwall mines having higher productivity of maintenance labour than the best practice United States mine. This highlights that an Australian longwall maintenance workforce can achieve best practice.

Figure 5.8: **Maintenance labour productivity of longwall mines[a]** (index: United States = 100)



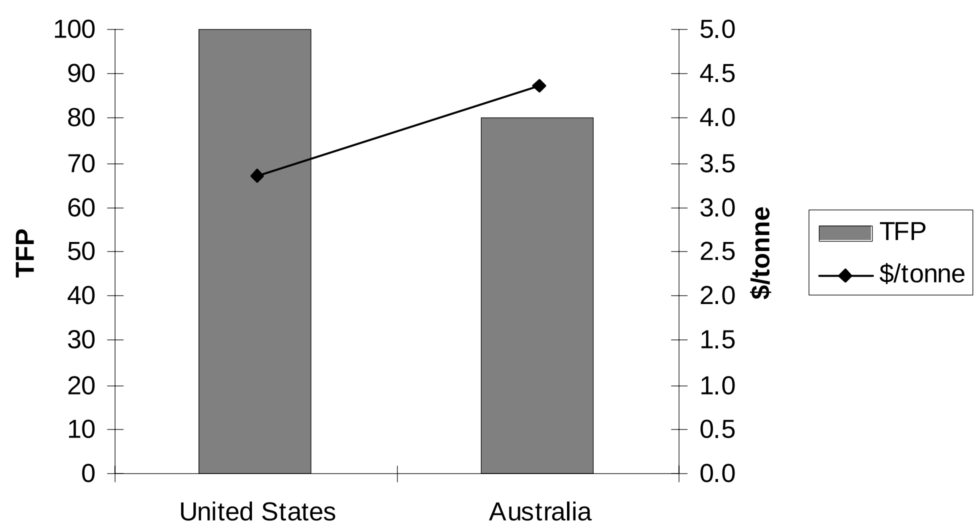
a Maintenance labour productivity equals output index divided by total maintenance hours worked.
Source: Survey undertaken by Tasman Asia Pacific (1998).

5.6 LONGWALL PRODUCTIVITY AND COST

As shown in Figure 5.9, the productivity advantages enjoyed by the two United States longwall mines translate into much lower costs.

This cost difference between the United States and Australian longwall mines surveyed is greater than the difference in productivity. In total, about 20 per cent of the cost difference between the United States and Australian mines in the sample was due to high unit costs — mainly labour costs, as discussed in Section 5.5.1.

Figure 5.9: **Total factor productivity and cost per tonne, Australian and United States longwall operations**
(index: United States coal = 100, cost $A)



Source: Survey undertaken by Tasman Asia Pacific (1997).

However, it is important to keep the scope of these costs in context. Firstly, they only relate to extraction of coal at the longwall. They also exclude overheads, spare parts and some materials costs. Finally, they do not include ex-mine costs such as rail, port and shipping costs. Longwall costs we have reported are those relating to the inputs listed in Box 5.2. Again, costs for United States mines have been converted to Australian currency using purchasing power parity estimates (OECD 1998). These equate to an exchange rate of about 76 US cents to the Australian dollar in 1996 and 1997.

5.7 SUMMARY OF LONGWALL ANALYSIS

The analysis presented above has been based on a relatively small sample of Australian and United States longwall mines. However, it is generally accepted by the industry that one of the United States mines included in the sample is a best practice performer. Given the small sample of Australian mines, the analysis should only be interpreted as indicative of the performance improvements necessary in the Australian longwall mine sector.

The analysis shows that the average productivity of the seven Australian longwall coal mines in 1997 was about 25 per cent below that of United States longwall mines. This lesser performance mainly stemmed from:

- higher idle times in shifts in Australian longwall mines;
- low utilisation of shearers in Australian longwall mines; and
- geological differences.

Low labour and shearer productivity in the Australian longwalls in the sample contributed to this total factor productivity difference. The productivity of Australian face conveyors was also relatively low — indicating possible excess capacity in a number of participating Australian longwalls.

