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Multifactor productivity growth and the Australian mining sector*

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A commonly used, but unadjusted, measure of Australian mining multifactor productivity (MFP) fell by about one-third over the first decade of the mining boom, coinciding with very large increases in resource prices. Using growth accounting methods and our own adjustments, based on energy use and capital-output lags to account for depletion effects we find (i) the Australian annual average MFP growth in mining was 2.5 per cent a year between 1985–1986 and 2009–2010 compared to –0.65 per cent for the unadjusted measure and (ii) productivity growth was positive in the 2000s, albeit at a lower rate than in the 1990s. Our adjusted MFP growth measures at a state level and subsector level are greater than unadjusted productivity measures. In a complementary study using an econometric decomposition of mining MFP at a state level, we find no statistically significant effect of technological change on MFP growth in the sector, but positive and statistically significant effects of technical efficiency and scale over the period 1990–1991 to 2009–2010. Our results do not support specific policy interventions to increase productivity growth in the mining sector beyond appropriate incentives for resource exploration including the provision of precompetitive resource data.

Key words: productivity, mining, depletion.

1. Introduction

There was an overall decline in Australia's market-sector multifactor productivity (MFP) growth from a 1.1 per cent average per year between 1990 and 2000 to a –0.7 per cent average per year over the period 2000–2009. This was more than double the average decline for 28 OECD countries with data going back to 1990 (Eslake 2011). Most of the deterioration in Australia's productivity performance was concentrated in the three sectors: mining, manufacturing and 'electricity, gas, water and waste services', which together accounted for around 60 per cent of the decline in MFP growth before and after 2003–2004 (Parham 2013).

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Gregory (2012) has argued that the Millennium Mining Boom that began in 2002–2003 arose from increased export prices emanating from the increased demand from China (Garnaut 2012), India, and other emerging economies, and not from the export volume growth generated by new discoveries. The empirical question in terms of mining productivity, suggested by Gregory's analysis, is whether technological change or technical progress has played a major role in the mining sector in Australia in recent times? We respond to this, and other key questions about Australian mining productivity, by answering: What is the adjusted trend in MFP growth in Australia; What are the policy implications of changes in this trend in the context of mineral and resources (Peterson and Cullen 2012)?

Our purpose is to explain the apparent decline in mining productivity growth that, according to the Australian Bureau of Statistics (ABS) data (ABS 2013), fell by almost a half between 2000–2001 and 2012–2013. This was the largest reduction in MFP of any Australian market sector over the past four decades and deserves a detailed analysis in a country that is highly dependent on mining in terms of its export income. Possible explanations for the apparent decline in mining productivity are that much high resource prices in the 2000s provided incentives to: one, extract from marginal resource deposits that were previously unprofitable due to high costs of extraction; and two, utilise proportionally more inputs in their operations, so as to increase their rates of extraction. Lags between increases in capital (assumed by the ABS to be productive as they occur) and growth in output (which occurs only when projects are completed) may also explain the productivity decline.

Topp *et al.* (2008) has investigated the effects of 'resource depletion' and capital lags on mining MFP and used yield variables to capture depletion effects. As their approach cannot be replicated, we develop our own adjusted and repeatable measures of MFP growth in the Australian mining sector over the period 1985–1986 to 2009–2010. Our findings are important given the direct and indirect importance of the mining sector in the Australian economy (Connolly and Orsmond 2011), and the possible policy implications of negative productivity growth on future prosperity in Australia (Grafton 2014; Australian Treasury 2015).

Our specific contributions in this study include the following: (i) the development and use of an easily computable measure of resource depletion when adjusting mining productivity growth; (ii) disaggregated MFP estimates at each of the national, state and subsector levels; and (iii) a decomposition of MFP into three components: technological change, technical efficiency and scale effects, and an estimate of their relative contributions to MFP growth.

In Section 2, we provide a background to the trends and previous analyses of Australian mining productivity. Section 3 examines the measurement issues of productivity, describes the adjustments we used to account for input–output lags and depletion effects, and presents both unadjusted and adjusted measures of Australian mining productivity performance. Section 4

evaluates productivity performance at the state and subindustry levels using growth accounting methods. In section 5, we outline a separate econometric decomposition of mining MFP that decomposes MFP growth into the three components: technological change, technical efficiency and scale effects. Our decomposition finds that technological change had no statistically significant effect on MFP growth over the study period, but that both technical efficiency and scale effects contributed positively and significantly to mining MFP, after removing the effect of output quality (depletion). In section 6, we offer concluding remarks.

2. Background

Mining involves the extraction and processing of a range of mineral deposits, many of which are spatially distributed unevenly across Australia. For example, Western Australia is heavily endowed with iron ore and gas; Queensland and New South Wales with coal, and also coal seam gas. Since the early 2000s, Australian mining has experienced a structural shift as prices for key resource exports rose dramatically in line with a surge in demand in emerging economies coupled with a short-run inelastic supply response. Higher resource prices (Figure 1) created substantial rents for mining companies with existing mines. In response, mining capital investment and employment grew rapidly up until 2011 with private new capital expenditures in the sector increasing fourfold as a proportion of the Australian total. Direct mining employment tripled from 2000–2001 to 2011–2012. This decade-long period has been called the price or development phase of the mining boom (Grafton 2012).

The 2000s ‘mining boom’ has been proportionally larger than any other commodity boom enjoyed by Australia since Federation (Grafton 2012). As a result of the boom, mining represented about 10 per cent of Australian GDP in value-added terms in 2011–2012 (Figure 2). At 2011–2012 prices, mining industry gross fixed capital formation represents about 4 per cent of GDP, the highest contribution of any single industry. In 2011–2012, new capital

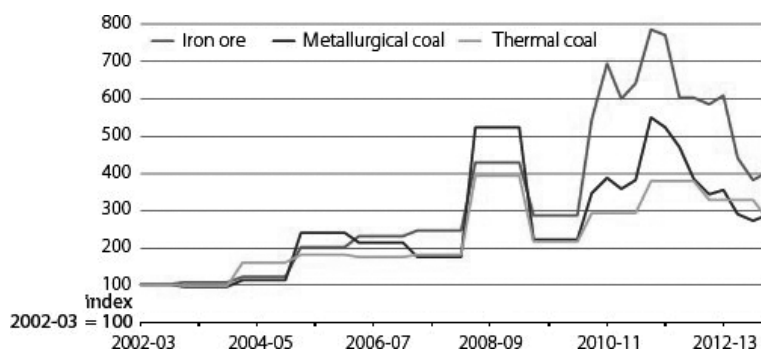


Figure 1 Index of real bulk commodity prices quarterly, 2002 to 2012 (Mar-00 = 100). Source: BREE, Resources and Energy Quarterly, 2012.

