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Productivity in the Australian Mining Sector

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Foreword

BREE has a program of long-term strategic research that is in addition to its regular publications. Where at all possible it is BREE's intention to release the outcomes of its long-term research as BREE Discussion Papers. The goal is for BREE Discussion Papers to provide an opportunity for dialogue on key issues facing Australia's resources and energy sectors. The views expressed in BREE Discussion papers will be the authors alone and will not necessarily be those of BREE or the Department of Resources, Energy and Tourism.

In this, the first BREE Discussion Paper, results are presented of a study on Australian mining productivity. The aim of this research was to provide estimates of trends in Australian mining productivity and, where possible, explain them.

Productivity growth is an important issue for Australia. Since the 1990s there appears to have been a productivity slowdown in most sectors. Using unadjusted numbers, the biggest decline in productivity in any sector over the past decade has been in mining which has experienced negative rates of productivity growth. Possible reasons for a slowdown in Australian mining productivity include: input to output lags, transition to lower yielding resources, inefficiencies of vintage capital, the lumpy nature of mining investment, and high commodity prices that place a priority on rates of extraction rather than costs of extraction.

In this Discussion Paper the authors find that after adjusting for capital lags and both endogenous and exogenous depletion effects, Australian mining productivity grew at a positive rate over the past decade, albeit at a slower rate than in the 1990s. A key finding is that deteriorating productivity performance in mining over the past decade is attributable to both exogeneous and endogeneous resource depletion.

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March 2013

Abbreviations

ABARE	Australian Bureau of Agricultural and Resource Economics
ABS	Australian Bureau of Statistics
BREE	Bureau of Resources and Energy Economics
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DCITA	Department of Communications, Information Technology and the Arts
GDP	Gross Domestic Product
GFCF	Gross Fixed Capital Formation
IEA	International Energy Agency
LNG	Liquefied Natural Gas
MFP	Multifactor productivity
OECD	Organisation for Economic Co-operation and Development
PC	Productivity Commission

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Executive summary

The past 25 years have witnessed oscillating productivity growth in most Australian sectors. The mining sector stands out from most other sectors in Australia in that there has been a major decline in measured (unadjusted) productivity. According to the Australian Bureau of Statistics (ABS) data unadjusted Multifactor Productivity (MFP) in the mining sector between 2000-01 and 2009-10 declined by about one third.

An explanation for the apparent decline in mining productivity is that high commodity prices have provided firms with 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 rates of extraction.

Objectives

The main purpose of this study is to examine the productivity growth in the mining sector in Australia at the national, regional and sector levels. The report examines the nature of technology change and input use prevailing in Australian mining from 1985-86 to 2009-10. It also identifies measurement and interpretation issues of relevance to productivity estimates in Australian mining.

The study provides quantitative estimates of productivity at each of the national, regional and sectoral levels. Further, it examines the technological relationships among inputs in Australian mining and the factors influencing mining productivity.

Reasons for mining productivity decline

Possible reasons for a slowdown in Australian mining productivity relate to the input to output lags, transition to lower yielding resources, inadequacy of vintage capital, lumpy nature of mining investment, high commodity prices that place a priority on rates of extraction rather than costs of extraction, infrastructure constraints, and an inappropriate mix of production inputs.

To analyse regional mining productivity, relevant data were collected from mainly ABS and BREE sources. These include: information on capital, labour, value added, and shares of labour and capital as well as data on energy use at the national, regional and sector levels.

Productivity measurement issue

Unlike many other industries, mining places a heavy reliance on the quality and size of the natural capital stock. Thus, measuring or interpreting productivity in the mining industry poses problems distinct from most other industries. This is because the quality of these mineral deposits are, typically, not included into the traditional productivity measurement methods. When ore grades or other aspects of resource quality decline as deposits are depleted, the measured productivity of mining declines because more inputs are needed to produce a unit of saleable output. This is not because mining companies are less productive in their operations.

When resources are depleted successively more fuel energy inputs are needed to produce the same amount of saleable output. Energy use data can, therefore, be used to proxy the extent to which changes in resources contribute to changes in output each year and to adjust measures of productivity.

Mining productivity in Australia

The study finds that that after removing the influence of both deposit quality depletion and production lags, the MFP growth rate in Australian mining increases from an average annual rate of negative 0.65 to positive 2.5 per cent between 1985-86 and 2009-10. That is, the measured productivity rises after the deposit quality and production lag adjustments.

At the national level, where studies are available for Australian mining, adjusted Australian mining MFP growth rates are as follows:

Present study: 2.3 per cent to 2.5 per cent (1985-86 to 2009-10)
Topp et al. (2008): 2.3 per cent (period 1985-86 to 2006-07)
Loughton (2011): 2.2 per cent (period 1985-86 to 2009-10)

The econometric decomposition of mining MFP in this study decomposes MFP growth into the three components: technological change, technical efficiency and scale effects. This analysis finds that Australian mining experienced no statistically significant technological change over the study period. The decomposition also shows that both technical efficiency and scale effects contributed positively and significantly to Australian Mining MFP, after removing the effect of output quality (depletion).

Implications

The present study does not recommend any industry specific policies to improve productivity growth in the mining sector above and beyond general public policies to improve productivity, such as investments in human capital. In other words, the apparently deteriorating productivity performance in mining is not an indication of a specific mining policy problem that necessarily requires a policy remedy, but is rather a result of factors, such as the strength of resource prices, that have contributed to endogenous resource depletion.

Innovations and technological progress are key derivers of productivity growth over the long term. A decline in the quality of resource deposits that results from the mining of marginal or deeper resources is associated with a rise in the unit cost of extraction. Growth in innovations, a more skilled workforce, a faster rate of adoption of better off-the-shelf technologies as well as new technological breakthroughs would all likely assist in productivity growth of the Australian mining sector.

1. Introduction

The decline in unadjusted mining multi-factor productivity (MFP) in the Australian mining sector over the 2000s has been marked. In particular, substantive growth in the use of capital and labour inputs has been accompanied by disproportionately low increases in real output. According to the Australian Bureau of Statistics (ABS) data, the decline in unadjusted MFP between 2000-01 and 2009-10 was 33 per cent. Despite a decline in productivity revenue and profit growth in the mining sector over this period was sustained by a substantial and a general rise in commodity prices.

1.1 Contrasting views

In recent years, the productivity performance of mining in many countries has been deteriorating (Eslake 2011, Bradley and Sharpe 2009). A number of possible explanations exist for the observed declines in labour productivity, capital productivity and multifactor productivity[1].

Following a series of enquiries into the nature and causes of Australian mining productivity growth (Topp et al. 2008, Zheng 2009, Parham 2012, Loughton 2011), a common view to explain the productivity decline is summarised as follows:

The decline in mining MFP has been due (in 'proximate' terms) to a combination of a slow rate of output growth over the period, very strong growth in labour inputs, and continued growth in capital inputs. This combination is of interest as it seems to imply that miners have continued to invest more capital and employ more labour, but this has yet to deliver a matching increase in output (Topp et al. 2008, p. xvi).

The Topp et al. 2008 study noted that the extent and duration of the decline in mining productivity has been surprising in view of the substantial increase in activity in the industry as a result of sharp increases in commodity prices in the 2000s.

According to this view mining productivity deceleration is the result of the lags in mining production in response to capital injections, and also resource depletion. Given this perspective, mining productivity should be expected to increase as the capital invested in the past decade pays dividends in terms of increased output.

The most recent ABS data shows that Australian mining unadjusted MFP declined by 7.4, 8.7, 1.7, and 12.2 per cent in each year from 2007-08 to 2010-11, respectively (ABS 2011).

An alternative view is that the slowing in Australia's measured productivity growth has been far more broad-based and systemic than what can be explained by special circumstances in a handful of industries (Eslake and Walsh 2011). If true, this would demand different policy implications compared to the Topp et al. 2008 finding.

1 The concept of productivity and the terms such as capital productivity, labour productivity and multifactor productivity (MFP) are defined in this section at 1.3 below.

A key feature of mining is that it is capital intensive. Over the 1990s capital in the sector grew at an average rate of 4 per cent. Nevertheless, the growth of capital over the last two decades has failed to increase mining productivity. A key issue is whether this is a capital efficiency problem and/or is there a lag between capital investment input and increased output?

Australian mining MFP productivity grew at 1.2 per cent a year in the 1990s, along with positive growth in labour productivity, but, capital productivity declined by 0.5 per cent a year. It would seem, therefore, that multifactor productivity grew positively over the 1990s despite negative capital productivity growth.

ABS data shows that, at least in the 1990s, mining productivity grew positively when capital grew at a faster rate than labour. By contrast, when capital grew at a slower rate than labour in the 2000s this coincided with a fall in measured mining productivity. Whatever the causes of poor mining productivity performance, and as noted by McKinsey Global Institute (2012), falling capital productivity is a possible explanation for a decline in productivity in the 2000s relative to the 1990s.

1.2 Objectives and scope of the study

Our study analyses the productivity growth in the mining sector in Australia. The period of analysis is 1985-86 to 2009-10, but a productivity estimate for 2010-11 is also provided. The study has the following objectives:

1. examine the trends in the Australian mining industry at the national level;
2. examine the trends in the Australian mining industry at the state level;
3. examine the trends in the Australian mining industry at the sector level;
4. examine the nature of technology change and input use prevailing in Australian mining; and
5. develop a better understanding of some of the factors contributing to trends in Australian mining productivity over the study period.

The nature of production in the mining industry, and the measurement of all inputs and outputs in mining, involves factors distinct from other sectors in the economy. These measurement issues, in turn, may have implications about measured productivity in the sector.

1.3 Productivity growth specification

Productivity represents the relationship between output and the inputs used to generate that output. The close link between productivity growth and economic growth makes productivity growth important from an economic welfare perspective. Simply put, productivity growth indicates that more output is being produced for a given level of inputs.

The partial or single factor productivity of an input is given by the average ratio of output per unit of input. An increase in this ratio, other things remaining the same, implies increased efficiency of input use whereby the same level of output can be produced using a smaller quantity of a given input.

When other factors cannot be assumed to remain the same, the interpretation of output-input ratios as indicators of production efficiency becomes problematic. For example, an increase in labour productivity may only reflect capital deepening, or a rise in the capital to labour use ratio. Consequently, a broader based measure of productivity is required.

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. Thus, a fall in MFP growth, or in partial productivity growth, all else equal, indicates that resources are being used *less* efficiently.

MFP is, typically, measured as an index that can be used to derive estimates of productivity growth. MFP growth usually exhibits annual fluctuations. In order to calculate a growth rate over a number of years, we calculate the compound growth rate for MFP over a decadal period.

1.4 Scope and organisation of the study

First, we update the Topp et al. (2008) analysis of Australian mining productivity between 1974-75 and 2006-07 to 1985-86 and 2009-10. We also extend and expand on their work to analyse Australian mining productivity at the state and sector levels. In particular, we provide quantitative estimates of productivity at each of the national, regional and sectoral levels and evaluate the technological relationships among inputs in Australian mining and the factors influencing mining productivity.

In this study of the Australian mining sector, we are the first to extend the scope of analysis to disaggregated MFP estimates at each of the national, regional and sectoral levels. We also develop and apply, for the first time, an easily available measure of resource depletion in the mining industry in the form of the use of energy input data.

With a couple of exceptions, there is a lack of data to construct data indexes at the sectoral level from the ABS national accounts. Consequently, other survey sources have been used to generate our output and input indexes. As a result, the sectoral indexes are not entirely consistent with the ABS mining industry data. Similarly, changes in industry classifications and published series by the ABS mean that consistent survey data for the sectoral analysis can only be back cast as far as 2001-02 and regional analysis was only undertaken for the period 1990-91 to 2009-10.

The sectoral productive capital stock estimates in the sectoral analysis for the initial period used in our study were derived using capital stocks estimates obtained from the Productivity Commission. Ideally, MFP analysis should be undertaken using productive capital stock measure, but due to the unavailability of such data, ABS provided (cat. 5220.0) capital stock data were used in regional analysis.

The rest of the paper is organised as follows: Section 2 provides an overview of recent trends in the Australian mining sector trends, including a literature review of previous mining productivity studies. Section 3 explores recent Australian mining and general economy-wide productivity trends. Section 4 examines Australian mining productivity performance at the national level. Sections 5 and 6 examine the productivity performance at the regional and sub-industry levels. Section 7 undertakes an econometric analysis and tests for technological relationships affecting mining productivity. Section 8 provides concluding comments.

2. Background on the Australian mining industry

In this section we provide a background on the nature and structure of the sector of the mining industry. We show the growing importance of mining to the Australian economy in terms of the mining output, investment, employment, commodity prices and export earnings. We also review the literature on mining productivity and outline productivity trends prevailing in the mining industry both in Australia and overseas.

2.1 Mining activities

The ABS classifies mining into the following main sub-divisions in accordance with the nature of mining activities. These include: Coal Mining, Oil and Gas Mining; Metal Ore Mining (Iron, Bauxite, Copper, Gold, Mineral sand, Nickel, Silver-Lead-Zinc mining); and Other Mining (construction material mining).

Mining involves the extraction and processing of a range of mineral deposits which are distributed unevenly in 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. Other resources are spread all over Australia, with more resources in some states than others. There are a number of common mining methods accross states, such as surface mining, underground mining and other mining methods.

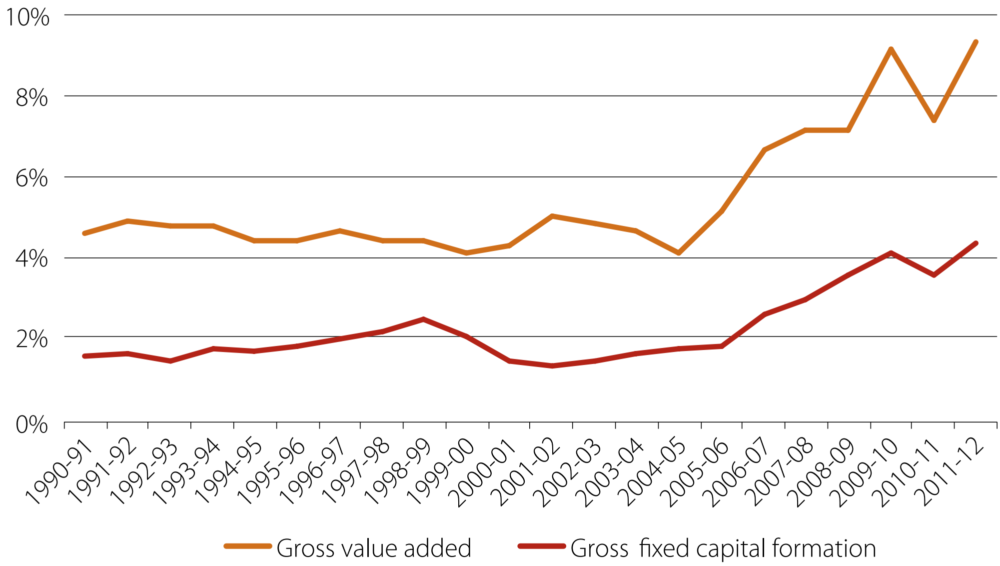
Australian mining experienced a structural shift from the beginning of the decade 2000s when prices for key resource exports were at their lowest levels in real terms for a century. Demand for commodities received a boost from fast growing emerging economies and the prices of commodities used in steel and energy production rose particularly sharply over the decade. To meet fast growing international demand, Australia placed increased focus on the extraction of coal, iron ore and gas (for LNG), and gradually shifted away from metals processing (aluminium, copper and gold). In response to higher resource prices, mining investment grew rapidly throughout the decade and also as a share of the economy.

2.2 Output and investment

In a historical context, the mining boom in the 2000s has been much larger as a share of the economy than the mining booms in previous decades in terms of sales revenue, investment and employment. This has increased the significance of the mining industry to the Australian economy and comprises about 10 per cent of Australian GDP in value added terms. At current prices, mining industry gross fixed capital formation was 4.3 per cent of GDP in 2011 (Figure 2-1), making this contribution the highest of any industry.

The rise in mining revenue over the 2000s has been dominated by iron ore and coal, while the largest investments have occurred in oil and gas, particularly LNG. By contrast, the mining of 'other ores' has experienced a much smaller rise while metals manufacturing has declined over the decade.

