Australian Government
Productivity Commission

Productivity in the Mining Industry:

Measurement and Interpretation

Productivity Commission
Staff Working Paper

December 2008

Vernon Topp
Leo Soames
Dean Parham
Harry Bloch

The views expressed in this paper are those of the staff involved and do not reflect those of the Productivity Commission.

ISBN 978-1-74037-271-8

This publication is available in hard copy or PDF format from the Productivity Commission website at www.pc.gov.au. If you require part or all of this publication in a different format, please contact Media and Publications (see below).

Publications Inquiries:
Media and Publications
Productivity Commission
Locked Bag 2 Collins Street East
Melbourne VIC 8003

Tel: (03) 9653 2244
Fax: (03) 9653 2303
Email: maps@pc.gov.au

General Inquiries:
Tel: (03) 9653 2100 or (02) 6240 3200

An appropriate citation for this paper is:

Topp, V., Soames, L., Parham, D. and Bloch, H. 2008, *Productivity in the Mining Industry: Measurement and Interpretation,* Productivity Commission Staff Working Paper, December.

JEL code: D, Q

The Productivity Commission

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

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

Information on the Productivity Commission, its publications and its current work program can be found on the World Wide Web at www.pc.gov.au or by contacting Media and Publications on (03) 9653 2244

Contents

BOXES

FIGURES

TABLES

Preface

This staff working paper examines the productivity of the Australian mining sector and highlights some significant issues relating to the measurement and interpretation of productivity trends within the sector.

An early version of the ideas developed in this paper was presented by then Assistant Commissioner Dean Parham at the Productivity Perspectives Conference in Canberra in December 2007 under the title *Mining Productivity: The Case of the Missing Input?*.

Helpful comments on the paper were received from Lindsay Hogan and Shiji Zhao (ABARE); Ellis Connolly, Anthony Richards and Michael Plumb (Reserve Bank of Australia); Dan Wood and Commissioner Matthew Butlin. Gavin Mudd (Monash University) and Alan Copeland (ABARE) also provided data and helpful comments on the paper. Ben Dolman, Paul Gretton, Tracey Horsfall and Tony Kulys from the Productivity Commission assisted in the preparation of the paper.

Abbreviations

ABARE	Australian Bureau of Agricultural and Resource Economics
ABS	Australian Bureau of Statistics
ACR	Accommodation, cafes and restaurants
AMMA	Australian Mines and Metals Association
APPEA	Australian Petroleum Production and Exploration Association
BHPB	Broken Hill Proprietary Billiton
BoM	Bureau of Meteorology
CRS	Cultural and Recreational Services
CSLS	Centre for the Study of Living Standards (Canada)
Ct	Carat
CVM	Chain Volume Measure
DCITA	Department of Communications, Information Technology and the Arts
EGW	Electricity, Gas and Water
FIFO	Fly-In, Fly-Out
GDI	Gross Domestic Income
GDP	Gross Domestic Product
GFCF	Gross Fixed Capital Formation
GL	Billion (10^9) Litres
Gm^3	Billion (10^9) Cubic Metres
GVP	Gross Value of Production
HPAL	High Pressure Acid Leach
ICT	Information and communications technology
JORC	Australasian Joint Ore Reserves Committee
LNG	Liquefied Natural Gas

LPG	Liquefied Petroleum Gas
MFP	Multifactor productivity
ML	Million Litres
Mm^3	Million Cubic Metres
OECD	Organisation for Economic Co-operation and Development
PC	Productivity Commission
SLZ	Silver, Lead and Zinc
VDPI	Victorian Department of Primary Industry
WADOIR	Western Australia Department of Industry and Resources

OVERVIEW

Key points

- Mining typically accounts for around 5 per cent of Australia's nominal market sector gross domestic product.
  - A 'once-in-a-generation' shock to demand for, and prices of, mining commodities saw this share rise to 8.5 per cent in 2006-07, stimulating substantial growth in new investment, employment, and profits.
  - Yet output growth in mining in recent years has been weak at best, and multifactor productivity (MFP) has declined by 24 per cent between 2000-01 and 2006-07.
- Long lead times between investment in new capacity in mining and the associated output response can lead to short term movements in mining MFP unrelated to underlying efficiency.
  - Around one-third of the decline in mining MFP between 2000-01 and 2006-07 is estimated to be due to this temporary effect. This effect was particularly important in the last few years of this period.
- Ongoing depletion of Australia's natural resource base is estimated to have had a significant adverse effect on long-term mining MFP.
  - In the absence of observed resource depletion, the annual rate of mining MFP growth over the period from 1974-75 to 2006-07 is estimated to have been 2.3 per cent, compared with the measured rate of 0.01 per cent.
- Over the longer-term, MFP impacts of resource depletion have been offset by technological advances and improved management practices. An increase in the use of open-cut mining has been a key development, along with a general increase in the scale and automation of mining equipment.
- An expected rebound in mining MFP from 2008-09 onward may be delayed as a consequence of the decline in world prices for many mineral and energy commodities in mid-to-late 2008. Any temporarily idle capital associated with production cut-backs and mine closures will tend to lower MFP. On the other hand, significantly lower commodity prices may lead mining companies to cut costs, with a positive effect on MFP.
- Despite the impact of the fall in mining MFP, the sector has made a significant contribution to the strong overall growth in national income so far this decade through a substantial improvement in Australia's' terms of trade.

Overview

The measurement and interpretation of productivity frequently presents significant challenges, especially when conducted at the industry level. In this regard the mining industry is no exception. This report identifies measurement and interpretation issues of relevance to productivity estimates for the mining industry in Australia. Quantitative evidence is presented regarding the effect on mining industry productivity growth of two important factors: systematic changes in the underlying quality of natural resource inputs used in mining; and production lags in response to increases in capital investment.

Productivity in the Australian mining industry

The mining industry has had a major influence on Australia's productivity performance and prosperity in recent years. While its influence on prosperity has been positive, the opposite has been the case in relation to productivity.

A surge in commodity prices (figure 1) from 2003-04 to 2006-07 has been the major influence on the sector. Higher commodity prices have resulted in large increases in the *value* of output as well as in income and prosperity. But they have not induced a commensurate increase in the *volume* of mining output. Because substantially increased usage of capital and labour inputs has accompanied only a modest increase in output, multifactor productivity (MFP) has fallen.

Review of productivity trends

Mining has been characterised by:

- a high level of labour productivity (output per hour worked);
- little overall growth in MFP from the mid-1970s to current times (see figure 2);
- long swings of positive growth in MFP (the 1980s and 1990s) and decline (the 1970s and 2000s); and
- significant volatility in MFP over shorter periods (a few years) compared with most other industries.

Figure 1 **Index of mineral and energy commodity prices, 1974-75 to 2006-07**

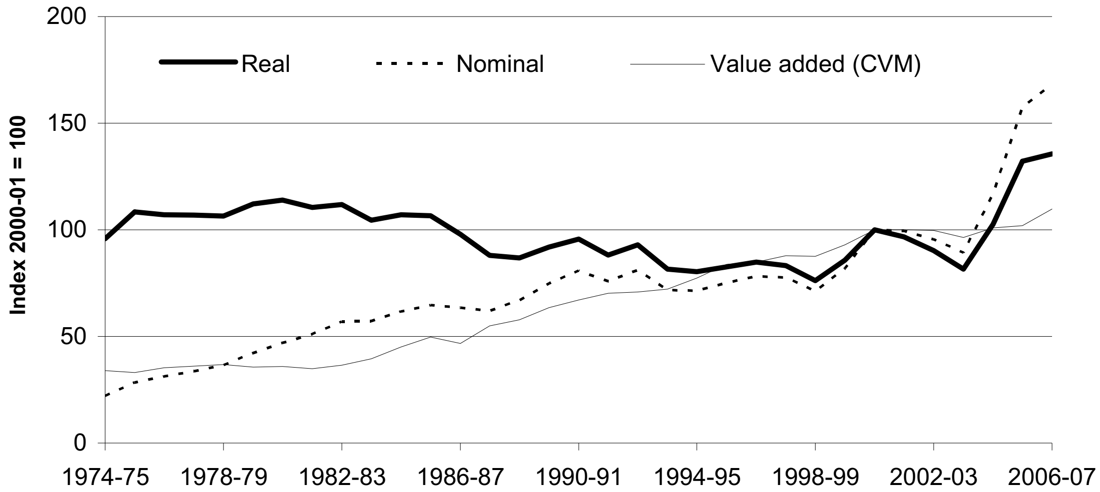
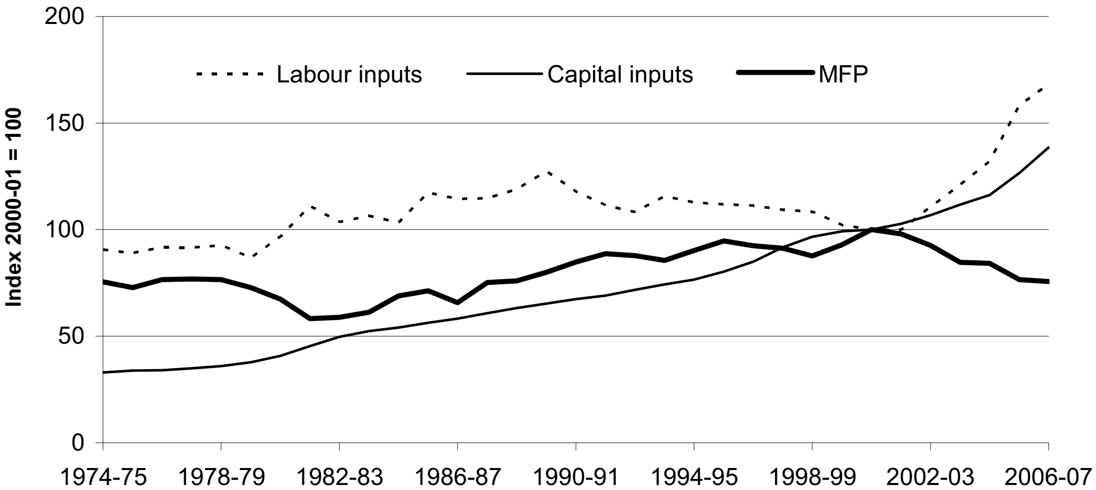


Figure 2 **Mining industry MFP and primary inputs**



The decline in mining MFP since the peak in 2000-01 has been quite marked. Australian Bureau of Statistics (ABS) estimates put the decline in MFP between 2000-1 and 2006-07 at 24.3 per cent. As a sector that generates a substantial proportion of market sector output (around 8.5 per cent of gross value added in 2006-07), the decline in mining productivity has contributed substantially to a slowdown in market sector productivity growth. The sharpest annual drop in mining productivity was in 2005-06, when a 8.8 per cent fall took close to a full percentage point off productivity growth for the market sector as a whole. (The latter was just 0.2 per cent in 2005-06, compared with the longer-term average of 1.2 per cent.)

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 (figure 2). 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.

Non-renewable resources and mining productivity

Mining differs from other sectors of the economy in that it relies on non-renewable resources as inputs to production, and generally requires large investments in new capacity that can take a considerable time to build and become operational. As a result, conventional estimates of productivity growth in the sector need to be interpreted carefully.

Different interpretation due to the major influence of natural resource inputs

Typically, MFP can be broadly interpreted as an indicator of the efficiency with which capital and labour inputs are used to generate output of goods and services. The efficiency of production is determined by factors such as technology, management, skills and work practices. However, productivity in mining also reflects the influence of a further factor, the influence of which is substantial.

That additional factor is the input of natural resources. While natural resources are obviously a major input into mining production, changes in their quality are not generally taken into account in standard measures of productivity. This omission would not be a problem if natural resources were in infinite supply and of homogeneous quality — that is, available without constraint at the same unit cost of extraction. But neither is the case: resource deposits are non-renewable, and depleted by ongoing extraction. And as mineral and energy deposits are depleted, the quality and accessibility of remaining reserves generally decline. Miners, by choice, focus initially on high-quality, readily accessible deposits, since they produce the highest returns. As these deposits are depleted, remaining deposits may be of lower grade, in more remote locations, deeper in the ground, mixed with greater impurities, require more difficult extraction techniques and so on.

As the quality and accessibility of deposits decline, greater commitments of capital and labour are generally needed to extract them. When deposits are deeper, more development work is needed to access the desired resources. If there are greater impurities, greater costs may be incurred in extracting and processing the material into saleable output. In short, more ‘effort’ is needed to produce a unit of output.

The additional capital and labour required per unit of output show up as a decline in measured productivity. Consequently, productivity in mining reflects not only changes in production efficiency, but also changes in the underlying quality and accessibility of natural resource inputs to mining.

Measuring the contribution of resource depletion to mining MFP

For the purposes of this paper, the extent to which resource depletion is occurring in the mining industry is measured by movements in a composite index of mining ‘yield’. This index is constructed using average ore grades in metal ore mining, the ratio of saleable to raw coal in coal mining, and the implicit flow-rate of oil and gas fields in the petroleum sector. Output in mining can be adversely affected if there is a decline in yield because of depletion.

Between 1974-75 and 2006-07, the composite index of the average yield in mining fell substantially (figure 3). If the changes in mining industry output due to the observed yield declines are taken into account, multifactor productivity in the mining industry is estimated to be significantly higher. That is, resource depletion in the form of yield declines is estimated to have had a significant adverse impact on multifactor productivity in the mining industry over the past thirty-two years (figure 4). Once the effect of yield changes is removed, mining MFP grows at an average rate of 2.5 per cent per year, compared with 0.01 per cent per year in conventionally measured mining MFP.

Figure 3 **Index of mining industry yield**

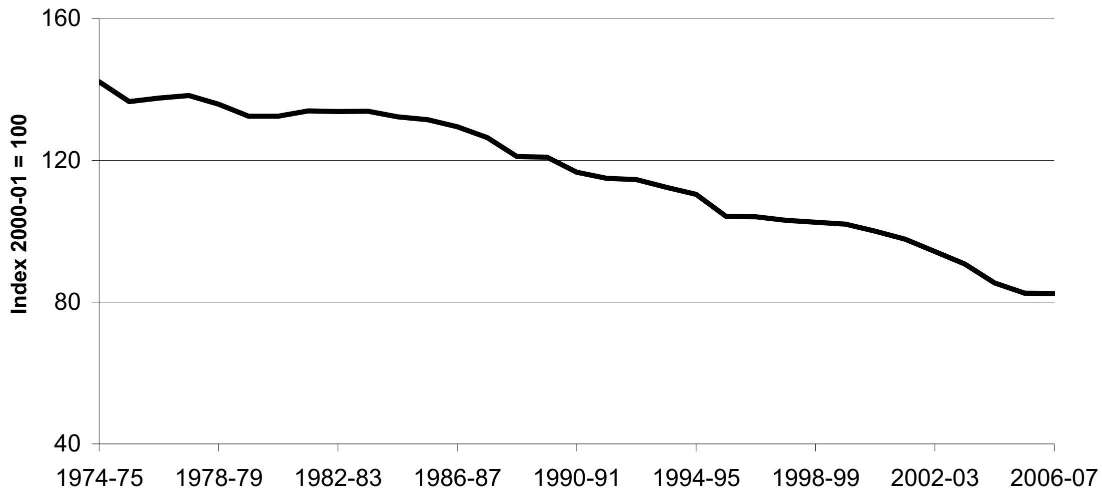
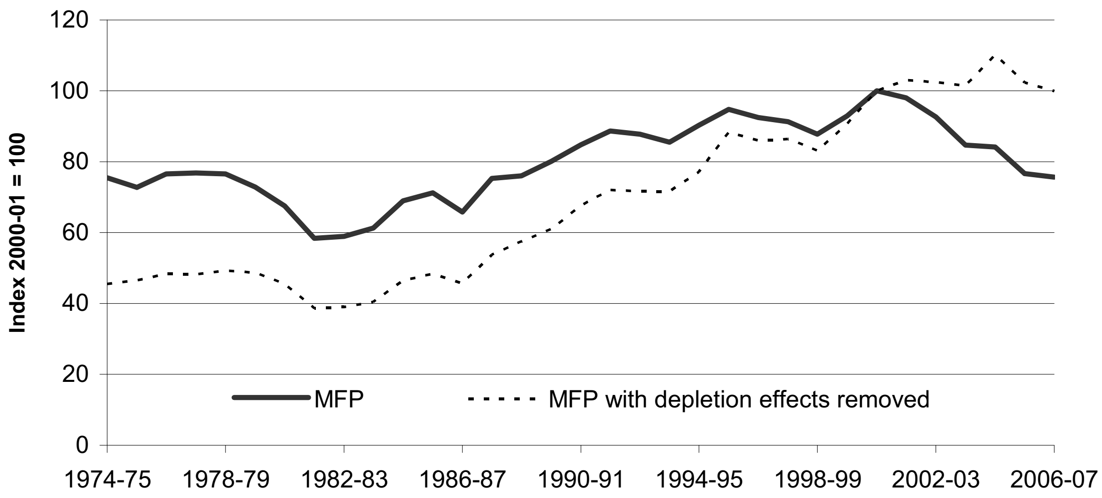


Figure 4 **Mining MFP**

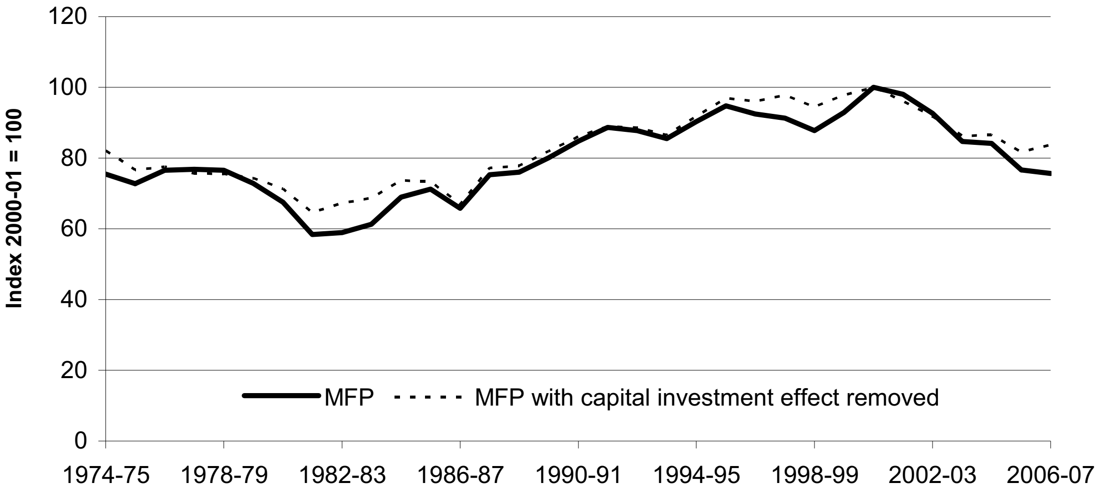


Long lead times in new mining developments

A second reason that movements in mining MFP need to be interpreted carefully is that there are usually long lead times between investment in new capacity in the sector (whether in the form of new mines or mine expansions) and the corresponding output. New investment in the mining industry is highly variable, with occasional surges often followed by large declines. Since new investment is generally recorded immediately in MFP calculations (as an increase in capital inputs), any lag in output response will have an immediate adverse effect on MFP. A concomitant positive effect on MFP will occur at some point in the future when output from previous new investment comes on stream. The consequence is that in times of major increases or decreases in investment, there can be short-term but substantial movements in MFP that *do not* reflect changes in the fundamental efficiency with which inputs are combined to produce outputs. Although these movements are essentially temporary, there is considerable scope for them to be misinterpreted as changes in underlying efficiency.