The relatively high idle time in the sample Australian longwall shifts was mainly due to longer times in joining and leaving shifts. The two United States mines took an average of around 30 minutes in joining and leaving shifts, 30 minutes quicker than the average Australian operations. Extra breaks totalling about 10 minutes per eight-hour shifts meant that an extra 40 minutes idle time per shift in the Australian longwall sample reduced labour productivity by about 10 per cent compared to the United States mines. Other causes of lower labour productivity in the sample Australian longwalls related to operating conditions, installed equipment and, most likely, an element of over-staffing.

Low shearer productivity resulted from lower utilisation in Australian longwalls surveyed. Some of this was due to planning — with spare capacity brought in to allow quicker longwall transitions. This was successful to a point, although there was evidence that some of Australian mines in the sample took much longer to achieve target production on new longwalls than the United States mines.

On average, longwall production costs were higher in the seven Australian mines, than in their United States counterparts. Most of this reflected the productivity differential, although labour costs were also higher in the Australia mines compared to the United States mines.

While the sample of longwalls was small, it was again evident that Australian mines can attain or approach world's best practice productivity performance. One of the Australian mines was only about 10 per cent below the best practice United States mine, which is an acknowledged efficient operator. This was over a period that was not particularly favourable for the Australian mine.

APPENDIX 1: PRODUCTIVITY PERFORMANCE MEASURES

Productivity is a measure of the physical output produced from the use of a given quantity of inputs. In practice, productivity is measured by expressing output as a ratio of inputs used. This report uses two methods for measuring mine productivity:

- total factor productivity (TFP); and
- partial factor productivity.

TFP measures total output relative to *all* inputs used. The TFP index measures the impact of all the factors affecting growth in output other than changes in input levels. It is now widely accepted that TFP is a robust measure of the overall performance of an organisation. Box A1 presents a more detailed description of the TFP measure.

Although TFP[1] is the more accurate productivity measure it provides little insight into the drivers of any inter-mine productivity differences. Partial productivity measures can help identify these drivers.

Partial factor productivity measures one or more outputs relative to one particular input (for example, labour productivity is the ratio of output to labour input). Partial productivity measures are widely used as they are simple to calculate. However, when used in isolation partial factor productivity measures should be interpreted with caution as a misleading impression of overall performance may result if analysis concentrates on only one input.

[1] Strictly speaking, the productivity analysis Tasman undertakes in this study is multi-factor rather than total factor productivity analysis. This is because the estimates exclude overheads and some materials costs. However, because the excluded materials and overheads represent a relatively small share of total costs, the multi-factor and total factor productivity analyses would be very similar. On this basis, we report our productivity analysis as total factor productivity.

Box A1.1: **Total factor productivity: a technical note**

Mathematically, TFP is defined as:

(1) $$TFP = \frac{Q}{I}$$

where Q is the quantity of outputs, and I is the quantity of inputs.

Mines produce several outputs and use a range of inputs. Calculating TFP requires a means of adding together these diverse output and input quantities into measures of total output and total input quantity. The different types of outputs and inputs cannot be simply added (for example, it is not meaningful to add the number of employees to the number of litres of fuel consumed). Index number theory is used to overcome this problem.

The multi-lateral TFP index methodology provides an ideal method of benchmarking an organisation's productivity performance. It represents a significant advance over earlier productivity indexes in that it enables total productivity levels as well as growth rates in productivity to be compared across firms. Lawrence, Swan and Zeitsch (1991a,b) outline the merits of this index.