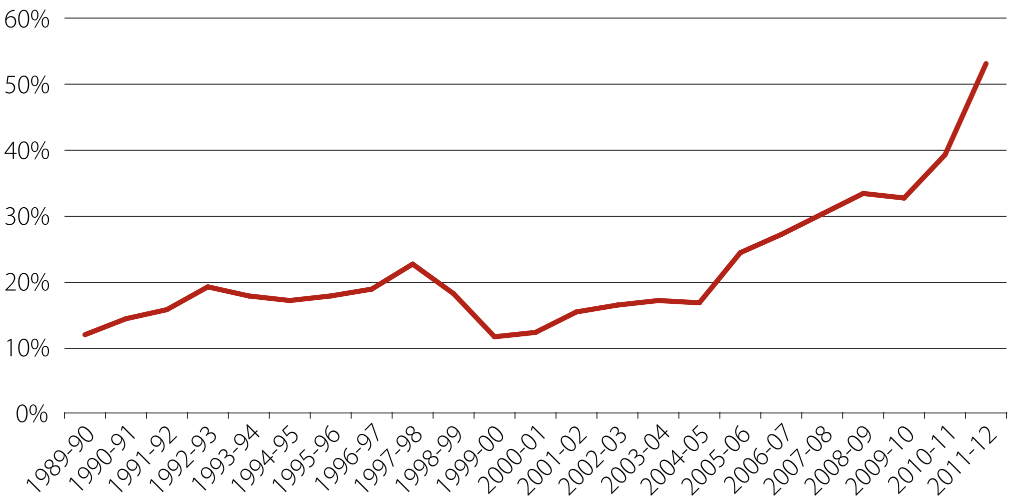
Figure 2-1: Mining industry relative to GDP, 1990-2011, current prices



Source: ABS (cat 5204, 2012a), BREE estimation

Rising commodity prices have provided Australian mining companies with a strong incentive to increase investment. Consequently, mining investment as a share of all industries rose over the second half of the 2000s (Figure 2-2) in response to these price changes.

Figure 2-2: Australian share of mining private new capital expenditure, 1990-2012



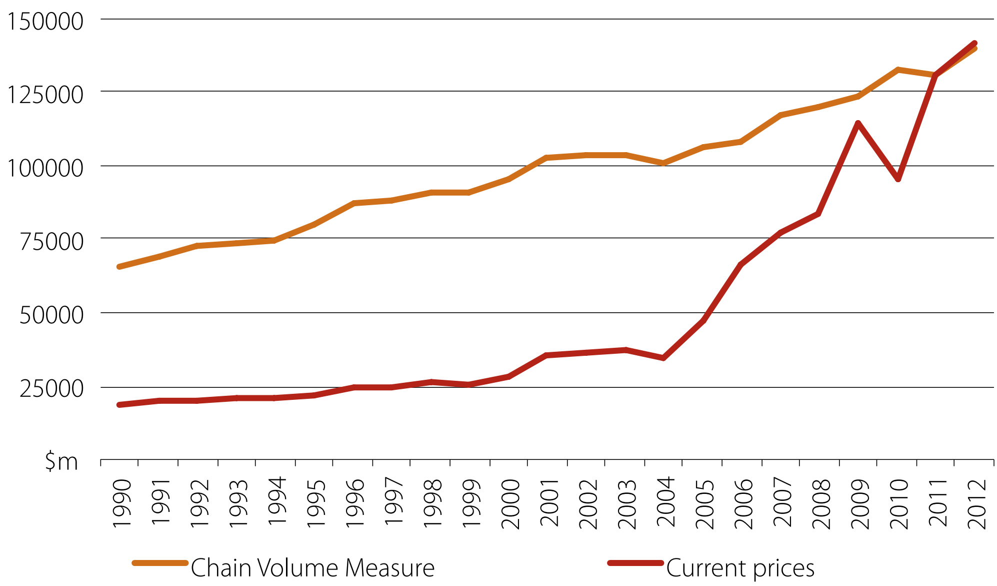
Source: BREE, Resources and Energy Quarterly, 2012

Over the past decade, there has been a significant increase in the value of investment in the mining sector. In 2011-12, investment in new capital expenditure (Figure 2-2) in the mining sector was 53 per cent of private new capital expenditure and was valued at $82 billion. This compares with inflation-adjusted figures of $7.6 billion a decade ago. Much of the current investment is underpinned by liquefied natural gas (LNG), iron ore and coal projects.

2.3 Output value versus volume

In 2011-12, 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. 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 2-3.

Figure 2-3: Mining industry value added, 1990-2012



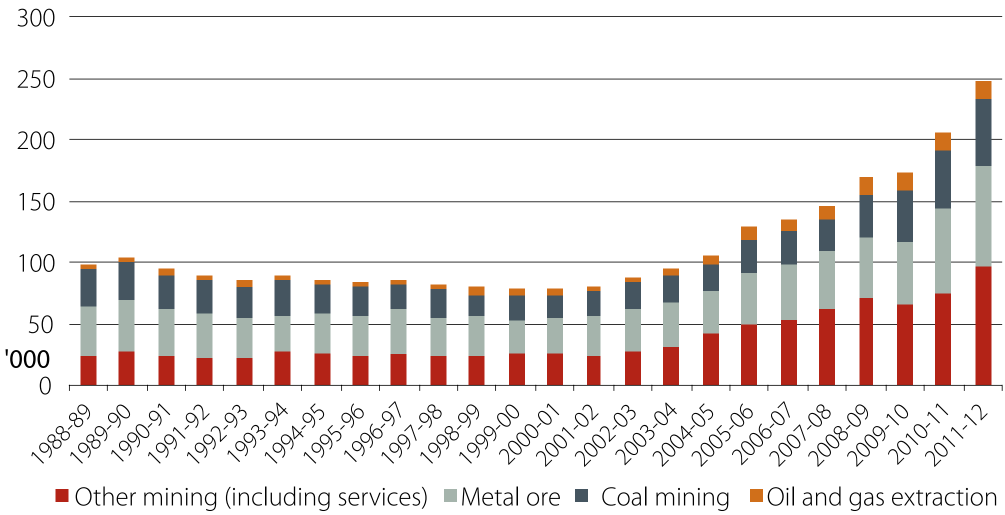
Source: ABS (cat. 5204, 2012a)

Mining output did not grow at the same rate of investment growth or in the same proportion to the rise in global commodity prices. As a result, although Australia experienced a mining 'boom' (Grafton 2012) that led to an unparalled rise in terms of trade and contributed to rapid income growth, especially in resource rich states, unadjusted MFP in Australian mining declined.

2.4 Mining employment

Most employees in the mining industry work in ores mining and mining exploration and support services. Average direct employment in mining comprised 173,000 persons in 2009-10 (Figure 2-4) and about 248,000 in 2011-12. Shares of both coal and iron ore sub-sectors increased in mining revenue, as well as investment and employment, from 1990-2000 to 2000-2010.

Figure 2-4: Employment in the Australian mining industry, 1989 to 2012

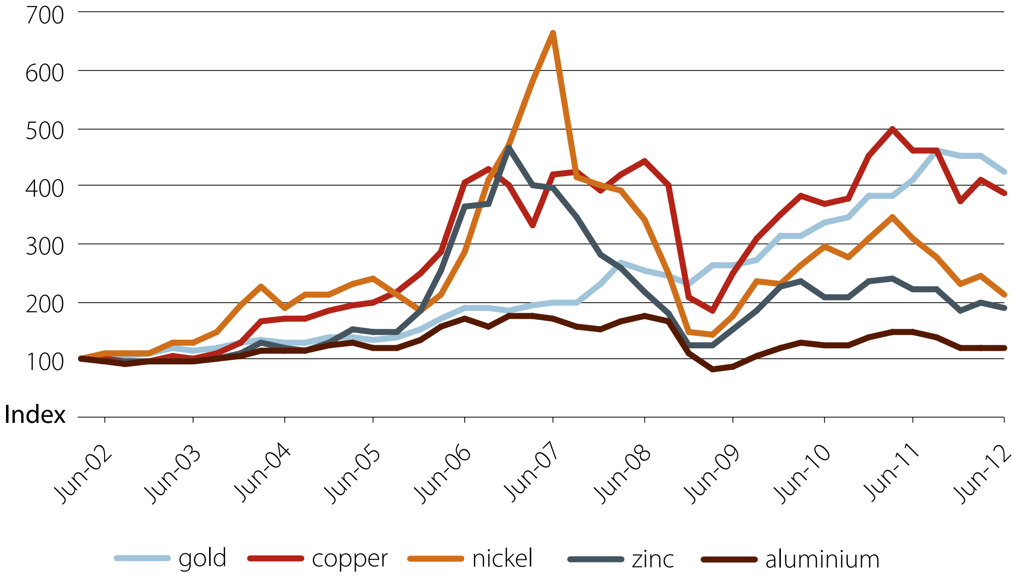


Source: BREE (Resources and Energy Quarterly, 2012).

2.5 Mining commodity prices

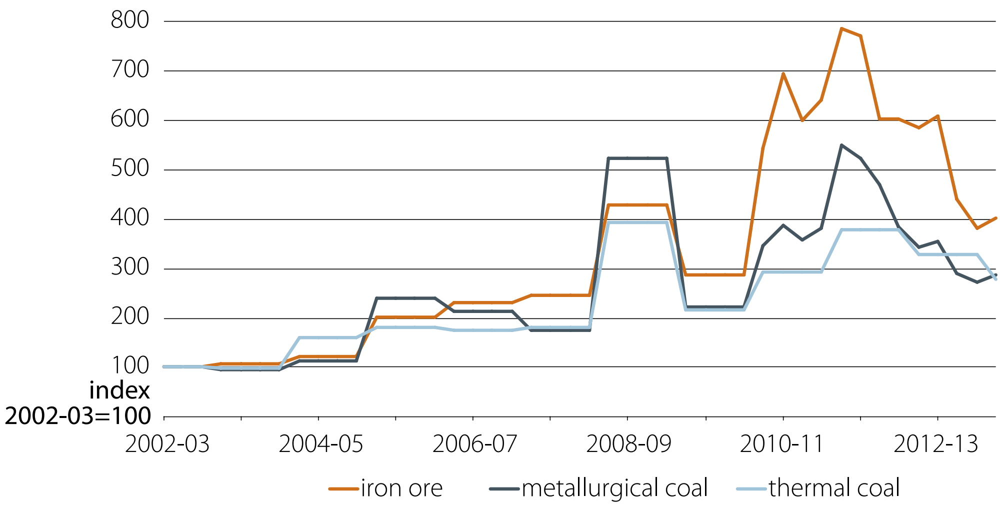
Global commodity prices experienced extraordinary growth during the 2000s driven by strong growth in the growing emerging economies, particularly China and India. The prices of bulk commodities rose strongly in response to global, and especially, Chinese demand. Thermal coal contract prices increased by 70 per cent in 2004, while coking coal prices rose by 120 per cent in 2005. Prices of bulk commodities surged strongly in 2008, but subsided after the global financial crisis (Figures 2-5 and 2-6) and rebounded, for key bulk commodities, until they peaked in 2011 (Grafton 2012).

Figure 2-5: Index of real metal prices, quarterly, 2000 to 2012 (Mar-00=100)



Source: BREE, Resources and Energy Quarterly, 2012

Figure 2-6: Index of real bulk commodity prices quarterly, 2002 to 2012 (Mar-00=100)



Source: BREE, Resources and Energy Quarterly, 2012

2.6 Mining exports

Resources exports (including oil and gas) accounted for 60 per cent of total Australian exports in 2012 compared to 35 per cent in 2000 (Table 2-1).

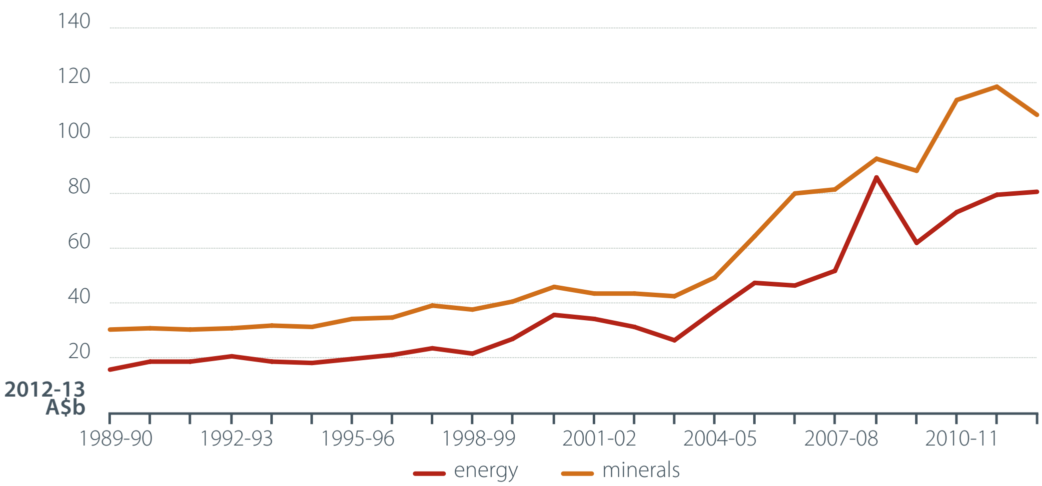
Table 2-1: Minerals exports – shares of total export values

Year	Share of Australian export value (%)
1990	41
2000	35
2010	54
2012	60

Strong demand from emerging economies has affected energy markets, and the share of global energy consumption by these economies rose from a little over 40 per cent in 2000 to 50 per cent by 2010 driven by growth in China, India and the Middle East. China and India are projected to consume 50 per cent of the growth in global energy use over the period to 2035, with strong demand for gas that will boost Australian LNG exports (IEA 2012a).

Export volumes of resource exports increased at the rate of 3 per cent over the past decade – which was about the half its rate of growth (5 per cent) during the 1990s (Connolly and Orsmond (RBA), 2011), and about a third of the increase in commodity prices.

Figure 2-7: Australian energy and mineral export earnings, 1990-2012



Source: BREE, Resources and Energy Quarterly, 2012

In volume terms, the rates of growth of Australian exports varied between the last two decades, 1990-2000 and 2000-2010 from 5 per cent to 3 per cent, respectively. The rates of growth in prices increased from 1 per cent a year over 1990-2000 to 9 per cent a year over 2000-2010. Similarly, shares of total export values varied from 41 per cent of total Australian exports in 1990 to 35 per cent in 2000 and increased to 60 per cent in 2012 and worth close to $200 billion (Figure 2-7).

2.7 Review of previous mining productivity studies

2.7.1 The Productivity Commission study on mining MFP growth adjustment

Using the ABS and other data sources, Topp et al. 2008 analysed mining productivity from 1974-75 to 2006-07. They found, over that time period, output growth did not keep pace with input growth, and MFP grew only at a negligible rate of 0.01 per cent a year. The study also found that between 2000-01 and 2006-07, measured MFP *declined* by 24.3 per cent. The study assigned this decline in MFP to a combination of a slow rate of output growth over the period, very strong growth in labour inputs, and continued growth in capital inputs (p. xvii).

Out of the possible reasons for deteriorating unadjusted mining MFP for the last three decades, Topp et al. (2008) concentrated on two key factors:

(1) resource depletion; and

(2) lags between the investment in capacity building and output growth.

Their study provided quantitative evidence regarding the effect on mining sector productivity growth of these two important factors: systemic changes in the quality of natural resources and production lags in capital investment. They also provided MFP estimates, with and without resource depletion, and investment lags.

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. As a result they constructed a depletion yield index using:

(1) average ore grades in metal ore mining;

(2) the ratio of saleable to raw coal in coal mining; and

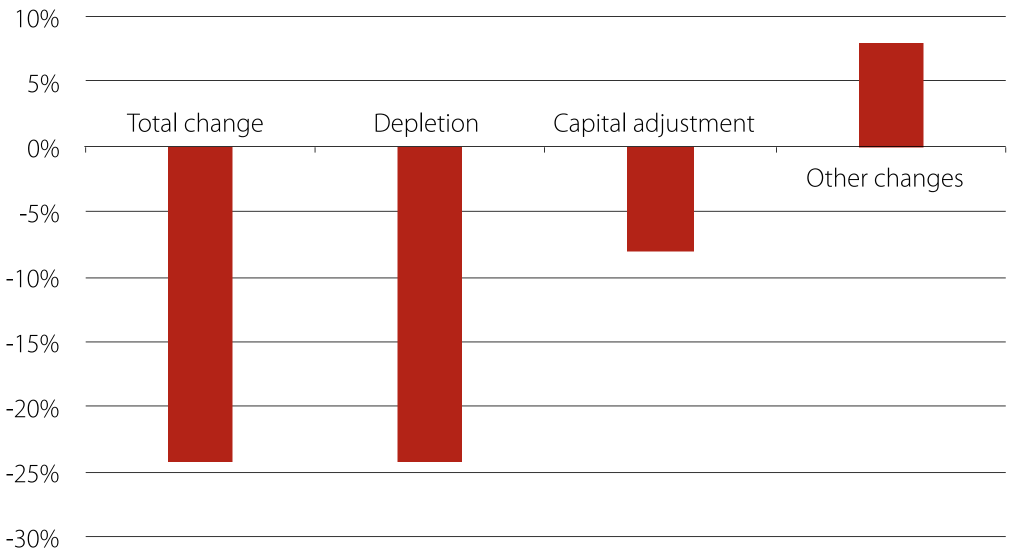
(3) the implicit flow-rate of oil and gas fields in the petroleum and gas sector.

Construction of the index involved a process of estimating information both from private and official sources, that involved gathering data from Gavin Mudd (Monash University), ABS, ABARE (Australian Bureau of Agricultural and Resource Economics), and the Victorian Department of Primary Industries, among others.

Between 1974-75 and 2006-07, the composite index of the average yield in mining fell by 39 per cent, or at an average rate of -1.5 per cent per year. Topp et al. (2008) concluded that if the changes in mining sector output due to the observed yield declines (resource depletion) are taken into account, MFP growth in the mining sector is substantially higher and grew at 2.5 per cent per year, compared with 0.01 per cent per year in conventionally measured mining MFP between 1974-75 to 2006-07.