The relationship between investment and output is complex and varies from project to project. Empirical and other data suggest that the lead time for new mining projects is, on average, around three years. That is, there is a delay of approximately three years between the time of initial commitment to or construction of new mining projects, and the time output from those developments approaches full or normal capacity. As a result of these lags, changes in the rate of growth in mining investment are found on occasions to contribute significantly to short-term movements in mining MFP. This is illustrated in figure 5, which shows conventionally estimated MFP in the mining industry along with 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.

Figure 5 **Mining MFP with capital lag effects removed**



The role of higher commodity prices

Higher output prices also raise resource rents (revenues in excess of costs of extraction) and encourage miners to increase the rate of extraction. This leads to lower productivity through a number of mechanisms. Higher prices and resource rents enable and induce:

- extraction of more-marginal deposits — that is, deposits that are of lower quality and accessibility and, hence, require more effort per unit of output to extract
  – existing operations can be continued longer than would otherwise be the case, previously mothballed mines can be reopened, and new mines that extract lower-quality, less-accessible and more-difficult deposits can come on stream – that is, higher prices temporarily add to the underlying ‘depletion’ effects.
- more costly production while the capacity of mines is constrained
  – since mines are usually run at or near full capacity, output can only be increased in the short to medium term by using more labour and intermediate inputs per unit of output (and generally less-efficient methods) with changes in capital constrained in the short run.

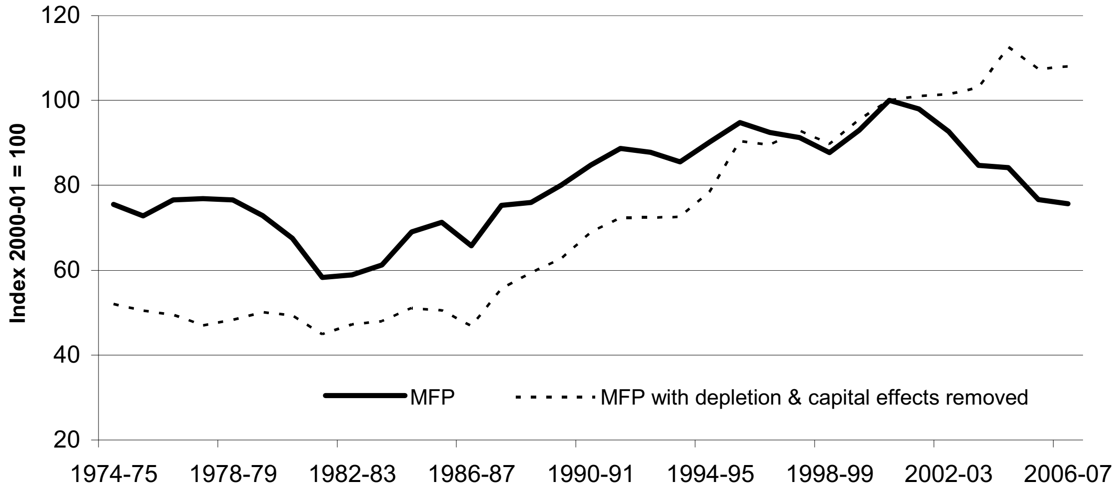
The effect of these phenomena is likely to be temporary or transitional, although they may be quite long lasting in the presence of sustained periods of high commodity prices. At the same time, sustained higher prices provide an incentive to expand exploration for new deposits. If new deposits are discovered they could provide opportunities to increase average productivity. However, some exploration is unsuccessful, and new discoveries may be below-average quality. Furthermore, the lags between discovery and extraction may be so long that any countervailing effect would come only after a considerable time.

Explaining longer-term productivity trends

Together, yield declines due to resource depletion and the temporary effects of long lead-times in new mining developments explain a large amount of the variability in mining MFP over time (figure 6). After removing the influence of these factors, it is estimated that there has been significant underlying MFP growth in mining over the past 32 years — around 2.3 per cent per annum — due to other factors.

Positive contributions to mining MFP over the longer-term include improvements in production efficiency through technological advances and improved management techniques. Some examples 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. Australia, with a long history of underground mining, 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 wells in deeper and deeper water.

Figure 6 **Mining MFP with depletion and capital effects removed**

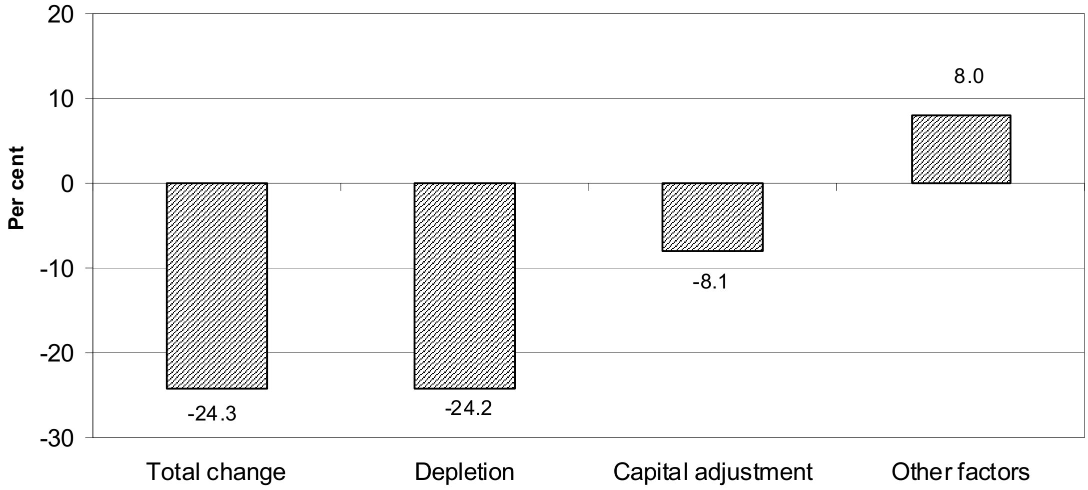


The recent decline in productivity

Yield declines and a surge in new capital investment are estimated to have contributed substantially to the decline in mining industry MFP between 2000-01 and 2006-07. Yield declines are the dominant factor in the first few years of the period, while production lags associated with the surge in new capital investment from 2004-05 to 2006-07 are the dominant factor in the last few years of the period. After removing the influence of yield changes and production lags, other factors are estimated to have raised mining MFP by 8 per cent over the period (figure 7).

Recently released data from the Australian Bureau of Statistics indicate that MFP in the mining industry has fallen again in 2007-08, by just under 8 per cent. Capital investment lags are estimated to explain around 5 percentage points of the decline. Unfortunately, data limitations mean that it is not possible at this time to estimate the extent to which resource depletion contributed to the decline. However, it seems likely that a decline in aggregate production of crude oil and condensate in 2007-08 reflects ongoing reductions in oil and gas flow rates in some fields. To the extent this turns out to be the case, resource depletion is likely to emerge as an important explanatory factor of the decline in mining MFP in 2007-08 as well.

Figure 7 **Contributions to the change in mining MFP between 2000-01 and 2006-07**



Beyond the estimated effects of yield declines and production lags associated with the surge in capital investment, a range of other factors are likely to have had an impact on mining MFP growth in recent years. Some of these factors, such as continued improvements in technology, are likely to have made a positive contribution to MFP, while others such as short-term infrastructure constraints and the weather are likely to have detracted from MFP growth. Higher commodity prices during the period are also likely to have detracted from MFP growth by encouraging higher cost production, as miners attempted to ramp-up production in the short-term. It is difficult to quantify the individual effects of these factors.

Prosperity versus productivity

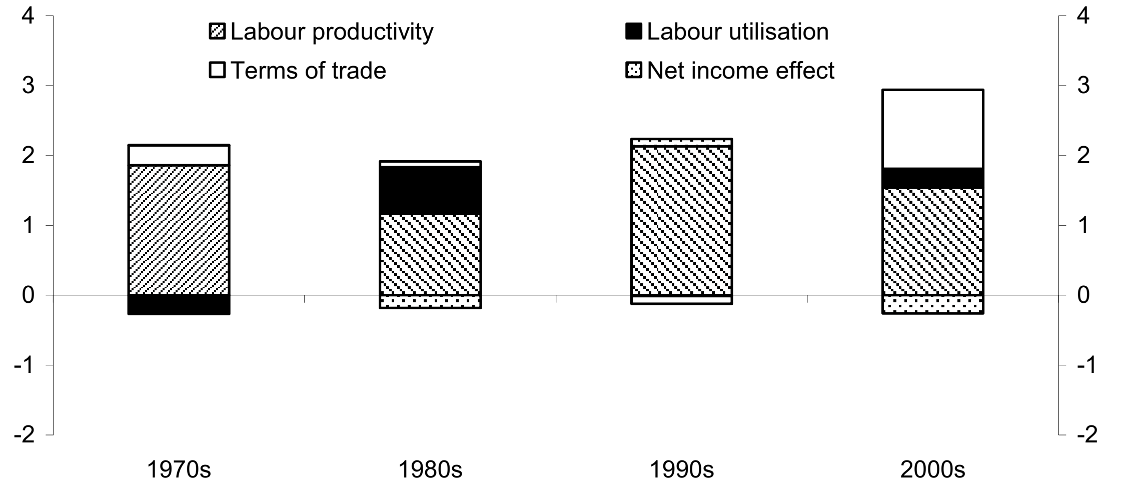
An increase in mining industry commodity prices was a major contributor to an improvement in Australia's overall 'terms of trade' — the ratio of export prices to import prices — between 2001 and 2007. In general, an improved terms of trade increases Australia's real income by allowing greater quantities of imports to be purchased for a given quantity of exports. An increase in the terms of trade is important because it provides a boost to national income, spending and economic activity. However, some of the profits associated with the resources boom accrue to foreign owners of Australian mining industry assets, so not all of the increased income associated with the mining boom necessarily flows through to the rest of the economy.

Figure 8 contains a breakdown of the factors that have contributed to national income growth in Australia over the past four decades, and illustrates the important role played by the higher terms of trade so far this decade. The 'net income effect' — which measures the change in gross national income due to the difference between domestically generated income payable to non-residents, and foreign sourced income payable to residents — detracted from income growth during the period, while improved labour productivity and higher labour utilisation (hours worked per capita) both made positive contributions.

Changes in the terms of trade, however, have had only a small effect when averaged over longer periods. Labour productivity growth, which reflects both MFP growth and the increase over time in the amount of capital per hour worked, has been the main source of income growth. Future income growth in Australia will continue to depend on strong underlying growth in labour and multifactor productivity, including in the mining industry.

Figure 8 **Contribution to income growth — the importance of the terms of trade**

Contributions to annual average growth in real gross national income per capita, percentage points per year



Impact of global economic developments and falling commodity prices

The expectation has been that mining MFP would begin to improve in 2008-09 as production associated with the surge in capital investment in the sector between 2004-05 and 2006-07 began to come on-stream.

However, these projections are now in question due to the decline in world prices of a number of mineral and energy commodities in mid-to-late 2008, and subsequent decisions by mining companies to postpone new developments, close mines, and cut-back production at other mines. Mine closures could be expected to have a positive effect on mining MFP, as higher cost mines will generally be closed first. On the other hand, cut-backs in output at existing mines may lead to lower MFP if they lead to temporarily idle capital.

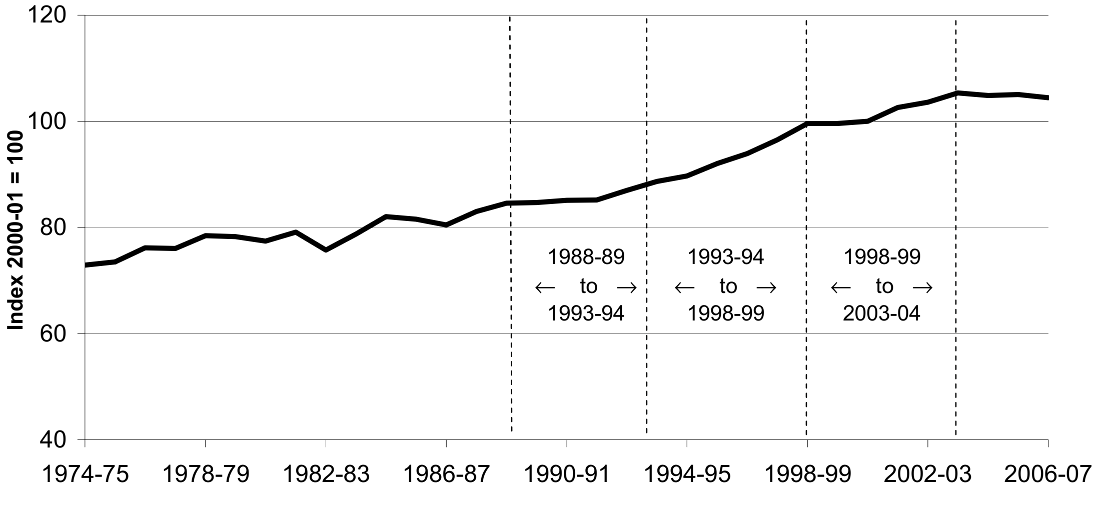
If mineral and energy commodity prices remain lower over the next few years, it is likely that mining companies will focus heavily on trying to reduce production costs. To the extent that they are successful in this, there will be a positive effect on mining MFP, supporting an expected rebound (albeit possibly further delayed) in MFP as production associated with the recent surge in capital investment comes on-stream.

1 Introduction

1.1 Background

Australia's aggregate productivity growth has been weaker in the 2000s compared with the strong performance in the 1990s (figure 1.1). The trend rate of multifactor productivity (MFP) growth, as represented by the annual average over a productivity cycle, dropped from an exceptionally-high 2.3 per cent in the cycle from 1993-94 to 1998-99 to 1.1 per cent in the next cycle ending in 2003-04.[1] (However, the latter rate is still only a little below the 1.3 per cent average over the period 1964-65 to 2003-04.) The years since 2003-04 have only covered an incomplete 'down' part of a cycle. While there is therefore no comparable trend figure as yet, it can be noted that productivity growth in the three years since 2003-04 has been unusually weak (see figure 1.1 and table 1.1)

Figure 1.1 **Market sector MFP, 1974-75 to 2006-07**

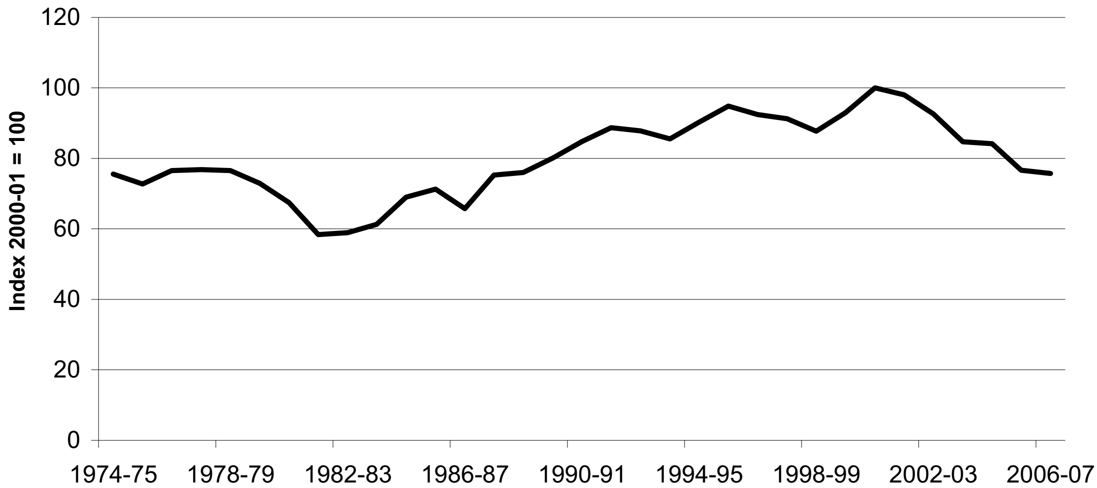


Data source: ABS (*Australian System of National Accounts 2007-08*, Cat. no. 5204.0).

[1] Productivity data are volatile from year to year and are also cyclical for a number of reasons, including that employment growth tends to lag output growth. To overcome these problems, the ABS measures underlying productivity trends by calculating annual average rates of growth between peaks in productivity cycles. For more information see the Productivity Commission website: http://www.pc.gov.au/research/productivity/estimates-trends/trends.

The weaker productivity performance of the market sector since 1998-99 has been characterised by slower rates of MFP growth across nearly all industries, including mining in more recent years. The wholesale trade, electricity, gas and water, and communications services industries have had the sharpest decline in the rate of MFP growth over the 1998-99 to 2003-04 period compared to the 1993-94 to 1998-99 period.[2] Since 2003-04, most industries have had lacklustre MFP growth, with the agriculture, mining and manufacturing industries in particular contributing negatively to overall productivity (table 1.1). With respect to the mining industry, measured productivity has fallen consistently since 2000-01 (figure 1.2), with the negative effect on aggregate productivity being especially strong in 2005-06, when a 8.8 per cent decline in mining MFP took almost one percentage point off market-sector productivity growth.

Figure 1.2 **Mining: MFP, 1974-75 to 2006-07**



Data source: Estimates are provided by the ABS for the period 1985-86 to 2006-07 (*Experimental Estimates of Industry Multifactor Productivity 2007*, Cat. no. 5260.0.55.002). The Productivity Commission extends the ABS estimates by calculating productivity related indexes for the period 1974-75 to 1985-86. These estimates are based on published and unpublished data provided by the ABS.

2 The industry contributions to weaker aggregate productivity growth are highlighted and discussed in Parham (2005) and Parham and Wong (2006).