The multi-lateral translog index is given by:

(2) $$\begin{aligned} Log\ (TFP_m / TFP_n) = & \sum_i (R_{im} + R_i^*) (\log Y_{im} - \log Y_i^*) / 2 - \\ & \sum_i (R_{in} + R_i^*) (\log Y_{in} - \log Y_i^*) / 2 - \\ & \sum_j (S_{jm} + S_j^*) (\log X_{jm} - \log X_j^*) / 2 + \\ & \sum_j (S_{jn} + S_j^*) (\log X_{jn} - \log X_j^*) / 2 \end{aligned}$$

where $R_i^* (S_j^*)$ is the revenue (cost) share averaged over all mines and time periods and log $Y_i^* (logX_j^*)$ is the average of the log of output *i* (input *j*). Using equation (1), comparisons between any two observations *m* and *n* will be both base-mine and base-year independent. This index can also be interpreted as comparing each observation to a hypothetical firm with output and input vectors equal to the geometric means of those variables for all observations, revenue shares R_i^* and cost shares S_j^*.

To implement this methodology data are required on the quantity of outputs and inputs used. Data on the prices received for outputs are required if more than one output is to be considered. Input prices are also required.

APPENDIX 2: ESTIMATION OF TRUCK AND SHOVEL OUTPUTS AND INPUTS

This appendix presents detailed information on the model that is used to calculate total factor productivity for truck and shovel operations.

A2.1 TRUCK AND SHOVEL OUTPUTS

A truck and shovel mining operation involves the excavation of material (ie coal and overburden) and its transportation to stockpiles or for processing.

Thus, to accurately compare the productivity of different mining activities, it is necessary to develop an output measure that includes the total excavation function as well as the transport function. Thus, in this analysis, we have used an overall output measure which incorporates a measure of the excavation function and a measure of the transport function (see Box A2.1).

Box A2.1: **Measuring truck and shovel mine outputs**

Excavation

$$\text{Tonnes excavated} = \begin{bmatrix}\text{Banked cubic} \\ \text{metres of} \\ \text{overburden removed} \\ \text{(BCM)}\end{bmatrix} * \begin{bmatrix}\text{Specific} \\ \text{gravity of} \\ \text{overburden} \\ \text{(Tonnes/BCM)}\end{bmatrix} + \begin{bmatrix}\text{Tonnes} \\ \text{of} \\ \text{coal/mineral}\end{bmatrix}$$

Transport

$$\text{Tonne kilometres} = \begin{bmatrix}\text{Tonnes} \\ \text{excavated}\end{bmatrix} * \begin{bmatrix}\text{Average} \\ \text{cycle distance} \\ \text{in kilometres} \\ \text{(one - way)}\end{bmatrix}$$

Total output

Index of transport and excavation outputs combined using

$$LogTFP_m = \sum_i (R_{im} + R_i^*)(\log Y_{im} - \log Y_i^*)/2 - \sum_i (R_{in} + R_i^*)(\log Y_{in} - \log Y_i^*)/2$$

from equation (2) in Box 1. Where R_i^* is the revenue share averaged over all mines and time periods and $\log Y_i^*$ is the average of the log of output *i.*

The output measure incorporates factors such as the gravities of material moved and the cycle distances for each mine. The direct incorporation of these site specific factors helps remove productivity differences related to geography rather than efficiency and provides a comprehensive measure of mine output.

Tasman converted the data on total excavation into an index by dividing the level of excavation in each mine category by the level of excavation in the United States coal mines. Similarly an index of transport by mine was formed by dividing the tonne kilometres of transport in each mine type by the tonne kilometres transported in the United States coal mines. Box A2.2 presents the components used to calculate mine output and the excavation and transport indexes by mine class.

Box A2.2: **Characteristics of truck and shovel operations — average per mine**

Excavation	*Overburden* (million BCM)	*Specific gravity* (tonnes/BCM)	*Overburden* (million tonnes)	*ROM coal/ore* (million tonnes)	*Total moves* (million tonnes)	*Index*
	(1)	(2)	(3) = (1) * (2)	(4)	(5) = (3) + (4)	
Aust metal	12	3.15	39	14	53	186
US coal	8	2.08	17	11	29	100
Qld coal	8	2.35	18	8	26	89
NSW coal	19	2.26	43	5	48	167

Transport	*Total movements*	*Average distance*	*Total transport*	*Index*
	(million tonnes)	(kilometres)	(million tonne-kms)	(US coal = 100)
	(1)	(2)	(3) = (1)*(2)	