Over the period 2000-01 to 2006-07, Topp et al. (2008) found that around one-third of the decline in mining MFP in this period can be accounted for by the temporary effect of long lead times between mining investment and the associated output. Overall, yield declines and a surge in new capital investment were estimated to have contributed substantially to the decline in mining sector MFP between 2000-01 and 2006-07. Their study found that yield declines were the more dominant factor in the first few years; whereas, the production lags associated with the surge in new capital investment from 2004-05 to 2006-07 were found to be the dominant factors in the last few years of their study period. After removing the influence of yield changes and production lags, other factors were estimated to have raised mining MFP by 8 per cent over their study period (see Figure 2-8).

Figure 2-8: Contributions to the changes in mining MFP, 2000-01 to 2006-07



Source: Topp et al. (2008)

2.7.2 Other studies on mining MFP growth adjustment

Loughton (2011) outlined a measure of mining MFP growth by explicitly using the natural resource inputs as a factor of production and noted the following:

Topp et. al. (2008) represented this characteristic using a representation of the change in natural resource input quality brought about by its cumulative extraction. While this analysis highlights the influence of natural resource inputs, the method proposed is impractical for a National Statistical Office (NSO) as the data used are not readily available on an annual basis. (Loughton 2011)

Instead, Loughton 2011 measured cumulative extraction (to account for the resource depletion) as the ratio of cumulative extraction to the total reserves available for extraction over the life of a particular natural resource. He argued that cumulative extraction of a range of commodities can be produced on an annual basis due to the availability of annual production and reserves data.

While applying this method to estimate mining MFP between 1985-86 and 2009-10, Loughton (2011) found that the cumulative extraction measure indicated that the quality of natural resources in mining decreased significantly over this period. Taking account of this decline amounted to about 2 per cent increase in the annual growth rate of mining sector MFP from 1985-86 to 2009-10.

2.7.3 Mining productivity growth in overseas countries

The trend of decelerating mining productivity growth is not confined to Australia. For example, Bradley and Sharpe (2009) analysed mining productivity in Canada and found that the productivity performance of mining in Canada has declined in recent years. For instance, labour productivity grew in the mining sector in Canada at an average annual rate of 6 per cent in the 1990s (1989-2000), but it fell to -2.21 in 2000s over the analysis period (2000-2007). Capital productivity growth fell by 0.28 per cent per year over the 2000s from 2.21 per cent per year growth rate over the 1990s. MFP growth declined from 1.92 per cent a year in the 1990s to -1.07 per cent per year in the 2000s. Their analysis indicates that this change arose because of the faster growth of inputs relative to output in mining.

In the 1990s, labour productivity in mining grew faster in Canada than in the United States, but from 2000 to 2007 labour productivity in mining continued to grow in the United States, while it declined in Canada. Both capital and multifactor productivity grew faster in Canada than the United States in the 1990s, and experienced slow declines in the 2000-2007 period.

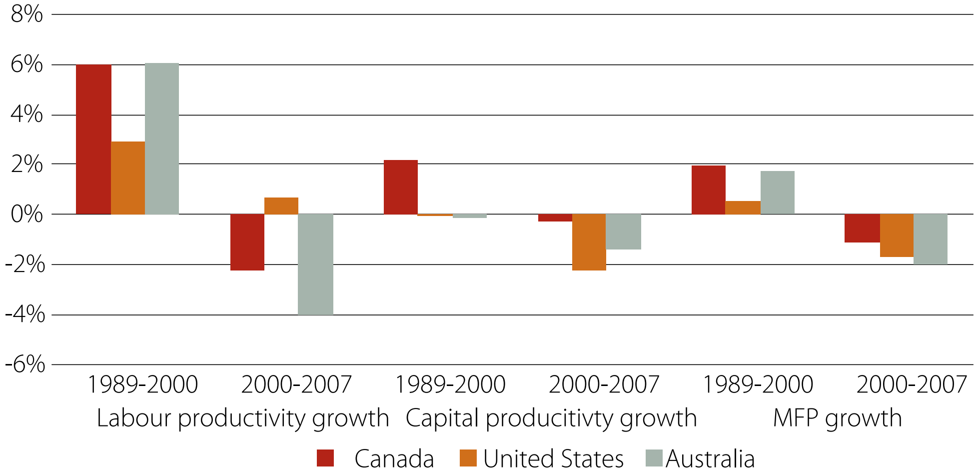
These growth rates, as provided in the Bradley and Sharpe (2009), are given in Table 2-2 and Figure 2-9.

Table 2-2: Labour productivity, capital productivity and MFP growth in mining, Canada, the United States, and Australia, Average annual growth rates (%), 1989-1990 to 2006-07

	Labour productivity growth		Capital producitivty growth		MFP growth	
	1989-2000	2000-2007	1989-2000	2000-2007	1989-2000	2000-2007
Canada	5.96	-2.21	2.21	-0.28	1.92	-1.07
United States	2.96	0.66	-0.04	-2.25	0.55	-1.68
Australia	6.05	-4.02	-0.12	-1.41	1.71	-1.99

Source: Bradley and Sharpe (2009)

Figure 2-9: Labour productivity, capital productivity and MFP growth in mining, Canada, the United States, and Australia, average annual growth rates (%), 1989-1990 to 2006-07



Source: Bradley and Sharpe (2009)

Whereas the mining MFP growth in each of the countries fell after 2000 (Table 2-2 and Figure 2-9), the rate of decline was the highest in Australia. In Australian mining, the extent of declines between the two time periods was the highest both for labour productivity growth and MFP growth.

Bradley and Sharpe (2009) ascribe the observed declines in all three measures of productivity growth (labour, capital and MFP) in Canadian mining to a number of factors. These include gradually declining capital intensity, higher mining output prices (and the associated lags in production due to input growth), compositional shifts within the industry, lagging innovation and technological progress, labour skills shortage, greater environmental regulation, deterioration of the average quality of resources exploited independent of price effects, labour relations, and taxation.

Out of all these factors, their study finds the strongest effect of higher prices is on both capital intensity and MFP, and they note:

"When the price of a natural resource increases it becomes profitable to increase extraction rates at existing deposits and to extract from marginal resource deposits that were previously unprofitable due to high costs of extraction" (Bradley and Sharpe 2009).

Analysing their data on MFP and capital intensity, Bradley and Sharpe found that falling capital intensity growth rates explained 42 per cent of the productivity slowdown in mining between 1996 to 2007.

Bradley and Sharpe (2009) do not recommend any industry specific policies to improve productivity growth in the mining sector in Canada above and beyond general public policies to improve productivity, such as investments in human capital and innovation. They maintain that the deteriorating productivity performance in mining is not an indication of crisis, but rather an indication of the strength of resource prices, and profit maximising decisions by the mining companies.

3. Australian mining and general economy-wide productivity trends

In this section we review the measurement issues associated with productivity. There are two different ways to measure output: value added output and gross output. Value added is the total value of production by all firms in an industry less the value of intermediate inputs used during the production. By contrast, gross output is the total value of production. ABS publishes both measures of MFP – based on value added as well as based on gross output.

The value added based MFP measure is preferred because it represents the contribution of labour and capital, and removes the value of intermediate inputs. Thus, it attributes productivity improvements gained through the more efficient use of intermediate inputs to capital and labour. Value added based MFP growth can be interpreted as the industry's capacity to translate technological change into income and into contributions to final demand (ABS 2007).

3.1 Measured Mining Productivity

Compared with the 1990s, Australia's productivity performance deteriorated in 2000s. Citing OECD data for various countries, Eslake (2011) showed that, in terms of decade-average comparison, Australia's market sector's MFP grew at an average rate of 1.1 per cent per year over 1990-2000, and -0.7 per cent per year over 2000-2009.

Using the OECD data, Eslake showed that the decline in Australia's MFP growth from 1.1 per cent a year to -0.7 per cent a year (1.7 percentage points reduction) was more than double the average decline for the 28 countries for which the OECD has estimates going back to 1990 (Eslake 2011).

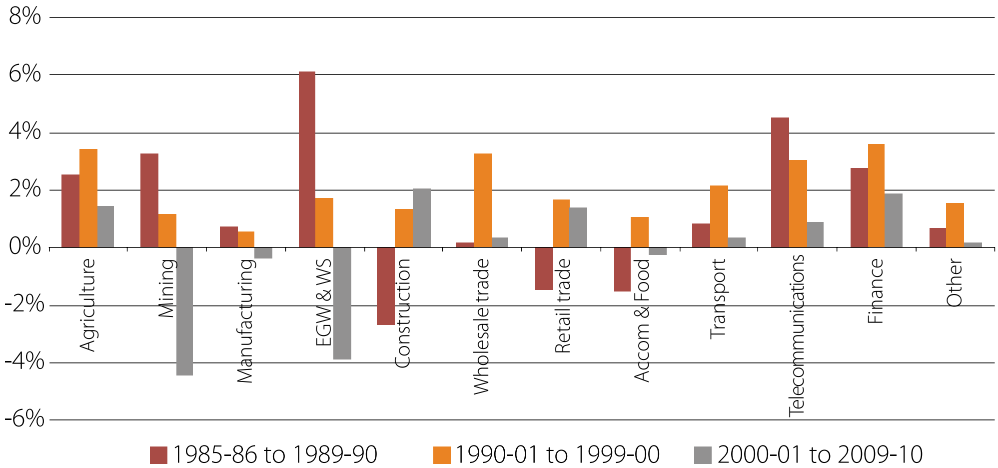
Most of the deterioration in Australia's productivity performance is concentrated in the two sectors: mining and 'electricity, gas, water and waste services' (EGW & WS). Eslake cites the Productivity Commission (PC) and its 2010 estimates that indicate that mining, EGW&WS and the 'agriculture, forestry and fishing sector' combined accounted for almost 80 per cent of the decline in MFP growth between 1998-99 and 2007-08 (Eslake 2011).

Using the ABS (2011) data, Figure 3-1 provides MFP growth over the last 25 years for a set of major sectors of the Australian economy.

Comparing the growth in MFP among the sectors decade by decade, MFP growth fluctuated substantially in each individual sector. The mining and 'electricity, gas, water and waste services (EGW & WS)' unadjusted MFP growth trended downwards from the late 1980s to 2000s. In the telecommunications sector, MFP growth gradually fell in each decade from the late 1980s to 2000s, but remained positive. In the mining and 'EGW & WS' sectors, MFP growth turned negative in 2000s. Thus, the two sectors, mining and 'EGW & WS' stand out from other

economic sectors of the Australian economy and warrant special attention. We note that, typically productivity comparisons are made over a business cycle. In the case of Australia this is problematic as the economy has experienced two decades of positive economic growth. Consequently, our comparisons are made at a decade level.

Figure 3-1: Multifactor productivity growth in Australia, selected sectors, average annual growth, 1985-86 to 2009-10



Source: ABS 2011, and BREE estimates

The observed decline in unadjusted mining MFP is striking. According to the ABS data, MFP declined one third between 2000-01 and 2009-10.

Unlike many other industries, mining has a heavy reliance on natural resource inputs. When ore grades or other aspects of resource quality decline as deposits are depleted, the measured productivity of mining declines because more inputs are needed to produce a unit of output. Topp et al. (2008, p. 4) observe that "…such a decline in measured productivity arguably does not represent a decline in production efficiency in mining activity".

Topp et al. (2008) give special emphasis to the impact on mining MFP of resource depletion and also capital lag effects. Their view is that resource depletion plays a role in the decline in measured productivity growth observed since the start of the 2000s. Consistent with this view, high resource prices of the 2000s affected mining MFP by providing incentives to producers to increase production from poorer quality deposits, and sometimes with lower quality inputs.

3.2 Causes of deterioration in Australia's sectoral productivity performance

Productivity growth, in general, was higher in the 1990s than in the 2000s. This is widely attributed to the impact of microeconomic reforms of the 1980s and early 1990s such as, abolition of input quotas, reductions in tariff assistance, liberalisation of financial markets, and floating of the exchange rate in 1983. Other reforms included: privatisation of government monopolies, competition policy, labour market reform and increases in working hours, institutional and regulatory reform to enhance efficient provision of infrastructure services, and monetary and fiscal policy changes to promote macroeconomic stability. By contrast, the slowdown in productivity growth overall in the Australian economy in the 2000s has been attributed to a reduced enthusiasm for productivity-enhancing reforms (Eslake 2011, Garnaut 2005), shortages of skilled labour, and the vintage of capital employed, and a decline in Australia's relative take-up of new technologies.

In terms of mining, higher profits due to the rise in commodity prices in the 2000s encouraged mining companies to increase output. This required a substantial increase in labour to raise output in the short-run and also capital investment to increase production in the medium to long-term. Higher commodity prices that increased input growth appears to be the prime reasons for decelerating MFP growth in Australian mining.

To test the effect of commodity prices on mining productivity, statistical tests on mining prices and productivity data show that prices 'Granger caused' mining productivity over the study period, 1990-91 to 2009-10. A positive and statistically significant relationship was also found between the mining capital-labour ratio and productivity. That is, it appears that higher commodity prices contributed to input growth, mostly in the 2000s which, in turn, contributed to declining MFP growth.

To examine the relationships between mining commodity prices, MFP and capital-labour ratio over the two decades of the 1990s and 2000s, a simple pair-wise correlation analysis is presented in Table 3-1. It indicates that the capital-labour ratio had a positive and relatively strong relationship with mining MFP in both the 1990s and 2000s. Further, and consistent with the Granger causality result, commodity prices and MFP displayed a negative and weak relationship over the 1990s, but a very strong negative relationship with MFP over the 2000s.

Table 3-1: Correlation matrix between national mining MFP, commodity price and capital-labour ratio

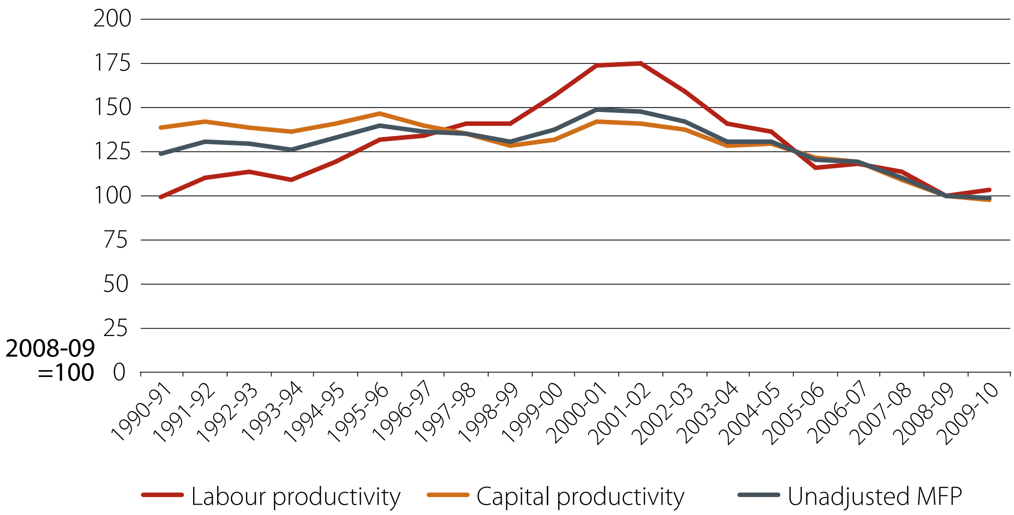
		1990 to 2000	
	MFP	Price	Capital-labour ratio
MFP	1		
Price	-0.3	1	
Capital-labour ratio	0.67	-0.16	1
		2000 to 2010	
	MFP	Price	Capital-labour ratio
MFP	1		
Price	-0.93	1	
Capital-labour ratio	0.88	-0.81	1

Source: BREE estimates

3.3 Productivity in the Australian mining sector

Figure 3.2 shows that each of the unadjusted measures of productivity: capital productivity, labour productivity and MFP in the Australian mining sector declined over the 2000s. Labour, capital and MFP fell by –5.6, –4.1 and –4.5 per cent a year, respectively, over the period 2000–01 to 2009–10.

Figure 3-2: Indexes of labour productivity, capital productivity and unadjusted MFP in the Australian mining sector, 1990–91 to 2009–10



Source: ABS (cat. 5260, 2011)

Figures 3-3 and 3-4 present the indexes of these productivity trends over 1990s and 2000s, respectively. Both labour and multifactor productivities fell in the 2000s, compared to 1990s. Capital productivity, which stagnated in the 1990s, fell in the 2000s.