Table 1.1 **Selected productivity estimates**
Per cent

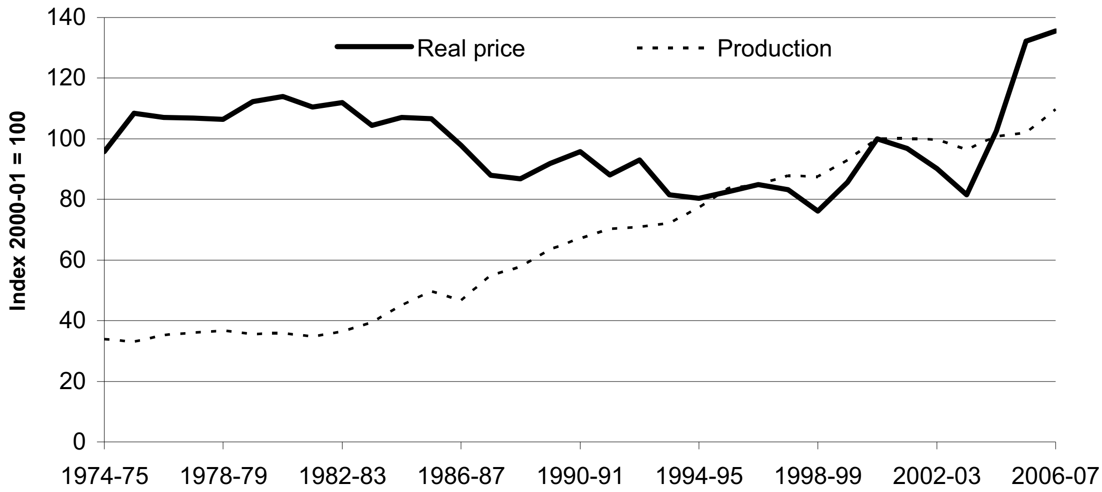
	1993-94 to 1998-99	1998-99 to 2003-04	2004-05	2005-06	2006-07	1974-75 to 2003-04
Market sector						
Labour productivity	3.3	2.1	0.3	2.5	0.4	2.1
MFP	2.3	1.1	-0.5	0.2	-0.6	1.1
	1993-94 to 1998-99	*1998-99 to 2003-04*	*2004-05*	*2005-06*	*2006-07*	*1974-75 to 2003-04*
Multifactor productivity (MFP)[a]						
AFF[b]	3.8	3.4	4.4	3.8	-23.9	1.8
Mining	0.5	-0.7	-0.6	-8.8	-1.3	0.0
Manufacturing	0.9	1.8	-3.5	-0.4	1.3	1.3
EGW[c]	2.0	-2.3	-1.8	-4.7	-4.7	1.4
Construction	2.7	0.9	-0.5	3.6	1.3	1.1
Wholesale trade	5.7	1.7	2.1	0.4	-4.2	0.7
Retail trade	1.9	1.3	-0.3	-0.1	3.1	1.0
ACR[d]	2.1	0.7	0.2	4.0	-1.9	-0.6
Transport and storage	2.2	2.4	1.8	-0.2	2.7	2.2
Communication services	4.7	0.1	-2.5	5.4	3.6	3.8
Finance and insurance	2.9	0.7	0.5	1.1	0.8	0.6
CRS[e]	-1.3	1.4	-0.6	-2.2	3.5	-0.6
Industry contributions to market sector MFP growth (percentage points)[f]						
AFF[b]	0.2	0.2	0.3	0.3	-1.3	
Mining	0.0	-0.1	0.0	-0.8	0.0	
Manufacturing	0.2	0.4	-0.8	-0.2	0.2	
EGW[c]	0.1	-0.1	-0.1	-0.1	-0.2	
Construction	0.3	0.1	-0.1	0.4	0.1	
Wholesale trade	0.5	0.1	0.2	0.1	-0.3	
Retail trade	0.2	0.1	-0.1	0.0	0.3	
ACR[d]	0.1	0.0	-0.1	0.2	-0.1	
Transport and storage	0.2	0.2	0.2	0.0	0.3	
Communication services	0.3	0.0	-0.1	0.2	0.2	
Finance and insurance	0.3	0.1	0.2	0.3	0.3	
CRS[e]	0.0	0.0	0.0	-0.1	0.1	

[a] Calculated as a value-added basis. [b] Agriculture, Forestry and Fishing. [c] Electricity, gas and water supply. [d] Accommodation, cafes and restaurants. [e] Cultural and recreational services. [f] Productivity Commission estimates.

Sources: ABS (*Australian System of National Accounts 2006-07,* Cat no. 5204.0); ABS (*Experimental Estimates of Industry Multifactor Productivity 2007,* Cat no. 5260.0.55.002).

The extent and duration of the decline in mining productivity has been surprising in view of the substantial increase in activity in the industry, especially in recent years. A 'once-in-a-generation' shock to demand for, and prices of, mining commodities has stimulated very substantial growth in new investment, employment and profits. And yet output growth has been weak at best and productivity has been in decline (figure 1.3).

Figure 1.3 **Mineral and energy commodities: production and output prices, 1974-75 to 2006-07[a]**



a 'Real price' is a composite index based on prices of: coal, crude oil, condensate and LPG, natural gas, iron ore, bauxite, nickel, manganese, uranium, tin, silver, lead, zinc, gold, copper, ilmenite, rutile, and zircon. Nominal prices deflated by the GDP deflator. Production is ABS Mining value added in CVM (Chain volume measure) terms with a reference year of 2006-07.

Data sources: Authors' estimates using data from ABARE (*Australian Commodity Statistics*, various issues); ABS (*Australian System of National Accounts 2007-08,* Cat. no. 5204.0 Table 9).

Indeed, developments in mining appear to be one of the factors at the heart of a more general paradox, most apparent in recent years. At the same time that there has been very strong growth in inputs, there has not been as strong growth in output and so there has been weak or negative growth in productivity. Income growth has been sustained, however, by the rise in commodity prices and the increase in the terms of trade. The sustainability of income growth driven by higher commodity prices is a key issue however, particularly in light of recent developments in global commodity markets and global financial sector. As a result, it is important that attention is given to explaining the comparatively slow rate of growth in real output so far this decade, including that observed in the mining industry.

1.2 Objectives and scope of the paper

This paper looks at mining industry productivity in depth. Its specific objectives are:

- to develop a better understanding of the factors that contribute to trends in mining productivity over long periods;
- to explore the reasons for the decline in productivity since the turn of the century; and
- to assess the implications of the movements in mining productivity and other developments in the sector for the economy as a whole and for growth in living standards.

The productivity measurement challenges in mining are different in several important respects from those in other sectors. Understanding the nature of mining activity, and in particular the nature of capital investment, is one key to understanding the factors that determine mining's productivity 'profile'. The nature of mining activity and the characteristics of mining productivity are discussed in the next chapter.

Mining differs from most other industries in its hefty reliance on natural resource inputs. Changes in the quality of these inputs are not generally taken into account in traditional productivity measurement methods. That would not be a big concern if an essentially continuous supply of constant grade resources or constant quality resources could be tapped.[3] But, if ore grades or other aspects of resource quality decline as deposits are depleted, then, the measured productivity of mining may decline (as it will take more inputs to produce a unit of output). Such a decline in measured productivity arguably does not represent a decline in production efficiency in mining activity. And so, some movements in mining productivity need to be interpreted differently.

The role of natural resource inputs, and the effects of depletion and new discoveries of deposits, in conditioning mining productivity has been somewhat overlooked or underplayed in the resource economics literature. It is given special attention in chapter 3.

Resource depletion plays a role in the decline in measured productivity observed since the turn of the century, along with another factor — the limited flexibility of capital in the mining industry to respond to a prices 'shock' of the like witnessed in recent years. Chapter 4 details the issue of long lead times in bringing new

[3] This is ultimately impossible with respect to non-renewable resources. However, the negative effect of depletion of deposits may be counterbalanced by new resource discoveries and the development of new mining techniques over time.

productive capacity on-line in mining, and the consequences for MFP, while chapter 5 reviews the extent to which a commodity price ‘shock’ impacts on mining MFP through greater incentives to produce from poorer quality deposits, or using lower quality inputs. Chapter 5 also reviews other factors that impact on mining MFP, and assesses the overall contributions made by resource depletion and capital lag effects to the decline in mining productivity.

Productivity is usually interpreted as an indicator of efficiency and productivity growth is usually viewed as the principal source of improvement in living standards. But, as suggested above, the decline in measured mining productivity has to be viewed in context. It is not necessarily indicative of a decline in the technical ability of miners to produce output from a given quantity (and quality) of inputs. In addition, the sharp increase in mining commodity prices counteracts the effect of lower measured productivity on prosperity. The recent contributions of prices and productivity to improvements in prosperity are assessed in chapter 6.

2 Mining and its measured productivity

Key points

- Mining is an important production activity within the Australian economy and has a relatively high level of labour productivity as measured using conventional national accounts. Its relatively high capital intensity is a major factor contributing to its high level of labour productivity.
- Mining tends to exhibit large swings in productivity over long periods of time, compared with other industries. Variations in labour productivity are due to a combination of variations in capital intensity and variations in multifactor productivity (MFP).
- Labour productivity in mining has grown over the longer term on average, but there has been comparatively little long-term growth in MFP.
- Mining MFP fell by 24.3 per cent between 2000-01 and 2006-07. The proximate cause of the decline is falling productivity within the major mining sub-sectors.
- Structural changes within the mining industry between 2000-01 and 2006-07 are not the cause of the marked decline in mining productivity during the period. Other factors are more important.

This chapter provides background on the mining industry and its productivity performance. It places the sector in its national economy context, and outlines the nature and structure of the sector. It reviews the characteristics of mining productivity and the sector's contribution to national productivity.

2.1 Australia's mining industry

Mining activity has been booming in recent years and has been a major driver of nominal economic growth in Australia. Even under 'normal' conditions, mining is a major part of the Australian economy.

Contributions to the national economy

According to Australian Bureau of Statistics (ABS) data, Australia's mining industry typically accounts for around 5 per cent of Australia's nominal GDP. Higher prices for mining industry commodities in recent years mean that this share had increased to 8.5 per cent by 2006-07 (table 2.1).

Table 2.1 **Sector contribution to total market sector output, investment, capital stock, exports, and employment**
Per cent

	Share of gross value added[a]		*Share of gross fixed capital formation*[a]		*Share of net capital stock*[a]	
	2000-01	2006-07	2000-01	2006-07	2000-01	2006-07
Agriculture, forestry & fishing	4.0	2.4	4.8	3.2	3.3	2.7
Mining	**5.5**	**8.5**	**6.2**	**12.7**	**6.5**	**7.1**
Manufacturing	12.7	10.7	8.5	6.9	5.1	4.4
Services & other	77.8	78.4	80.4	77.2	85.1	85.8
Total economy	100.0	100.0	100.0	100.0	100.0	100.0

	Share of exports[a]		*Share of hours worked*		*Share of employed persons*	
	2000-01	2006-07	2000-01	2006-07	2000-01	2006-07
Agriculture, forestry & fishing	18.7	11.7	6.1	4.4	4.1	2.9
Mining	**31.8**	**40.7**	**1.2**	**1.8**	**0.9**	**1.3**
Manufacturing	17.5	13.6	14.0	12.0	12.3	10.2
Services & other	32.0	34.1	78.8	81.8	82.8	85.6
Total economy	100.0	100.0	100.0	100.0	100.0	100.0

[a] In current prices. Errors due to rounding.

Sources: ABS (*Australian System of National Accounts 2007-08,* Cat. no. 5204.0 Table 11); ABS (*International Trade in Goods and Services 2008*, Cat. no. 5368.0 Table 3); ABS (*Australian Labour Market Statistics 2008*, Cat. no. 6105.0).

Mining is export oriented, with around one half of total mining output being exported each year. For some mineral resource commodities — notably iron ore, alumina and uranium — the share of total output that is exported is particularly high, approaching 100 per cent (table 2.2 and figure 2.18).

Table 2.2 **Estimated proportion of total mining commodity production exported[a]**

Per cent

	2000-01	*2006-07*
Coal	75	75
Crude Oil and Condensate[b]	62	56
Liquefied Petroleum Gas[b]	69	62
Natural Gas	31	51
Iron ore	90	89
Gold[c]	87	101
Nickel	95	87
Copper	79	81
Zinc	98	96
Lead	93	99
Silver	22	26
Alumina	96	98
Uranium	102	99
Manganese	78	92

a Numbers can exceed 100 if exports included a rundown in stocks. **b** Australia imports and exports significant quantities of petroleum products. As such, the *net* exports as a share of production may be of relevance. For crude oil and condensate, this figure is -6 per cent and -33 per cent for 2000-01 and 2006-07 respectively. For LPG, the figure is 53 per cent and 46 per cent for 2000-01 and 2006-07 respectively. **c** Significant amounts of gold are imported into Australia for refining. This figure is an estimate of how much gold produced in Australia is exported.

Sources: Authors' estimates using data from ABARE (*Australian Commodity Statistics 2007*); ABARE (*Australian Mineral Statistics, various issues*).

Mining exports make a major contribution to Australia's total export revenue (table 2.1). Between 2000-2001 and 2006-07, the mining industry's share of the value of total Australian exports of goods and services increased from 31.8 per cent to 40.7 per cent. It is useful to note, however, that depletion of key Australian crude oil reserves has led to an increase in imports of oil and petroleum products during this period, meaning that 'net' mining exports have not increased by as much as 'gross' exports.

The mining industry is comparatively capital intensive[1], and accounts for a significant share of aggregate investment in Australia. For example, during the last ten years the mining industry has accounted for just under 9 per cent of aggregate capital investment in Australia, although the nature of mining means that there can be fairly large swings in the share from year to year. With the surge in commodity prices in recent years and a general sense of economic prosperity in the sector, capital investment also surged, accounting for 12.7 per cent of aggregate capital investment in Australia in 2006-07.

The flipside of its high capital intensity is that mining employs a small proportion of the Australian workforce. Mining accounted for 0.9 per cent of total employment in the early 2000s (table 2.1). While mining employment has grown substantially in recent years (around 9.5 per cent a year, on average, between 2000-01 to 2006-07), the employment share remains relatively low at 1.3 per cent.

In terms of regional location, mining accounts for a higher share of economic activity in the economies of Western Australian, the Northern Territory and to a much lesser extent Queensland, than in other state and territory economies (box 2.1). Recent boom conditions have therefore been most prominent in these economies.

The structure of the mining industry

Mining is a diverse and heterogeneous production sector. It encompasses:

- a range of distinct activities;
- extraction of a diverse range of commodities, the deposits of which are distributed unevenly in terms of:
  - geographic location;
  - qualities or grades; and
- a variety of techniques of extraction and processing.

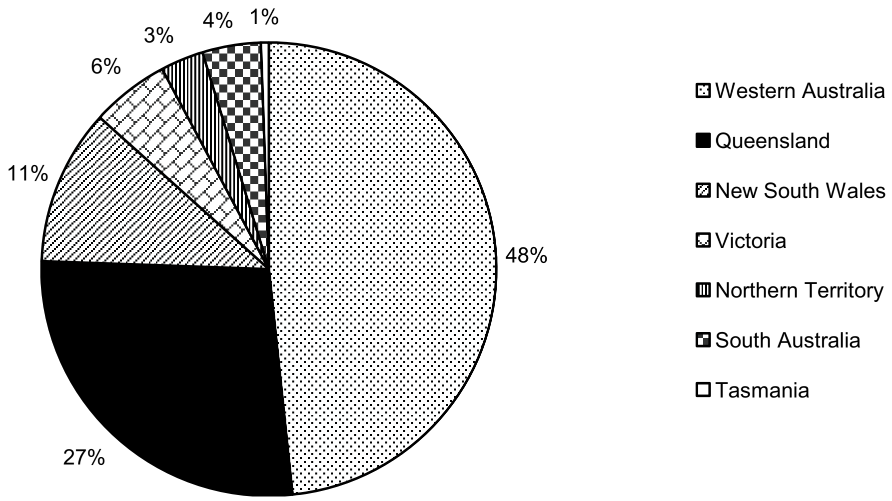
[1] Mining has a capital income share averaging around 76 per cent, compared with 38 per cent in manufacturing, 30 per cent in the construction sector, and 60 per cent in agriculture. The capital intensive nature of mining and the implications for productivity calculations is discussed in more detail in chapter 4.

Box 2.1 **The regional dimension of mining**

Mining activity is not distributed uniformly among the states of Australia and, even within states, most mining activity takes place in rural and remote areas, including in off-shore locations. Hence developments in the mining industry can have particularly strong effects on sub-state or regional economic activity.

In terms of the value of production, the vast majority of mining activity in Australia takes place in Western Australia and Queensland (figure 2.1). Between them the two states account for nearly three quarters of total production. This apparently disproportionate share is less anomalous given that the two states also account for well over one half of Australia's total land area.

Figure 2.1 **State shares of total mining production[a], 2005-06**



[a] Measured in terms of industry value added.

Data source: ABS (*Mining Operations, Australia, 2005-06*, Cat. no. 8415.0).

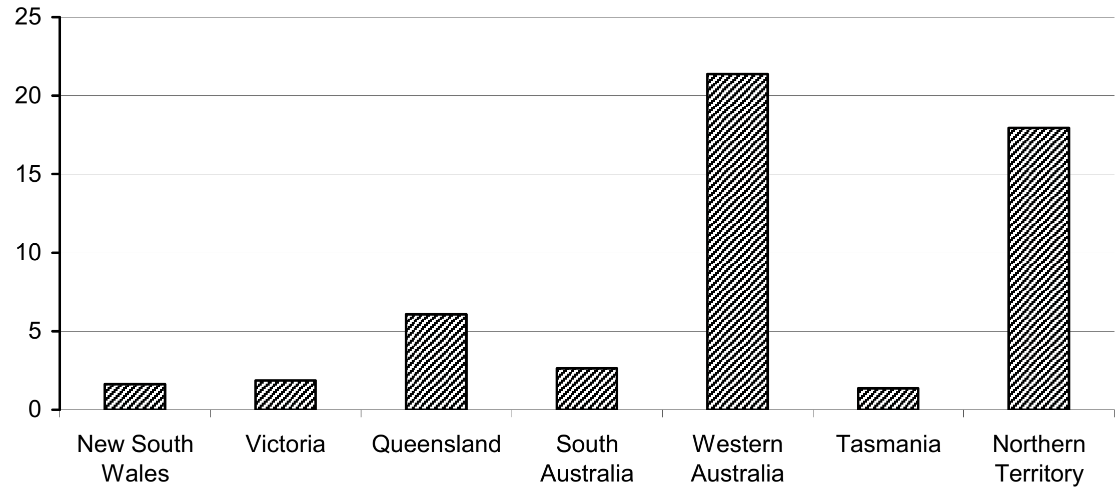
Mining is particularly important to the economies of Western Australia and the Northern Territory, and is also important to the economy of Queensland (figure 2.1)

(continued next page)

Box 2.1 **(continued)**

Figure 2.2 **Mining share of state output[a]**

Average 2001-02 to 2005-06



[a] Mining value added as a share of gross state product (in current prices).

Data sources: ABS (*Mining Operations, Australia 2005-06*, Cat. no. 8415.0); ABS *(Australian National Accounts: State Accounts 2006-07*, Cat. no. 5220.0).

