# At the coal face: mine-level productivity in Australia

**Resources and Energy Quarterly September 2019**

## Australia's resource sector
strong global performers operating at the innovation frontier

## Growth in productivity
is the key to higher wages & living standards

Internationally, Australian iron ore producers are world best, with the **highest productivity growth**

## Productivity is crucial
in an era of declining ore grades and limited discoveries

## Traditional measures show mining productivity falling but mine-level analysis shows:

2007 – 2018 productivity in iron ore mining **grew by 71%**

adjusting for the impact of higher prices

adjusting for the impact of higher prices

2007 – 2018 productivity in metallurgical coal mining **only fell by 2%**

## Australian mining company Rio Tinto uses the world's largest robot – a self-driving train – to haul ore from mine to port

# Executive summary

Multifactor productivity, the conventional productivity statistic, shows that mining sector productivity fell by 20 per cent between the start of the mining boom in 2003–04 and the peak of the investment phase in 2012–13. Productivity has been rising since the industry transitioned into the production phase, but the recovery appears to be slow.

Falling productivity growth contrasts with the industry's otherwise strong performance. Australia's global share of iron ore trade grew from 33 to 52 per cent between 2001 and 2018. For metallurgical coal, the share rose from 54 per cent in 2001 and reached 61 per cent in 2016, before falling due to weather-related events. Further, the resources sector has been at the global frontier in innovation, introducing fleets of self-driving trucks and a self-driving train that is, effectively, the world's largest robot.

Much of mining's negative productivity performance was driven by impacts of the mining boom. This special topic uses mine-level data for iron ore and metallurgical coal mining to explore some of these impacts on productivity measurement.

A proxy of mine-level productivity, the output-cost index, is calculated using the real costs required for a tonne of production. Direct comparisons with the Australian Bureau of Statistics' (ABS) measure of multifactor productivity should be avoided, yet both are considered reasonable measures of productivity given they capture the major factors driving productivity growth (see the Technical Appendix for more).

The output-cost index analysis considers the impact of the mining boom on productivity growth in two ways.

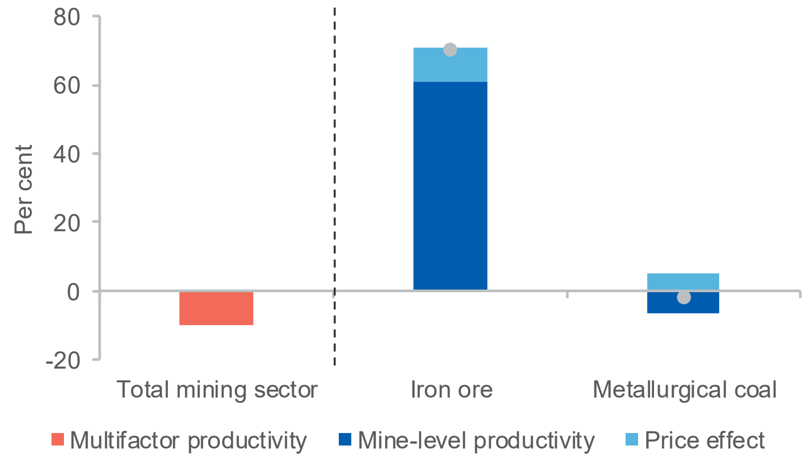
First, the investment boom affected multifactor productivity, given that mines have lags of around five years between turning the first sod and reaching peak capacity. This output-cost index avoids this issue by only analysing producing mines. The results show mine-level productivity in iron ore rose by 61 per cent between 2007 and 2018

Second, the price phase of the boom (beginning in 2003–04) resulted in higher cost mines operating than would have under lower prices. These high cost mines reduced productivity in the resources sector, due to the rapid scaling up and extraction of lower grade deposits.

The effect of higher prices on productivity is approximated by examining a simple counterfactual scenario, where new mines do not operate if their costs are above pre-boom prices. The analysis indicates that between 2007 and 2018, mine-level productivity growth in iron ore mining would be 10 percentage points higher with pre-boom prices. For metallurgical coal, the productivity growth would be 5.0 percentage points higher (Figure 1.1).

Adjusting the output-cost index for the price effect, productivity would be 71 per cent higher for iron ore from 2007 to 2018. For metallurgical coal, productivity would be just 2.0 per cent lower even in the face of considerable headwinds, including tropical cyclone disruptions.