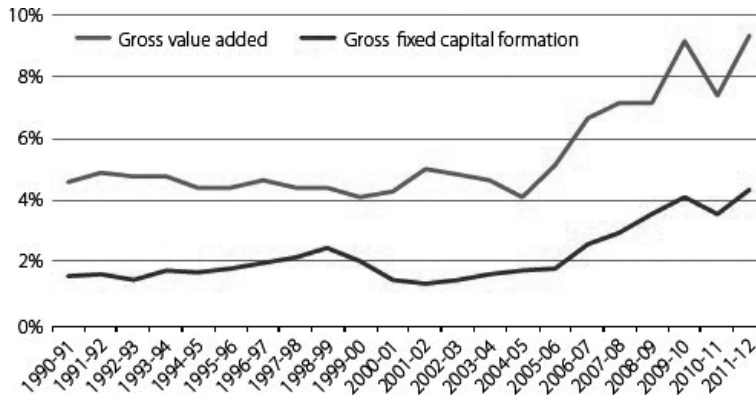


Figure 2 Mining industry relative to GDP, 1990–2011, current prices. Source: ABS (2012a cat 5204), BREE estimation.

expenditure in the mining sector was 53 per cent of private new capital expenditure and was valued at \$82 billion (Figure 3). This compares with an inflation-adjusted figure of \$7.6 billion a decade ago.

From 1990 to 2012, mining industry output surged in current price terms (9.7 per cent a year), but its growth in volume or real output terms was relatively modest (3.5 per cent a year), as shown in Figure 4. In 2011–2012, the gross value added produced by the mining industry was approximately \$140 billion. Of this total, the mining sector (excluding services to mining) contributed about 90 per cent while the exploration and mining support services generated much of the remainder.

2.1. Multifactor productivity growth

We used two adjustment methods to measure changes in mining productivity. First, the capital input was lagged. Second, the natural resource input (output) was adjusted for resource depletion. Both of these adjustments are

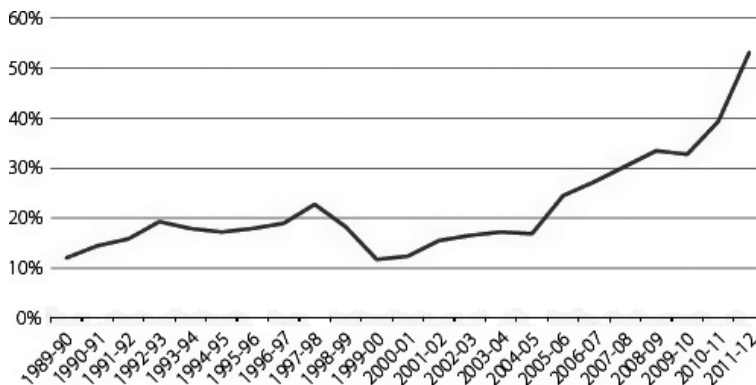


Figure 3 Mining share of private new capital expenditure (Australia), 1990–2012. Source: BREE, Resources and Energy Quarterly, 2012.

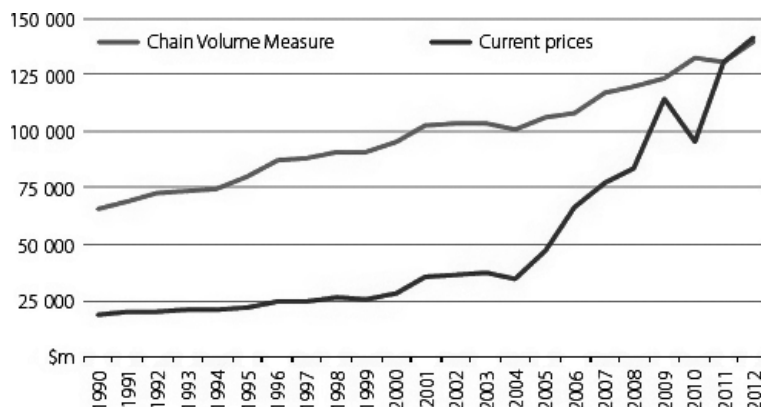


Figure 4 Mining industry value added, 1990–2012. Source: ABS (2012a, cat. 5204).

described below. As with the ABS measure of mining productivity, capital services are assumed to be proportional to the Productive Capital (K) Stock (PKS). Thus, there is no analytical distinction between growth in PKS and growth in capital services.

The value-added measure of output used to measure mining productivity in this paper is the same as that provided by Australian Bureau of Statistics (ABS 2012b, 2012e) and is a volumetric measure that is insensitive to price and exchange rate changes. A value-added MFP measure is the starting point for the market sector and is the focal point for assessing the contribution of mining to aggregate productivity and mining productivity trends. We note that a value-added MFP measure identifies only Capital (K) and Labour (L) as inputs and are derived as a Tornqvist index.

The need to account for capital-output lag is due to the misallocation of current investment to contemporaneous output. Specifically, ABS treats investment as entering the productive capital stock as it occurs, but there is typically a lag between when an annual investment is made and when accumulated investments result in a completed project that generates output. To resolve the measurement issue, it is possible to delay portions of investment spends (to replicate the accumulation of investment in work in progress) or alternatively to lag the growth in the capital stock. Following Topp *et al.* (2008), we lag growth in the capital stock by two years (whereas, output and labour input are for the current year).

Topp *et al.* (2008) used a 3-year lag from the year of investment and start of the mining output and analysed data from 1974–1975 to 2006–2007. The project-level data at the Bureau of Resources and Energy Economics (BREE) show that the time taken between the mining investment decisions and output production depends upon the size of project, regional environment (environmental issues, community views), and prospective yield of investment. We find that a two-year lag is a more accurate representation of the capital-output lag relationship.

Given the importance of mining to the Australian economy, the decline in unadjusted mining multifactor productivity in the Australian mining sector over the 2000s is an important public policy issue. The proximate cause of the decline is substantive growth in the use of capital and labour inputs that has been accompanied by disproportionately low increases in real output. According to ABS estimates, the *decline* in unadjusted MFP between 2000–2001 and 2009–2010 was 31 per cent. The ABS data show that Australian mining unadjusted MFP declined by a further 23 per cent in the three years since 2009–10 (ABS 2013).