Mining activities, who undertakes them, and how they are measured

Table 2.3 summarises major activities undertaken in the mining industry. 'Mining' consists of a number of quite distinct components — exploration, mine development, extraction, processing, transportation and restoration of land. The component activities can all be undertaken by mining companies, although the sector has become more specialised in recent times. Increasingly, mining companies have specialised in extraction and have contracted out exploration to mining services companies and mine development to construction companies. Depending on the circumstances of individual mines, processing and transport may also be contracted out.

The distinction between in-house and contracted-out activities can be important for statistical purposes. The ABS assigns data to industries according to the principal activity of a 'management unit' (usually a business division within conglomerates). Thus, some construction activity would be allocated to the mining industry if it was undertaken by a mining company incidental to its prime extraction activity, but would be allocated to the construction industry if it was undertaken under contract by a construction company. Other examples are listed in table 2.3. Any processing or refining of a resource by a miner at the mine site is included in the mining industry, whereas processing and refinement undertaken elsewhere (even if undertaken by the same company, but in a different division) is allocated to manufacturing (for example, manufacture of petroleum, coal or mineral products).

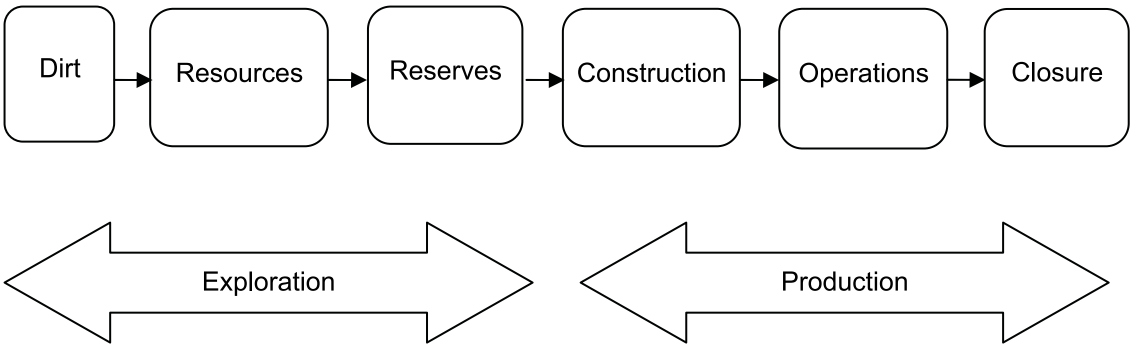
Table 2.3 **Overview of mining and related activities**

Activity	*Examples*	*Undertaken by*	*ABS industry classification*
Exploration	• Prospecting • Determine characteristics of deposit • Feasibility analysis	• Mining services companies • Mining companies	• Mining (Services to Mining)
Mine development	• Acquire mining rights • Construct access roads and infrastructure • Construct mine to access deposit • Install plant and equipment	• Contractors • Mining companies	• Construction (if contracted) • Mining (if in-house)
Extraction	• Remove deposit from the ground	• Mining companies	• Mining
Processing	• Crushing • Milling • Concentration	• Mining companies (at mine head) • Processors	• Mining (if in-house at mine head) • Manufacturing (if at another site)
Transport	• Move extracted material or milled product to transport head	• Mining companies • Transport contractors	• Transport (if contracted) • Mining (if in-house)
Reclamation	• Remove buildings, plant and equipment • Treat waste and tailings • Environmental rehabilitation	• Mining services companies • Mining companies	• Mining

The life cycle of mines and the measurement of mining productivity

The life cycle of most mines involves the various activities listed in table 2.3 above, and is represented schematically in figure 2.3.

Figure 2.3 **Stages in the life cycle of mines**



The first three phases in this process — dirt to resource to reserve — are the outcome of exploration activity, and reflect the transformation of a physical location (a place on the earth or a place under water in the case off-shore oil and gas extraction) into first a 'resource', and subsequently a 'reserve'.[2] Market conditions also influence the transition of a 'resource' into a 'reserve', in the sense that price changes may encourage further drilling and development activity that turn a known but unprofitable 'resource' into a profitable 'reserve', and vice versa. But exploration is the basic activity that identifies resources in the first place.

Once the decision is made to develop a reserve, the next three phases of the cycle — construction, operation, and, ultimately, closure — characterise the production stage of mining.

The ABS measurement of productivity in the mining industry effectively covers the productivity of all of the stages shown in figure 2.3. Hence, changes over time in measured productivity reflect not just changes in the amounts of labour and capital inputs used to extract and process mineral and energy resources, but also changes in the quality of new reserves as discovered through exploration. The latter may vary as a consequence of improved tools and techniques in exploration, but may also be adversely affected by the possibility that as time goes by and existing reserves are depleted, the probability of finding new reserves of comparable quality to those already in production generally declines. The idea that systematic changes in the quality of natural resources used in mining can have an impact on conventional

[2] A 'resource' in this context is loosely defined as a significant but imprecisely measured deposit that may be profitable to mine at current and expected future prices, while a 'reserve' is a more precisely measured deposit that is profitable to mine at current and expected future prices. It is important to note that the terms 'mineral resource' and 'ore reserve' have a formal definition according to the Australasian Joint Ore Reserves Committee (JORC), which can be found on their website: www.jorc.org.

measures of productivity in mining is a key outcome of this paper, and is covered in detail in chapter 3.

Changes in market prices — particularly unexpected changes — influence miners decisions about what is valuable material and what is waste (the 'resource' to 'reserve' stage shown above). Hence, changes in market prices can also influence mining productivity through changes in the average quality of natural resources being targeted by miners. This is another important issue raised in this paper, and is taken up in more detail in chapter 5.

Commodities produced

In global terms, Australia is a significant world producer of a number of mineral resources, including alumina, iron ore and lead (table 2.4). While Australian coal production is only a comparatively small proportion of global coal production, Australia is the world's largest exporter of coal, accounting for around 30 per cent of global trade in recent years. This is because many large coal producing countries, such as the United States and China, do not export significant quantities of coal.

More broadly however, the Australian mining industry produces a vast range of commodities. Table 2.5 contains estimates of production in 2005-06 of a range of individual mineral and energy commodities, along with the percentage breakdown of total production by state.

Table 2.4 **Australian share of world minerals production in 2006**

	Per cent
Copper	6
Silver	9
Gold	10
Nickel	13
Zinc	13
Manganese	15
Lead	18
Iron ore	19
Ilmenite	20
Uranium	22
Alumina	31
Rutile	44

Source: Authors' estimates using data from ABARE, (*Australian Commodity Statistics* 2007).

Table 2.5 **Production of selected mineral and energy commodities**

Quantity produced and state shares of Australian production, 2005-06

		State shares						
	Australia	*NSW*	*Vic*	*Qld*	*SA*	*WA*	*Tas*	*NT*
	Qty	%	%	%	%	%	%	%
Fuel minerals								
Black coal ('000t)	310 101	40.2		56.4	1.1	2.2	0.1	
Brown coal ('000t)	67 737		100.0					
Crude oil (ML)	19 029		25.3	2.2	3.9	60.6		7.9
Condensate (ML)	8 109			2.8	3.3	69.4		24.6
Shale oil (ML)								
Natural gas (Mm^3)	23 838		38.1	13.3	9.4	32.4	0.0	6.8
Coal seam methane ('000m^3)	1 662 448			100.0				
Liquefied natural gas (t)	12 543 261					93.1		6.9
Liquefied petroleum gas – propane (t)	n.a.							
Liquefied petroleum gas – butane (t)	n.a.							
Total liquefied petroleum gas (t)	1 740 091			9.6	8.2	50.1		32.1
Ethane (t)	n.a.							
Carbon dioxide (t)	12 959				100.0			
Metallic minerals								
Antimony (metal content) (t)	-							
Bauxite (t)	60 729 597			26.4		64.7		8.9
Cadmium (metal content) (t)	-							
Cobalt (metal content) (t)	5 069					100.0		
Copper (metal content) (t)	910 089	22.4		44.3	21.8	7.8	3.6	0.0
Gold (metal content) (kg)	241 780	12.0	2.6	8.2	2.7	66.6	2.9	5.0
Iron ore and concentrate (t)	247 281 104				1.5	98.5		
Iron ore pellets (t)	2 132 232						100.0	
Lead (metal content) (t)	711 862	15.3		71.2		8.3	5.2	
Nickel (metal content) ('000t)	191					100.0		
Palladium (metal content) (kg)	622					100.0		
Platinum (metal content) (kg)	n.p.							
Silver (metal content) (kg)	2 002 816	4.8		84.2	1.3	5.0	4.6	0.0
Tin (metal content) (t)	1 548					39.4	60.5	
Uranium oxide (t)	9 949				47.9			52.1
Zinc (metal content) (t)	1 213 035	14.7		69.0	0.3	8.9	7.2	
Zinc/lead concentrate (t)	224 276							100.0

(continued on next page)

Table 2.5 **(continued)**

		State shares						
	Australia	*NSW*	*Vic*	*Qld*	*SA*	*WA*	*Tas*	*NT*
	Qty	%	%	%	%	%	%	%
Industrial minerals								
Barite (t)	18 466	4.2			95.8			
Chromite (t)	105 951					100.0		
Bentonite (t)	n.a.							
Attapulgite (t)	n.a.							
Kaolin (t)	n.a.							
Structural clays (t)	n.a.							
Total clays (t)	n.a.							
Diamond (ct)	29 263 869					100.0		
Diatomite (t)	23 442	82.5		17.5				
Basalt (t)	21 552		100.0					
Granite (t)	n.p.							
Limestone (dimension stone) (t)	15 158				100.0			
Marble (t)	n.p.							
Sandstone (t)	120 798	42.4	4.2	48.3	4.8		0.2	
Slate (includes flagstone) (t)	9 703		3.4	0.8	95.7			
Other dimension stone and/or unspecified rock (t)	25 905			41.6			52.4	5.9
Total dimension stone (t)	226 819	27.3	12.2	32.5	20.4	0.8	6.1	0.7
Feldspar (t)	n.a.							
Garnet (t)	278 577					100.0		
Staurolite (t)	n.a.							
Gypsum (t)	4 249 286	4.0	12.7	1.1	45.0	37.1		
Iron oxide – magnetite (t)	130 550	49.6					50.4	
Iron oxide – other (t)	n.a.							
Total iron oxides (t)	n.a.							
Limestone for cement (t)	6 671 151		9.3	31.4	32.2		27.1	
Limestone for lime (t)	802 583		25.6	45.9	22.5		6.0	
Limestone for agricultural use (t)	742 333		66.0	2.4	15.7		15.8	
Limestone for metallurgical flux (t)	142 597			60.1	0.2		39.6	
Limestone for chemical uses (t)	667 943				100.0			
Limestone for other and/or unspecified uses (t)	n.p.							
Total Limestone (t)	n.p.							
Limesand (t)	n.p.							
Total limestone and limesand (t)	18 279 900	26.6	7.2	16.2	17.1	21.4	11.1	0.5
Magnesite (t)	482 027	7.0		92.7	0.3			
Dolomite (t)	716 178	1.1		3.5	94.5			
Serpentinite (t)	130 397	100.0						
Total magnesium-rich materials (t)	1 328 602	13.0		35.5	51.1			
Manganese ore (t)	3 825 730					23.2		76.8
Mica (t)	-							

(continued on next page)

Table 2.5 (**continued**)

		State shares						
	Australia	*NSW*	*Vic*	*Qld*	*SA*	*WA*	*Tas*	*NT*
	Qty	%	%	%	%	%	%	%
Peat (t)	1 559			100.0				
Perlite (t)	12 057			100.0				
Phosphate rock (t)	2 083 454			100.0	0.0			
Pyrophyllite (t)	-							
Salt (t)	11 467 399				5.5	94.5		
Silica – lump (quartz, quartzite, chert) (t)	207 091	100.0						
Silica – sand (t)	n.p.							
Silica – unspecified (t)	n.p.							
Total silica (t)	4 386 311	15.1	7.7	47.6	7.7	17.7	4.2	
Sillimanite (t)								
Spodumene (t)	193 229					100.0		
Spongolite (t)	n.a.							
Talc (t)	n.a.							
Tantalum (t)	871					100.0		
Ilmenite (t)	708 197			21.7		78.3		
Synthetic rutile (t)	n.a.							
Leucoxene (t)	75 663					100.0		
Rutile (t)	n.a.							
Total titanium minerals (t)	n.a.							
Vanadium (t)	n.a.							
Vermiculite (t)	9 392							100.0
Zeolite (t)	3 405	67.3		32.7				
Zircon (t)	423 911	0.0		12.3		87.7		
Total industrial minerals	81 939 958	9.6	4.3	11.9	8.8	58.8	2.9	3.7
Construction materials								
Total crushed and broken rock (t)	81 071 514	17.4	34.6	36.7	5.4	1.8	3.4	0.7
Total construction sand (t)	31 220 695	25.9	24.2	23.4	12.9	11.5	1.8	0.3
Total gravel (t)	8 702 081	45.5		24.7	2.3	1.1	24.3	2.1
Total soil, loam & garden sand (t)	801 444	36.0		18.9	42.8			2.4
Total other construction materials (t)	23 682 264	15.7	33.1	26.7	24.5			
Total construction materials (t)	145 77 998	20.8	29.9	31.4	10.1	3.5	3.7	0.6

n.a. Not available. n.p. not available for publication but included in totals where applicable.

Source: ABS *(Mining Operations, Australia 2005-06*, Cat. no. 8415.0).

Mining industries within the sector

Table 2.6 lists the major subdivisions and classes within the mining industry as defined by the ABS for the purposes of many of their statistical reports. Output in this table is measured by value added, and covers production in both primary and incidental activities.

The coal mining and the oil and gas extraction industries are by far the two largest sub-sectors in the mining industry, with each accounting for around a quarter or more of the value of total mining output. Iron ore mining accounts for around 15 per cent of industry value added, meaning that the three industries — coal, oil and gas, and iron ore — account for around 70 per cent of the value of mining industry output.

Table 2.6 **Value added in the mining industry, by subdivision and class, in 2006-07**

			Industry output	
			$m	*per cent*
11	*Coal mining*			
	110	*Coal mining*	*16 364*	*22.8*
12	*Oil and gas extraction*			
	120	*Oil and gas extraction*	*22 420*	*31.2*
13	*Metal ore mining*			
	131	*Metal ore mining*		
		Iron ore mining	*11 208*	*15.6*
		Bauxite mining[a]		
		Copper ore mining	*3699*	*5.2*
		Gold ore mining	*2629*	*3.7*
		Mineral sand mining	*373*	*0.5*
		Nickel ore mining[a]		
		Silver-lead-zinc ore mining	*4339*	*6.0*
		Metal ore mining nec	*5141*	*7.2*
14	*Other mining*		*2034*	*2.8*
15	*Services to mining*		*3563*	*5.0*
B		*MINING*	*71 770*	*100.0*

[a] Bauxite mining and nickel ore mining results are included in 'Metal ore mining nec'.

Source: ABS (*Mining Operations, Australia 2006-07*, Cat. no. 8415.0).

2.2 Measured productivity of mining

The ABS has recently commenced publication of productivity estimates for industry sectors, including mining. The estimates cover the period 1985-86 to 2006-07. A further backcast to 1974-75 is possible through estimates constructed by the Productivity Commission.

The ABS does not publish equivalent productivity estimates for individual classes or sectors within the mining industry. However, it was possible to construct estimates for some mining sub-sectors as part of this project. These estimates are of lesser quality than the mining industry estimates published by the ABS and are used only as a means of indicating whether there are industry differences within the sector.[3]

Productivity levels

Mining has a high level of productivity in comparison to other industries. Figure 2.4 shows that labour productivity, measured by value added per hour worked, in Australian mining greatly exceeds the corresponding measure for the manufacturing industry, and that of the market sector of the economy as a whole.[4]

Labour productivity in mining is high because the sector is relatively capital intensive. At the same time, labour productivity in mining is also more variable over time, again because labour represents a comparatively small share of total inputs to mining. Hence even relatively small changes to output or labour inputs from year to year can lead to comparatively large changes in the level of labour productivity.

Figure 2.5 shows the ratio of physical capital to labour for the mining and manufacturing industries in Australia as well as for the market sector as a whole. (Note that this a dollar measure of net capital stock, rather than the capital services measure used in index form in ABS productivity calculations.) The extra capital per unit of labour input in mining provides the means to produce more output per unit of labour input.

Differences in labour productivity can also be due to differences in MFP. However, estimates of comparable MFP *levels* are not available and are not easily constructed.

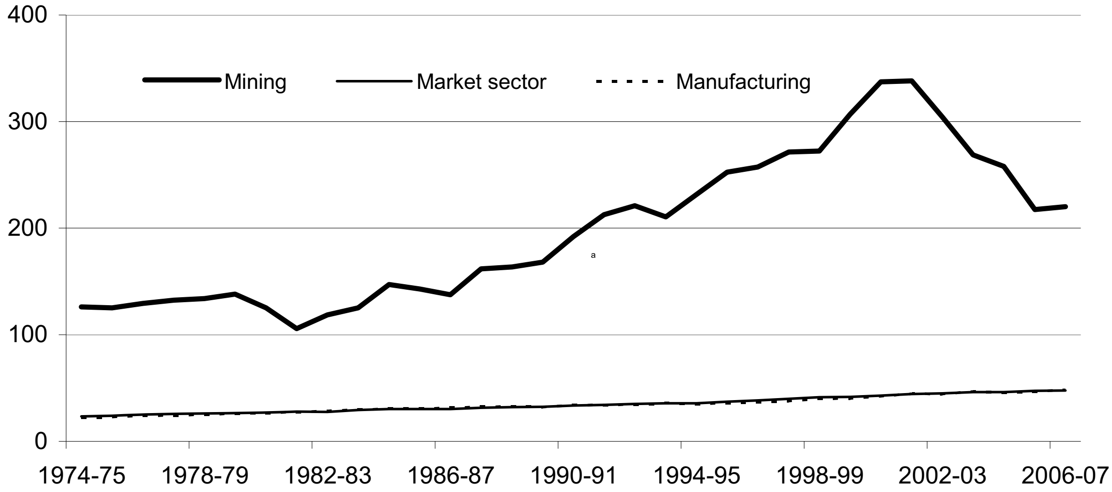
---

3 The industry estimates are of lesser quality for two main reasons. First, any errors in the allocation of mining outputs and inputs to individual industries are likely to 'wash out' in aggregation to the sector level. Second, there are methodological differences in input measures — persons employed, rather than hours worked, as the labour input measure, and differences in age-efficiency profiles used to estimate capital services. The methodology used to derive the mining sub-sector productivity estimates presented in this report is described in appendix B.