**Figure 1.1: Increase in mining productivity, 2007 to 2018**




Notes: *Multifactor productivity are the experimental mining productivity measures calculated by the ABS. Other figures are mine-level proxies of productivity using Office of the Chief Economist (OCE) calculations. The ABS and OCE measures of productivity are calculated on different bases but both capture many of the major factors that drive productivity growth.*

Source: *ABS Cat. No. 5260.0.55.002 - Estimates of Industry Multifactor Productivity, 2017–18; OCE calculations using AME Group Cost Modeler database.*

International comparisons of the output-cost index highlight the competitiveness of Australian mining. Australian iron ore miners had the best mine-level productivity performance of major exporters between 2007 and 2018. In metallurgical coal, productivity in Australian lagged behind competitors but retained a competitive advantage due to the high quality and low impurities of its metallurgical coal. Population growth and urbanisation in key Asian economies are likely to buttress strong demand for Australian metallurgical coal.

## 1.1 The mining boom distorted productivity statistics

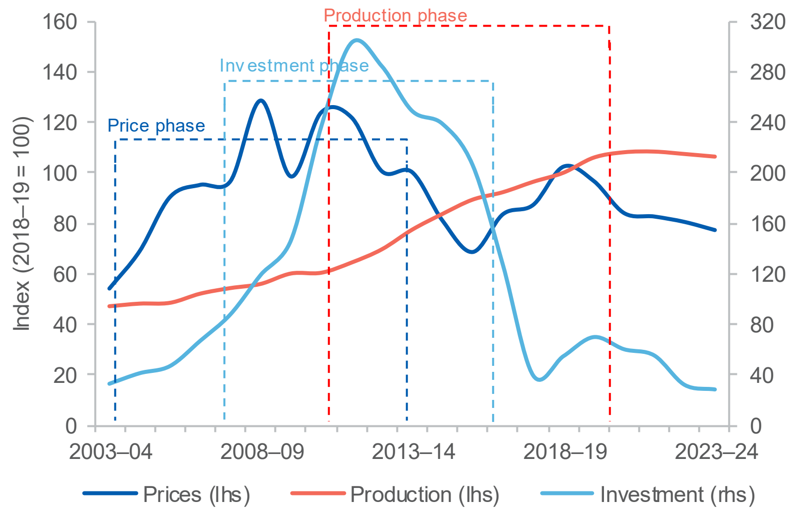
The conventional productivity statistics produced by the ABS show that multifactor productivity in mining declined significantly between the start of the mining boom and the peak of the investment phase. Since the end of the investment phase, productivity growth in mining has been slow.

This decline and weak recovery in mining productivity does not accord with what we know about the industry's strong global performance, the large boost in production capacity, the efficiency measures deployed in the industry and its large-scale technology use. Though multiple factors underpin the competitiveness and global dominance of an industry, productivity growth is a key determinant.

Reconciling the ABS productivity statistic and the developments in the industry, including its strengths, requires some understanding of the three distinctive stages of the mining boom (Figure 1.2). These massive economic events affected the standard productivity measures (Figure 1.3).

- First, the price phase from 2004 to 2012, driven by high economic growth in Asia drove commodity prices to record levels. Australian producers responded by bringing higher cost production online, which reduced productivity.
- Second, the investment phase from 2007 to 2017 saw unprecedented investment in response to higher prices. Higher investment and additional workers were included in the input statistics used to calculate multifactor productivity. Yet there were years of lags between the initial investment and new mines scaling up to full production.
- Finally, during the production phase from 2011 to 2019, investment began to generate large volumes of output. However, the full scaling up of production did not take place until 2019, later than the current productivity statistics which are for 2017–18.

**Figure 1.2: The three phases of the mining boom**

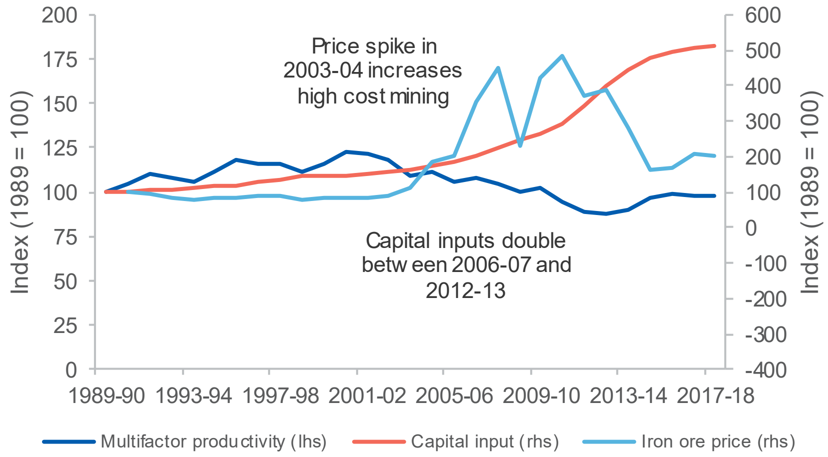



Source: *OCE calculations*

The first two phases of the boom had a strong negative impact on mining productivity. From the start of the price phase in 2003–04 to the peak of the investment phase in 2012–13, multifactor productivity in mining fell by 20 per cent. Since 2012–13, mining multifactor productivity has recovered somewhat but remains below pre-boom levels.