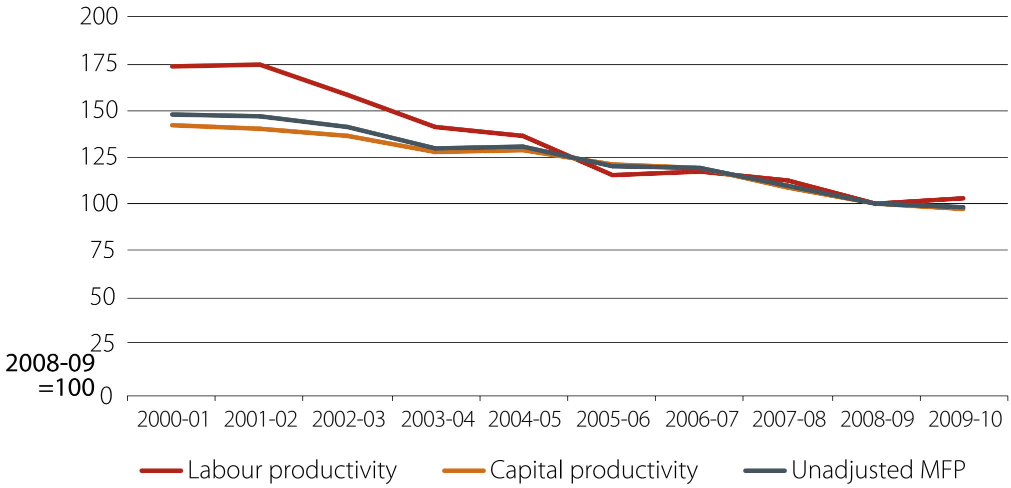
Figure 3-3: Indexes of labour productivity, capital productivity and unadjusted MFP, mining sector, Australia, 1990s

Source: ABS (cat. 5260, 2011)

Average annual growth rates over the whole of the two decades show that labour productivity grew between 1990-91 and 1999-2000 at an average annual rate of 5.2 per cent while capital productivity and multifactor productivity, respectively, grew at -0.5 per cent and 1.2 per cent.

By the 2000s each of the labour, capital and multifactor productivity growth rates fell at the rate of -5.6, -4.1 and -4.5 per cent per year, respectively, over the decade.

Figure 3-4: Indexes of labour productivity, capital productivity and unadjusted MFP, mining sector, Australia, 2000s



Source: ABS (cat. 5260, 2011)

3.3.1 Growth in the levels of inputs and outputs

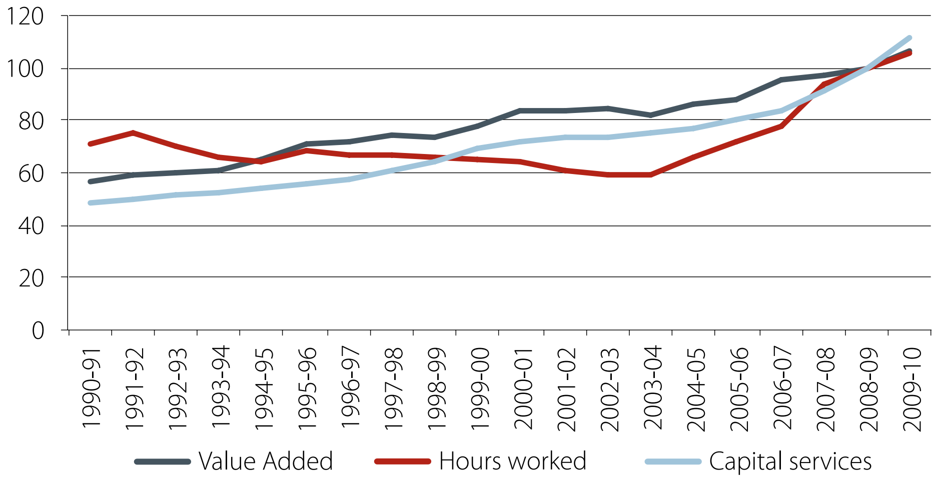
In the 1990s, the average annual growth in the index of hours worked (measure of labour) in mining fell by -1 per cent a year, and the index of capital services (measure of capital) grew at the rate of 4 per cent per year. Overall, mining output in the 1990s rose at the rate of 2.7 per cent a year.

Over the 2000s, both labour and capital grew rapidly at the rate of 6 and 5 per cent per year, respectively. However, output growth only grew at about half the rate of inputs, by less than 3 per cent per year. As a result, multifactor productivity and labour and capital productivities fell.

Input-output lags

Output growth does not immediately follow input growth in mining. This is due to the lags in capacity building through capital and labour investment, and the corresponding increase in output. Figure 3-5 traces the path of labour, capital and output indexes, with a two-year lag in both inputs. Labour is not a 'lumpy' factor of production, and should positively affect production in the same year in most industries, but in mining where the share of capital is around 80 per cent, labour alone may not generate sufficient output growth by itself. As a result of these special considerations in the mining sector, both labour and capital inputs were lagged whereas output is presented for the current year. When both capital and labour are lagged by two years, they more closely track output than if lagged differently. Figure 3-5 shows that the gross value of output and lagged capital grew in what appears to be a stable relationship.

Figure 3-5: Labour and capital stock, and output, mining sector, Australia (two-year lagged inputs, current output), 1990-91 to 2009-2010



Source: ABS (cat. 5260, 2011)

Deeper natural resources (endogenous factor)

A second possible reason for output not fully responding to input growth, and therefore causing deterioration in MFP growth, is the exploitation of previously marginal or uneconomic resources (at lower commodity price) that yield a relatively lower volume of output. For example, 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. In order to sustain production, from depleted resources at higher prices more labour and capital inputs are required, thereby reducing productivity.

Low yielding resources (exogenous factor)

A third and related possible reason for declining unadjusted measure of MFP is that depletion of resources requires more inputs to generate additional unit of production that cause costs to rise and factor productivities to fall. In this view, 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.

Inadequacy of vintage capital

A productivity slowdown may also be attributed to slow technology upgrades in existing mines that reduces both capital and labour productivity. This is because the most efficient combination of capital and labour inputs may change over time. In this case, capital of a later vintage may be required to maintain productivity growth. In practice, technology uptake may be sluggish in the existing mines because capital in mining is lumpy and inflexible once a mine is built and is in operation.

Mismatch of labour and capital

In 2000s labour growth exceeded capital growth (6 per cent a year compared to 5 per cent, respectively), whereas in the 1990s, capital growth was much higher than labour growth (Figure 3-5). The lack of commensurate capital growth may indicate that in the 2000s miners were uncertain about future resource demands, and tried to increase output in the short-term with the help of more variable labour increments rather than with fixed capital increments. In turn, this may have deteriorated the optimum productive combination of labour and capital and diminished productivity performance.

Lumpy nature of mining investment

Mining investment is, typically, lumpy and there are considerable lags between investment and the time it takes to achieve desired capital capacity. In addition, capacity expansion may disrupt existing equipment and infrastructure and, thus, current period output growth.

Unpredictable nature of commodity prices

Miners may be unwilling to invest in capital capacity in the presence of high prices, if such prices are not expected to persist. This stickiness in investment will cause slower output growth than there would have been if these prices were expected to persist.

Positive contributions to mining MFP over the longer-term include improvements in production efficiency through adopting new technology and improved management techniques. Some innovations that can contribute to productivity include the expansion of open-cut mining (particularly in coal mining, but also in metal ore mining), the development of longwall operations in underground coal mining, and greater automation and scale of plant and equipment.

3.4 Adjustment to MFP estimation in the mining sector

Given that the nature of natural resource production is different to other production activities in that natural resource deposits deplete in quality as the resource extraction activity increases, conventionally measured MFP can change as a result of factors other than production efficiency. If the production is homogeneous, and each additional unit of output can be produced by the equal amount of labour and capital input as the previous output unit, then a fall in MFP conveys inefficient use of inputs, due to management or other external reasons. In mining, if resource quality declines, each additional unit of output warrants more and more units of labour and capital inputs that is not due to management performance.

3.4.1 Measurement problems

Wedge (1973) used an index of ore grades as a proxy for declining natural resource inputs, and found that measured productivity increased significantly compared to the case when natural resource inputs were 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), Zhang (2009), and Loughton (2011) adjusted for exhausting natural resources inputs utilising different measures (level of reserves, cumulative production, ore grades, etc.) in their analyses and found measured productivity *increased* after the adjustment.

Using data collected by Gavin Mudd of Monash University, and other sources, Topp et al. (2008) examined the evidence of the prevailing resource depletion in Australian mining on a commodity by commodity basis. They found there was observable depletion of resources in most sectors of mining including oil and gas, coal, iron ore, and other metal products over the study period.

Beyond the estimated effects of yield declines and production lags associated with the surge in capital investment, other factors may have had an impact on mining MFP growth in recent years. These may include infrastructure constraints, an inappropriate mix of productive inputs, and the changing efficiency of some factors of production.

Overall, it seems possible that the slowdown in Australian mining productivity may relate to the input-output lags, the transition to extraction of deeper ores and lower-yielding resources, inadequacy of vintage capital, lumpy nature of mining investment, the unpredictability of commodity prices, infrastructure constraints, inappropriate mix of production inputs, and lower efficiency inputs. Many of these factors work together and influence each other so that it is difficult to decompose the individual effects by each factor.

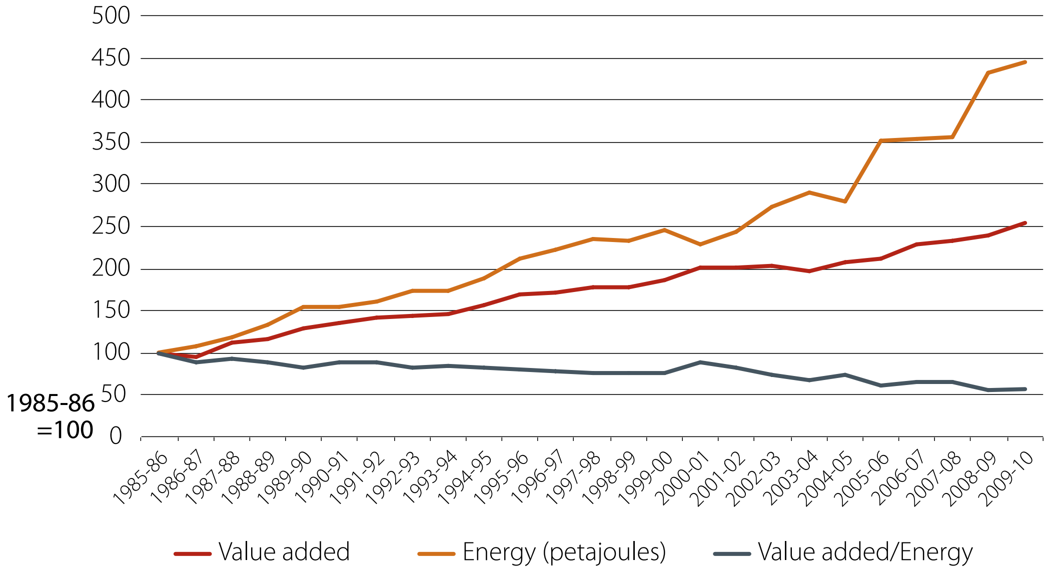
4. National mining MFP growth

4.1 Adjustment to MFP measurement in the study

The amount of energy input represents a measure of the amount of effort that must be expended in mining and can be used to proxy changes in resource quality. Thus, a decline in either the quality or accessibility of ore bodies will increase the use of energy use per unit of output. Energy use data can, therefore, be used to estimate the extent to which changes in ore bodies contribute to changes in output each year.

BREE data shows the use of physical amount of energy (petajoules) per unit of mining output (energy intensity) has constantly increased over the past decade and caused energy productivity to decline (Figure 4-1).

Figure 4-1: Index of mining value added, energy use, and energy productivity, 1986-2010



Source: ABS (cat 5204, 2012a) and BREE (AES, various years)

High-grade ores, or oil and gas basins with higher flow rates, or those minerals that can be accessed easily are, typically, extracted first. Over time, resource deposits are depleted and mining shifts to lower-grade ores that consume more inputs per unit of output. The depletion of higher quality ore bodies, the so-called 'low hanging fruits', and the transition to lower quality reserves require more inputs to generate additional unit of production and will, all else equal, cause costs to rise and factor productivities to fall.

The need for increased inputs in the mining industry can be represented by the use of energy input, given that mining is a capital intensive industry. The finding of declining energy productivity (increased energy intensity) has been shown by several authors including Sandu and Syed (2008), Petchey (2010), Che and Pham (2012), among others. Their work indicates that,

1. when resources are depleted successively more fuel energy is needed to produce the same amount of net output;

2. gradual reduction in 'energy productivity' (output to energy ratio) can reveal the extent of resource depletion; and

3. ratio of value added in mining sector to energy use (petajoules, PJ) in a year can be used as a measure of energy productivity.

It follows that potential or quality 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 comparing the use of energy in a given year with the first year's energy productivity. The resulting adjusted output provides a measure of actual output that would have been produced if energy productivity had not declined from year to year.

In addition to the energy input adjustments, adjustment to capital and labour inputs can be made by taking two year lags for these inputs to account for the investment-output lags to obtain a measure of productivity that accounts for these special factors in the mining industry.

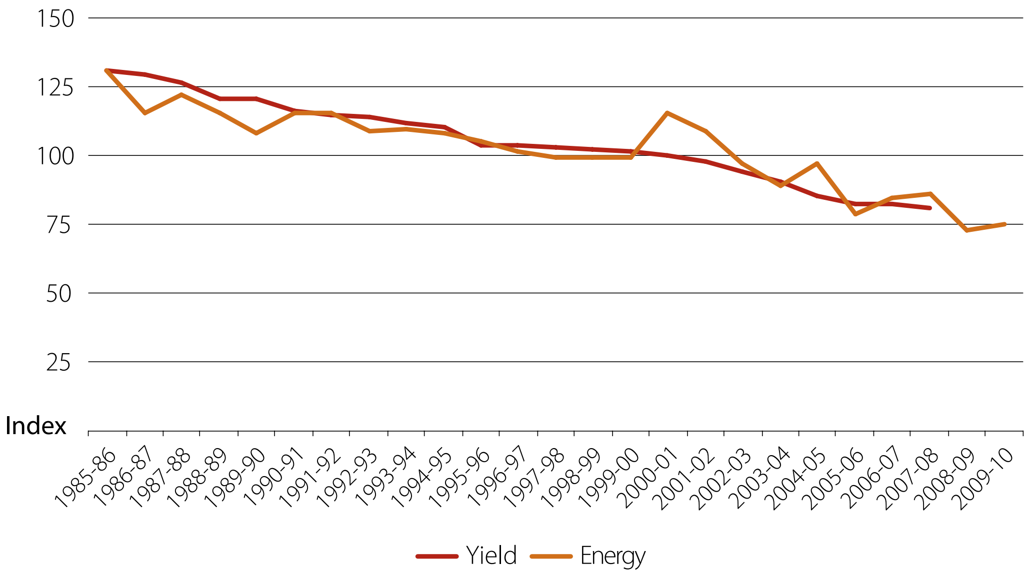
4.1.1 Measurement of resource depletion

As an alternative to the resource depletion measurement used by Topp et al. (2008), 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 cumulative extraction may be estimated, total reserves change each year, as the remaining life of a particular natural resource alters with geological survey techniques and also commodity prices.

4.2 Yield versus energy based measures of depletion

Topp et al. (2008) measured resource depletion by collating an index of yield from different sources between 1974-75 and 2006-07. Figure 4-2 shows the measure of resource depletion based on the declining productivity of energy and their measure of depletion based on yield. The two measures are broadly consistent with each other, but the measure we use in our study based on energy use is more variable.

Figure 4-2: Yield versus energy based measures of depletion



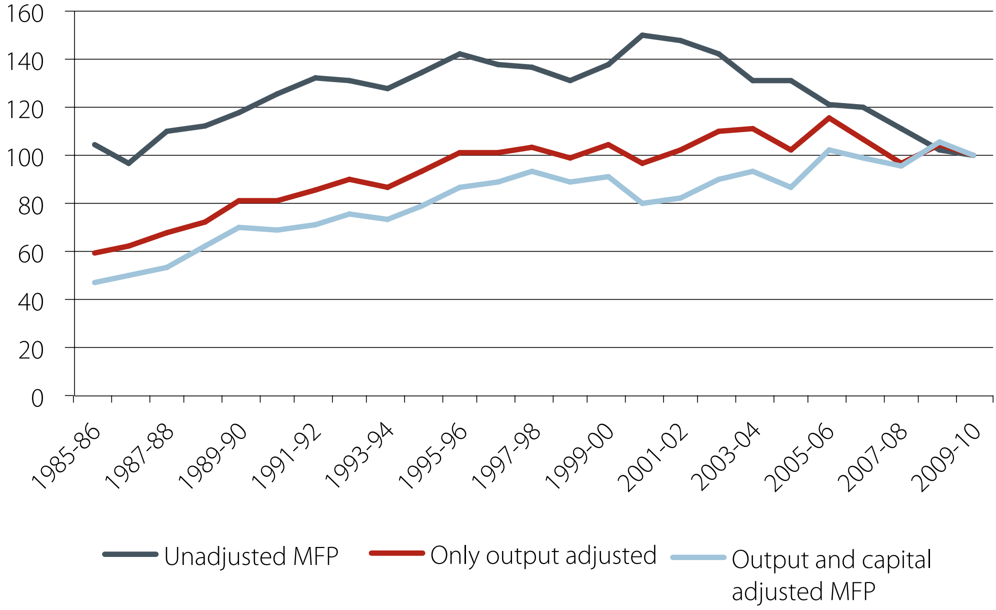
Source: BREE (AES, various years), and Topp et al. 2008

4.3 Output quality adjusted MFP growth in the Australian mining industry, 1989 to 2010

Figure 4-3 illustrates conventionally estimated MFP in the Australian mining industry along with two other MFP estimates: 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 (labelled as capital adjusted), and an estimate of mining MFP that has been adjusted for natural resource depletion or output quality (labelled as output adjusted).