Aust metal	53	3.5	187	172
US coal	29	3.8	109	100
Qld coal	26	3.3	85	78
NSW coal	48	2.4	114	105
Total output	(US coal = 100)			
Aust metalliferous	179			
US coal	100			
Qld coal	84			
NSW coal	133			

As described in Box A2.1, Tasman combined the excavation output index with the transport index to derive an overall index of mine output. Mine level data on the cost, or relative cost, of the transport and excavation functions are required to calculate this combined output index. Tasman derived relative costs by assuming that the total cost of each activity would be proportional to the capital cost associated with the two activities. Thus the transport capital cost was set equal to the capital cost of the truck fleet and the capital cost of excavation was set equal to total capital costs minus the capital cost of the truck fleet. Figure 3.1a in Chapter 3 presents the resulting mine output index.

A2.2 INPUTS USED IN TRUCK AND SHOVEL OPERATIONS

The estimation of an aggregate input volume index is an integral part of the calculation of the multi-lateral TFP index outlined in Appendix 1 (Box A1, equation 2). This index is derived by weighting together inputs used in different mines where the weights used are input cost shares.[2] Thus implementation of the formula requires both price and quantity data on inputs used.

Mine inputs were broken down into the 11 categories listed in Box A2.3.

[2] As outlined in Box 1 the input index is calculated as follows:

$$\sum_j (S_{jm} + S_j^*)(\log X_{jm} - \log X_j^*) / 2 +$$
$$\sum_j (S_{jn} + S_j^*)(\log X_{jn} - \log X_j^*) / 2$$

where S_j^* is the revenue (cost) share averaged over all mines and time periods and $logX_j^*$ is the average of the log of input j.

With the exception of contracting out, the quantity of inputs was specified in physical units. In many cases, mines employed several pieces of equipment of varying capacity. In these cases a linear relationship was assumed to apply between the name plate capacity of the machine and its physical ability to work. Thus total capacity was found by multiplying the rated capacity of each machine times the number of machines in each capacity range and then summing these products.

With the exception of the capital input costs, the cost of using each input was obtained from the survey forms.

Box A2.3: **Specification of inputs used in truck and shovel operations**

Input	*Comments*	*Unit of measurement*
Labour	Includes all mine equipment workers, supervisors, Shot-firers, cleaners and staff on general duties. Input calculated as the number of workers times typical hours worked	hours worked
Shovels	Digging capacity of bucket	loose cubic metres
Front-end loaders	Digging capacity of bucket	loose cubic metres
Trucks	Capacity of truck	tonnes
Bulldozers	Capacity of bulldozers	kilowatts
Drills	Capacity of drills	bore hole diameter in centimetres
Other equipment	Includes all other equipment associated with truck and shovel operations	kilowatts
Explosives	Quantity of explosives used in blasting overburden and coal	tonnes
Diesel fuel	Total quantity of diesel used by machinery	'000 litres
Electricity	Total quantity of electricity used by machinery	megawatt hours
Contracting out	Value in Australian dollars.	Australian dollars

In addition to the items outlined in Box A2.3, Tasman also obtained survey data on materials and overhead costs. However, the size of the variation in these costs between participating mines (ie in terms of cost per unit of output) suggested that there was not a consistent coverage of cost items or approach to cost allocation or both. Thus it was decided to drop these costs from the analysis. These costs represent a relatively small share of total costs.

Capital inputs are different from inputs discussed above in that they are not fully consumed in the year of purchase. The cost of employing a capital input consists of two components:

- the depreciation of the capital item; and
- a return on the capital employed.

These two costs can be considered as an annual fee for the use of capital. This fee covers the depreciation of the equipment and provides a return to the owners of the equipment. As outlined in Box A2.4, the methodology used to calculate the cost of capital inputs requires data on the replacement cost of the asset and its expected life.