The impact of investment and the corresponding production lag on mining multifactor productivity is temporary. Going forward, multifactor productivity is expected to recover further as production phase peaks and the effect of the lag dissipates.

**Figure 1.3: Aggregate mining multifactor productivity and effects of the boom, 1989–90 to 2017–18**




Source: *ABS Cat. No. 5260.0.55.002 - Estimates of Industry Multifactor Productivity, 2017–18; World Bank, "Pink Sheet" data, Annual prices, September 2019.*

To overcome issues with the interaction between the mining boom and the productivity statistics, we use a measure of mine-level cost efficiency termed the 'output-cost index'. The index is used as a proxy for productivity changes in the iron ore and metallurgical coal industries.

The output-cost index shows the average change in output per unit of real input cost in Australian mines. Costs associated with extraction, processing, transport and administration and technical support of operational mines are encompassed in the index. As the index reflects the ratio of output to inputs, changes in the index broadly reflect productivity growth and should be similar to changes in the ABS multifactor productivity measure.

Due to the approach used to derive the output-cost index, changes in the index have a more direct link to changes in production costs. Multifactor productivity, on the other hand, is estimated as a residual of the portion of output growth not attributed to the accumulation of capital and labour. As such, growth in the ABS measure of productivity has a much broader interpretation, and includes changes resulting from improvements in knowledge, competition effects, and the effects of policy reform. Multifactor productivity also reflects improved efficiency in input costs, which are particularly important for capital inputs.

The Productivity Commission previously examined issues in measuring mining productivity in their 2008 paper, *Productivity in the Mining Industry: Measurement and Interpretation*. The analysis illustrated that the depletion of mineral and energy resources and investment lags both had negative impacts on measured productivity.

Supporting this finding the ABS have published experimental multifactor productivity estimates for mining, which control for the effect of depletion in the natural resource base. These alternative estimates show productivity growth is significantly higher after accounting for the depletion effect.

Despite both measures having similar interpretations, direct comparisons between the output-cost and the ABS mining multifactor productivity measure should be avoided given their different conceptual bases (see the Technical Appendix for more details).

## 1.2 Controlling for the investment boom

The level of mining investment during the boom was unprecedented: capital inputs for the mining sector doubled in the six years to 2013–14 and annual investment peaked at just under $100 billion in 2012–13.

Yet the nature of large mining projects is for a long lag between capital investment and production, often taking more than half a decade from commencement to peak production levels. For example, Caval Ridge is an open-cut coal mine located in the northern Bowen Basin. The mine produces 7.5 to 8 million tonnes per annum (Mtpa) of predominately high-quality metallurgical coal for export. The mine took six years to reach its current capacity: construction began in early 2012, full operation was reached in 2015, and an expansion was completed in late 2018.

As another example, Hope Downs 4, an iron ore mine, is one of 16 mine sites operated by Rio Tinto in the Pilbara Region of Western Australia. Iron ore is exported to East Asia via a 412km railway link to the Rio Tintoowned export terminal at Dampier Port. Construction began in 2011 and the mine commenced production in 2013 at 6Mtpa. Three years later, the mine reached full capacity of 15Mtpa in 2016 and further improvements boosted capacity to 16.5Mtpa in 2017.

The large influx of investment — combined with the long construction time of mining projects — reduced measured productivity, as the large investment was factored into the productivity statistics but many of the new mines had not commenced the new or expanded production.

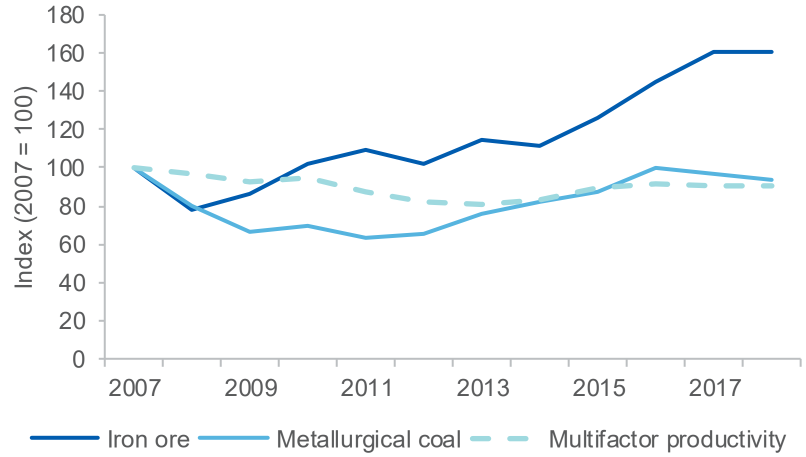
To control for this investment boom effect, this chapter uses mine-level data to look at operational mines only. The mine-level data contains information on the costs of extracting output for every iron ore and metallurgical coal mine in Australia and internationally. For example, the Yandi Joint Venture iron ore mine was the largest producer by volume in 2018, producing about 70 million tonnes at a cost of $16 per tonne.[1]

Delving into the mine-level data of operational mines reveals a difference in growth between the mine-level productivity, measured by the output-cost index and ABS mining multifactor productivity measure (Figure 1.4).