4 The market sector includes mining and manufacturing.

Figure 2.4 **Labour productivity (value added per hour worked), 1974-75 to 2006-07[a]**

Dollars per hour (2005-06 prices)

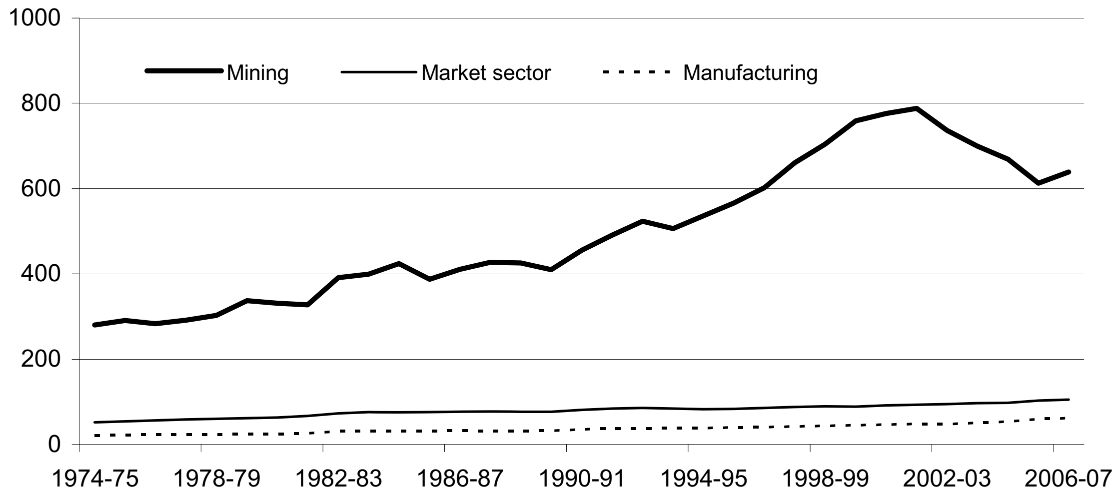


a Value added is measured in chain volume terms in 2005-06 prices.

Data sources: ABS (*Australian System of National Accounts 2007-08*, Cat. no. 5204.0); ABS *(Experimental Estimates of Industry Multifactor Productivity 2006-07*, Cat. no. 5260.0.55.002).

Figure 2.5 **Capital stock per hour worked, 1974-75 to 2006-07**

Dollars per hour (2005-06 prices)



a Capital stock is measured in chain volume terms with a base year of 2005-06.

Data source: ABS *(Experimental Estimates of Industry Multifactor Productivity 2006-07*, Cat. no. 5260.0.55.002).

Sub-sectors within the mining industry

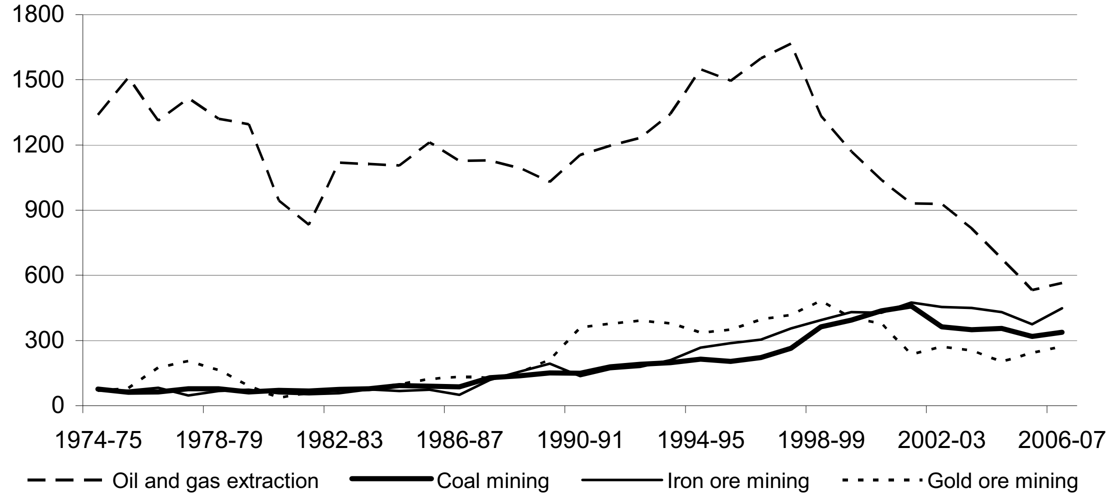
Figure 2.6 shows labour productivity (measured as value added per *employee*) in important sub-sectors of Australian mining, while figure 2.7 shows corresponding capital-to-labour ratios (net capital stock per employee).

Oil and gas production has traditionally had the highest *level* of labour productivity among the different mining sub-sectors (figure 2.6). In 1998-99, for example, value added per employee was $1.7 million in oil and gas extraction, whereas it was below $500 000 per employee in coal mining, iron ore mining and gold mining. The high level of labour productivity in the oil and gas extraction industry is primarily because this sub-sector uses very little labour relative to physical capital. However, since the late 1990s labour productivity in oil and gas extraction has fallen dramatically, partly as a result of the rapid depletion of key oil reserves.[5]

There has also been a reduction in the amount of capital stock per employee in the oil and gas extraction sector since the late 1990s, although this is primarily due to faster growth in labour inputs relative to capital inputs, rather than a decline in capital inputs (figure 2.7).

Figure 2.6 **Value added per employee — key mining sub-sectors, 1974-75 to 2006-07[a]**

Thousands of dollars (1998-99 prices)



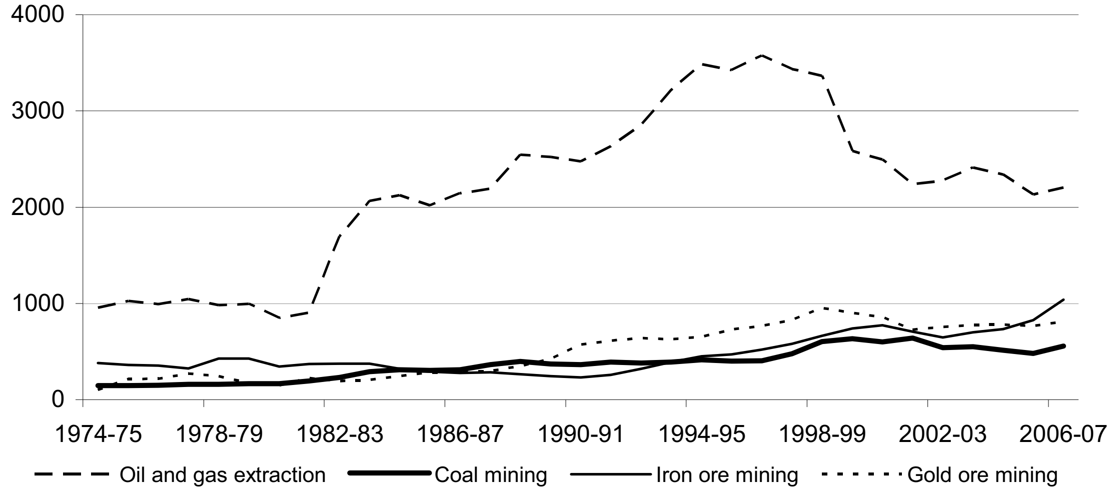
[a] Value added is measured in constant prices with a base year of 1998-99.

Data source: **Authors' estimates using data from ABS (*Mining Operations, Australia,* various issues, Cat. no. 8415.0).**

5 Issues associated with the depletion of resources in the oil and gas sector are taken up in more detail in chapter 3.

Figure 2.7 **Capital stock per employee**[a]

Thousands of dollars (1998-99 prices)



[a] Capital stock is measured in constant prices with a base year of 1998-99.

Data source: **Authors' estimates using data from ABS (*Mining Operations, Australia,* various issues, Cat. no. 8415.0).**

Productivity growth

Mining industry

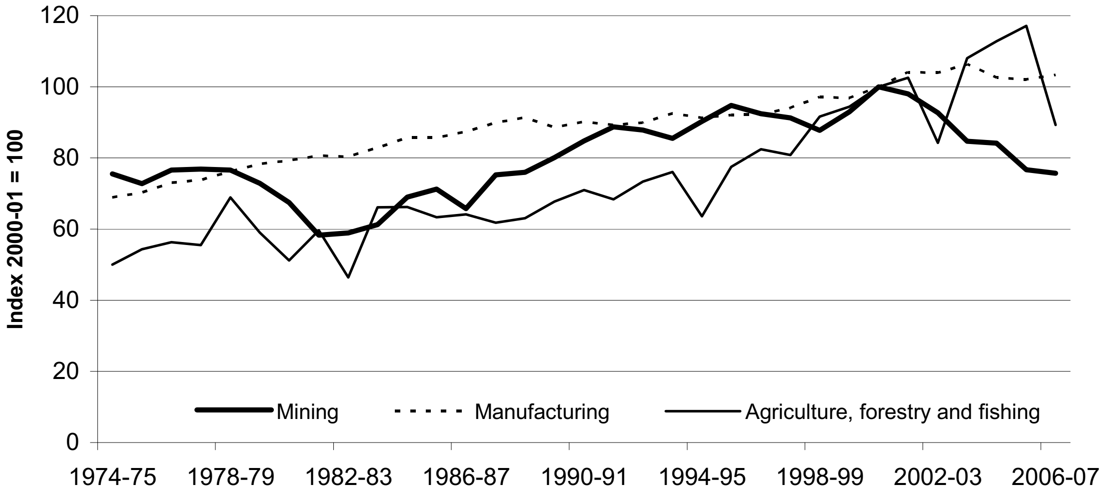
Mining has shown reasonably strong labour productivity growth over the long term, although the downturn in productivity since 2001 has tempered the overall gains somewhat (figure 2.8). The longer-term growth in labour productivity in mining is mostly due to capital deepening (more capital available per worker hour). In contrast, there have been large fluctuations or cycles in MFP growth but very little overall growth over the longer term.

The cyclical behaviour of mining productivity means that there is greater year to year variability in mining MFP than is found in most other industries. In fact, the year to year variability of MFP in mining is second only to annual variability in MFP in agriculture, an industry known for large swings in measured productivity due to fluctuating weather conditions. In general, mining lies between agriculture and manufacturing in terms of the volatility of measured productivity (figure 2.9).

Figure 2.8 Mining MFP, labour productivity and capital/labour ratio, 1974-75 to 2006-07

Data source: ABS (*Experimental Estimates of Industry Multifactor Productivity 2006-07*, Cat. no. 5260.0.55.002).

Figure 2.9 MFP in selected industries, 1974-75 to 2006-07



Data source: ABS (*Experimental Estimates of Industry Multifactor Productivity 2006-07,* Cat. no. 5260.0.55.002).

Sub-sectors within the mining industry

Longer-term trends in productivity growth among the individual sub-sectors that make up the mining industry are largely consistent with movements in the industry average (figures 2.10 to 2.17). However there is generally greater year-to-year variability in the sub-sector productivity estimates, partly reflecting the fact that some of the sectors are comparatively small, and their results can be affected by changes occurring within a relatively small number of individual mines.[6] For example, the entry or exit of large mines can influence the estimates, as can investment decisions regarding large developments.

Labour productivity within most mining sub-sectors grew particularly strongly between 1980 and 2000, with associated capital deepening and MFP growth (table 2.7). An exception to the rule was oil and gas extraction, where MFP fell during the period, and there was little growth in labour productivity. The mineral sands sub-sector also showed little growth in labour productivity over the period.

The marked decline in sub-sector labour productivity between 2000-01 and 2006-07 is generally associated with falling MFP, and a decline in the amount of capital available per employee. The exception to this is iron ore mining, where a large increase in the capital to labour ratio over the period partially offset the negative effect on labour productivity of falling MFP.

6 As noted earlier, measurement errors may also contribute to greater variability of mining sub-sector productivity estimates.

Table 2.7 **Productivity measures by mining sub-sector**
Annual compound percentage change

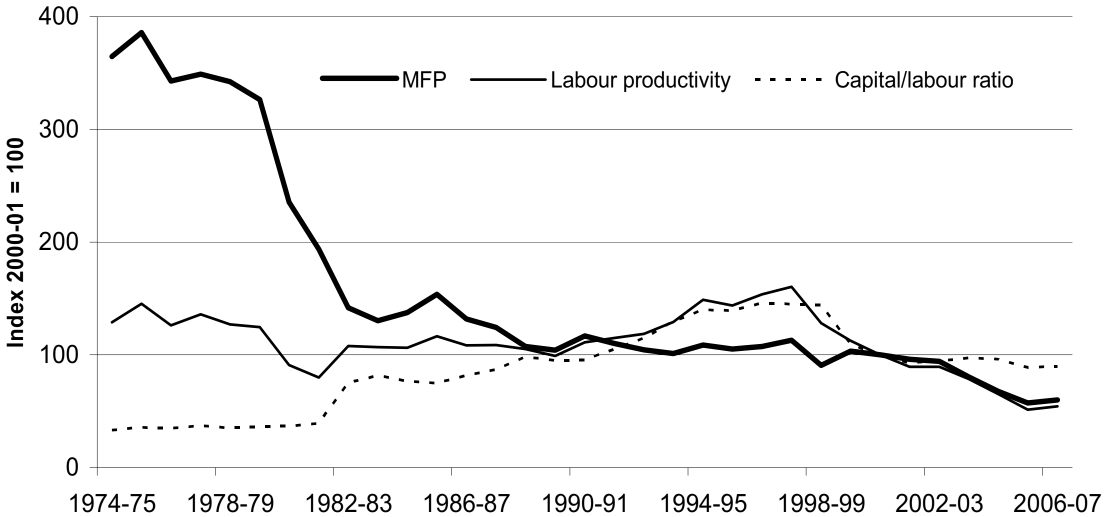
	1974-75 to 1979-80	*1979-80 to 2000-01*	*2000-01 to 2006-07*
Labour productivity			
Coal mining	-3.6	9.6	-4.2
Oil and gas extraction	-0.6	-1.0	-9.7
Iron ore mining	0.4	8.8	0.8
Other metal ores (including bauxite)	-7.2	11.1	-11.9
Copper ore mining	10.7	6.7	-2.1
Gold ore mining	6.0	7.0	-5.3
Mineral sand mining	11.7	1.4	0.1
Silver-Lead-Zinc ore mining	-0.6	9.6	-13.0
MFP			
Coal mining	-6.5	5.5	-4.6
Oil and gas extraction	-2.2	-5.5	-8.1
Iron ore mining	-1.9	5.9	-5.5
Other metal ores (including bauxite)	-10.4	3.8	-2.0
Copper ore mining	7.5	5.0	-2.7
Gold ore mining	2.6	1.1	-5.0
Mineral sand mining	5.9	-2.5	4.3
Silver-Lead-Zinc ore mining	-2.2	3.7	-6.1
Capital to labour ratio			
Coal mining	4.9	6.4	0.5
Oil and gas extraction	1.7	4.9	-1.8
Iron ore mining	3.2	3.3	7.5
Other metal ores (including bauxite)	4.9	9.1	-12.1
Copper ore mining	8.2	2.6	0.8
Gold ore mining	10.1	8.0	-0.9
Mineral sand mining	10.9	5.2	-5.7
Silver-Lead-Zinc ore mining	2.6	9.3	-7.9

Source: Authors' estimates using data from ABS (*Mining Operations, Australia,* various issues, Cat. no. 8415.0).

Figure 2.10 **Coal mining: MFP, labour productivity and capital/labour ratio, 1974-75 to 2006-07**

Data source: Authors' estimates.

Figure 2.11 **Oil and gas extraction: MFP, labour productivity and capital/labour ratio, 1974-75 to 2006-07**

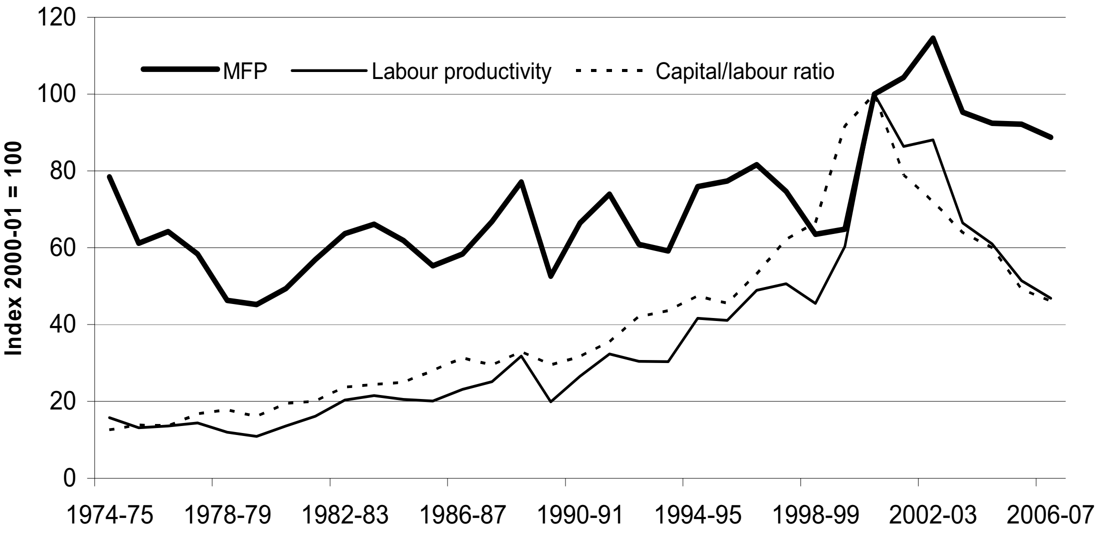


Data source: Authors' estimates.

Figure 2.12 **Iron ore mining: MFP, labour productivity and capital/labour ratio, 1974-75 to 2006-07**

Data source: Authors' estimates.