A trend of declining mining MFP growth is not unique to Australia. Bradley and Sharpe (2009), for example, estimate that in both Canada and the US the annual average growth in mining MFP (unadjusted) was 1.91 per cent a year (Canada) and 0.55 per cent a year (US) over the period 1989–2000 and fell to –1.07 per cent a year (Canada) and –1.68 per cent a year (US) over the period 2000–2007. By contrast, according to Bradley and Sharpe (2009), Australia's MFP annual growth rate fell from 1.71 per cent over the period 1989–2000 to –1.99 per cent over the period 2000–2007.

The special characteristics of the mining sector mean that unadjusted measures of productivity warrant careful interpretation. This is because mining activity is heavily reliant on the quality and size of the natural resource stock. Further, the quality of these mineral deposits is, typically, not controlled for in traditional productivity measurement methods. Consequently, when ore grades decline as deposits are depleted, the measured productivity of mining falls because more inputs are needed to produce a unit of saleable output. Another reason for adjusting productivity measures in mining is because of the long lags between capital investments and increased output which distorts unadjusted measures of MFP when there are substantial year-on-year increases in capital expenditures, as occurred during the Millennium Mining Boom.

Using the ABS and other data sources, Topp *et al.* (2008) analysed mining productivity from 1974–1975 to 2006–2007 and adjusted productivity by using a measure of ore quality. They found that, over that time period, unadjusted MFP grew only at a negligible rate of 0.01 per cent a year. However, adjustment for depletion and capital lag effects took the annual MFP growth rate to 2.3 per cent. They also found that over the period 2000–2001 and 2006–2007 measured MFP *declined* by 24.3 per cent, but increased by 8 per cent once depletion and capital lag effects were considered. They found the depletion effect to be three times the capital lag effect.

In another study, Loughton (2011) adjusted mining MFP growth using the ratio of cumulative extraction (to account for the resource depletion) to the total reserves available for extraction over the life of mines. He estimated an adjusted mining MFP between 1985–1986 and 2009–2010 and found that the quality of natural resources in mining decreased substantially over this period.

3. Measuring Australian mining productivity growth

MFP is measured in terms of real output per unit of labour and capital and represents changes in output that are not directly attributable to changes in measured inputs. These nonmeasured factors, such as technological progress, economies of scale, capacity utilisation, market efficiency and qualitative changes in inputs, make the use of inputs more efficient and generate higher production from the same quantity of inputs. Thus, a fall in MFP growth, or in partial productivity growth, all else equal, indicates that resources are being used less efficiently.

3.1. Unadjusted productivity measures

The ABS presently classifies mining into the following main subdivisions in accordance with the nature of mining activities: coal mining, oil and gas extraction; metal ore mining (iron, copper, gold, mineral sand, silver–lead–zinc mining and bauxite, nickel and other metals); nonmetallic mineral mining; and exploration and other support services. Using ABS data, a measure of unadjusted MFP and labour and capital productivity in the Australian mining sector over the period 1990–1991 to 2012–2013 is provided in Figure 5. It shows that each of the unadjusted measures of productivity: capital productivity, labour productivity and MFP in the Australian mining sector, declined over the 2000s. In particular, the labour productivity, capital productivity and MFP fell by –6.1, –4.3 and –4.7 per cent a year, respectively, over the period 2000–2001 to 2010–2011 (the height of the mining price boom). By contrast, both labour and multifactor productivities grew in the 1990s (at 5.0 and 1.7 per cent a year, respectively) while capital productivity did not.

Over the 2000s, both labour and capital inputs grew rapidly at over 7 and 9 per cent a year, respectively, but output grew at about 3 per cent per year. Consequently, MFP and labour and capital productivities fell.

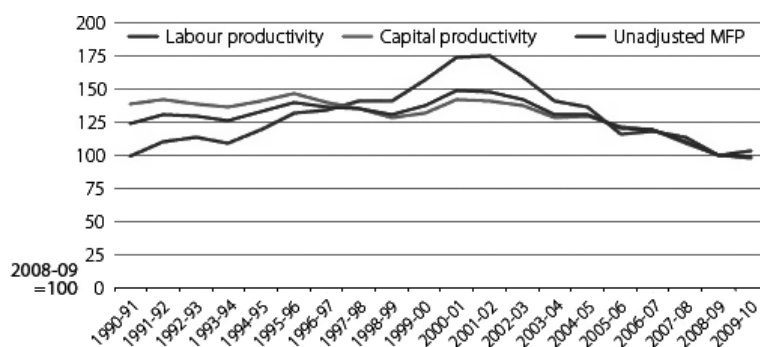


Figure 5 Indexes of labour productivity, capital productivity and unadjusted MFP in the Australian mining sector, 1990–91 to 2009–10. Source: ABS (2011, cat. 5260).

3.2. Adjustments to mining productivity growth

Several possible adjustments are required to adequately represent 'nonproduction' changes in productivity over time in the mining sector. These are summarised as follows:

1. Input–output lags: Output growth does not immediately follow input growth in mining because of lags between when investments are made and labour is employed and when output increases. Thus, when year-on-year input growth increases rapidly unadjusted MFP growth is biased downwards until the output growth that is a result of these investments occurs.
2. Endogenous depletion: As the easily accessed resources (those generally closer to the surface) are depleted, the incentive to extract resources that are harder to access (those generally located deeper underground) increases with higher commodity prices. This change in resource quality, which requires more labour and capital inputs, reduces productivity.
3. Exogenous depletion: High-grade ores, or oil and gas basins with higher flow rates, or those minerals that can be accessed easily are generally extracted first. Over time, these deposits are depleted, irrespective of commodity price levels, and mining shifts to lower-grade ores that consume more inputs per unit of output.

To account for depletion effects, Wedge (1973) used an index of ore grades as a proxy for declining natural resource inputs in Canada. He found that measured productivity increased significantly compared to the case when the quality of natural resource inputs was not included in the analysis. Others, such as Tilton and Landsberg (1997), Lasserre and Ouellette (1988), Stollery (1985), Young (1991), Managi *et al.* (2005), DCITA (2006), Fairhead *et al.* (2006), Rodriguez and Arias (2008), Topp *et al.* (2008), Zheng (2009), and Loughton (2011), have all adjusted for natural resource depletion utilising different measures (level of reserves, cumulative production, ore grades, etc.) in their analyses and found measured productivity increased after the adjustment.