The output-cost index grew by 61 per cent in iron ore mining between 2007 and 2018. This increase was significant and consistent, reflecting cost cutting in the sector achieved through cost cutting in the sector and greater economies of scale, particularly in the sparse Pilbara region.[2 3]

For metallurgical coal, the output-index performance was more mixed, falling by 37 per cent over the period to 2011. The index then rose steadily by a similar amount from 2011 until 2017, before cyclone events in Queensland disrupted supply. Overall, the output-cost index fell by 7.0 per cent in metallurgical coal mining.

**Figure 1.4: Iron ore and metallurgical coal output-cost indices and aggregate mining multifactor productivity, 2007 to 2018**




Notes: *Mining multifactor productivity are the experimental estimates calculated by the ABS. Comparisons between the ABS and OCE measures are indicative only.*
Source: *OCE calculations using AME Group Cost Modeler database; ABS Cat. No. 5260.0.55.002 — Estimates of Industry Multifactor productivity, 2017–18*

Several factors underpin the differences in mine-level productivity growth between iron ore and metallurgical coal.

- Compared to iron ore, the metallurgical coal industry is of smaller scale and generally has greater difficulties in scaling up due to the smaller nature of the deposits and their location in more populated areas.
- Capacity constraints relating to rail and port infrastructure — used to move mine production to its final destination or port-of-exit — resulted in significant bottlenecks for coal mining.

[1] Estimates are based on data sourced from AME Group Cost Modeller database.

[2] Humphreys D (2019) Mining productivity and the fourth industrial revolution, Mineral Economics: Raw materials report, 9. pp 1-11

[3] Salisbury C (2018) Delivering the value from flexibility and optionality [pow er point presentation script] 180618 view ed 19 August 2019, https://www.riotinto.com/documents/180618_Presentation_Chris_Salisbury_Iron_Ore_script.pdf

## 1.3 Controlling for the price boom effect

The price phase (2004 to 2012) of the mining boom also affected the official productivity statistics. As prices rose — with prices for iron ore increasing by 79 per cent and by 90 per cent for metallurgical coal — producers could mine lower grade deposits at a profit. However extracting lower grade deposits increased costs and lower productivity.

Broadly speaking, the ABS measure of mining productivity is the outputs over inputs but controlling for price effects. Take the example of a mining sector producing 10 million tonnes of iron ore at a price of $45 a tonne. If prices doubled to $90 a tonne but input costs and output volumes otherwise stayed the same, there would be no change in productivity.

However, suppose the higher prices raise the incentive of producers to extract lower grade deposits that are twice as costly to mine. Despite profits rising for the industry, productivity would fall, due to the higher costs of extraction.

In the above example, the mining sector would become less productive, due to the scaling up in response to higher prices. Productivity in mining naturally falls as higher grade deposits are depleted and as new mines extract lower grade deposits. However, the price boom during the early 2000s accelerated this effect.

Disentangling the impact of prices on productivity is difficult, even when using detailed mine-level data. For example, ascertaining whether existing mines experience growing costs due to shifting to lower grade deposits in response to higher prices, or due to natural increases as the mines aged, is difficult. An added complication is that mine-level production and operating costs prior to 2007 — and therefore before the price boom — are not available.

Nevertheless, assessing the impact of higher prices on mining productivity is worthwhile. To do so, a counterfactual scenario was developed, in which iron ore and metallurgical coal mines do not operate if their costs of production exceed the real pre-boom prices for the two commodities. The real pre-boom price is assumed to be the 10-year average of prices from 1990 to 2000, which is $77 for iron ore and $110 for metallurgical coal.

**Table 1.1: Hypothetical example of the price boom effect**

| | Before | After: no production change | After: lower grade deposits extracted |
|---|---|---|---|
| Output | 10 million tonnes | 10 million tonnes | 20 million tonnes |
| Price (per tonne) | $45 | $90 | $90 |
| Average extraction cost per tonne | $40 | $40 | $60 |
| Productivity (tonnes of output per $million) | 25,000 | 25,000 | 16,667 |
| Profits | $50 million | $500 million | $60 million |

Source: *OCE calculations*.