Figure 2.13 **Non-ferrous metal ores n.e.c. mining[a]: MFP, labour productivity and capital/labour ratio, 1974-75 to 2006-07**



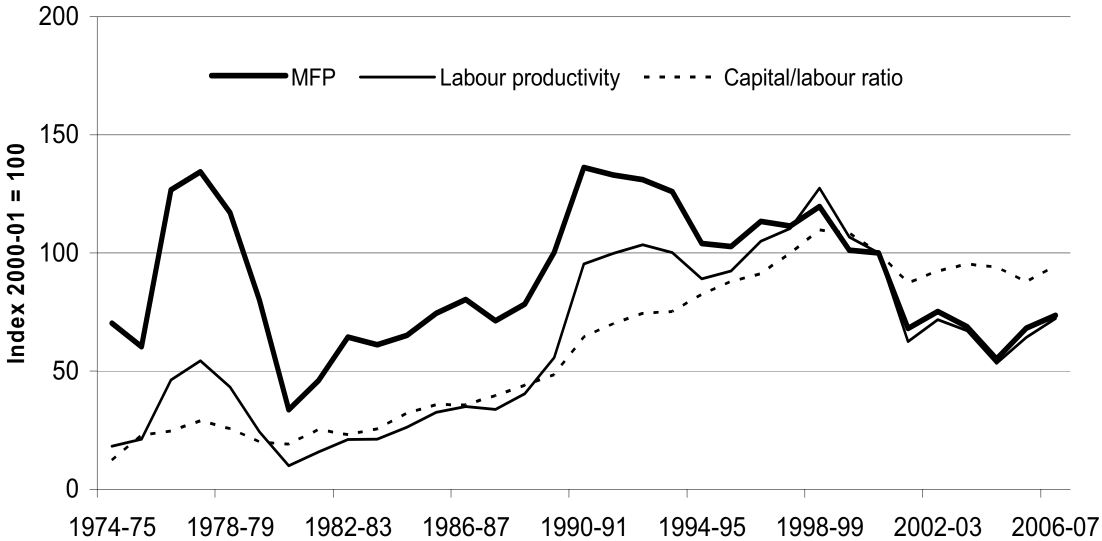
[a] The major commodities included within this group are nickel, bauxite, manganese ore, and uranium

Data source: Authors' estimates

Figure 2.14 **Copper ore mining: MFP, labour productivity and capital/labour ratio, 1974-75 to 2006-07**

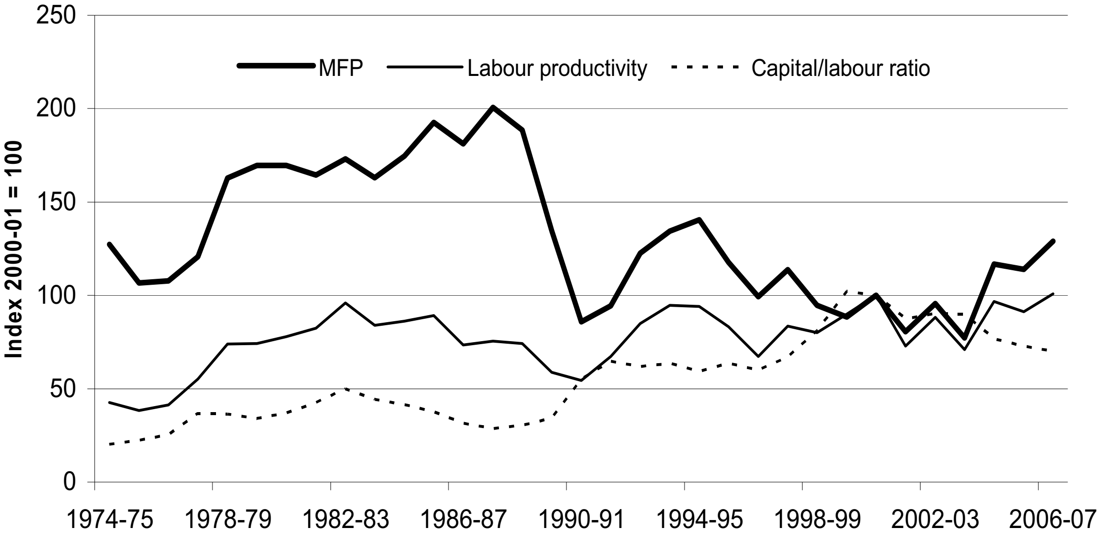
Data source: Authors' estimates.

Figure 2.15 **Gold ore mining: MFP, labour productivity and capital/labour ratio, 1974-75 to 2006-07**



Data source: Authors' estimates.

Figure 2.16 **Mineral sands mining: MFP, labour productivity and capital/labour ratio, 1974-75 to 2006-07**



Data source: Authors' estimates.

Figure 2.17 **Silver/Lead/Zinc ore mining: MFP, labour productivity and capital/labour ratio, 1974-75 to 2006-07**

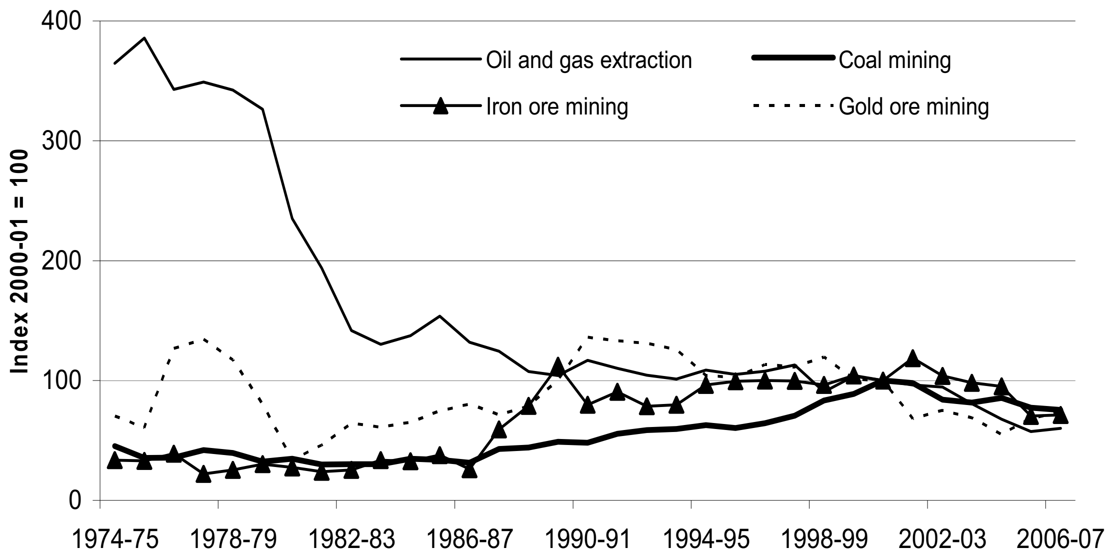
Data source: Authors' estimates.

Industry composition effects

As table 2.7 and figures 2.10 to 2.17 illustrate, there are significant differences among the individual mining sub-sectors in terms of their levels of labour productivity, and in their productivity growth rates over time. It is possible that changes in the composition of the mining industry could have contributed to the decline in overall productivity in the sector since 2001. Compositional changes have an adverse effect on aggregate mining productivity if less productive sub-sectors expand relative to more productive sub-sectors, or if resources shift towards sub-sectors where productivity is falling more quickly.

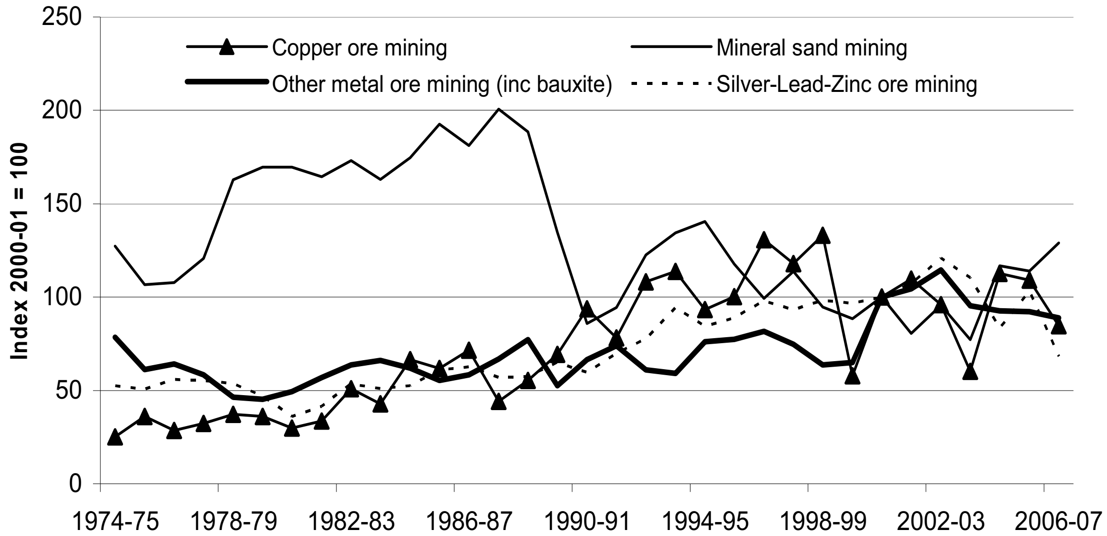
Figures 2.18 and 2.19 indicate that the decline in mining industry productivity since 2001 can largely be explained by declining productivity in the larger sub-sectors — that is, coal, oil and gas, iron ore and gold — as productivity trends in the smaller sub-sectors (as defined by share of value added) such as copper and mineral sands mining were less clear.

Figure 2.18 **MFP by sub-sector, 1974-75 to 2006-07**



Data source: Authors' estimates.

Figure 2.19 **MFP by sub-sector, 1974-75 to 2006-07**



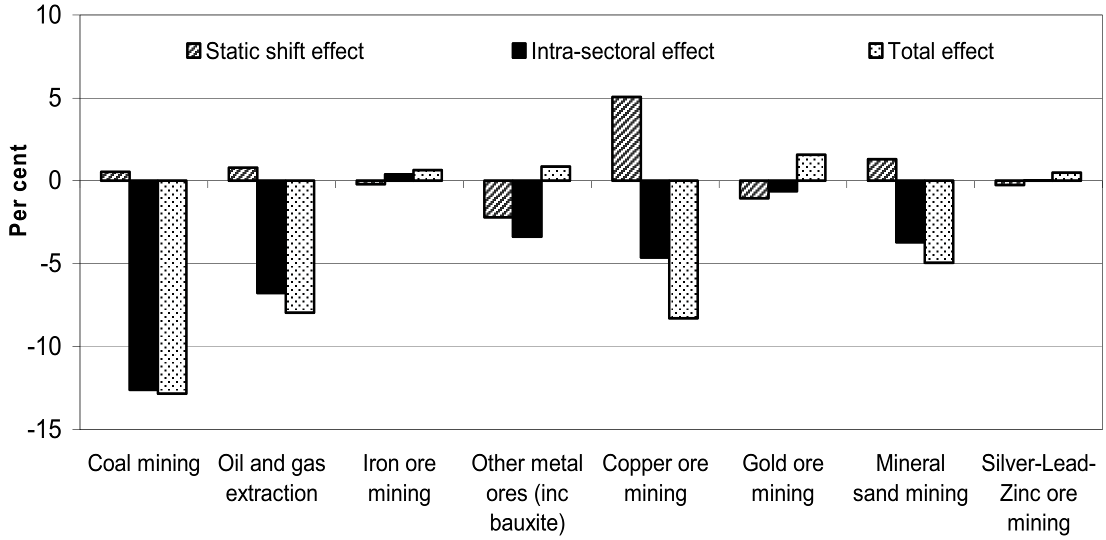
Data source: Authors' estimates.

A shift-share analysis[7] of the decline in labour productivity in the mining industry between 2000-01 and 2006-07 shows that changes in the composition of the sector actually made a *positive* contribution of around four percentage points to the change in labour productivity over the period (figure 2.20). Declines in the labour shares of the other metal ore, silver-lead-zinc ore, coal, and oil and gas sub-sectors acted to improve overall labour productivity, and more than offset the negative effect on productivity of increases in the labour shares of the gold, copper, and mineral sands sub-sectors.

But the positive effect on labour productivity of changes in the composition of the mining industry are far outweighed by the negative effects of declining productivity growth during the period within many of the mining sub-sectors. That is, the overall decline in mining productivity over the period was primarily due to reductions in labour productivity *within* the major sub-sectors (figure 2.20). The results in figure 2.20 also illustrate the significance of the oil and gas sub-sector in explaining the overall decline in labour productivity in the mining industry between 2000-01 and 2006-07. Specifically, just over two fifths (42 per cent) of the decline was due to reduced productivity in the oil and gas sub-sector. Other large contributors to the decline in labour productivity were coal mining and other metal ore mining.

[7] Shift-share analysis decomposes the change in total mining industry labour productivity into a component due to productivity changes within the various sub-sectors of mining, and a component due to changes in the relative size of different sub-sectors of the industry. For a more detailed description of the shift-share analysis methodology and the interpretation of results see OECD (2002).

Figure 2.20 **Shift-share analysis of mining industry productivity**[a]
Labour productivity change from 2000-01 to 2006-07



[a] This analysis is based on the eight mining industries described in chapter 1, and for which labour productivity and MFP estimates have been made. Excluded in the analysis are 'Services to mining' and 'Other mining', which collectively account for approximately 8 per cent of mining industry output. The 'intra-sectoral effect' is the contribution of labour productivity growth within individual industries to aggregate labour productivity growth. The 'static shift effect' measures the contribution from changes in the allocation of labour from low labour productivity level sectors to high labour productivity level sectors.

Data source: Authors' estimates.

Developments in mining MFP in 2007-08

Data released by the ABS in November 2008 show that productivity in the mining industry has deteriorated further in 2007-08. Labour productivity is estimated to have fallen by 4 per cent, while MFP has fallen by 7.9 per cent. As was the case in the period from 2000-01 to 2006-07, the proximate reasons for the most recent decline are comparatively strong growth in inputs coincident with weak growth in output. While productivity growth estimates for 2007-08 are not available at the mining sub-sector level, it is likely that the decline in MFP has occurred as a result of poorer productivity performances in the individual industries, rather than as the result of changes in composition of the mining industry. The decline in output in the oil and gas sector in 2007-08 supports this line of reasoning.

3 Understanding productivity in mining: natural resource inputs

Key points

- Changes in the quality of natural resource inputs used in mining are not generally taken into account in standard estimates of mining productivity. They are generally overlooked because the natural resources are not a purchased input. That is, natural inputs tend to be taken as 'given' or 'environmental variables'.
- The effect on mining MFP of resource depletion is found to be significant. After removing the influence of resource depletion on mining MFP, the long-run compound growth rate of mining MFP is estimated to be substantially higher (2.5 per cent instead of the measured 0.01 per cent between 1974-75 and 2006-07).
- Resource depletion is found to account for a large component of the decline in mining MFP between 2000-01 and 2006-07, particularly over the period from 2000-01 to 2004-05. A surge in commodities prices from around 2004 may have exacerbated ongoing resource depletion in mining as it provided an incentive to exploit lower grade or lower quality resources.
- Full and accurate adjustment of measured multifactor productivity (MFP) to remove the effects of depletion, new discoveries and the exploitation of marginal resources due to unexpectedly higher prices would be difficult to achieve in practice. Information requirements are substantial, and much of the required information is generally only available with a substantial lag. Hence conventional or standard measures of productivity in the mining industry need to be interpreted carefully to avoid reaching unjustified conclusions regarding technical progress and changes in the efficiency of operations.

Typically, MFP is determined by factors such as technology, management, skills and work practices. However, MFP in mining also reflects the influence of another factor – the input of natural resources. While natural resources are a major input into mining production, changes in their quality over time are not generally taken into account in standard measures of productivity. This omission would not be a problem if natural resources were in infinite supply and of perfectly homogeneous quality — that is, available without constraint at the same unit cost of extraction. But resource deposits are non-renewable; they are depleted by ongoing extraction.

This chapter examines the role played by natural resource inputs in the mining industry, and provides quantitative estimates of the effects of resource depletion on mining MFP.

3.1 The input of natural resources

A necessary input to any mining activity is the *in situ* deposit that contains the mineral or energy resource to be mined. These *in situ* deposits properly constitute a resource input into production, much as the use of machines constitutes a capital input. Indeed, the extracted deposits can be thought of as an input of 'natural' capital to mining production.

Changes in the quality of natural resource inputs used in mining are not generally taken into account in standard estimates of mining productivity. They are generally overlooked because the natural resources are not a purchased input. That is, natural inputs tend to be taken as 'given' or 'environmental variables'.[1]

That said, the ABS does treat exploration expenditure as a capital input to mining, and therefore it could be argued that resource deposits are implicitly included in the capital stock of mining, and hence do indeed contribute to MFP estimates.

However, there are two reasons why the ABS capitalisation of exploration expenditure does not measure changes in the effective input of natural resources to mining. First, exploration expenditure is not adjusted for the quantity or quality of newly discovered deposits that are ultimately brought into production. All exploration expenditure is recorded as a capital input, with a constant asset life assumption (34 years). Hence, any changes over time in the quantity or quality of new deposits are not explicitly taken into account. As argued later in this chapter, there have been significant changes to the level of natural resource inputs used in mining due to the general depletion of resources over time. The capitalisation of exploration expenditure by the ABS does not take these changes into account.

[1] This is not to say that the issue of natural resource inputs to mining and the relationship to productivity has not been considered previously (see box 3.1).

Box 3.1 **Mining productivity and natural resource inputs**

Even though the resource economics literature on productivity in mining is well established, if not extensive, the effect of inputs of natural resources on measured productivity has not received a lot of attention. Some studies do acknowledge the negative effects of resource depletion and declining accessibility on measured productivity, but do not explicitly analyse or quantify the effects.

Canada appears to be the leader on analysis of this issue. Wedge (1973) observed that natural inputs are an important but generally ignored input in mining productivity estimates. He challenged earlier estimates of poor productivity growth in Canadian mining on the grounds that changes in the quality of resource inputs had not been taken into account. By using an index of ore grades as a proxy for these factors, Wedge found an 'order of magnitude' jump in the measured rate of productivity increase.

Lasserre and Ouellette (1988) built on the contributions of earlier resource theorists, who included the 'missing' resource input as an explicit factor in the mining production function, to make explicit allowance for changes in the quality of the resource input as approximated by changes in ore grade. Stollery (1985) used a cost function approach to investigate factors that contributed to productivity change in Canadian mining industries. He found that decline in grades had increased costs because lower mineral yields require more capital and energy-intensive processing. Young (1991) found econometric evidence that lower geological accessibility of a deposit — as proxied by cumulative production — as well as lower ore grades, lowered MFP in copper-mining firms. StatsCanada has begun investigating methods for including natural resources in national accounts estimates, including with respect to measurement of mining productivity. More recently, Rodriguez and Arias (2008) used an econometric approach to measure the extent to which cumulative depletion (as measured by changes in the level of reserves) affects extraction costs in Canadian coal mining. The authors found that depletion of natural resources requires an annual increase of input use of 1.3 per cent. They stress the importance of correcting for depletion in 'any extractive industry in which the level of reserves is likely to affect extraction costs' (Rodriguez and Arias 2008, p. 407).

There are a few non-Canadian studies. (Managi et al. 2005) note, in a study of the impact of technological change on oil and gas production in the Gulf of Mexico, that the costs of offshore oil and gas operations have generally increased, and productivity has declined, because of 'cumulative depletion and the associated decline in resource accessibility such as exploitation moving to fields that are more remote, deeper and smaller'. They adjust MFP growth for resource depletion effects. Rodriguez and Arias (2008) allow for resource depletion in the measurement of productivity in Spanish coal mining and find that resource depletion accounts (negatively) for 1.3 per cent of annual growth in MFP. Tilton and Landsberg (1997) discuss the role that changing head grades of ore may have played in explaining productivity changes in the US copper industry.