Topp *et al.* (2008) measured the extent to which resource depletion occurred in the mining sector by movements in a composite index of mining 'yield'. Output in mining can be adversely affected if there is a decline in yield because of depletion. Topp *et al.* (2008) constructed the yield index using:

1. average ore grades in metal ore mining;
2. the ratio of saleable to raw coal in coal mining; and
3. the implicit flow rate of oil and gas fields in the petroleum and gas sector.

While specification of a yield index is appropriate, with caveats (Topp *et al.* 2008), the construction of their index involved estimating information both from private and official sources and data collection from Gavin Mudd

(2007), ABS, Australian Bureau of Agricultural and Resource Economics (ABARE), and the Victorian Department of Primary Industries, among others. Importantly, Topp *et al.* (2008) measured resource depletion by collating an index of yield from different sources between 1974–1975 and 2006–2007. This measure of depletion cannot be extended beyond 2006–2007 due to data unavailability. By contrast, Loughton (2011) accounted for the depletion of resources by using the ratio of cumulative extraction to the total reserves available for extraction over the life of a particular natural resource. Whereas the cumulative extraction may be estimated, total reserves change each year with the advancements in the geological survey techniques. Consequently, this makes the use of a ratio of cumulative extraction to total reserves problematic.

The logic for our energy-based resource depletion measure to evaluate growth in mining productivity is that a decline in the deposit of certain depth will, typically, increase the use of energy use per unit of output due to depletion. This is because when resources are depleted successively more fuel energy is needed to produce the same amount of net output such that the gradual reduction in ‘energy productivity’ (output to energy ratio) can reveal the extent of resource depletion. Energy use data can, therefore, be used to estimate the extent to which changes in resources contribute to changes in output each year. Specifically, a measure of the value added in mining sector to energy use (petajoules) in a year can be used as a measure of energy productivity.

BREE data show the use of physical amount of energy (petajoules) per unit of mining output (energy intensity) has been constantly increasing over the last several years. Changes in the gradual deepness or characteristics of a resource will influence the quantity of inputs used to process or prepare a unit of resource output. Potential or adjusted output in mining can be estimated by keeping the first year’s energy productivity constant over the period of study. That is, each successive year’s potential or adjusted output is obtained by multiplying the use of energy in the year with the first year’s energy productivity. This adjusted output provides a measure of actual output that would have been produced if energy productivity had not declined from year to year. Given that energy productivity in the first year does not cause energy use in the later years, this adjustment process will not cause any endogeneity issue in the production process.

The energy use measure of adjustment refers to energy productivity, and falling energy productivity in mining is a general finding elicited in all energy productivity studies in Australia (Che and Pham 2012; Petchey 2010, Sandu and Syed 2008). A comparison of our energy productivity adjustment with a resource quality measure used by Topp *et al.* (2008) is provided in Figure 6. Both approaches are broadly consistent although the yield adjustment based on energy productivity is more variable.

The growth accounting analysis of mining productivity has been performed at three levels: national, state and sector levels. The main variables used in the

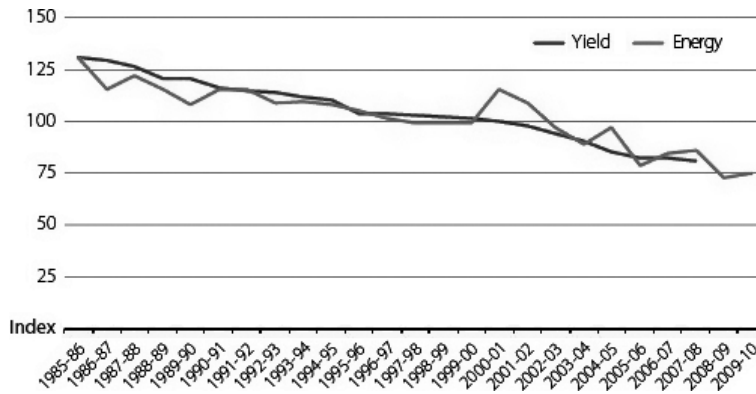


Figure 6 Yield versus energy-based measures of resource depletion. Source: BREE (AES, various years), and Topp *et al.* 2008.

analysis included labour, capital and energy inputs. The period of the analysis at each level had to be confined by data availability. For example, at a national level, all variables needed for the analysis were available from 1985–1986 to 2009–2010 (from the Australian Bureau of Statistic (ABS 2012e) and the Bureau of Resources and Energy Economics (BREE)). For the state and sector levels, data were available from 1989–1990 to 2009–2010 (state level) and 2001–2002 to 2009–2010 (sector level).

3.3. Comparison of adjusted and unadjusted productivity measures

Figure 7 compares an unadjusted MFP in the Australian mining industry along with an adjusted MFP estimate: an estimate of mining MFP that has been adjusted to take into account the average lead-time between construction and production for new mining investments (capital adjusted), and also adjusted for natural resource depletion or output quality (output adjusted). It

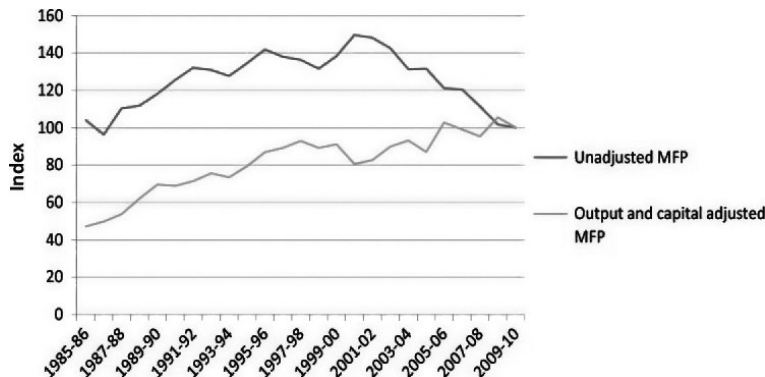


Figure 7 MFP index with and without adjustment, Australian mining, 1985–1986 to 2009–2010. Source: ABS (2011, cat. 5260), authors’ estimates.

shows that unadjusted MFP for Australian mining, as measured by the ABS, *declined* at an annual average growth rate of 0.65 per cent between 1985 and 2010. The adjusted MFP measure grew at an average annual growth rate of 2.5 per cent.