Box A2.4: **The cost of capital inputs**

The annual fee for the use of capital inputs has been calculated using the formula:

$$\text{(3)} \qquad \text{Annual fee} = \frac{\text{Replacement cost}}{\text{of equipment}} \;/\; \left[\left(1 - e^{-r\,n}\right) / \, r\right]$$

Where r is the real return here assumed to be eight per cent; and
n is the expected life of the equipment in years and is equal to the assumed life in hours divided by *actual operating hours per annum*.

The analysis assumes that each piece of equipment provides a constant flow of services over its life.

The replacement cost of each piece of equipment was derived from data reported in the survey. The expected life of each piece of equipment, in operating hours, was based on assumptions about maximum useful working life for the various classes of equipment. The assumptions used were based on information and estimates provided by representatives of the coal and equipment manufacturing industries (see Table A2.1).

Table A2.1: **Assumed working life for equipment used in truck and shovel mines** (hours of operation)

	Assumed working life (hours)
Shovels	100,000
Front-end loaders	40,000
Trucks	45,000
Bulldozers	30, 000
Drills	50,000
Other equipment	30,000

Source: Information obtained from representatives of the coal and equipment manufacturing industries.

These estimates should be treated as broad averages, as equipment life is significantly affected by operating and maintenance practices. However, the productivity analysis is not sensitive to these assumptions. Dividing the expected life reported in Table A2.1 by the survey data on each piece of equipment's hours of operation gave an expected life, in years, for equipment used by each mine.

Table A2.2 summarises the cost data derived from both the survey and the equipment cost calculations outlined above.

Table A2.2: **Cost shares in truck and shovel operations: weighted average per mine** (per cent)

	Equipment	*Labour*	*Explosives*	*Diesel*	*Electricity*	*Contracting*	*Total*
United States coal	38	36	10	12	4	1	100
Australia metalliferous	38	30	14	15	2	0	100
Queensland coal	35	40	14	11	1	0	100
NSW coal	34	42	14	9	1	1	100
Total	36	38	13	11	2	1	100

Source: Survey undertaken by Tasman Asia Pacific (1998).

Table A2.2 shows that equipment and labour inputs comprise a large share of the costs of excavating and moving materials by truck and shovel technologies within mines. Capital cost shares were fairly similar between all mine categories examined. NSW and Queensland truck and shovel coal mines were the most intensive in their use of labour. Diesel fuel was between nine and 15 per cent of costs in both Australia and the United States. Explosives comprised a much lower share of total costs in the United States coal mines than in Australian mines. This can be explained mainly by the lower price of explosives in the United States. Electricity was a relatively small cost for all mine categories, however, the two Australian coal mine categories had the lowest electricity cost shares.

The estimates presented above allow us to calculate the aggregate input volume index for each mine category. The results are summarised in Figure 3.1b.

These data are used in conjunction with the output index data to estimate the total factor productivity of the four truck and shovel mine categories (Section 3.3).

APPENDIX 3: ESTIMATION OF DRAGLINE OUTPUTS AND INPUTS

This appendix presents detailed information on the model that is used to calculate total factor productivity for dragline operations.