(continued next page)

Box 3.1 **continued**

These studies are not well known (at least outside of Canada) and the issue is not well established in the literature. Rodriguez and Arias (2008) went so far as to state '… to the best of our knowledge the analysis of the effects of the level of reserves of natural resources on [MFP] has not yet been analysed.' (p. 399)

Within Australia there does not appear to be any explicit treatment in the literature of the resource input problem in relation to measuring mining industry productivity, although there is an understanding that depletion can result in slower productivity growth. For example, in a review of future productivity trends in Australia conducted by the Australian Government published in 2006, the authors explain the slowdown in mining industry productivity growth in the ten years to 2003-04 as partly the result of the depletion of oil reserves (DCITA 2006). Further, they argue that future productivity in mining will be lower than in the past due to the likelihood that oil and gas productivity will continue to suffer from the adverse effects of depletion — that is, lower quality crude, deeper wells needing to be sunk, and more funds being channelled into expensive off-shore developments. In relation to coal, a recent ABARE report describes geological constraints such as deeper coal seams and more difficult geology as a 'significant factor' in explaining the decline in coal mining productivity in Australia since 2000 (Fairhead et al. 2006).

Second, even if exploration expenditure could be considered as a proxy for resource inputs to mining, the long lead time between when exploration expenditure is incurred and when any production based on newly discovered resources is recorded would make the connection between current exploration expenditure and current inputs to mining from natural resource deposits tenuous at best. There is generally a long lead time between exploration expenditure and mine production — in some cases decades.[2]

The significance of natural resource inputs to production is not unique to mining, although the non-renewable aspect of mineral and energy resources helps to sharpen the focus on the issue in this sector. Natural resource inputs to agriculture — such as land — may have the capability of being a perennial input to agricultural production of a more or less fixed capacity, but clearly management and random factors have the potential to reduce the effective inputs supplied by land over time. In extreme cases — say in the event of severe soil erosion or salinity — the natural resource inputs to agricultural production from a given piece of land may fall significantly. In the absence of a quality adjusted measure of land inputs to farming, there is therefore a possibility that lower output growth may be attributed to less efficient allocation of labour and capital, when it is actually due to a decline in the

[2] The issue of lead times in capital investment in the mining industry is taken up in detail in chapter 4.

effective inputs of natural resources to agricultural production. A common, albeit temporary, manifestation of this type of problem occurs during droughts, when the decline in agricultural output reduces measured 'productivity' in the national accounts, with the primary reason for the decline in output being a reduction in natural resource inputs — in this case rainfall (see Kokic, Davidson and Boero Rodriguez 2006 for a discussion on the role played by rainfall in explaining changes in agricultural productivity).

Similarly, output in the fishing industry is a function not just of conventional inputs, but also of the underlying stock of fish in the sea. Measuring the productivity of fishing fleets is confounded by the fact that the discovery and exploitation of fish stocks frequently leads to large changes in the catch per unit of effort expended by fishermen over time. In studies of productivity in fishing industries, accounting for changes in underlying fish stocks is a key issue (Grafton et al. 2006).[3]

In mining however, the non-renewable nature of natural resource inputs is the central issue. Once a high-grade or high-yielding resource is exploited, it cannot be exploited again. If remaining resources or reserves are of a lower quality or yield, then there is a permanent decline in natural resource inputs to production.

From a practical point of view, the features that characterise the quality of natural resource inputs used in mining include the following:

- Ore grade (metal per tonne of ore)
- Ore quality (impurities, milling characteristics etc)
- Reservoir pressure (flow rates of crude oil or gas)
- Overburden ratio (waste material to ore or coal production)
- Mine or well depth
- Distance from markets or key inputs
- Complexity of terrain/mine geology

Because of its central importance to mining activity, inputs of resources can have a major influence on mining productivity. Mining's labour productivity is relatively high, not only because the sector is relatively intensive in the use of conventional physical capital but also because it has the benefit of an additional major input of natural resource capital. That is, the true capital-labour ratio in mining is even higher than depicted in figure 2.7. Conventional measures of MFP for the mining industry account for inputs of physical capital, labour and intermediate inputs, but

[3] For an empirical analysis of the importance of fish stocks in explaining productivity (see Fox et al. 2006).

not for changes in the quality of natural resource inputs. Thus, MFP is in an important sense only a partial measure of productivity in the mining context.

The input of natural resources and other inputs of physical capital, labour and intermediates are interdependent. The combinations of inputs required to produce a unit of output differ, depending on the accessibility and quality of a resource deposit. For example, the physical capital, labour and intermediate inputs required to produce a ton of iron ore are much less when a deposit is close to the surface and are within easy reach of transport infrastructure than when a deposit is less accessible.

Because of this interdependence, variations in the quality and characteristics of a resource deposit can lead to variations in MFP as conventionally measured. In particular, as the quality (for example, ore grade) of a deposit declines, measured MFP will also decline, all other things equal, as more intense use of purchased inputs is required to produce a unit of output. When this happens, the decline in MFP does not reflect a decline in the (technical) efficiency of use of purchased inputs in mining. Rather, it reflects the fact that economic circumstances (output prices) make it worthwhile for proportionately more resources to be devoted to the production of output.

A systematic reduction in the quality or accessibility of deposits, due to depletion, will have a systematic negative effect on MFP over time. Compared with other industry sectors, efficiency growth in mining will be understated if estimates of MFP growth are interpreted as measures of efficiency gains. Mining productivity, specifically in relation to MFP, is therefore a ‘special case’. The significance of the unaccounted input of natural resources could invoke two possible responses — either do nothing, and qualify the interpretation of MFP growth estimates for mining accordingly, or explicitly include the input of resources in productivity calculations so that the resultant MFP growth estimates are more closely aligned with efficiency gains. The measurement of resource input in productivity calculations is revisited in section 3.4.

3.2 Optimal extraction, depletion of deposits and productivity

Natural resource inputs to mining bring ‘resource rents’ — surpluses of revenue above the costs of production (allowing for a ‘normal’ rate of return on purchased capital). Resource rents arise because the natural resource inputs are not paid for, and they arise even in competitive conditions for miners.

Exploitation of a deposit generates resource rents in the period of extraction. But there is also an opportunity cost associated with current extraction — the ability to generate a future resource rent by delaying extraction.

Hotelling (1931) shows that there is an optimal pattern of exploitation over time for an exhaustible resource. At any point in time the resource stock is exploited to the extent that the resource rent on the deposit mined is just equal to the expected increase in resource rent if the input were left in the ground. For the quality of deposit that represents the limit of exploitation, the implicit price of the resource input rises at a rate equal to the rate of return on the investment alternative (see box 3.2).

Deposits of the best quality are exploited first to realise their high resource rent, which can then be invested to generate an income stream greater than the appreciation in the value of the *in situ* resource. Resource of quality inferior to that at the limit of exploitation is left in the ground as the resource rent and implicit price of the resource input are initially low, but rising at a rate faster than the return on the alternative investment.

A hypothetical example serves to illustrate the mechanism at work on productivity. Suppose that deposits of gold-bearing rock vary only in terms of the gold content, such that a constant amount of labour, capital and intermediate inputs are used to mine and process a given amount of rock. An implication of Hotelling's analysis is that the gold yield per tonne of rock mined can be expected to decline over time as exploitation moves from rock with the highest gold content and resource rent to rock with the lower content. Thus, over time there is a decline in the quality of the resource input being utilised in production.[4]

In the hypothetical example, declining gold content means that more ore must be mined to produce a given amount of gold and that more labour, capital and intermediate inputs are required for that output. There is a decline in measured MFP as calculated by subtracting the increased labour, capital and intermediate inputs from the given gold output.

[4] In this example it is clear that the contribution of the resource input is diminished, but referring to this as a decline in resource quality rather than a decrease in input quantity is arbitrary. There is no independent measure of quantity versus quality. In the analogous case of capital input it is common to call a rise in the expenditure on capital input as a rise in capital quantity, but this could just as easily be called a rise in capital quality. For the example of a falling gold content in ore, a decline in resource quality sounds more intuitively appealing than a decline in quantity.

Box 3.2 **The 'Hotelling rule' for non-renewable resources**

Hotelling (1931) wrote the seminal article on the rate of extraction of a non-renewable resource. The article gave rise to what has become known as the 'Hotelling rule'.

Hotelling wrote his article against a background of popular concern that competition between producers would lead to an over-rapid depletion of natural resources. He explored the conditions under which producers would maximise their returns over time and showed that, at least under certain assumptions, they would extract deposits at a rate that was socially optimal.

Extracting an additional unit of ore from a deposit in the current period has an opportunity cost. In the presence of rising prices, which it is assumed would accompany depletion of the resource as it became more scarce, miners could also gain from leaving the marginal deposit in the ground for the time being and extracting it later.

Miners would gain nothing from shifting extraction between periods if the net present value of returns in all future periods were equal. In other words, and this is the Hotelling rule, the optimal rate of extraction over time requires that the rate of increase in the price of a non-renewable resource must equal the rate of interest or discount rate.

He also showed that the optimal extraction path involved a declining rate of extraction over time.

The rule assumes away the costs of extraction. It can, however, be easily modified to replace output prices with resource rents — the difference between output price and unit extraction costs.

Hotelling also considered a number of variations to this base case: monopoly, extraction costs that rise with cumulative production, demand (for durable minerals) influenced by cumulative production, fixed investments (mine development) and taxes. These issues were not treated in the same detail or rigour in the original paper, but have since been further investigated and elaborated by others.

That costs might rise with cumulative production (or depletion of a resource) is of specific interest in this study. David Ricardo is credited with bringing this notion to the fore as well as the implication that, in the presence of a variety of ore grades, the best quality deposits are mined first. Higher grade deposits will realise higher resource rents, which can then be invested to generate an income stream greater than the appreciation in the value of the resource left *in situ*. Resource of inferior quality is left in the ground as the resource rent is initially low, but its expected resource rent must rise at a rate faster than the return on the alternative investment, otherwise there would have been an incentive to mine the resource.

While Hotelling covered the increasing cost issue, it was more rigorously investigated by others in the 1960s and 1970s. The consequences for the Hotelling rule are that resource rents will rise with the rate of interest less the rate of increase in costs.

Source: Based on Hotelling (1931) and Devarajan and Fisher (1981).

New discoveries

New discoveries expand the resource base from which production is carried out. If the discoveries are of deposits with higher quality than those currently exploited, the associated resource rents will exceed those for the currently exploited deposits and they will likely enter into production quickly. If the input discovery is too small to affect market prices of the resource product and there is no change in technology, the pattern of product price and resource input price will remain unchanged. Both the output and the quality of resource input associated with the new discovery will be high relative to current standards.

Conventionally measured MFP increases with the development of any new, higher quality deposits, as output is high relative to the measured inputs of capital, labour and intermediates. The increased quality of resource input that is being utilised from the new high-quality deposits is not reflected in the measured inputs. There is no technical progress or improvement in production efficiency, just an increase in the quantity or quality of the resource input being used up in production.[5]

The increase in MFP from the development of new discoveries may be large or small depending on the size of the discovery and the extent to which its quality exceeds that of other deposits currently being exploited. There is no systematic pattern that can be expected as in the case of optimal depletion, so it is not possible to develop a systematic adjustment factor for correcting measured MFP. Also, as the impact of new discoveries invariably occurs against the backdrop of depletion of existing deposits, it cannot be assured that measured MFP will increase following even a significant new discovery.

3.3 Evidence of depletion

The observation that depletion of mineral and energy reserves can have a detrimental effect on conventionally measured productivity raises the question of how big is this effect? Unfortunately it is not a simple question to answer as the data required are far from readily available. For one thing, measured productivity is itself a residual, so systematically unravelling the various components of productivity change to isolate the effect of resource depletion alone is likely to be complicated. Nevertheless, when resource depletion is significant, it is more likely that (a) the depletion can be identified, and (b) the flow-on effect to productivity can be

5 Instead, the increased productivity is in the exploration/development stage of the industry, where additional *in situ* deposits have been generated from exploration efforts. More valued deposits mean a higher productivity of these exploration resources in terms of amount of resource input discovered per unit effort expended on exploration/development.

estimated. In the rest of this section we examine evidence for resource depletion on a commodity by commodity basis, beginning with the oil and gas sector.

The case of oil and gas extraction

The influence of depletion on oil and gas production is more obvious than for other mining industry commodities. This is partly a consequence of the characteristic pattern of oil and gas production at an individual well or field over time. Typically, oil production from an individual well or field increases to a maximum output, when it plateaus before gradually decreasing. Aspects of this pattern differ from well to well with considerable variations in the time taken to reach a maximum, the length of the plateau period, and the speed of the decline from maximum production to the exhaustion of the economic resource.

However, when enough individual fields of different sizes are combined, the resulting pattern of production can be modelled and resembles a bell curve. The popularisation of this feature of oil and gas production is credited to M. King Hubbert, who lends his name to the associated statistic — the Hubbert Curve.[6] An important observation made by Hubbert regarding the pattern of oil production when aggregated over a large number of fields is that, once approximately half of oil reserves have been extracted, aggregate production will inevitably decline.

In the case of Australia, the production profile of crude oil, condensate and LPG appears to be broadly consistent with the theoretical Hubbert Curve, although the comparatively small number of fields means that aggregate production displays a fair degree of noise (figure 3.1). In general, production appears to have risen comparatively quickly, reached something of a plateau before eventually peaking in 2000-01, and then begun to decline.

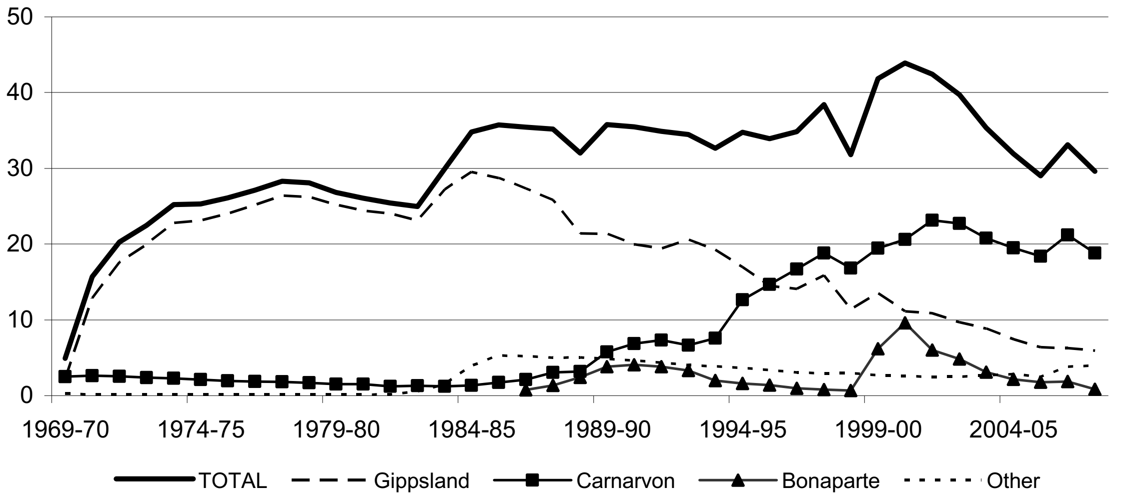
By examining the production profile of individual basins (also shown in figure 3.1) both the shorter and longer-term changes in aggregate production can be better understood. In the 1970s and 1980s production of crude oil, condensate and LPG in Australia was dominated by output from the Gippsland basin. Production in Gippsland had grown rapidly in the early 1970s, before reaching an initial peak in 1977-78. Production then began to decline, although there was a brief resurgence in the mid-1980s associated with the drilling of the large Fortescue oil field in 1984. From that point onwards however, oil production in the Gippsland basin has trended quite strongly downwards (figure 3.2).

---

[6] The Hubbert Curve is most commonly applied to oil production, although in principle it should also apply to in-situ mineral commodities and other energy commodities like coal.

Figure 3.1 **Production of crude oil, condensate and LPG, by basin**

Billions of litres

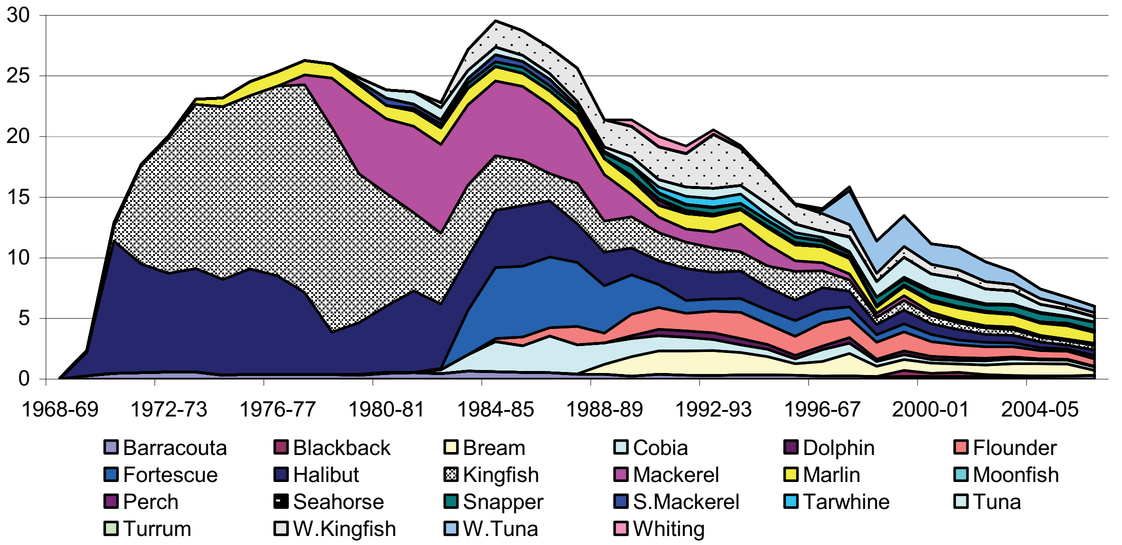


[a] Simple sum of crude oil, condensate and liquid petroleum gas (LPG). 'Other' represents all other production of crude oil, condensate or LPG in Australia.

Data source: ABARE (*Australian Commodity Statistics*, various issues).

Figure 3.2 **Gippsland basin: production of crude oil, condensate and LPG**

By field, billions of litres



Data source: VDPI (2008).

But as oil production in Gippsland was trending downward, output from other basins, particularly the Carnarvon basin in Western Australia, was rising. As a result aggregate oil production in Australia was largely unchanged from the mid-1980s to the end of the 1990s, although there was considerable year-on-year variability. Toward the end of the 1990s there was another surge in aggregate oil production associated with the development of new oil fields in the Bonaparte basin. However, the growth in aggregate output was short-lived, and with oil production in the three major basins (that is, Carnarvon, Gippsland and Bonaparte) on the decline, aggregate Australian oil production began to fall rapidly. The decline in aggregate output following the peak in 2000-01 was reversed in 2006-07 as production from a number of new fields in the Carnarvon basin came on stream. However, aggregate production is forecast to fall again in 2007-08 (ABARE 2008b).