Figure 4-3 shows unadjusted MFP for Australian mining, as measured by the ABS, *declined* at an average growth rate of 0.65 per cent between 1985 and 2010. The two MFP measures grew at an average annual growth rate of 2.3 per cent (only output quality adjusted MFP) and 2.5 per cent (output quality and capital-lag adjusted MFP). That is, after adjusting for the productivity loss due to output quality alone, Australian mining productivity grew at the rate of 2.3 per cent a year from 1985-86 to 2009-10.

Figure 4-3: MFP index with and without adjustment, Australian mining, 1985-86 to 2009-10

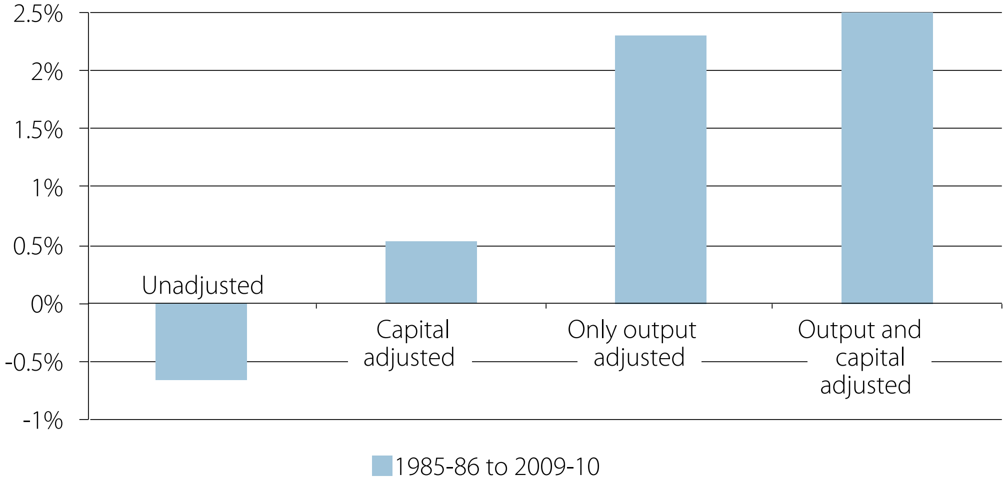


Source: ABS (cat. 5260, 2011), BREE estimates

The MFP growth rates before and after adjustment are represented in Figure 4-4. This figure shows that the MFP growth rate gradually lifts at an average annual rate of growth between 1985-86 and 2009-10 from -0.65 per cent to 2.5 per cent as successive adjustments are made.

In addition to the MFP growth rates shown in Figure 4-3, Figure 4-4 shows 'only capital-lag adjusted' (input adjusted) MFP growth rate of 0.54 per cent a year over 1985-86 to 2009-10.

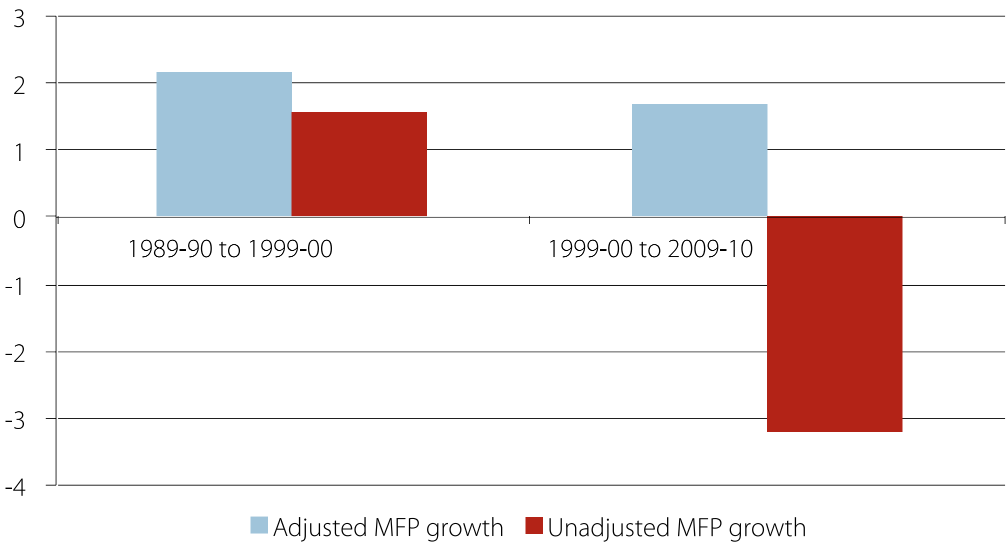
Figure 4-4: MFP Growth with multiple adjustments, Australian mining, 1985-86 to 2009-10



Source: BREE estimates

Neither unadjusted (conventionally measured by ABS) MFP nor the adjusted MFP grew at the same rate throughout the study period. Therefore, MFP growth rates are divided into two periods. Figure 4-5 shows MFP growth rates over two time periods – from 1985-86 to 1999-2000, and from 2000-01 to 2009-10 that includes the millennium mining boom period. This figure shows that in the 2000s, unadjusted MFP declined at the rate of 3.1 per cent a year.

Figure 4-5: Unadjusted and adjusted MFP growth rates, over time intervals, Australian mining, 1989-90 to 2009-10



Source: BREE estimates

Observed or unadjusted mining MFP growth sharply declined during the period 1999-2000 to 2009-10. In Figure 4-5, both unadjusted and adjusted MFP grew positively over the 1990s. Unadjusted MFP sharply fell and declined at an average rate of 3.1 per cent over the 2000s which indicates that natural resource depletion was much grearter in the 2000s than in the 1990s when MFP grew at a positive rate. In the 2000s, after the adjustment for deterioration and lagging capital and labour, the growth of MFP was 1.6 per cent a year, compared to the 2.1 per cent adjusted MFP growth rate in the 1990s.

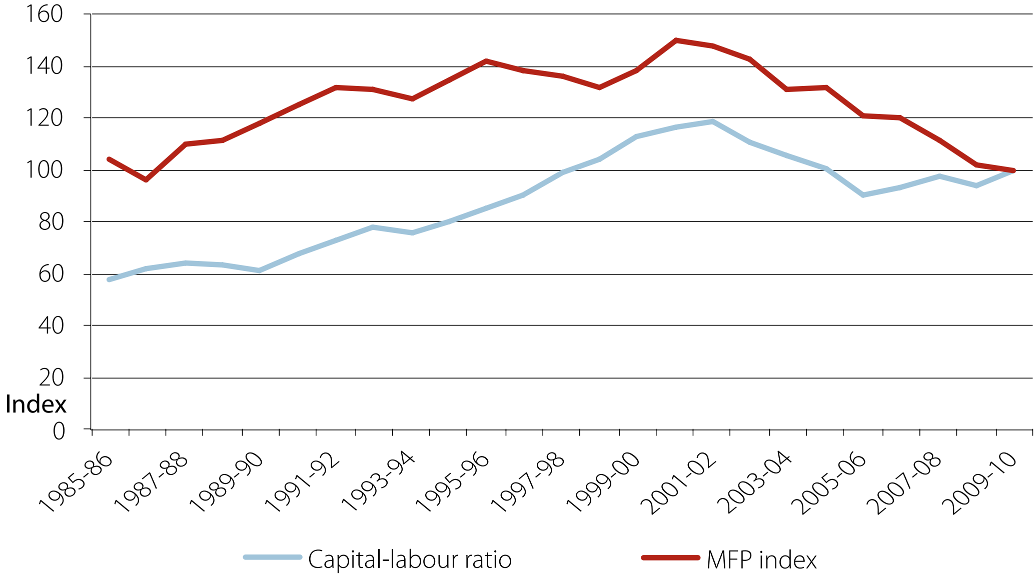
4.4 Capital-Labour Ratio in Australian mining

Increased effectiveness of capital that relates to the vintage and productivity of capital can mitigate the impact of resource depletion, but does not appear to have occurred over the past decade. In part, this might be explained by the possibility that once a mine of a certain type and size is in operation, its capital stock cannot be increased in the short term (Topp et al. 2008), even if commodity demand and prices were expected to continue over the short to medium term.

The ratio of capital per unit of labour increased gradually between 1986 and 2000 in the Australian mining industry, but subsequently reduced over the decade. Consequently, the mining capital-labour ratio grew at 5.8 per cent a year (Figure 4-6) in the 1990s, and -1.65 per cent a year in 2000s. It would seem, therefore, that as commodity prices increased in the early 2000s, miners were able to increase output supply by employing more labour without increasing capital in the same proportion as labour. Contemporaneous with labour working with proportionally less and less capital, MFP fell in the 2000s (Figure 4-6).

We note that there was substantial capital investment over the 2000s, but much of it appears to have been directed to develop new mines and new resources, albeit with successively lower capital per unit of labour in the 2000s than in the 1990s.

Figure 4-6: Capital labour ratio and unadjusted MFP growth in Australian mining, 1985-86 to 2009-10



Source: ABS (cat. 5260, 2011)

One possible explanation for the decline in the capital-labour ratio is that the period 2000-01 to 2004-05 coincides with mining companies' expectation that price increases were a temporary shock. As a result, miners may have chosen to increase output by using a more variable input (labour) than fixed capital. This may have changed after 2004-05. High profit margins and the prospect of high commodity prices contributed to high capital investments, but not at a faster rate than the growth in labour use. As a result, the capital-labour ratio has remained more or less unchanged from 2004-05.

4.5 Innovation and new technology

The cost of digging deeper and processing the net ores from gross ores can be reduced by better machinery and equipment. This occurs with innovation and technological progress that can vary from mine to mine and by sector and commodity. A 2001 study by Global Economics Limited found that the majority of mining industry R&D expenditures world-wide were designed to improve processes or develop new processes to reduce extraction costs.

Australia has a long history of underground mining and has also employed innovations in hard-rock mining, such as block-caving and sublevel-caving technologies. In oil and gas production, developments in drilling technology have led to an increase in the use of steeply inclined and even horizontal drilling during the past three decades, allowing access to resources that were not economic using standard vertical wells. Continued developments in drilling technology have also allowed oil to be extracted from what would have previously been uneconomic wells.

Bradley and Sharpe (2009), in a study of Canadian mining, concluded that, "…the perception of Canada as a world leader in mining technology suggests that lagging technical progress does not explain the post-2000 mining productivity growth slowdown". The report found half of the mining establishments introduced new technologies, and most mining establishments in Canada purchase off-the-shelf technologies, or customise and modify existing technologies.

In Australia, the extent of resource depletion has long been established (Mudd 2007, Topp et al. 2008, Loughton 2011); however there has not been any serious study on the number of establishments implementing 'modified' technology to reduce extraction costs. Thus, although new technology is being applied in Australian mining in new mine establishments, R&D expenditure relative to mining output reduced over 2000s (Fisher and Schnittger 2012). Nevertheless, a number of mining businesses in Australia are known to be investing in and trialling automated technologies, although much of this effort remains commercial-in-confidence and, therefore, not in the public domain.

Some examples of technological developments in the public domain include increases in truck sizes from a 25 tonne payload to some 400 tonnes today (along with dramatically improved energy efficiency) and the use of safer and cheaper explosives. Fisher and Schnittger (2012) list many incremental innovations that mining establishments are beginning to use. These innovations are implemented at different stages of mining activities. They state that step-change innovations are not forthcoming rapidly and, as yet, are in their infancy.

In Australia, most automation effort has concentrated on the component or subsystem level, and at a relatively small scale relative to the number of mines, processing plants and export facilities. Innovations in mining automation include automated surface haul trucks, automated underground load-have dump loaders, and autonomous blast-hole drilling equipment (Fisher and Schnittger 2012). CSIRO (2009) suggest that advances that can be achieved from increased mine automation include the level of control. Reducing human intervention and running end-to-end with machine control can improve efficiency and repeatability, or true process quality.

LKAB's Kiruna iron ore mine in Sweden, considered to be the world's largest, most modern underground iron ore mine, has used driverless underground trains since the 1970s (mining-technology.com, 2011; Arvidsson, 2005; Fisher and Schnittger 2012). Recently, Australia has increased its efforts in automation with three main research centres at CSIRO (the Commonwealth Scientific and Industrial Research Organisation), CRCMining (the Cooperative Research Centre for Mining), and the Rio Tinto Centre for Mine Automation (RTCMA), established at the University of Sydney.

Rio Tinto is rolling out its 'Mine of the Future'. At its core is the operations control centre located in Perth, which has been operational since 2009-10. The centre currently undertakes the remote monitoring of a number of significant assets and oversees full-scale trials of autonomous trucks, drills and ship and train loading operations.

As Australian resources become progressively more difficult to mine, mining companies will need to continue to innovate to remain competitive. While Rio Tinto and some other international mining businesses provide information about ongoing innovation and

automation efforts, most, including many Australian businesses, do not. It is, therefore, difficult to gauge overall trends in automation in Australia. What is clear, however, is that information and communications technology (ICT) expenditure in the mining industry has increased rapidly in recent years. Given intense competition and other challenges facing the Australian mining sector today, the application of automation technologies may be critical to support output growth of the sector.

Costs

Implementing automation in mining can be costly. Creating step-change innovation is a long and complex process that stretches from R&D undertaken in research centres to multiple intermediate stages until the full-scale roll-out and commercial use of technologies. This is subject to possible failures at each step of the innovation cycle.

Fisher and Schnittger (2012) maintain that funding costs of Rio Tinto's research centres alone amount to several tens of millions of dollars. Expensive prototypes of complex large machines such as Rio Tinto's underground drills must be designed, built, tested in an appropriate environment, and further refined in an intensive process involving multiple partners and many different types of expertise.

5. Regional mining MFP growth

In this section we examine the impact of natural resource inputs on the productivity of Australian regional mining industry, and present quantitative estimates of mining MFP in the presence of resource depletion.

To analyse regional mining productivity, relevant data were collected (Appendix B) mainly from ABS and BREE sources. The data were consistently available from 1990-91 to 2009-10 and included, information on capital, labour, value added, and shares of labour and capital.

By contrast to the national level where ABS publishes estimated MFP values for Australian mining, no such MFP values are available at the regional or sectoral levels for Australian mining. Hence, both the unconventional and conventional MFP levels were calculated for this study.

5.1 State output shares

Western Australia (WA) and Queensland produced more than 75 per cent of Australian mining production in 2009-10 (Table 5-1). These two states constantly raised their shares of output from 1990 to 2010, which shows increasing regional mining concentration in Australia. The same trend was true in the case of the share of the mining capital stock for these two states, which increased from 69 per cent in 1989-90 to 83 per cent in 2009-10 (Table 5-2).

Tables 5-1 and 5-2 show the increasing importance of WA and Queensland in Australian mining relative to New South Wales (NSW), Victoria and Northern Territory (NT). Growth in the output of iron ores in the presence of rising resource prices, and discoveries of unconventional gas are two main factors responsible for mining output and capital concentration in WA and Queensland. Except in Victoria, where mining output has fallen due to the depletion of oil and gas reserves over the study period, the absolute value of real mining output increased in all states.