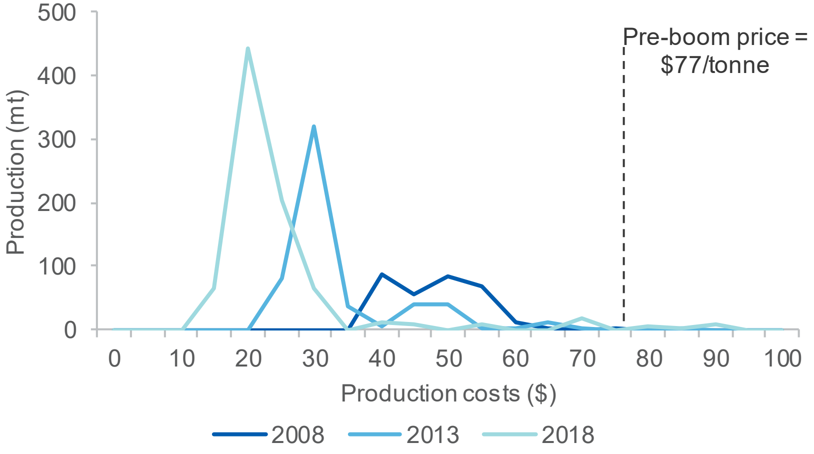
The impact of this assumption can be seen by examining the distribution of mine production costs over time.

In 2008, production costs for most iron ore mines ranged between $40 and $60 per tonne (Figure 1.5). In the next decade, iron ore mines became much more efficient, with the average real production costs falling to a low of $20 a tonne by 2018. The range of production costs across mines also narrowed significantly.

The estimated price effect for iron ore is low: productivity is estimated to be six per cent higher in 2018 if mines with costs above pre-boom prices do not produce.

Iron ore producers greatly improved efficiency over the period, resulting in the assumption having little effect on hypothetical production, with just 48 million tonnes of production (or about one per cent of total production) turned off.

### Figure 1.5: Distribution of iron ore real production costs, select years




Notes: *Production costs are in Australian 2018 constant producer prices.*
Source: *OCE calculations using AME Group Cost Modeler database*

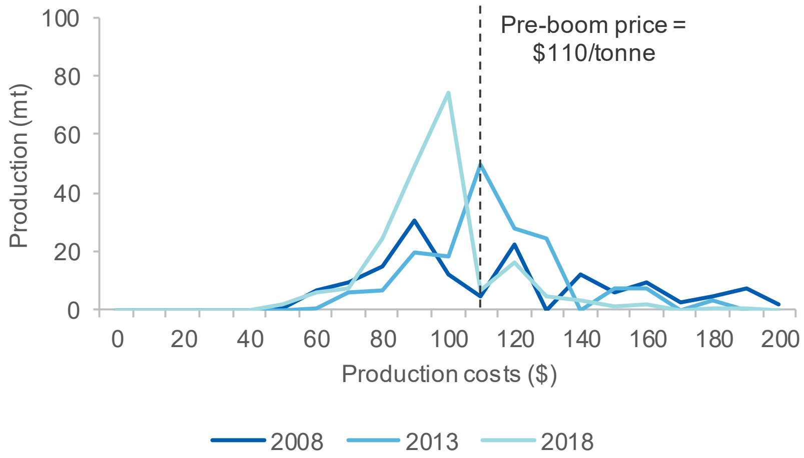
For metallurgical coal, the distributions show mine-level costs were more varied, and were mostly between $60 and $140 per tonne over the same period (Figure 1.6). There were some efficiency gains, as average costs declined and the amount of high-cost production fell. However, costs did not fall as much as iron ore mines, and a long tail of high cost mines remained in operation between 2008 and 2018.

The estimated price effect for metallurgical coal is that productivity would be about 26 per cent higher in 2018. The assumption results in approximately 619 million tonnes of lost production or about 34 per cent of the total production to 2018.

The greater impact of the price boom for metallurgical coal compared to iron ore has two main drivers.

- First, prices for metallurgical coal have almost tripled in real terms above their pre-boom levels, while real iron ore prices have largely returned closer to pre-boom levels (Table 1.2).
- Second, metallurgical coal production is of lower scale compared to iron ore. The industry generally had greater difficulties in scaling up, due to the smaller nature of the deposits and their location in more densely populated areas. Iron ore is predominantly mined in the sparsely-populated Pilbara region. This factor allows the sector to achieve cost reductions through scale. But, concerted efforts to reduce costs and boost productivity in iron ore mining have also contributed.