A3.1 DRAGLINE OUTPUTS

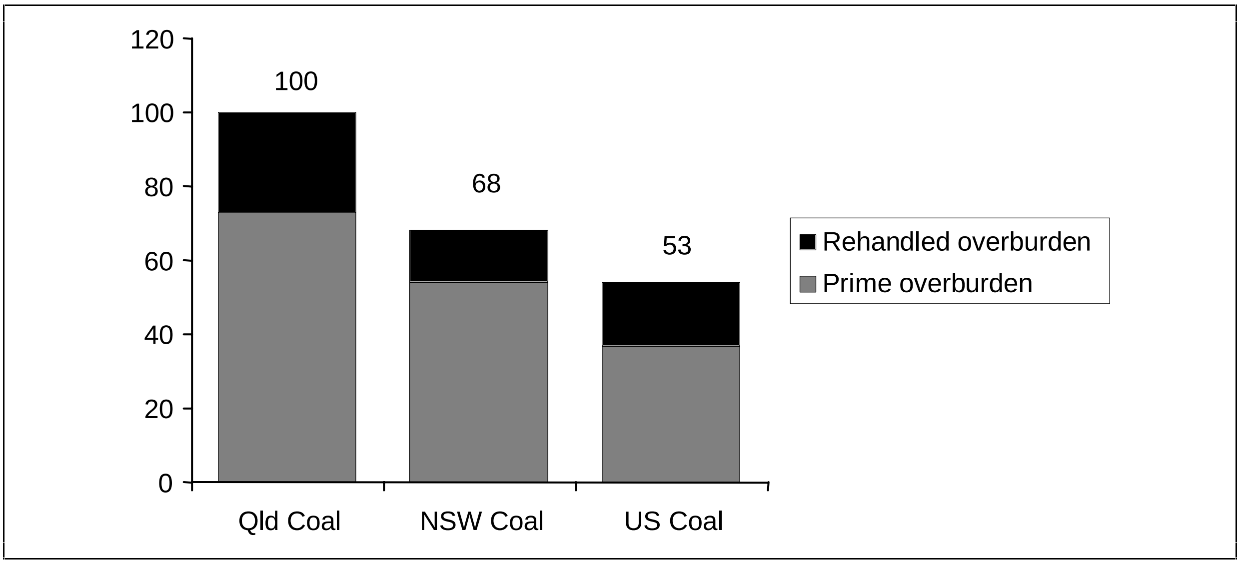
The sole purpose of dragline operations is to move overburden. Overburden removed is typically classified into "prime" overburden and re-handled overburden. For the purpose of calculating total productivity, Tasman has defined the dragline output to be the sum of prime and re-handled overburden expressed in banked cubic metres.

Following the methodology outlined in Appendix 1 (Box A3.1) and used in the benchmarking of truck and shovel operations, Tasman has calculated an output index from these quantities. This index has been derived by dividing the overburden moved in each mine by the overburden moved in Queensland, with each quotient then multiplied by 100. This method produces an output index with Queensland equal to 100. Figure A3.1 presents the resulting output index.

Box A3.1: **Specification of inputs used in dragline operations**

Input	*Comments*	*Unit of measurement*
Draglines	Digging capacity of bucket	Cubic metres
Bulldozers	Capacity of bulldozers used	Kilowatts
Drills	Capacity of drills	Bore hole diameter in centimetres
Labour	Includes supervisors, dragline operators and operators of other equipment involved in dragline operations.	Hours worked
Explosives	Quantity of explosives used in blasting overburden moved by the dragline.	Tonnes
Electricity	Quantity of electricity used by draglines.	Megawatt hours
Diesel fuel	Total quantity of diesel used by machinery supporting the dragline	'000 litres

Figure A3.1: **Dragline output: average per mine**
(index: Queensland Coal = 100)



Source: Survey undertaken by Tasman Asia Pacific (1998).

A3.2 INPUTS USED IN DRAGLINE OPERATIONS

Dragline inputs can be broken down into the eight categories shown in Box A3.1. With the exception of capital input costs, the survey questionnaire sent to participating mines was the source of information on the inputs used by the three mine categories. In all cases the survey questionnaire specified the quantity of inputs in physical units. In many cases, mines employed several pieces of equipment of varying capacity. In these cases, Tasman assumed a linear relationship applied between the name plate capacity of the machine and its physical ability to work. Thus total capacity was found by multiplying the rated capacity of each machine times the number of machines in each capacity range and then summing these products. As was the case for the truck and shovel analysis, Tasman did not use the survey data collected on materials and overhead costs because of apparent inconsistencies in reporting between different mines.

To calculate the cost of using capital equipment in dragline operations, Tasman used the same methodology as in the truck and shovel analysis reported in Chapter 3. This methodology, which is outlined in Appendix 2, requires data on the replacement cost of equipment and the expected life of equipment in years. Table A3.1 presents estimates of the expected life of each piece of equipment, in operating hours. Tasman estimated the expected life, in years, for equipment used by each mine by dividing the data presented in Table A3.1 by the annual hours of operation of each piece of equipment. Tasman derived the replacement cost of each piece of equipment from information in the survey.