Since neither unadjusted (conventionally measured by ABS) MFP nor the adjusted MFP grew at a steady rate throughout the study period, the MFP growth assessment is split into two subperiods. Figure 8 shows MFP growth rates over two time periods – from 1989–1990 to 1999–2000, and from 1999–2000 to 2009–2010 which coincides with the first phase of the mining boom (Grafton 2012). Figure 8 shows that in the 2000s the unadjusted average MFP growth rate declined by 3.1 per cent a year. In the 2000s, after the adjustment for depletion and lagged capital inputs, the average MFP growth rate was 1.6 per cent a year, compared to the 2.1 per cent adjusted MFP growth rate in the 1990s.

4. State-level and subsector mining productivity growth

In this section, we examine the impact of natural resource inputs on the productivity of Australian regional mining industry, and by sector where data are available (from 1990–1991 to 2009–2010 at the state level, and from 2001–2002 to 2009–2010 at the sector level).

4.1. State-level measures of mining productivity

To analyse regional mining productivity, relevant data were collected from both ABS 2012d and BREE sources (see Appendix). The data were consistently available from 1990–1991 to 2009–2010 and included information on capital, labour, value added and shares of labour and capital. We

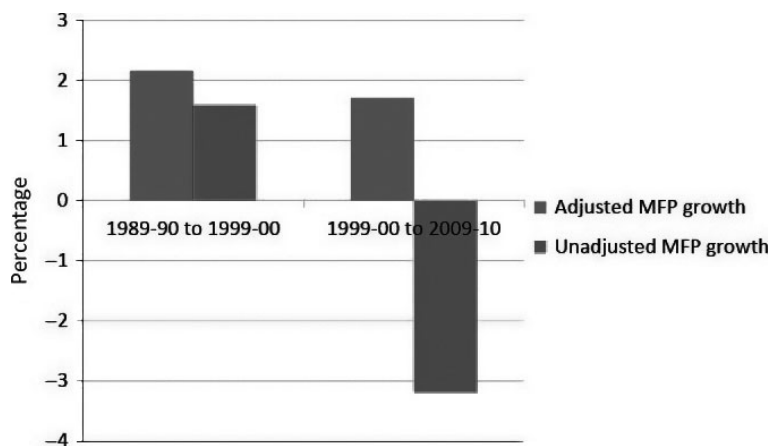


Figure 8 Unadjusted and adjusted MFP growth rates, over time intervals, Australian mining, 1989–1990 to 2009–2010. Source: Authors' estimates.

note that whereas the ABS publishes estimated MFP values for Australian mining at the national level, it does not do so at the regional level.

The highest growth in state mining output in the 1990s, as well as the 2000s, was in Western Australia (6.3 per cent and 3.8 per cent a year, respectively) followed by Queensland (4.8 per cent and 3.3 per cent, respectively). In the 1990s, capital growth in Western Australian mining was just 2.9 per cent a year compared to Queensland’s 5.5 per cent a year. By contrast, in the 2000s Western Australia achieved much higher growth in capital than Queensland (12.6 per cent in Western Australia and 6.7 per cent in Queensland). In these two major mining states, Western Australia and Queensland, growth in unadjusted mining MFP displayed a similar trend as in overall Australian mining (Figure 9).

Adjustments for resource depletion to state mining MFP estimates were made using the measure of energy productivity in each state over 1990–1991 to 2009–2010. Results by state are provided in Table 1.

Energy use data for South Australia and Tasmania were considered not reliable and, thus, these states were excluded from the State analysis. Table 1 shows that when resource depletion and capital lag effects are controlled for, adjusted MFP in each state grows at a higher rate. Victoria is the only state where MFP grew at a slightly negative rate even after the adjustment. This is attributed to exogenous depletion in oil and gas resources in the state, and weak mining capital productivity growth of –9 per cent a year.

4.2. Subsector productivity measures

The ABS ANZSIC 2006 classification divides the mining industry into five subsectors: 1. coal mining, 2. oil and gas extraction, 3. metal ore mining, 4. nonmetallic mineral mining and quarrying, and 5. exploration and other

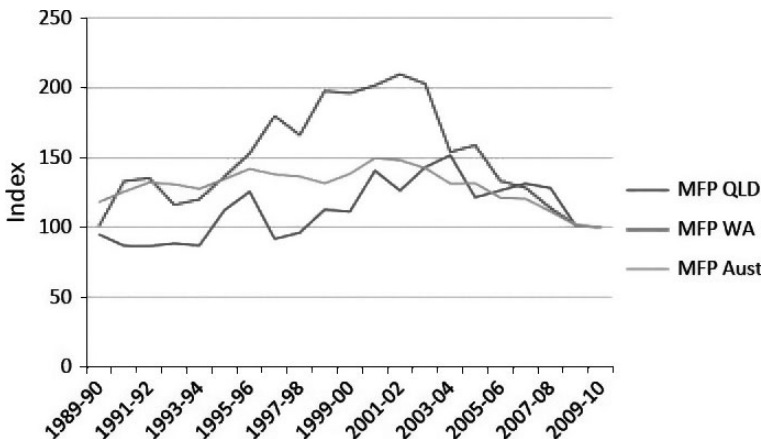


Figure 9 Australian and selected regional unadjusted MFP index, 1989–1990 to 2009–2010. Source : ABS 5220.0 and 5260.0, 2011, and authors’ estimates.

Table 1 Adjusted and unadjusted state MFP growth rates 1990–1991 to 2009–2010

	Unadjusted MFP	Adjusted MFP
Western Australia	−1.48	0.96
Queensland	0.74	3.65
New South Wales	1.7	5.1
Victoria	−9.1	−0.6
Northern Territory	2.5	10.3
South Australia	−1.87	NA
Tasmania	1.89	NA

Source: ABS 5220.0 and authors' estimates.

mining support services. At a subsector level, energy productivity data are only available for coal mining, and oil and gas extraction through BREE's annual publication, *Australian Energy Statistics*. Due to the change in the ABS ANZSIC classification system from 1993 to 2006, a productive capital stock series could not be developed for metal or nonmetallic mining. Consequently, the subsector level mining productivity analysis is restricted to two sectors: coal mining and oil and gas extraction. Our estimates were formed as an update of the Topp *et al.* (2008) unadjusted MFP estimates.