Table 5-1: Regional mining value added shares, 1989-90 to 2009-10 (%)

	NSW	VIC	QLD	SA	WA	TAS	NT
1989-90	11.83	26.03	19.26	3.88	34.26	0.68	4.07
1990-91	11.77	24.14	19.36	3.56	36.56	0.69	3.92
1991-92	11.63	23.20	19.19	3.68	37.77	0.78	3.76
1992-93	11.90	24.01	18.46	3.61	37.89	0.91	3.23
1993-94	11.61	22.66	18.21	3.72	40.56	0.87	2.36
1994-95	11.51	19.81	18.34	3.39	44.26	0.72	1.97
1995-96	11.59	17.46	18.79	3.16	46.09	0.66	2.26
1996-97	12.12	16.27	18.41	3.17	47.38	0.54	2.12
1997-98	12.09	16.86	17.20	2.96	48.06	0.57	2.26
1998-99	11.75	13.52	21.41	3.05	47.69	0.54	2.04
1999-00	10.98	13.79	21.85	3.20	46.64	0.47	3.06
2000-01	10.64	11.74	22.91	3.41	47.34	0.45	3.50
2001-02	10.62	11.52	24.08	3.02	47.22	0.44	3.11
2002-03	10.79	10.67	23.77	2.81	48.80	0.43	2.72
2003-04	11.46	10.49	24.46	2.77	47.63	0.44	2.74
2004-05	11.37	9.11	24.94	3.06	48.15	0.41	2.96
2005-06	11.54	9.14	24.94	2.80	48.12	0.38	3.07
2006-07	11.49	8.50	23.89	2.92	49.79	0.32	3.09
2007-08	11.02	8.26	24.19	3.14	49.71	0.34	3.33
2008-09	10.86	8.07	23.83	3.34	50.35	0.33	3.21
2009-10	10.89	7.54	23.87	2.92	51.51	0.31	2.96

Source: ABS 5220.0 (various years)

Table 5-2: Regional mining capital stock shares, 1989-90 to 2009-10 (%)

	Capital Share NSW	Capital Share VIC	Capital Share QLD	Capital Share SA	Capital Share WA	Capital Share TAS	Capital Share NT
1989-90	14.28	9.79	16.47	2.44	51.25	0.96	4.81
1990-91	21.18	2.99	21.89	3.05	41.81	1.59	7.49
1991-92	15.77	3.82	24.09	4.78	45.32	1.28	4.93
1992-93	10.24	6.04	22.04	4.54	54.87	0.64	1.63
1993-94	8.78	8.62	21.36	1.80	56.38	1.14	1.93
1994-95	12.50	9.41	15.47	1.99	56.88	1.36	2.39
1995-96	13.87	8.32	13.37	2.69	54.28	2.18	5.30
1996-97	11.68	10.17	21.53	6.01	43.40	1.82	5.38
1997-98	8.05	8.07	19.17	13.08	49.10	0.63	1.89
1998-99	6.02	15.39	20.25	5.85	37.14	4.05	11.29
1999-00	9.19	12.54	25.04	4.95	38.22	1.55	8.52
2000-01	9.60	7.75	20.96	8.80	40.93	1.55	10.40
2001-02	12.26	10.37	24.08	4.58	37.09	1.65	9.98
2002-03	12.73	9.02	20.16	7.24	39.18	1.84	9.84
2003-04	12.39	8.29	17.88	5.97	49.22	1.00	5.24
2004-05	12.07	7.61	24.57	4.08	48.93	0.38	2.37
2005-06	9.47	10.14	19.98	4.14	54.62	0.21	1.45
2006-07	7.57	6.55	18.04	5.82	58.59	0.36	3.06
2007-08	8.10	6.39	16.85	5.55	59.42	0.38	3.31
2008-09	6.56	5.37	20.18	3.60	61.63	0.28	2.39
2009-10	9.30	4.54	19.66	2.24	62.32	0.20	1.73

Source: ABS 5220.0 (various years)

5.2 Capital to labour ratio and MFP growth

Table 5-3 show that there was a relatively high average growth rate in the mining capital-labour ratio in most Australian states over the 1990s. An interesting observation is that the capital-labour ratio declined in most states in the 2000s compared to the 1990s. This reflects higher growth in labour input over capital input through much of the past decade. We note that state growth in the capital-labour ratio over the two decades from 1990 is broadly consistent with the national capital labour ratio growth shown in Figure 4-6.

High resources prices in 2000s, and the short term inflexibility of capital growth in mining, provided incentives to miners to increase output by increasing labour in the short term. In the 1990s, unadjusted MFP of the two large mining states (Western Australia and Queensland) increased at a positive growth rate, respectively, of 4.4 per cent and 2.8 per cent. Whereas, in the 2000s, MFP growth in these two states was -7.5 per cent and -3.7 per cent a year (Western Australia and Queensland), respectively (Figure 5-1 and 5-2).

Table 5-3: Regional mining capital-labour ratio growth, 1990-91 to 2009-10 (%)

	NSW	VIC	QLD	SA	WA	TAS	NT
1990-91 to 2009-10	0.8	5.6	1.9	1.9	3.5	-5.9	-11.9
1990-01 to 1999-00	-0.6	23.3	8.7	12.9	5.0	10.7	4.9
2000-01 to 2009-10	2.4	-3.4	-1.8	-13.2	1.6	-20.7	-28.1

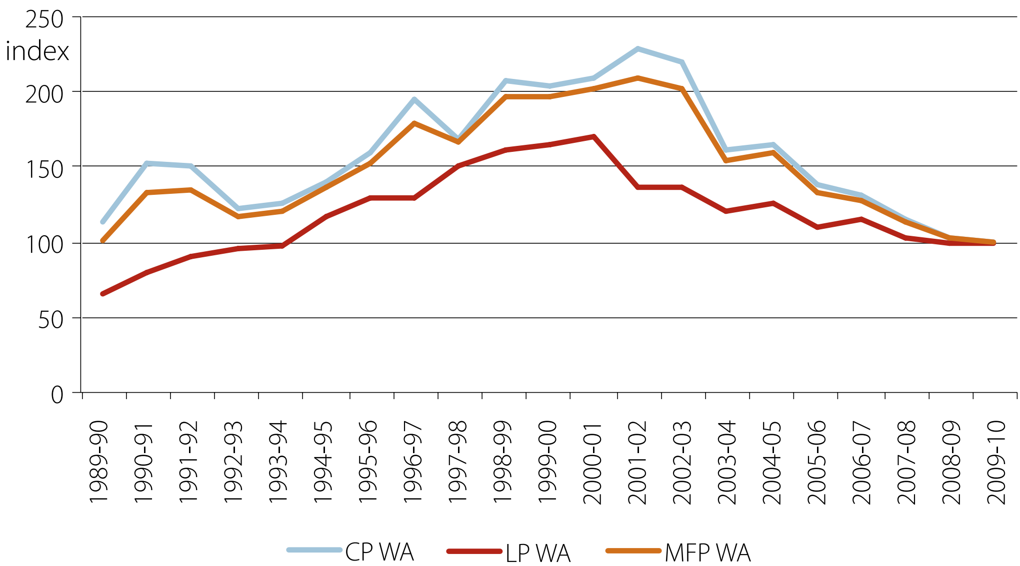
Source: ABS cat. 5220.0 (various years), and BREE calculations

5.3 Capital productivity, labour productivity, and MFP

In Western Australia, average annual growth remained significant and positive in the 1990s in terms of capital productivity, labour productivity and unadjusted MFP; but each of these positive growth rates turned negative in the 2000s (Figure 5-1). In Queensland, labour productivity growth and unadjusted MFP remained positive in the 1990s, and negative in the 2000s (Figure 5-2). Both figures show a close relationship between capital productivity and MFP.

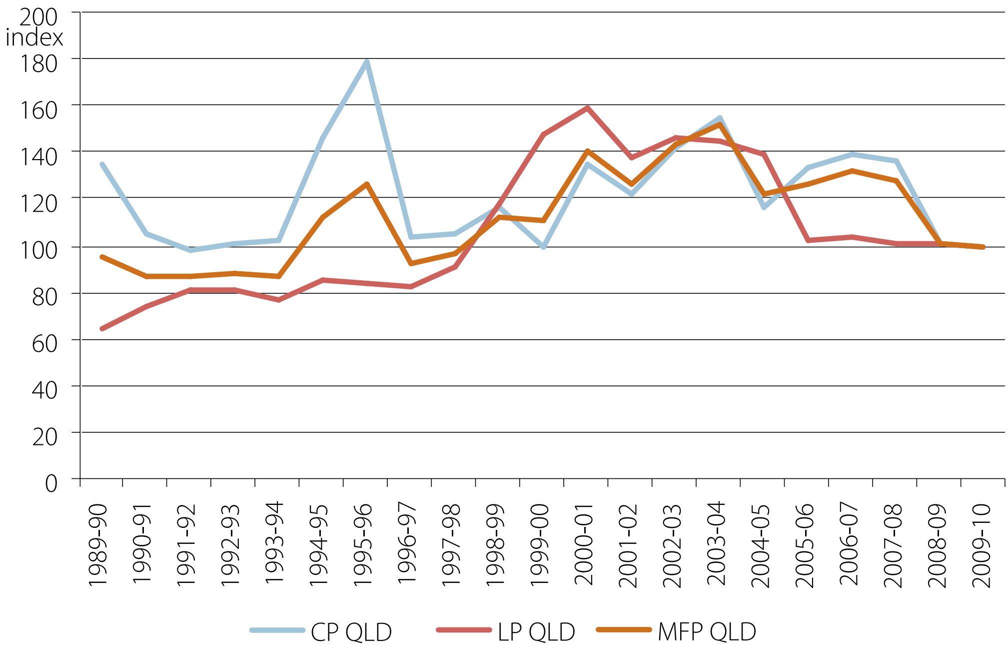
Given that Western Australia accounts for more than half of the total Australian mining output and capital stock, trends in this stock affect Australia's mining as a whole. Western Australia's capital productivity fell -7.8 per cent per year over the 2000s while it grew at 3.3 per cent per year over the 1990s. Similarly, unadjusted MFP growth shrunk from 4.4 per cent a year in the 1990s to -7.5 per cent per year in the 2000s.

Figure 5-1: Capital productivity, labour productivity and unadjusted MFP growth, WA, 1989-90 to 2009-10



Source: ABS cat. 5220.0 (various years), and BREE estimates

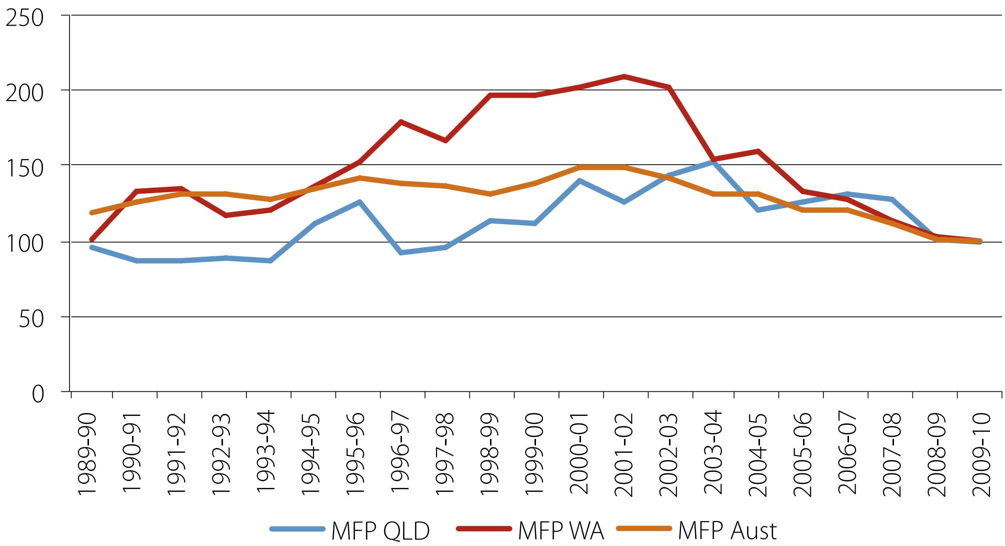
Figure 5-2: Capital productivity, labour productivity and unadjusted MFP growth, Queensland, 1989-90 to 2009-10



Source: ABS 5220.0 (various years), and BREE estimates

The highest growth in the state 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 percent respectively). In the 1990s, capital growth in Western Australia 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 the two major mining states, Western Australia and Queensland, growth in mining MFP displayed a similar trend as in overall Australian mining (Figure 5-3).

Figure 5-3: Australian and selected regional unadjusted MFP index, 1989-90 to 2009-10



Source ABS 5220.0 and 5260.0, 2011, and BREE estimation

5.4 Adjustment to state MFP growth

Adjustments for depletion of resources to state mining MFP were made using the measure of energy productivity in each state over 1990-91 to 2009-10. Adjustments were made in the same manner as described in section 4. Results by state are provided in Table 5-4.

Figures 5-4 to 5-8 show for selected Australian states the conventionally estimated MFP in the state mining industry along with an estimate of mining MFP that has been adjusted to take into account the resource depletion and average lead-time between initiation and production for new mining investments. Energy use data for South Australia and Tasmania were considered not reliable and, thus, these states were excluded from the State analysis.

Table 5-4: Adjusted and unadjusted state MFP growth rates 1990-91 to 2009-10

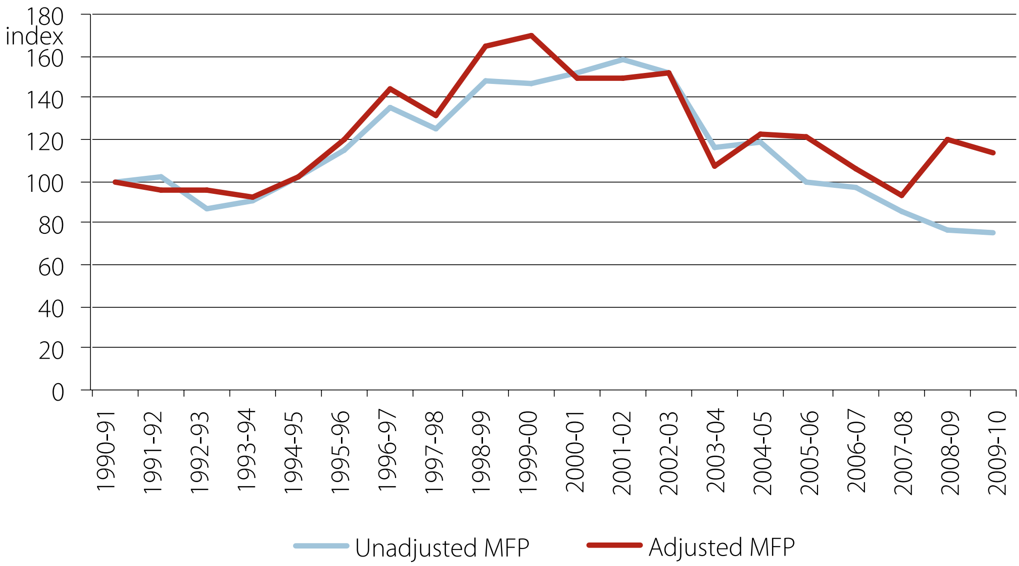
	Unadjusted MFP	Adjusted MFP
Western Australia	-1.48	0.96
Queensland	0.74	3.65
New South Wales	1.7	5.1
Victoria	-9.1	-0.6
Northern Territory	2.5	10.3
South Australia	-1.87	NA
Tasmania	1.89	NA

Source, ABS 5220.0 and BREE estimates

Table 5-4 shows that when resource depletion and capital lag effects are removed, adjusted MFP in each state grows at a higher rate compared to when depletion and lag effects are not considered.

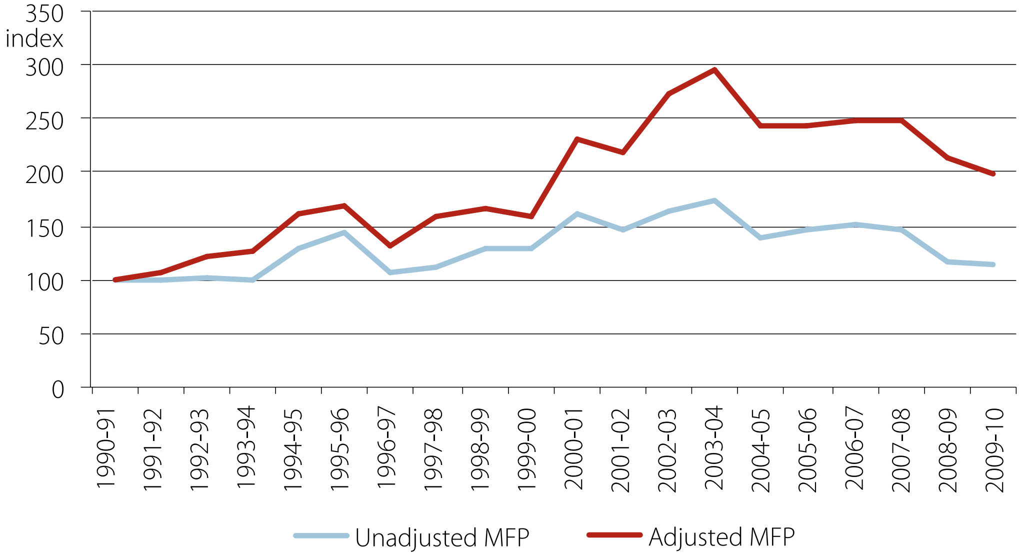
After accounting for the influence of resource depletion and production lags, adjusted MFP grew at a positive rate in most states. Victoria is the only state where MFP grew at a slightly negative rate even after the adjustment. This is attributed to exogenous depletion in oil and gas resources in the state, and weak capital productivity (-9 per cent average annual growth over the entire study period 1990-91 to 2009-10); Table 5-1 shows the share of Victorian mining output in total Australian mining output fell from more than 26 per cent to 7.5 per cent over the study period.