### Figure 1.6: Distribution of metallurgical coal real production costs, select years




Notes: *Production costs are in Australian 2018 constant producer prices.*
Source: *OCE calculations using AME Group Cost Modeler database*

### Table 1.2: Iron ore and metallurgical coal prices

| | Pre-boom Price (2000) | Peak price (2008) | Post-boom price (2018) |
|---|---|---|---|
| Iron ore | $83 | $122 | $94 |
| Metallurgical coal | $94 | $282 | $231 |

Notes: *Prices are expressed in Australian 2018 constant producer prices. OCE estimates based on data from World Bank and* June 2019 *Resources and Energy Quarterly.*

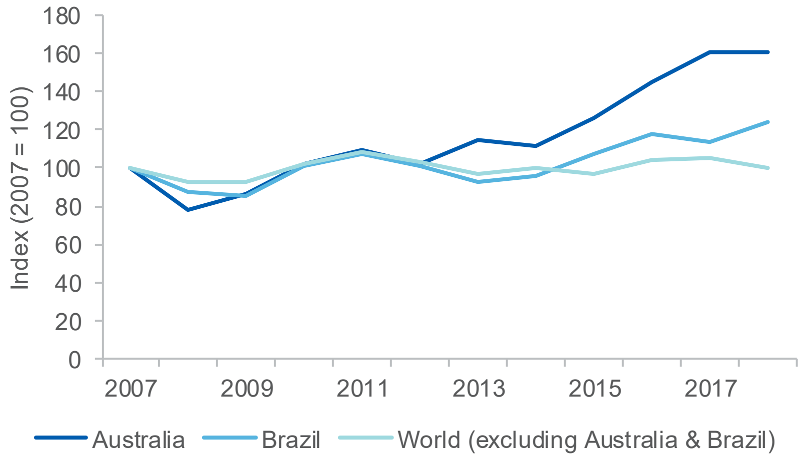
## 1.4 International comparison

The global demand for iron ore and metallurgical coal, particularly from China, exceeded the growth in global supply. The marked increase in prices led to a substantial expansion of iron ore and metallurgical coal capacity across Australia's key competitors and globally.

Australian mine-level productivity in iron ore — measured by the output-cost index — outpaced Brazil and the rest of the world, as domestic producers drastically reduced costs over the period (Figure 1.7).

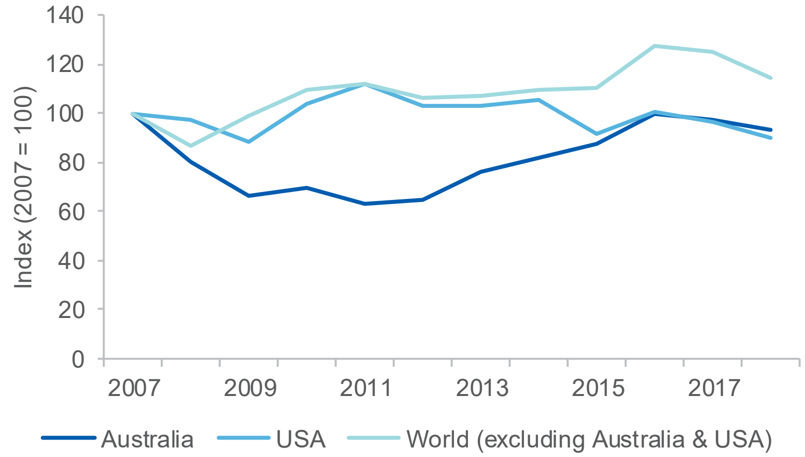
For metallurgical coal, mine-level productivity fell behind international competitors during the price and investment phase of the mining boom (Figure 1.8). However, during the production phase, productivity grew and Australian miners gained ground, catching up to the United States, one of its key competitors. Despite trailing key competitors on cost improvements, Australia has a competitive advantage relative to other producers, in mining high-quality coal. Further, rising incomes and ongoing urbanisation in China and India are expected to support demand for Australia's metallurgical coal.

**Figure 1.7: Output-cost index, iron ore, select countries, 2007 to 2018**




Source: *OCE calculations using AME Group Cost Modeler database*

**Figure 1.8: Output-cost index, metallurgical coal, select countries, 2007 to 2018**




Source: *OCE calculations using AME Group Cost Modeler database*

## 1.5 Technical appendix

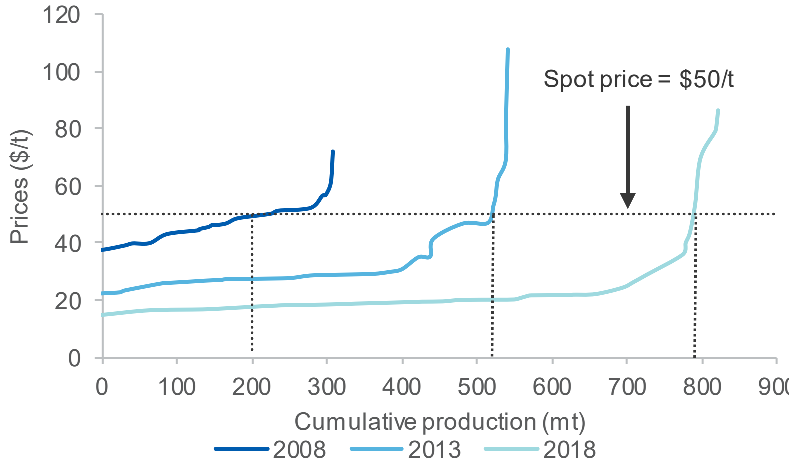
### The mine-level data

The analysis is based on data sourced from AME Group's Cost Modeller database, which provides mine-level cost, revenue and output information of key commodities from 2007 onwards. The data can be aggregated by company or country, allowing for comparisons.