Adjustments for depletion of resources to the two mining subsectors' MFP growth rate were made using the measure of energy productivity in each mining subsector over the period 2001–2002 to 2009–2010. Figures 10 and 11, respectively, show the unadjusted and adjusted for the coal mining and the oil and gas subsectors. The two figures indicate that when resource depletion and capital lag effects are removed, MFP in both subsectors grew at a higher rate compared to when depletion and lag effects were not removed.

In coal mining, the adjusted MFP growth rate was an annual average rate of 0.83 per cent compared to 0.46 per cent growth with an unadjusted MFP. The finding of a negligible resource depletion effect in coal mining is consistent with the result of Topp *et al.* (2008) for the period 1974–1975 to

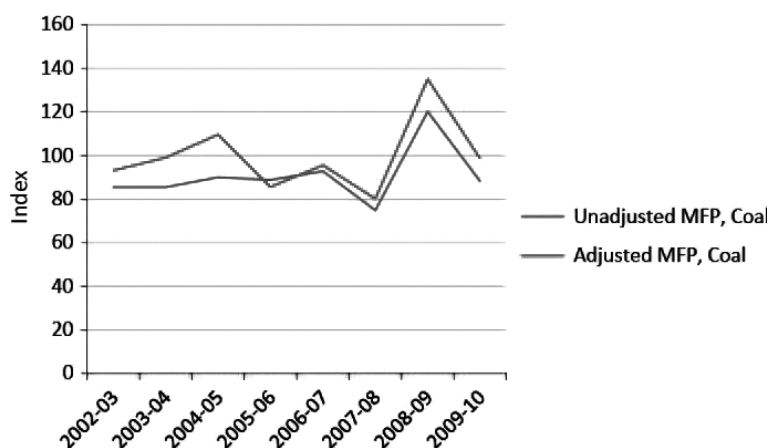


Figure 10 Adjusted and Unadjusted MFP index, coal mining, 2002–2003 to 2009–2010. Source: Authors' estimates.

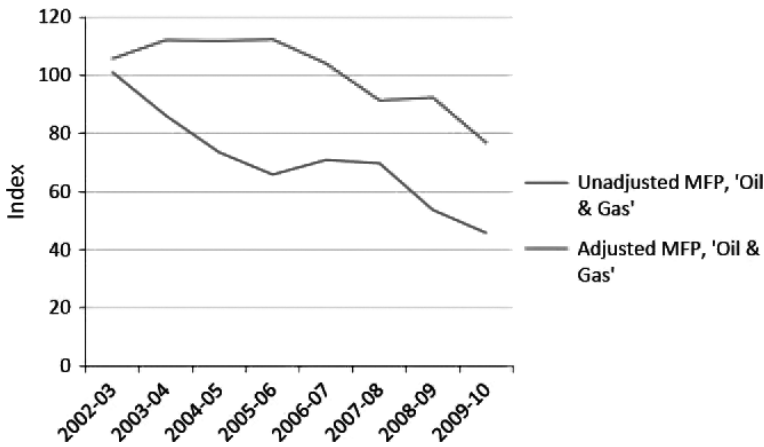


Figure 11 Adjusted and Unadjusted MFP index, oil and gas mining, 2002–2003 to 2009–2010. Source: Authors' estimates.

2006–07. In oil and gas extraction, unadjusted MFP fell at an annual average rate of 10.70 per cent. After adjustment, MFP declined at a more modest 4.5 per cent a year.

5. Technological change, input bias and MFP decomposition

In this section, we provide a separate econometric and frontier analysis to understand the proximate causes of changes in mining productivity. We note that while the Tornqvist index approach assumes that all production units are operating on the frontier, the stochastic frontier approach relaxes that assumption and allows the production units to operate below the frontier due to existing bottlenecks to production. Thus, the two analyses are different based on different objectives and need not indicate any inconsistency in our analytical procedures.

Our econometric analysis is complementary to the findings presented in Sections 3 and 4 based exclusively on growth accounting methods. Our focus in this section is on decomposing changes in MFP into three components: technical efficiency change (TEC) or 'catching up' to the frontier, technological change (TP) or a shift in the production frontier, and scale effects (SC) that arise from changes in levels of output. The dependent variable in the analysis is the value added in the mining sector and calculated as per standard approach used by the ABS.

MFP is measured in terms of real output per unit of labour and capital. It measures changes in output that are not directly attributable to changes in individual inputs. These non-input factors, such as technological progress, economies of scale, capacity utilisation, market efficiency and qualitative changes in inputs, make the use of inputs more efficient and generate higher production from the same quantity of inputs. Both the accounting (Tornqvist) and econometric (stochastic frontier production function) methods

measure the impact of these non-input factors. The accounting method only measures this total effect in terms of a number or index, whereas the econometric MFP decomposition method attempts to further explain the effect of non-input factors in terms of technological change, input-use technical efficiency and scale effect.

The estimated Translog production function used in this study with capital, labour and a time variable as independent variables, and the value added in mining as the dependent variable, is given by Equation (1).

$$\ln y_{it} = \beta_0 + \beta_1 \ln K_{it} + \beta_2 \ln L_{it} + \beta_3 t + \beta_{11} (\ln K_{it})^2 + \beta_{22} (\ln L_{it})^2 + \beta_{33} (t)^2 + \beta_{12} \ln K_{it} * \ln L_{it} + \beta_{13} t * \ln K_{it} + \beta_{23} t * \ln L_{it} + v_{it} - u_{it} \quad (1)$$

where y_{it} refers to value added of the i th observation in the t th period; K_{it} refers to capital of the i th observation in the t th period; L_{it} stands for labour of the i th observation in the t th period; t refers to time period; and β 's are parameters to be estimated. The error component v_{it} refers to the conventional statistical error term that includes omitted variables, measurement errors associated with inputs and value added and specification errors associated with the functional form. The error component u_{it} refers to observation-specific characteristics that influence technical efficiency of observations.

We used state-level observation at different times and, thus, a time variable is included in the analysis. State-specific effects are incorporated through the one-sided error term, u . Technical efficiency is assumed to be time varying in Equation (1), as defined by Equation (2), and which allows for the separate specification of technical change.

$$u_{it} = \{\exp[-\eta(t - T)]\}u_i \quad (2)$$

Diagnostic and model tests can be performed to ascertain whether:

1. technological progress is Hicks-neutral;
2. there is no technological progress in the production frontier;
3. production technology can be represented by a Cobb Douglas production function; and
4. the efficiency framework is a suitable modelling framework.