Figure 5-4: Adjusted and Unadjusted MFP index, WA, 1990-91 to 2009-10



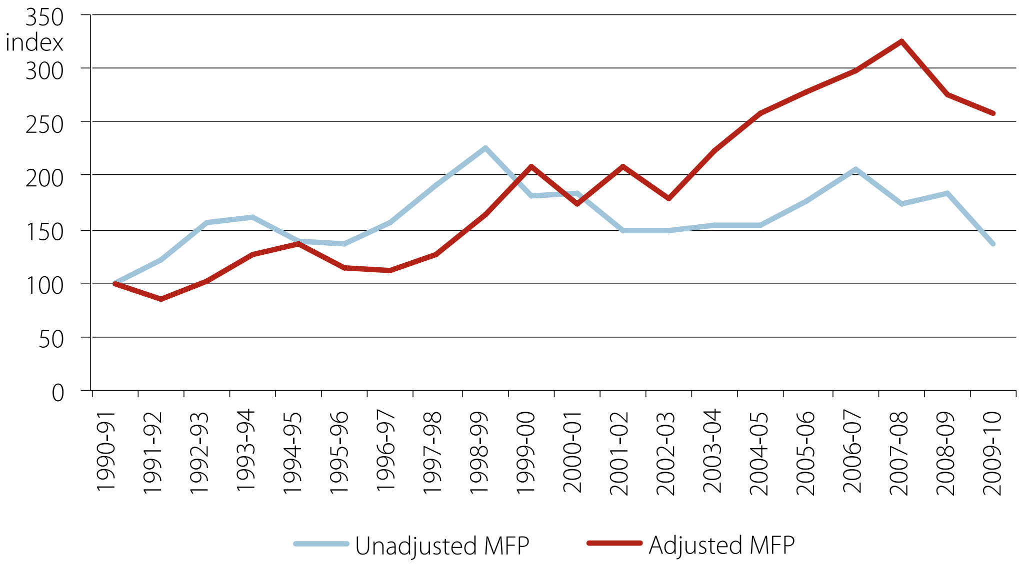
Source: BREE estimates

Figure 5-5: Adjusted and Unadjusted MFP index, Queensland, 1990-91 to 2009-10



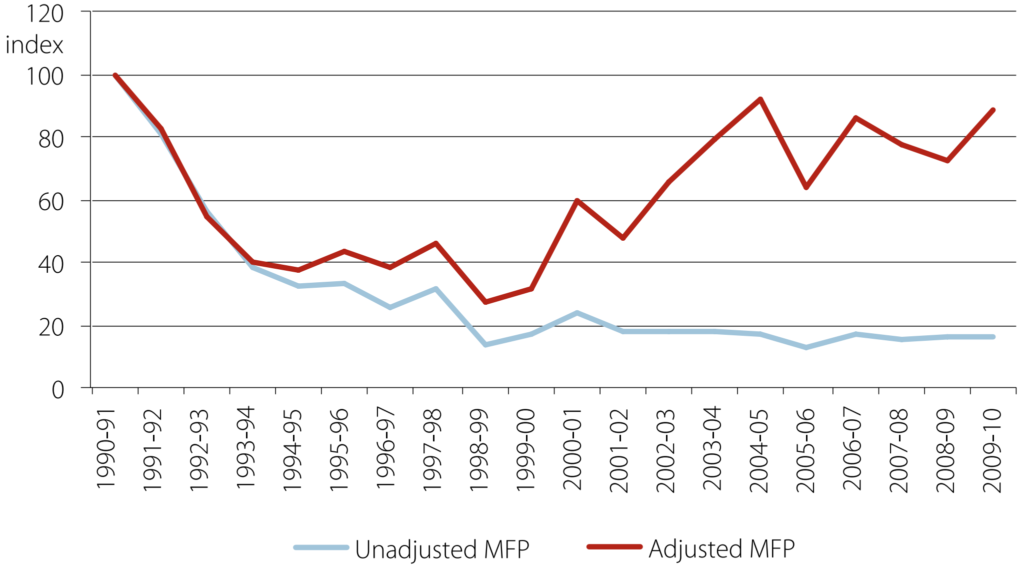
Source: BREE estimates

Figure 5-6: Adjusted and Unadjusted MFP index, New South Wales, 1990-91 to 2009-10



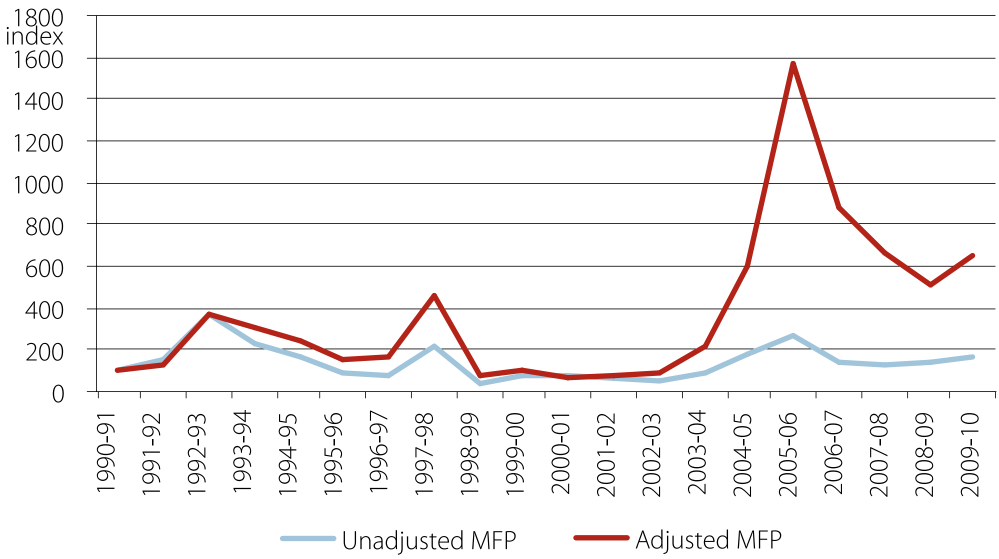
Source: BREE estimates

Figure 5-7: Adjusted and Unadjusted MFP index, Victoria, 1990-91 to 2009-10



Source: BREE estimates

Figure 5-8: Adjusted and Unadjusted MFP index, Northern Territory, 1990-91 to 2009-10

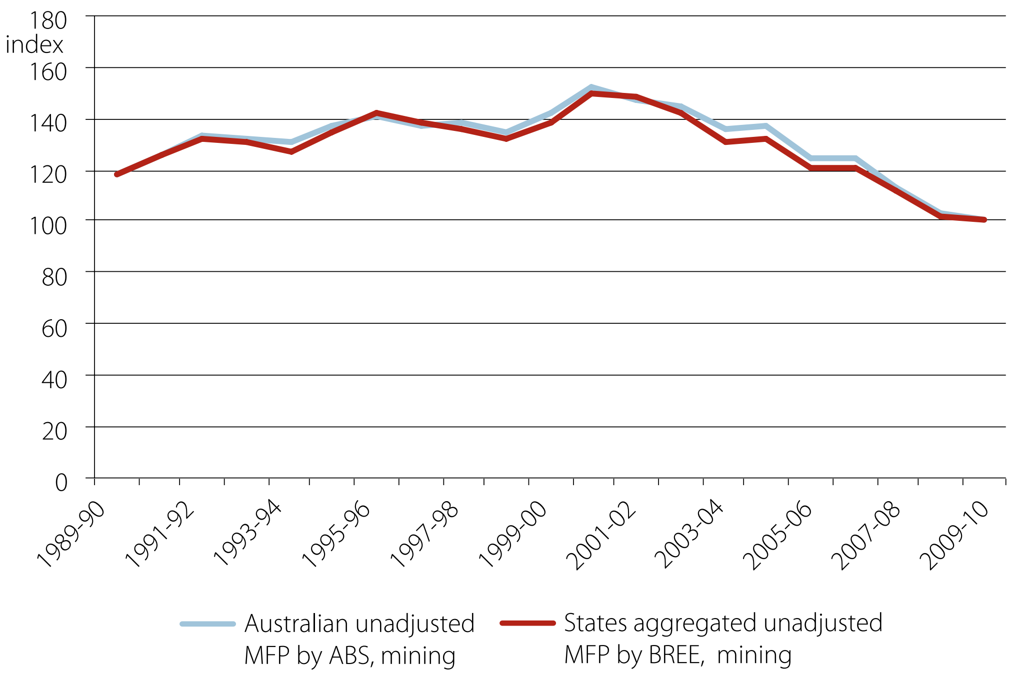


Source: BREE estimates

5.5 Testing regional data reliability: comparing aggregated state level unadjusted MFP with Australian unadjusted MFP

In order to test the reliability of the regional data provided by ABS (cat. 5220.0), state level data were compared with the Australian level MFP provided by the ABS (cat. 5260). State level data on capital (net capital stock), labour and output were aggregated to calculate (unadjusted) MFP estimate for Australia. The aggregated level (unadjusted) MFP measure was compared with the ABS provided (unadjusted) measure by the ABS. From 1989-90 to 2009-10, the two MFP measures coincided with each other, as shown Figure 5-9.

Figure 5-9: ABS Australian unadjusted MFP, and BREE's states aggregated unadjusted MFP



Source: BREE calculations, ABS (cat 5260, 2011)

6. Sectoral mining MFP growth

In this section we examine the impact of natural resource inputs on the productivity of Australian mining sub-sectors, and present quantitative estimates of the mining MFP in the presence of resource depletion.

To analyse productivity in mining sectors, relevant data were collected from ABS and BREE sources on sectoral capital use, labour use, output produced, input shares and energy use (Appendix B).

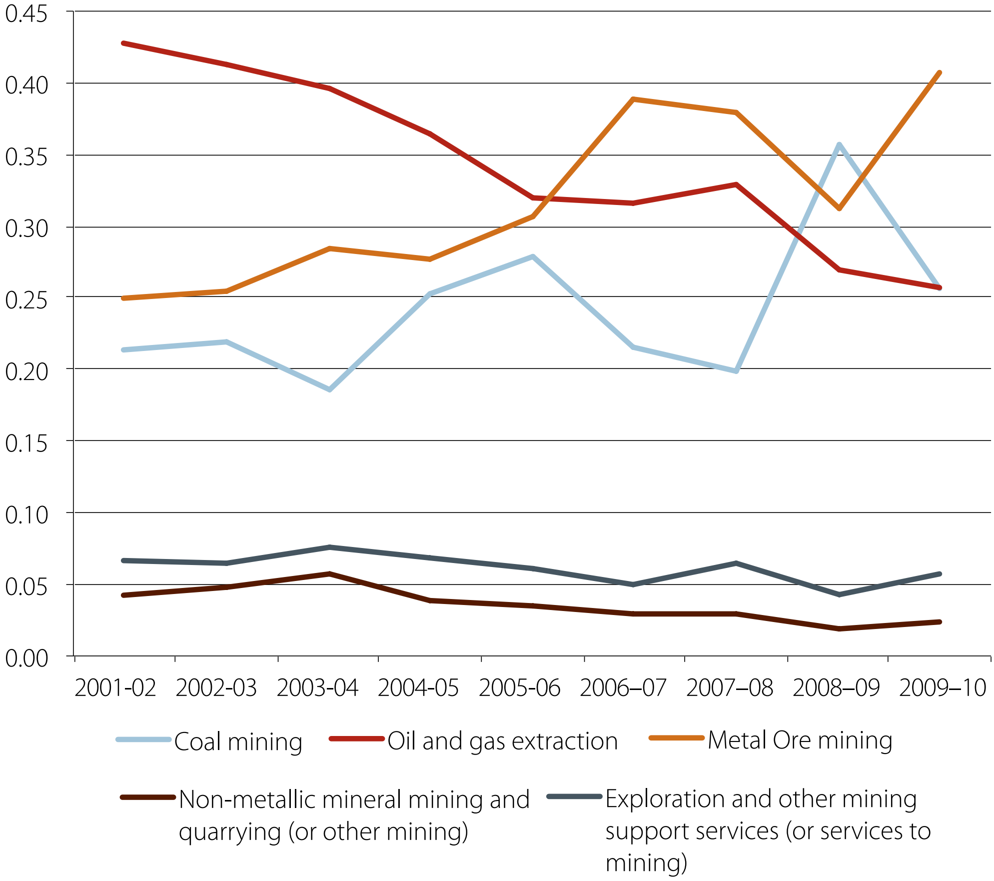
Time series data going back to the 1980s by mining sub-sectors has been interrupted since ABS discontinued its regular publication that provided sectoral time-series data to 2000. Currently, mining sub-sector level data is available on an annual basis from catalogue ABS 8155.0. Unfortunately, it is not possible to construct a smooth time series data for mining sub-sectors from 1990 to 2010, the analysis period of this study. As a result the analysis is confined to the 2000s period only.

The ABS ANZSIC 2006 classification divides the mining industry into five sub-sectors: 1. coal mining, 2. oil and gas mining, 3. metal ore mining, 4. non-metallic mineral mining, and 5. quarrying and exploration and other mining support services. At a sub-sector level, BREE only has data for coal mining, and oil and gas mining through its annual publication, *Australian Energy Statistics*. The International Energy Agency (IEA) data on energy use for Australia also does not go beyond these two sectors. Further, due to the change in the ABS ANZSIC classification system from 1993 to 2006, productive capital stock series could not be developed for metal or non-metallic mining. For these reasons, the sub-sector level mining productivity analysis was restricted to two sectors: coal and oil and gas.

6.1 Structural adjustments in mining

Export prices increased unevenly among the mining sectors from the early 2000s. This led to a shift in the activity of various sectors causing some structural change within mining. As a result, sectoral shares in Australian mining value added changed rapidly from 2002 to 2010. In particular, the share of the metal ore sector has increased substantially from 25 per cent in 2001-02 to 40 per cent in 2009-10, while oil and gas declined from 43 percent to 26 per cent over this period (Figure 6-1). The share of coal in mining value added increased slightly from 21 per cent in 20001-02 to 26 per cent in 2009-10. It is noteworthy that the share of coal in mining value added climbed to 35 per cent in 2008-09 before the Queensland floods in 2010, when coal mines could not be operated due to mine flooding. The growth in the coal and oil and gas mining value added from 2001-02 to 2009-10 was 2.3 per cent and -6.2 per cent, respectively.

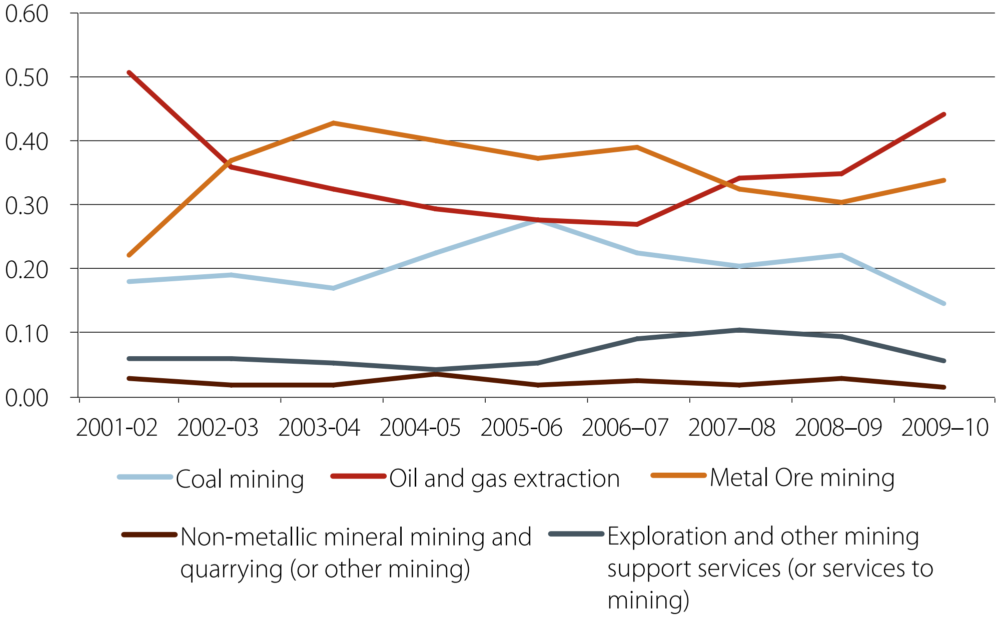
Figure 6-1: Relative growth in value added share, mining sub-sectors, 2000-01 to 2009-10



Source: ABS cat. 5204 and 8155 (various years)

Including the year 2009-10, the growth in the coal, and oil & gas mining investment from 2001-02 to 2009-10 was -2.8 per cent and -1.6 per cent, respectively. It is worth noting that for LNG (liquefied natural gas), investment, employment and value added are categorised in the manufacturing sector by ABS.

Figure 6-2: Relative growth in investment share, mining sub-industries, 2000-01 to 2009-10



Source: ABS cat. 5204 and 8155 (various years)

6.2 Adjustment to mining sectoral growth

Adjustments for depletion of resources to the two mining sectors' MFP were made using the measure of energy productivity in each mining sector over the period 2001-02 to 2009-10 in the same way as for the national productivity adjustments. Only two sectors, coal-mining and oil and gas mining were evaluated because the energy use data are available just for these two sectors.

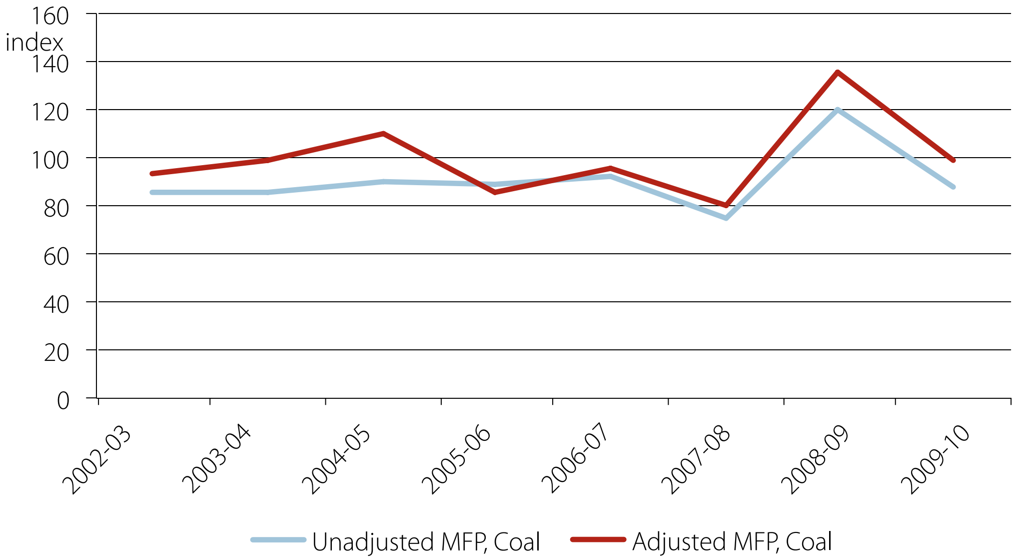
Figures 6-3 and 6-4 show for both coal-mining and oil and gas-mining, the conventionally estimated MFP, along with an estimate of adjusted MFP. These figures show that when resource depletion and capital lag effects are removed, MFP in each sector, coal mining, and oil & gas-mining, grew at a higher rate compared to when depletion and lag effects were not removed.