Table A3.1: **Assumed working life of equipment used in dragline operations** (hours of operation)

Equipment types	*Assumed working life*
Draglines	200,000
Bulldozers	30,000
Drills	50,000

Source: Information obtained from representatives of the coal and equipment manufacturing industries.

Table A3.2 summarises the cost data derived from the survey and the capital cost calculations outlined above in terms of cost shares.

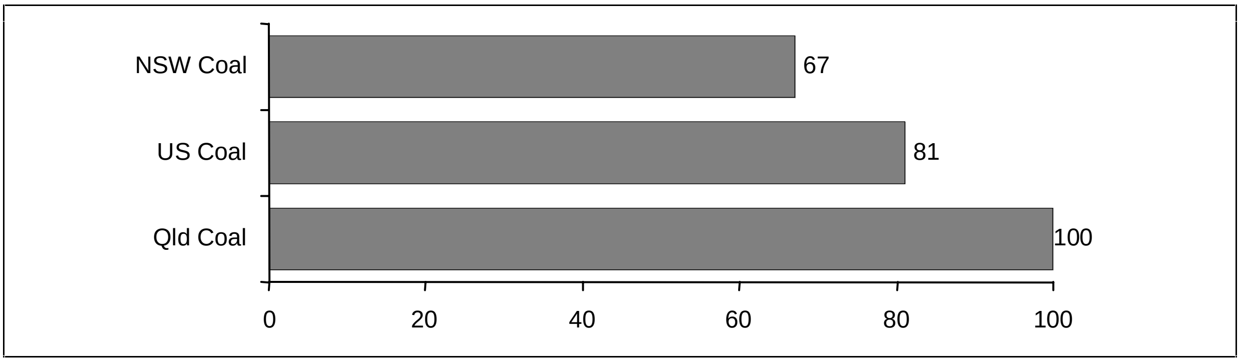
Table A3.2: **Cost shares in dragline operations: weighted average per mine** (per cent)

	Equipment	*Labour*	*Explosives*	*Electricity*	*Diesel*	*Total*
Queensland coal	47	18	20	12	2	100
NSW coal	42	26	23	7	1	100
United States coal	39	22	20	15	5	100
Total	43	21	21	12	3	100

Source: Survey undertaken by Tasman Asia Pacific (1998).

The NSW dragline operations had similar equipment cost shares but higher explosives cost shares compared to the Queensland and United States mines. Following the methodology used in the truck and shovel analysis and outlined in Appendix 1 and Appendix 2, Tasman developed an aggregate dragline input cost index. The methodology weights together differences in inputs used in different mines where the weights used are input cost shares. Figure A3.2 presents information on the average level of input use by mine category.

Figure A3.2: **Total input use in dragline operations, average per mine** (index: Queensland Coal = 100)



Source: Survey undertaken by Tasman Asia Pacific (1998).

These data are used in conjunction with the output index data to estimate the total factor productivity of the three dragline mine categories (Section 4.2.3).

REFERENCES

Barlow Jonker (1997), "Coal Supply Series, Volumes 1&2, available on subscription, October.

Lawrence, D., P. Swan and J. Zeitsch (1991), "The Comparative Efficiency of State Electricity Authorities", in *Contemporary Issues in Australian Economics*, edited by M.R. Johnson, Peter Kriesler and Anthony D. Owen, MacMillan, Melbourne.

National Institute of Labour Studies (1997), *Employee Relations Indicators: Coal Mining and other Industries Compared*, Working Paper No. 143, June.

OECD (1998), *Main Economic Indicators,* February.

Swan Consultants (Canberra) (1994), "International Benchmarks for Australia's Black Coal Industry", Report prepared for ACIL Economics and Policy.

Tasman Asia Pacific (1997), *"The Scope for Improvement in Australia's Open Cut Black Coal Industry*", October.