These diagnostic tests are summarised in Table 2 and test results given in Table 3. Technological change is measured as the partial derivative of the function with respect to time while the scale effect is the total output elasticity contribution to MFP growth. Technical efficiency change is measured as the change in technical efficiency which is assumed to be time-varying observation-specific characteristics in the error term of the production frontier that influence technical efficiency.

Table 2 Specification tests for the translog model

Characteristics	Functional form	Null hypothesis
Hicks-Neutral technological progress	$\ln y_{it} = \beta_0 + \beta_1 \ln K_{it} + \beta_2 \ln L_{it} + \beta_3 t$ $+ \beta_{11} (\ln K_{it})^2 + \beta_{22} (\ln L_{it})^2 + \beta_{33} (t)^2$ $+ \beta_{12} \ln K_{it} * \ln L_{it} + \beta_{13} t * \ln K_{it}$ $+ \beta_{23} t * \ln L_{it} + v_{it} - u_{it}$	$\beta_{13} = \beta_{23} = 0$
No-technology progress in the production frontier	$\ln y_{it} = \beta_0 + \beta_1 \ln K_{it} + \beta_2 \ln L_{it} + \beta_3 t$ $+ \beta_{11} (\ln K_{it})^2 + \beta_{22} (\ln L_{it})^2 + \beta_{33} (t)^2$ $+ \beta_{12} \ln K_{it} * \ln L_{it} + \beta_{13} t * \ln K_{it}$ $+ \beta_{23} t * \ln L_{it} + v_{it} - u_{it}$	$\beta_3 = \beta_{33} = \beta_{13} = \beta_{23} = 0$
Cobb Douglas with efficiency model.	$\ln y_{it} = \beta_0 + \beta_1 \ln K_{it} + \beta_2 \ln L_{it} + \beta_3 t$ $+ \beta_{11} (\ln K_{it})^2 + \beta_{22} (\ln L_{it})^2 + \beta_{33} (t)^2$ $+ \beta_{12} \ln K_{it} * \ln L_{it} + \beta_{13} t * \ln K_{it}$ $+ \beta_{23} t * \ln L_{it} + v_{it} - u_{it}$	$\beta_{11} = \beta_{22} = \beta_{33} = \beta_{13}$ $= \beta_{12} = \beta_{23} = 0$
Cobb Douglas without efficiency model	$\ln y_{it} = \beta_0 + \beta_1 \ln K_{it} + \beta_2 \ln L_{it} + \beta_3 t$ $+ \beta_{11} (\ln K_{it})^2 + \beta_{22} (\ln L_{it})^2 + \beta_{33} (t)^2$ $+ \beta_{12} \ln K_{it} * \ln L_{it} + \beta_{13} t * \ln K_{it}$ $+ \beta_{23} t * \ln L_{it} + v_{it} - u_{it}$	$\beta_{11} = \beta_{22} = \beta_{33} = \beta_{13}$ $= \beta_{12} = \beta_{23} = 0$ $\mu_{it} = 0$, which is equivalent to $\gamma = \mu = \eta = 0$

Table 3 Tests of hypotheses for the specification of the translog frontier function and specification of the technical inefficiency (u_{it}) effects

Null Hypothesis	Test stat (λ)	χ^2 (0.010)	χ^2 (0.050)	χ^2 (0.10)	Decision
$H_0: \beta_{13} = \beta_{23} = 0$	180.94	9.21	5.99	4.61	Reject H_0
$H_0: \beta_{33} = \beta_{13} = \beta_{23} = 0$	97.00	13.28	9.49	7.75	Reject H_0
$H_0: \beta_{11} = \beta_{22} = \beta_{33} = \beta_{23} = \beta_{13} = \beta_{12} = 0$	41.38	10.65	12.59	16.81	Reject H_0
$H_0: \beta_{11} = \beta_{22} = \beta_{33} = \beta_{13} = \beta_{12} = \beta_{23} = 0$ $\gamma = \mu = \eta = 0$	135.88	6.64	3.84	2.71	Reject H_0

The test results indicate that the stochastic frontier Translog Equation (1) conforms to a time-varying technical efficiency specification. The rejection of the Hicks-neutral technical progress test indicates that technical progress in the mining industry involves a technical bias towards material inputs (inputs other than capital and labour) use, which can be verified from the signs of the coefficients of the variables $t^* \ln K_{it}$ and $t^* \ln L_{it}$.

Equation (1) was estimated using data from seven regional Australian states over the period 1990–1991 to 2009–2010. The parameter estimates are

Table 4 Panel estimation of stochastic frontier production function with technical efficiency effects

Variable	Parameter estimate
$\ln(K)$	-0.71*** (-3.29)
$\ln(L)$	1.59*** (4.94)
t	-0.39*** (-7.65)
$0.5[\ln(K)]^2$	0.13*** (3.16)
$0.5[\ln(L)]^2$	-0.10* (-1.99)
$0.5t^2$	-0.002* (-1.80)
$\ln(K) \ln(L)$	-0.07* (-1.90)
$t \ln(K)$	0.02*** (5.18)
$t \ln(L)$	0.02*** (4.51)
Constant	7.07*** (5.95)
η	0.04*** (5.70)
$\ln\sigma^2$	0.06 (0.09)
γ	0.74*** (9.58)
Log-likelihood	105.66

Notes: The dependent variable for frontier estimation is the natural logarithm of value added and total number of observations is 147. The values in parentheses below the coefficients show the t -statistics. *, **, *** show the 10 per cent, 5 per cent and 1 per cent level of significance respectively. The estimates of the production coefficients of the translog frontier all are significant at least at the 10 per cent level. The coefficients of variables $t^*\ln K_{it}$ and $t^*\ln L_{it}$ both are positive and significant, which means that technical progress in the Australian mining industry is both capital and labour using rather than capital and labour saving.

provided in Table 4. All estimates are statistically significant at the 10 per cent level. The estimated coefficients on the terms $t^*\ln K_{it}$ and $t^*\ln L_{it}$ are both positive which implies that technical progress in the mining sector is both capital saving and labour saving.