In coal-mining, adjusted MFP grew at an annual average rate of 0.83 per cent against 0.46 per cent growth in unadjusted MFP. The finding of a negligible or a very low depletion in this study is consistent with the result of Topp et al. (2008) for the period 1974-75 to 2009-10. Namely, that depletion in coal mining is relatively minor, and is even less of an issue for open cut coal mining.

In oil and gas extraction, unadjusted MFP fell at an annual average rate of decline of 10.70 per cent a year. After adjustment, MFP declined by 4.5 per cent a year. Hence, the rate of MFP deceleration moderated from 10.7 to 4.5 per cent a year, yet the MFP in oil and gas still

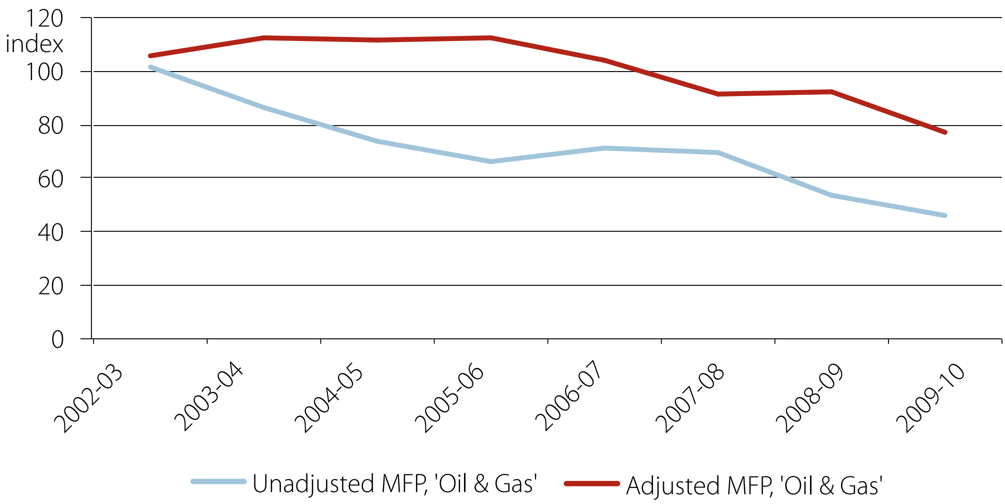
declined in the 2000s. That is, this sector appears to have suffered MFP decline that was not due to endogenous depletion alone (deliberate or deeper extraction), but due to the exogenous depletion of oil as a result of a reduction in the flow rate in many traditional exploration sites, particularly in Victoria.

Figure 6-3: Adjusted and Unadjusted MFP index, coal mining, 2002-03 to 2009-10



Source: BREE estimates

Figure 6-4: Adjusted and Unadjusted MFP index, oil & gas mining, 2002-03 to 2009-10.



Source: BREE estimates

7. Examination of the technological change, input bias, and MFP decomposition.

In this section we provide an econometric estimation of MFP over time. In particular, we focus on decomposing changes in MFP into three components.

7.1 MFP growth and decomposition: Theoretical Framework

MFP studies facilitate the decomposition of MFP growth into technical efficiency change, technological change, and scale effects, that is.

MFP = *TP+SC+TEC* where *MFP* =Multifactor productivity growth; *TP* = technological change (progress); *SC* = scale effects; and *TEC* = technical efficiency change.

TEC refers to catching up of firms in an industry where there already exists better technology in the industry. It is the process of catching up with the leader. In other words it is the process of moving to a higher point on a production function (given the technology) by effective use of production inputs. By contrast, the process of technological progress (TP) depicts a shift in the production function to a higher level using the same inputs.. Scale effects represents changes in MFP that arise from changes to the scale of output on production that may be favourable or unfavourable.

The technical efficiency of production is the ability and willingness of a firm/farm to produce the maximum possible output from a given set of inputs and technology by using the best practice techniques of the chosen technology. It can be measured by either data envelopment analysis (DEA) or stochastic frontier analysis (SFA). (Kalirajan and Shand, 1994). The stochastic frontier estimation provides standard errors of production coefficients, which facilitates testing of different hypotheses related to firms' decision making process, whereas a deterministic DEA approach cannot provide standard errors of coefficients (Coelli et al., 2003)[2]

The empirical translog production function used in this study with capital, labour and time as independent variables along with value added in mining as the dependent variable is as follows:

$$lny_{it} = \beta_0 + \beta_1 lnc_{it} + \beta_2 lnl_{it} + \beta_3 t + \beta_{11} (lnc_{it})^2 + \beta_{22} (lnl_{it})^2 + \beta_{33} (t)^2 + \beta_{12} lnc_{it} * lnl_{it} + \beta_{13} t * lnc_{it}$$

$$+ \beta_{23} t * lnl_{it} + v_{it} - u_{it} \qquad (1)$$

2 It is possible to combine stochastic frontier models and the DEA measures as priors of efficiency in the stochastic frontier model. These prior measures are revised to obtain posterior measures using Bayes' theorem (Tsionas, 2003).

Where y_{it} refers to value added of the i^{th} observation in the t^{th} period; c_{it} referes to capital of the i^{th} observation in the t^{th} period; l_{it} stands for labour of the ith observation in the t^{th} period; t refers to time period; and β's are parameters to be estimated. v_{it} refers to the conventional 'statistical error'term, which includes other left out variables, measurement errors associated with inputs and value added and specification errors associated with the functional form. u_{it} refers to observation-specific characteristics that influence technical efficiency of observations.

Technical efficiency is assumed to be time varying in equation (1), that is,

$$u_{it} = \eta_{it} u_i = \{exp[-\eta(t-T)]\}u_i \quad (1a)$$

Diagnostic and model tests can be performed to ascertain whether there is:

1. Hicks-Neutral technological progress;

2. No technological progress in the production frontier;

3. Production technology is represented by a Cobb Douglas production function; and

4.Efficiency framework is suitable (Table 7-1).

Table 7-1: Specification Tests for the Translog Model

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

In addition to the above tests the following test is done to verify the specification of the technical efficiency measure whether it is time-varying (the null of $\eta = 0$).

Using the data on seven regional Australian states between 1990-91 to 2009-10 equation (1) was estimated. After estimating equation (1) and calculating observation-specific technical efficiencies, drawing on the Malmquist index approach, MFP growth can be decomposed into three components namely: 1. rate of technological change (TP), 2. a scale component (SC), and 3. a change in technical efficiency (TE).

Technological change is measured by the partial derivative of the production function with respect to the time. The scale component 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; and the technical efficiency changes are given in equation 6. Based on the translog model and time varying technical efficiency model, technological progress and scale component can be formulated as follows:

$$TP = \frac{\partial \ln(y_{it})}{\partial t} = \beta_3 + \beta_{33}t + \beta_{13}\ln c_{it} + \beta_{23}\ln l_{it} \tag{2}$$

$$SC = (\xi - 1)\sum_j \left(\frac{\xi_j}{\xi}\right) X_j \tag{3}$$

Where ξ_j is the elasticity of output with respect to jth input and x_j is the growth rate of *j*th input and η is the sum of all elasticities. The elasticity of output with respect to each input measures the relative change in each input owing to a relative change in output. Output elasticity with respect to capital and labour respectively can be calculated as follows:

$$\xi_1 = \frac{\partial \ln(y_{it})}{\partial c} = \beta_1 + \beta_{13}t + \beta_{11}\ln c_{it} + \beta_{12}\ln l \tag{4}$$

$$\xi_2 = \frac{\partial \ln(y_{it})}{\partial l} = \beta_2 + \beta_{23}t + \beta_{12}\ln c_{it} + \beta_{22}\ln l \tag{5}$$

From the estimated observation-specific technical efficiency measures, the change in technical efficiency can be defined as

$$TEC = \frac{TE_{i(t+1)}}{TE_{it}} \tag{6}$$

Using the results from equations (2), (3), and (6) , the MFP growth decomposition by the Malmquist production index approach can be calculated by $MFP^* = TP+SC+TEC$.

7.2 MFP growth and decomposition: Empirical Results

Table 7-2 shows the characteristics of variables used in the empirical estimation.

Table 7-2: Key Statistics, 1989-2010

Variables	Mean	Std. Dev.	Minimum	Maximum
Output (Value Added)	10036.90	11158.85	280.00	49496.00
Capital (net capital stock)	23818.16	30925.18	397.42	189324.30
Labour (employment)	13167.90	13732.60	578.00	60824.00
Output (Index of Value Added)	87.93	32.21	33.53	179.97
Capital (Index of net capital stock)	117.42	123.49	24.26	1049.28
Labour (Index of employment)	67.68	25.20	13.23	129.15
Labour Share	0.25	0.13	0.03	0.63
Capital Share	0.75	0.13	0.37	0.97
Depletion	281.31	172.88	37	874.3

Following Battese and Coelli (1992), the unrestricted translog equation (1) and five restricted models were estimated in order to choose the appropriate functional form to check the validity of the modelling of the technical efficiency effects and technical change captured by a time trend.

The test results are given in Table 7-3. These results indicate that the stochastic frontier translog equation given in equation (1) has 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, which can be verified from the signs of the coefficients of the variables t^*lnc_{it} and t^*lnl_{it} in equation (4). When the coefficients are positive, it indicates that there is technical bias in terms of input use. The negative sign of the coefficients indicate that there is technical bias in terms of saving the usage of those concerned variables. The estimated values of the production parameters along with parameters related to technical efficiency specification are provided in Table 7-4.

Table 7-3: 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)	X^2(0.010)	X^2(0.050)	X^2(0.10)	Decision
H_0: $\beta_{13} = \beta_{23} = 0$	180.94	9.21	5.99	4.61	Reject H_0
H_0: $\beta_{33} = \beta_{13} = \beta_3 = \beta_{23} = 0$	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: $\mu = \eta = 0$	137.20	9.21	5.99	4.61	Reject H_0
H_0: $\eta = 0$	135.88	6.64	3.84	2.71	Reject H_0

Table 7-4: Panel Estimation of Stochastic Frontier Production Function with Technical Efficiency Effects

Variable	Equation 4
Log(K)	-0.71***(-3.29)
Log(L)	1.59***(4.94)
t	-0.39***(-7.65)
$0.5(Log(K))^2$	0.13***(3.16)
$0.5(Log(L))^2$	-0.10*(-1.99)
$0.5t^2$	-0.002*(-1.80)
Log(K) Log(L)	-0.07*(-1.90)
t Log(K)	0.02***(5.18)
t Log(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: (1) The dependent variable for frontier estimation is log of value added and total number of observations is 147. All models are significant.

(2) The values in parentheses below the coefficients show the t-statistics.

(3) *, **, ***, 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 $t*lnc_{it}$ and $t*lnl_{it}$ 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.

The implication of the estimation results is that the proportional saving in the use of capital and labour is less than the average proportional savings over material inputs. The results also show that capital and labour are substitutes, and imply that more labour than capital has been used in the production process. In other words, although the production technology used both capital and labour relatively more than the material inputs, the technology was relatively more labour intensive.

The results show the coefficient of the *t* variable in Table 7-4, where the coefficient of the variable *t* is negative and significant (-0.39). This implies no technological progress during the period of analysis. The decomposition of the MFP growth is given in Table 7-5.

Table 7-5: Mean technical progress (TP), technical efficiency (TE), scale effects (SC) and multifactor productivity, 1990-91 to 2009-10

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

The mining MFP growth decomposition over the study period shows that Australian mining experienced no statistically significant technological change. The decomposition further shows that technical efficiency and scale effects contributed positively and significantly to Australian Mining MFP, after removing the effect of depletion.

8. Conclusions

Mining provides an important contribution to the Australian GDP, and it is a major component of exports. Thus, what happens to productivity in this sector is important from both a national perspective as well for the resources sector.

In this study we provide quantitative estimates of mining productivity at each of the national, regional and sectoral levels and examine the technological relationships among inputs in Australian mining and the factors influencing mining productivity.

Our study examines the effect on mining industry productivity growth as a result of changes in the underlying quality of natural resource inputs used in mining, production lags in response to increases in capital investment and the technological nature of capital and labour input use in Australian mining.

We find that Australia's mining capital-labour ratio grew at 5.8 per cent a year in the 1990s, but fell 1.65 per cent a year in 2000s. In Australia, as resource commodity prices increased over the early 2000s, miners were able to increase output by employing more labour without increasing capital in the same proportion as labour. Contemporaneous with labour working with proportionally less capital, unadjusted multifactor productivity (MFP) fell in the 2000s.

To analyse regional mining productivity, relevant data were collected from ABS and BREE sources. The data included information on capital, labour, value added, and shares of labour and capital. Due to the lack of availability of consistent time-series data, national mining analysis was undertaken from 1985-86 to 2009-10, whereas the regional and sectoral analysis were completed for 1990-91 to 2009-10, and 2001-02 to 2009-10 periods, respectively.

Typically, when resources are depleted successively more fuel energy is needed to produce the same amount of net output. Energy use data can, therefore, be used to estimate the extent to which changes in the quality of resource deposits contribute to changes in output each year. In particular, the amount of energy used can represent the amount of effort that must be expended in mining resources. This is because a decline in the deposit of certain depth will increase the use of energy use per unit of output due to depletion. Adjustments for depletion of resources to mining MFP were made using a measure of energy productivity.

Our mining productivity analysis was conducted at the national, regional and sectoral levels. At the sectoral level, only two sectors, coal-mining and oil and gas mining were analysed because the energy use data were only available for these two sectors. We find that for Australian mining as a whole, after removing the influence of both output quality depletion and production lags, the MFP growth rate rose at an average annual rate of 2.5 per cent between 1985-86 and 2009-10. When resource depletion and capital lag effects are removed, MFP in each state grows at a higher rate compared to when depletion and lag effects are not removed. Our study also shows that when resource depletion and capital lag effects are removed, MFP in the coal mining, and oil and gas-mining sectors grows at a higher rate compared to when depletion and lag effects are not considered.

As part of our study, we also undertook an econometric decomposition of mining MFP. 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, distinct from technical efficiency, was observed over the study period.

In sum, we find that although productivity fell in the first decade of the Millennium Mining Boom relative to the 1990s, adjusted MFP increased. It would seem that much of the apparent decline in unadjusted MFP in Australian mining over the past decade is attributable to both exogenous and endogenous resource depletion.

Appendix A: Measurement of productivity in mining

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.

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):

(1) $$MFP_i^t = \frac{Y_i^t}{I_i^t}$$

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).

(2) $$I_i^t = T(K_i^t,\ L_i^t)$$

T(.) 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:

(3) $$\frac{I_i^t}{I_i^{t-1}} = \left[\frac{K_i^t}{K_i^{t-1}}\right]^{w_{ki}^t}\left[\frac{L_i^t}{L_i^{t-1}}\right]^{w_{li}^t}$$

where:

(4a) $$w_{ki}^t = \frac{1}{2}\left[s_{ki}^t + s_{ki}^{t-1}\right]$$ and

(4b) $$w_{li}^t = \frac{1}{2}\left[s_{li}^t + s_{li}^{t-1}\right]$$

Where s^t_{ki} is the capital share and s^t_{li} is the labour share of income (value added) in industry *i* 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.

Forming the output and input indexes

The required data indexes are not available at the sub-industry level from the ABS national accounts, with a couple of exceptions. Consequently, other 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-industry 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.

Appendix B: Data sources

In order to estimate various MFP estimates, 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, 2011-12*

ABS cat. no. 5204.0, *Australian System of National Accounts, 2011-12*

ABS cat. no. 8155.0, *Australian Industry, 2010-11*

ABS cat. no. 5220.0, *Australian National Accounts: State Accounts, 2011-12*

ABS cat. no. 5625.0, *Private New Capital Expenditure and Expected Expenditure, Australia, Dec 2012*.

ABS cat. no. 6291.0.55.003, *Labour Force, Australia, Detailed, Quarterly, Nov 2012*

BREE, *Australian Energy Statistics*.

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ABS 2012a (various years), *Australian System of National Accounts* cat. no. 5204.0, Canberra.

ABS 2012b (various years), *Australian Industry,* cat. no. 8155.0, Canberra.

ABS 2012c (various years), *Australian National Accounts: State Accounts,* cat. no. 5220.0, Canberra.

ABS 2012d (various years), *Private New Capital Expenditure and Expected Expenditure, Australia,* cat. no. 5625.0, Canberra.

ABS 2012 (various years), *Labour Force, Australia, Detailed, Quarterly,* cat. no. 6291.0.55.003, Canberra.

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