AME utilises engineering costing models to calculate costs using a wide range of specific data, including labour rates, production capacities, waste ratios, transport distances, port costs, product recoveries, and state- and country-specific royalty/energy formulae. These modelled results are then reconciled against reported company information.

Combining all mines gives the amount producers are willing to supply at a particular price. These are known as cost curves. Typically, lower cost producers will be at the lower end of the cost curve, while higher cost (and less productive) producers will be at the higher end.

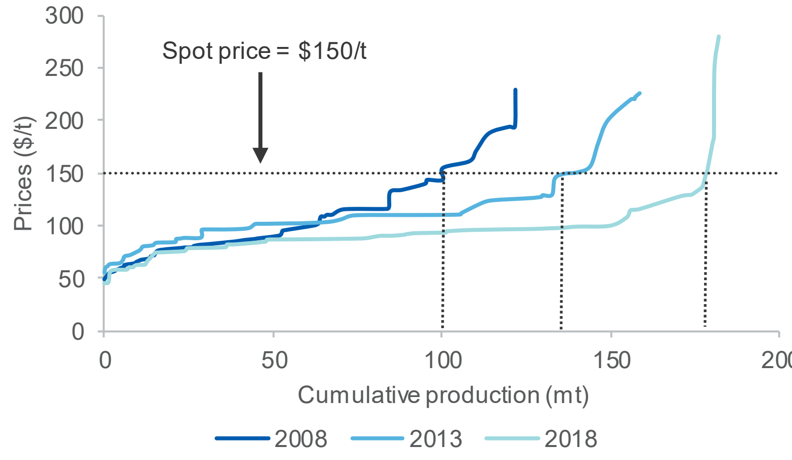
**Figure 1.9: Iron ore cost curves, select years**




Notes: *The curves were constructed from average variable costs of production of mines. Only includes trade coal production. Prices are expressed in Australian 2018 constant producer prices.*

Source: *OCE calculations using AME Group Cost Modeler database*

**Figure 1.10: Metallurgical coal cost curves, select years**




Notes: The curves were constructed from average variable costs of production of mines. Only coal production that is traded is reflected. Prices are expressed in Australian 2018 constant producer prices.

Source: OCE calculations using AME Group Cost Modeler database

Changes in the cost curves for iron ore and metallurgical coal reflect the findings in the chapter.

The iron ore cost curve has shifted out and flattened in the decade to 2018 (Figure 1.9). This dynamic reflects the significant increase in iron ore production capacity from substantial new investment, particularly from lower-cost iron ore mines. For example, at a real spot price of $50 a tonne, iron ore mines in 2008 were able to produce around 200 million tonnes of iron ore (the intersection between the $50 spot price and the 2008 cost curve). In 2018, production capacity quadrupled to almost 800 million tonnes.

As with iron ore mines, there have been substantial expansions in metallurgical coal production — leading to an outward shift of the cost curves between 2008 and 2018 (Figure 1.10). Compared to iron ore mining, however, the expansion in production capacity were from higher cost mines and require a much higher real spot price of $150 a tonne to remain profitable. At this spot price, coal mines were able to produce around 100 million tonnes of metallurgical coal in 2008, almost doubling to 180 million tonnes by 2018. Similar to the distribution analysis in Section 1.3, the cost curves suggest that metallurgical production spans a wider range of low-cost to high-cost mines relative to mines in the iron ore industry.

### Scope of commodities considered

The scope of the analysis was limited to Australia's iron ore and metallurgical coal industries.

In 2018–19, these two commodities accounted for 28 per cent and 16 per cent of Australia's resources and energy exports, respectively. Further, these two commodities have dominated the share of resources and energy exports since 2003–04, with shares averaging approximately 30 and 15 per cent, respectively, from 2003–04 to 2018–19.

Liquefied Natural Gas (LNG), thermal coal and gold are also key resource and energy exports. These industries were also affected by the phases of the mining boom and would have been an interesting case study. Extending analysis to these other commodities would be worthwhile in the coming years, however they were exclude from this initial chapter as:

- the ramp up in LNG production has been relatively recent and so largely sits outside the available productivity statistics with implications for data reliability and comparability; and
- thermal coal and gold's share of resource and energy exports were significantly lower than that for iron ore and metallurgical coal at 9.0 and 7.0 per cent, respectively, in 2018–19.

As iron ore and metallurgical coal comprise a large share of mining production, both currently and historically, changes in industry aggregates are likely to be driven heavily by developments in these two commodities.