After estimating Equation (1) and calculating observation-specific technical efficiencies, MFP growth can be decomposed into the three components (see Appendix). Technical efficiency effects account for a positive 82 per cent of the change in MFP while scale effects account for a positive 28 per cent over the period 1990–1991 to 2009–2010. There is no statistically significant effect in terms of measured technical change, but the overall effect is measured as a negative 10 per cent (see Table 5). In sum, the decomposition implies that technical efficiency and scale effects contributed positively and significantly to annual Australian Mining MFP growth, after removing the effect of depletion.

Table 5 Mean technical progress (TP), technical efficiency (TE), scale effects (SC) and multifactor productivity, 1990–1991 to 2009–2010

	TP (%)	TE (%)	SC (%)	MFP (%)
Australian mining industry	-10.2	82.4	27.8	100

Note: The change in technical change (TP) is not statistically different from zero at the 10% level of significance.

6. Concluding remarks

The questions of what is the trend in mining productivity growth, and what explains the trend, are important for a country such as Australia that is a major mineral exporter. Using a growth accounting method, we provide quantitative estimates of mining productivity at each of the national, state and subsector levels, and also examine the technological relationships among inputs in Australian mining and the factors influencing mining productivity.

At a national level, we find that after accounting for depletion effects using a measure of energy productivity, and also for input–output lags, that an unadjusted average annual multifactor productivity (MFP) growth rate of -0.65 per cent becomes 2.5 per cent for the period 1985–1986 to 2009–2010. By comparison, adjusted annual measures of mining MFP growth are 2.3 per cent for the period 1974–1975 to 2006–2007 from a 2008 Productivity Commission study and 2.2 per cent for the period 1985–1986 to 2009–2010 from a 2011 Australian Bureau of Statistics study. At the subsector level, we find for coal mining and oil and gas extraction that measured MFP growth also increases after accounting for depletion and production lags. Similarly, mining MFP in each state grows at a higher rate compared to when depletion and lag effects are not removed.

In a complementary analysis, based on an econometric decomposition of mining and using state-level data over the period 1990–1991 to 2009–2010, we find that technical efficiency and scale effects contributed positively and significantly to Australian mining MFP, after removing the effect of depletion. No positive effect of technological change, as distinct from technical efficiency, was observed over the study period.

In sum, we find that although unadjusted mining productivity fell by a third in the 2000s, coincident with a boom in commodity prices and mining investment, much of this change can be explained by resource depletion and input–output lags. Our decomposition analysis of MFP implies that, overall, there has been a substantial ‘catch up’ in terms of technical efficiency within the sector over the past two decades. Overall, adjusted measures of MFP do not indicate the need for any particular policy intervention for the mining sector except for consideration of depletion effects and adequate incentives for resource exploration including the provision of precompetitive resource and reserves data.

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Appendix

Method, Decomposition and Data for Measuring Mining Productivity

The approach to measuring productivity for the mining industry at the state and sub-industry level follows the index-number methodology used by the ABS in estimation of aggregate and industry productivity for the national accounts.

1. Method

Multifactor productivity in sub-industry i (MFP_i) is measured as the ratio of an index of industry output (Y_i) to an index of combined inputs (I_i):

$$MFP_j^t = \frac{Y_j^t}{I_j^t} \quad (A1)$$

where the superscript refers to the year t .

Output is measured as value added and the combined input index is an aggregation of an index of capital input (K_i) and an index of labour input (L_i).

$$T(K_j^t, L_j^t) \quad (A2)$$

$T(\cdot)$ is a Tornqvist aggregator function that combines the indexes of capital and labour recursively from a geometric mean of the growth in capital and in labour. That is:

$$\frac{I_j^t}{I_j^{t-1}} = \left[\frac{K_j^t}{K_j^{t-1}} \right]^{w_{kj}^t} \cdot \left[\frac{L_j^t}{L_j^{t-1}} \right]^{w_{lj}^t} \quad (\text{A3})$$

where:

$$w_{kj}^t = \frac{1}{2} [s_{kj}^t + s_{kj}^{t-1}] \text{ and} \quad (\text{A4a})$$

and

$$w_{lj}^t = \frac{1}{2} [s_{lj}^t + s_{lj}^{t-1}] \quad (\text{A4b})$$

where s_{kj}^t is the capital share and s_{lj}^t is the labour share of income (value added) in industry j in year t .

The use of income shares stems from two assumptions: (1) that the underlying production function exhibits constant returns to scale and (2) that capital and labour are paid according to their marginal products. Under these assumptions, the income shares can be used in the place of capital and labour output elasticities derived from optimisation conditions based on the underlying production. The advantage of this approach is that the capital and labour income shares can be estimated from data, rather than necessitating econometric estimation.

The required data indexes are not available at the sub-sector level from the ABS national accounts, with a couple of exceptions. Consequently, other mining census and survey sources had to be used to form the output and input indexes in the majority of cases. Because the ABS processes survey data in various ways to form its national accounts estimates (which are used in the ABS estimates of productivity for the mining industry as a whole), the sub-sector indexes will not be entirely consistent with the mining industry data. Changes in industry classifications and published series have meant that consistent survey data can only be backcast as far as 2001–02.

2. Decomposition of MFP

Technological change (TP) is measured by the partial derivative of the production function with respect to the time.

The scale component (SC) that arises from changes in the level of outputs is the total of the elasticity contribution to MFP growth. It proxies the rate of output growth in the absence of any technical progress or technical efficiency. The elasticity of output with respect to each input measures the relative change in each input owing to a relative change in output.

From the estimated observation-specific technical efficiency measures, the change in technical efficiency (TEC) is defined as the ratio of technical efficiency in period $t + 1$ over technical efficiency in period t .

The MFP growth decomposition by the Malmquist production index approach is calculated by $MFP^* = TP + SC + TEC$.

3. Data sources

To estimate productivity measures in the Australian mining sector relevant data on energy use, output, capital and labour inputs use were collected from the following sources.

- ABS cat. no. 5260.0.55.002, Estimates of Industry Multifactor Productivity,
- ABS cat. no. 5204.0, Australian System of National Accounts,
- ABS cat. no. 8155.0, Australian Industry,
- ABS cat. no. 5220.0, Australian National Accounts: State Accounts,
- ABS cat. no. 5625.0, Private New Capital Expenditure and Expected Expenditure, Australia,.
- ABS cat. no. 6291.0.55.003, Labour Force, Australia, Detailed, Quarterly,
- BREE, Australian Energy Statistics.