### Output-cost index

A measure of mine-level cost efficiency called the output-cost index was derived for the purpose of this analysis. This metric shows the average change in output per unit of total input cost and is a proxy measure of mine-level productivity. Further, mine production costs were weighted by their level of production and then aggregated across all producing mines to generate the aggregated output-cost index.

The AME production data broadly aligns with industry-level production from the national accounts. Growth in both iron ore and metallurgical coal production in AME data tracks closely with growth in gross value added at chain volume measures (i.e. adjusting for prices) for relevant sub-industries in the national accounts.

The index does not account for intermediate inputs in the production process. Therefore, the measure is akin to a gross output measure of productivity rather than a value add measure. As a result, index changes can be attributed to improvements in both primary capital and labour inputs, and intermediate inputs.

Due to data limitations, the output-cost index does not control for changing input prices and capacity use. For example, lower input costs (such as labour and contract costs) as the mining boom receded could lead to an overestimate of productivity growth.

Significant drivers of productivity — such as cost reductions, better capacity utilisation, efficiency of input use and economies of scale — are reflected in the output-cost index measure.

### Box 1.1: ABS Multifactor productivity vs output-cost index

The ABS multifactor productivity measure is the increase in output beyond that stemming from changes in inputs used in production processes. It can be thought of as the efficiency with which inputs such as labour and capital are combined to produce goods and services.

The metric is measured as a residual of the portion of output growth that cannot be attributed to the accumulation of capital and labour. As such, changes in multifactor productivity have a broader interpretation and reflect the effects of changes in management practices, brand names, organisational change, general knowledge, network effects, spill overs from production factors, adjustment costs, economies of scale, the effects of imperfect competition and measurement errors.

The output-cost index represents a composite of broad features of production costs: mining costs, processing costs, administration and support costs and freight and logistics. As a result, changes in the index have a more direct link to changes in production costs, compared to the conventional ABS measure of productivity.

In addition, embedded in and across the broad cost categories used in the output-cost index are capital and labour inputs. These factors of production are not separated. Consequently, growth in the output-cost index cannot be decomposed into changes in labour or capital inputs.

Mine-level data prior to 2007 is not available in the AME Cost modeller database. Therefore, ascertaining whether the output-cost index and the ABS multifactor productivity would track closely in the years preceding the mining investment boom is difficult.

The commodities included in the calculation of each measure also differ. Multifactor productivity is also measured at the entire industry level, whereas the output-cost index has only been calculated for iron ore and metallurgical coal.

As all figures presented in this chapter are weighted by their production, non-operational mines and inputs attached to those mines have no effect on the output-cost index results. On the other hand, the ABS do not use a direct method to exclude the capital of non-operational mines from their estimates of multifactor productivity. Rather, they apply methods to account for age-related depreciation (including foreseen obsolescence), that smooths out the usage of capital over time. As a result of this indirect method of accounting for capital inputs, there is a potential for capital still attached to non-operational mines to be counted in the multifactor productivity calculations.

Direct comparisons between the output-cost index and the ABS productivity measure should avoided due to the different data sources and methodologies used to derive each measure.

Source: ABS (2015) Australian System of National Accounts: Concepts, Sources and Methods, 5216.0, Canberra; ABS (2005) Estimating industry-level multifactor productivity for the market-sector industries in Australia: methods and experimental results, ABS research paper, Canberra

### Deflator

The AME database expresses all historic production costs for each year and each mine in that specific year’s nominal US dollars. This was done by AME converting local currencies to US dollars through estimates of annual exchange rates.

For the purpose of this analysis and comparability across years, all figures were:

- converted to nominal Australian dollars, based on estimates of the annual Australian-US dollar exchange rate for that year
- deflated and expressed as 2018 prices, using the Australian GDP price deflator.

The ABS publish a coal mining input price index in *6427.0 - Producer Price Indexes*, but do not publish an equivalent index for iron ore. Therefore, to ensure consistency in the analysis and in the absence of more valid and specific iron ore and coal mining input price indices, production costs were deflated using the GDP price deflator. The GDP price deflator with the coal mining input price index track each other closely, suggesting the GDP price deflator is a good indicator of costs in the mining sector generally.

### Pre-boom price assumption

Section 1.3 illustrates a counterfactual scenario that attempts to control for the impact of the substantial increase in commodity prices on mine-level productivity. The counterfactual assumes this price effect does not occur, by simulating production costs of mines under the following assumptions:

- World spot prices for iron ore and metallurgical coal are reduced to and held constant at the 10-year historical average between 1990 and 2000. For iron ore, this was $77 and for metallurgical coal it was $110.
- Mines remain operational if their per tonne production costs remain below the price assumption and shut down when they are above.

The price assumptions is similar to those used by the Reserve Bank of Australia in analysis of the impact of the mining boom in the paper *Tulip P (2014) The Effect of the Mining Boom on the Australian Economy*' and lead to significantly lower production costs in the counterfactual scenario.