Over the medium term it is predicted that Australian oil production will eventually reach a level above the 2006-07 level, but will remain considerably below the 2000-01 level (ABARE 2008b). Beyond that point crude oil production is expected to continue to trend downwards. Ultimately, whether or not the year 2000-01 represents the 'peak' of Australian oil production can only be tested by the passage of time. However, longer-term forecasts by industry indicate that future oil production in Australia will not surpass the 2000-01 level (APPEA 2007).

From a productivity perspective it is likely that future oil production will come at a higher real cost (per unit of output), as oil is sourced from deeper, more remote, or more difficult locations. The end result will be further downward pressure on conventionally measured productivity growth in the sector. This result, however, is predicated on the assumption that there is no major change in oil and gas extraction technology in the future, and that there is no further discovery within Australia of major, high-yielding oil and gas deposits. According to ABARE's *Energy in Australia* (ABARE 2008c), significant areas of Australian territory remain unexplored, and hence there is a possibility that future productivity gains will occur in oil and gas extraction due to new resource discoveries.

Recent events in crude oil production

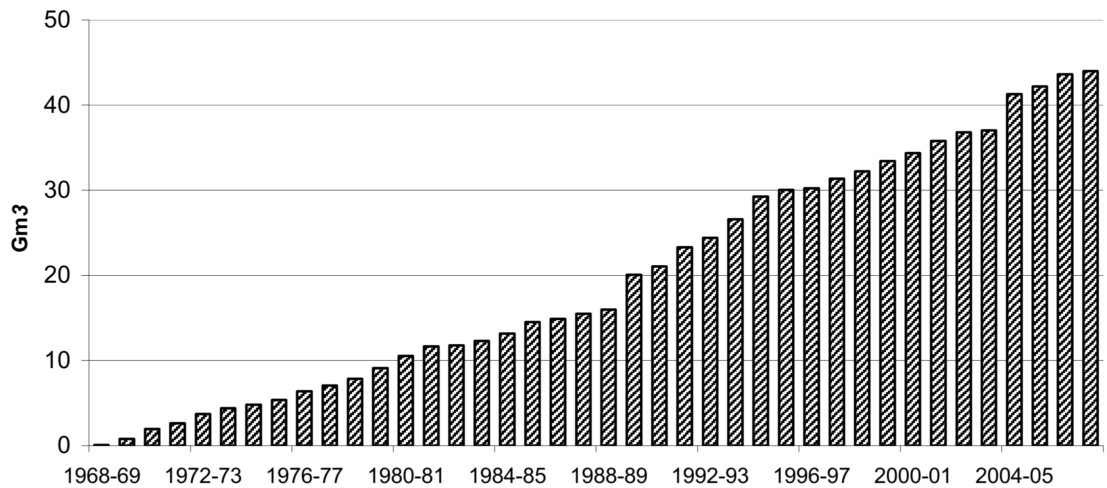
Figure 3.1 also helps to shed some light on the particularly rapid decline in oil and gas productivity since 2001. In the Gippsland basin oil production continued its long-term decline. Meanwhile, oil production in Carnarvon rose initially to peak in 2001-02, but then fell away quite quickly until 2005-06. Compounding these declines, oil production in the Bonaparte basin — which had grown very rapidly in the late 1990s — did not show the expected 'plateau' period of production, and fell very quickly after reaching a peak in 2000-01.

So, for most of the period in question oil production in Australia's three largest producing regions was in serious decline, leading to a marked reduction in aggregate oil production. In at least one of these regions — the Bonaparte basin — the decline in production was faster than anticipated (see Powell 2008 and WADOIR 2004), and this contributed to the sharp decline in MFP in the sector between 2000-01 and 2006-07.

Natural gas

In contrast to crude oil, resource depletion has been much less significant in the natural gas sector. Growth in Australian LNG production has been strong and consistent since initial production began in the late 1960s (figure 3.3), and this partly reflects the fact that Australia still has abundant reserves of natural gas. A shift in relative prices in recent years has slowed growth in the relative importance of LNG to the sector as a whole, but as oil production continues to fall in the future, LNG is expected to dominate the oil and gas extraction sector.

Figure 3.3 **Natural gas production**



Data source: ABARE (*Australian Commodity Statistics* 2007).

Depletion in other mining sub-sectors

In relation to mining commodities other than oil and gas, perhaps the best source of information regarding the longer-term depletion of resources in Australia is a recent study by Mudd (2007). In reviewing the future sustainability of mining in Australia, Mudd provides a comprehensive assessment of long-term trends in mineral and energy commodity production, along with long-term trends in resource quality and other aspects of production. Mudd contends that a serious consequence of the long-term depletion of Australia's mineral and energy reserves is the need for greater and greater effort to produce a unit of output, with greater and greater stress on the physical environment in terms of overburden and mine tailings produced, and water and energy inputs required per unit of output (Mudd 2007).

Mudd concludes after examination of long term trends in resource production and quality that most ore grades have declined significantly since mining began in Australia (Mudd 2007, p. 126) and that gradual declines in ore grades can be expected to continue into the future, with 'no real prospect of ever returning to the high grades of the past' (Mudd 2007, p. 119). He acknowledges that there are differences from commodity to commodity however, and reviews individual commodities on that basis.

The case of coal

In the case of coal Mudd argues that the main issue of concern is declining accessibility of remaining reserves. In particular, Mudd argues that in many cases the amount of earth or waste rock that must be moved or removed per unit of coal production is increasing over time (or conversely, that the ratio of coal produced per unit of overburden production is decreasing) (figure 3.4). Mudd cites early evidence of increasing overburden ratios in open-cut coal mining around 1980, and provides more recent evidence highlighting increases in overburden ratios in open-cut coal mining since 2001 (Mudd 2007, p. 17).[7] An ABARE report also explains an increase in the 'strip ratio' — the ratio of the volume of overburden moved to the tonnage of saleable coal produced — between 2000 to 2005 as being due to the 'increased depth of open-cut mines' (Fairhead et al. 2006).

The broader issue of the declining accessibility of Australian coal reserves was flagged in a paper presented by the Chairman of the Australian Coal Association, Dr C.D. Rawlings (Rawlings 1997). Dr Rawlings observed that, 'the easy coal has been taken', and highlighted the challenges faced by the industry in terms of increasing amounts of overburden produced in open cut mines as shallower coal deposits were exhausted, along with the problems and difficulties associated with greater depths required in underground coal mines.

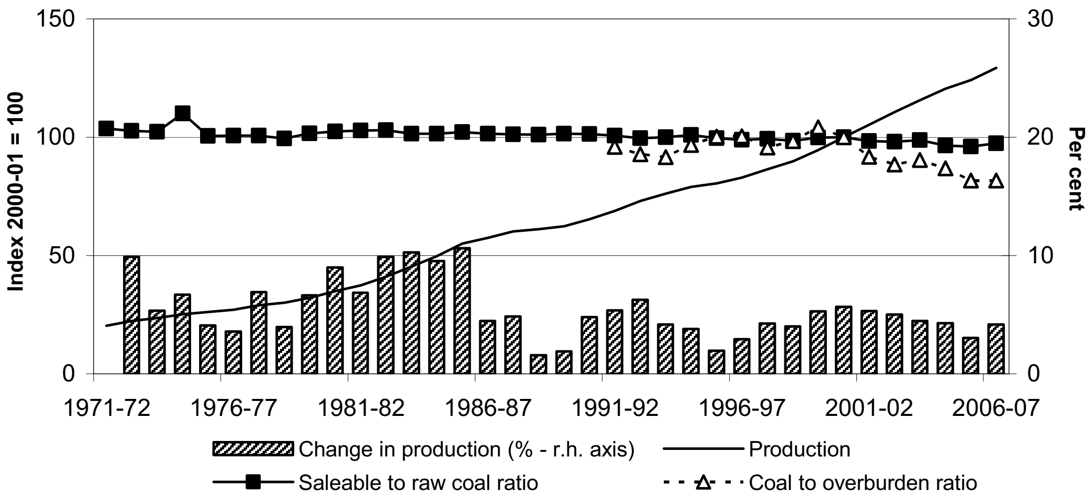
Apart from the reduced accessibility of new deposits, another adverse consequence of the depletion of coal reserves relates to possible declines in the quality of coal, as measured by the proportion of saleable coal produced per unit of 'raw' coal extracted. Time series data show a decline in this ratio since the early 1960s (of

[7] Unfortunately, consistent and comprehensive national data on overburden production are not available, and time series data are limited to the past 14 years for Queensland only.

around 0.2 per cent per year), with a further modest decline since 2001 (figure 3.4). Mudd also points to the fact that nearly all coal mines in Australia now use beneficiation or treatment plants to improve the quality of coal. And while this development may have been a response to market conditions, the increase in coal treatment expenses would nevertheless have acted as a drag on productivity growth (given that output is not quality-adjusted in MFP calculations).

With regard to future productivity trends in coal mining, any further reductions in the average quality of coal will act to reduce conventionally measured productivity growth in the sector, ceteris paribus, as more inputs are needed to produce a given quality of final output, or as less saleable output is produced from each unit of raw coal extracted.

Figure 3.4 **Coal production, coal overburden, and coal quality trends**[a]



[a] 'Production' (gross output in constant prices) and the 'Saleable to raw coal ratio' are four-year moving averages. The coal to overburden ratio is calculated using coal production and overburden production in Queensland open-cut mining only, and is a simple yearly average. Open-cut coal mining in Queensland accounts for around 48 per cent of total coal production.

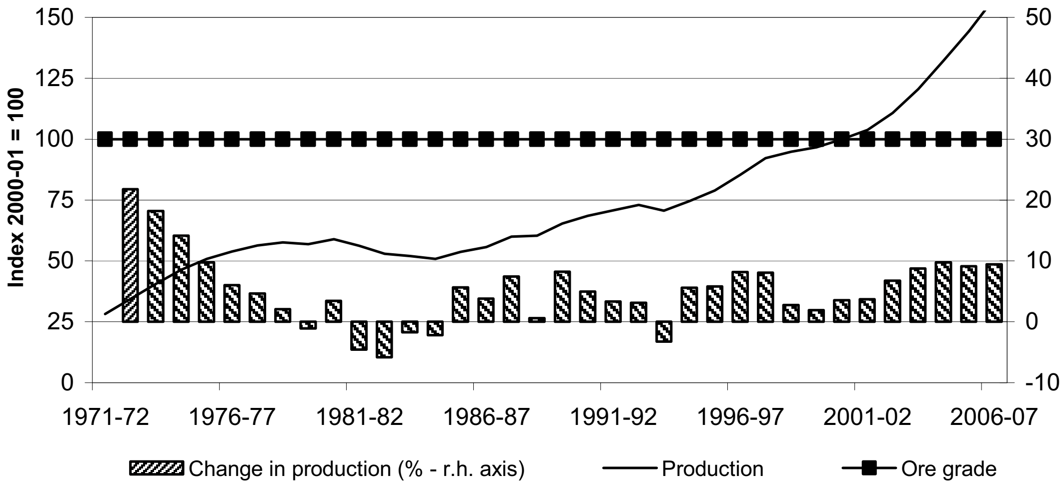
Data sources: Mudd (2007); ABARE (*Australian Commodity Statistics*, 2007).

The case of iron ore

In the case of iron ore it is more difficult to assess the nature and extent of depletion as the available data are limited (Mudd 2007, p. 43). For example, while time series data relating to bulk iron grade are available, the data refer to the quality of 'as shipped' production, not the quality of 'as-mined' iron ore. In most cases, iron ore is now processed to meet buyer requirements, and this affects the reported bulk grade.

At first glance it seems unlikely that depletion could be having a systemic negative effect on productivity in the sector. For one thing, iron ore reserves in Australia are estimated to be extensive, and are among the largest and highest quality in the world. Production in 2006-07 was 288 Mt, with known potentially economic resources of around 30 000 Mt — enough to sustain production at current production levels for well over 100 years (Mudd 2007, p. 47) (figure 3.5).

Figure 3.5 **Iron ore mining: production and ore grade[a] ,1971-72 to 2006-07**



[a] Ore grade is the grade of 'as shipped' ore. 'Production' (gross output in constant prices) is a four-year moving average.

Data sources: Mudd (2007); ABARE (*Australian Commodity Statistics*, various issues)

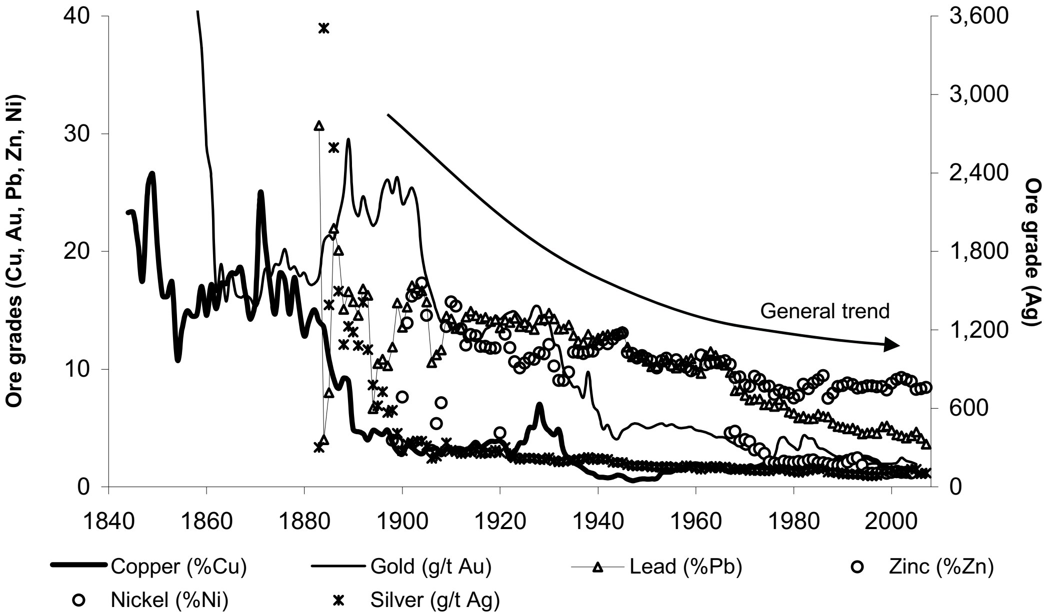
Nonetheless, Mudd contends that the issue of concern in iron ore mining is not so much the grade of as-mined iron ore, but the level of impurities and overall smelting characteristics of the ore. Like coal, most iron ore projects now include plants for improving the quality of iron ore in order to maintain high iron grades and to reduce or remove impurities that are disadvantageous to smelting and steel production (Mudd 2007). Although data are limited, Mudd argues that future iron ore projects will continue to rely on beneficiation and/or concentration, and possibly greater degrees of processing to meet market standards (Mudd 2007, p. 44)

Mudd also notes that there has been no systematic data collected on waste rock/overburden production in iron ore, limiting the extent to which changes in resource accessibility over time can be examined. Although only ad hoc evidence is available, Mudd argues that iron ore production now involves production of overburden/waste rock of around two tonnes for each tonne of saleable iron ore production (Mudd 2007, p.44).

The case of other metal mining

Although information regarding longer term trends in ore grades is not available for all of the metal industries analysed in this report, Mudd's report includes details for a number of significant metals produced in Australia. His broad conclusion, as noted above, is that metal ore grades have been falling over time, and are likely to continue falling into the future. A diagrammatic representation of the long-run decline in ore grades is shown in figure 3.6.

Figure 3.6 **Combined average ore grades over time for base and precious metals**



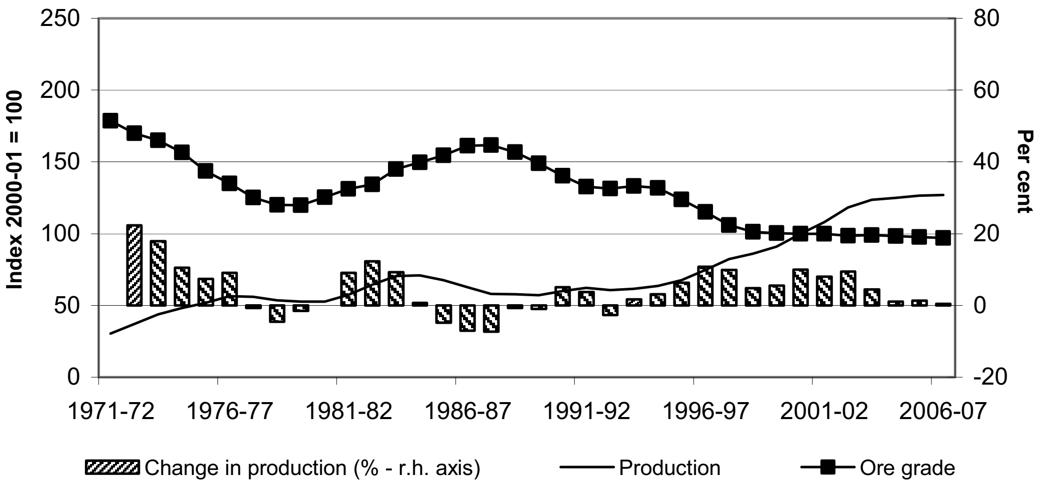
Data source: Adapted from Mudd (2007, p. 119).

In relation to individual industries, figures 3.7 to 3.10 illustrate trends in ore grades and production over the past 34 years for four of the individual metal industries considered in this report — copper ore mining, gold ore mining, lead/silver/zinc ore mining, and other metal ore mining. The production and ore grade series in each figure have been 'smoothed' by using a four-year moving average, in order to remove the influence of ad hoc or transitory factors in the production and ore grade series.

The (smoothed) average ore grades tend to swing or cycle over time, but in three of the four cases are trending downwards over time. And while there is no strong evidence of a downward trend in the average ore grade in copper mining over the period considered, there has nevertheless been a significant decline since 1994-95. In contrast, production growth in the four industries has been strong (albeit cyclical) since 1971-72, with faster growth generally occurring in the second half of the period rather than the first.

The more recent period from 2000-01 to 2006-07 is characterised by a slowdown in the rate of growth of production in the four industries (or a decline in production in the case of gold ore mining) coincident with ore grades either declining or showing little growth. It is possible that these outcomes reflect a short-run phenomenon, whereby higher output prices have encouraged production from lower grade ores, dragging down average ore grades.[8] But it is also possible that the decline in ore grades since 2001 reflects the general adverse effects of cumulative production on resource quality, and particularly the effect of more rapid depletion of reserves that began during the 1980s and 1990s in most of these industries.

Figure 3.7 **Other metal ores n.e.c.: production and ore grade[a], 1971-72 to 2006-07**

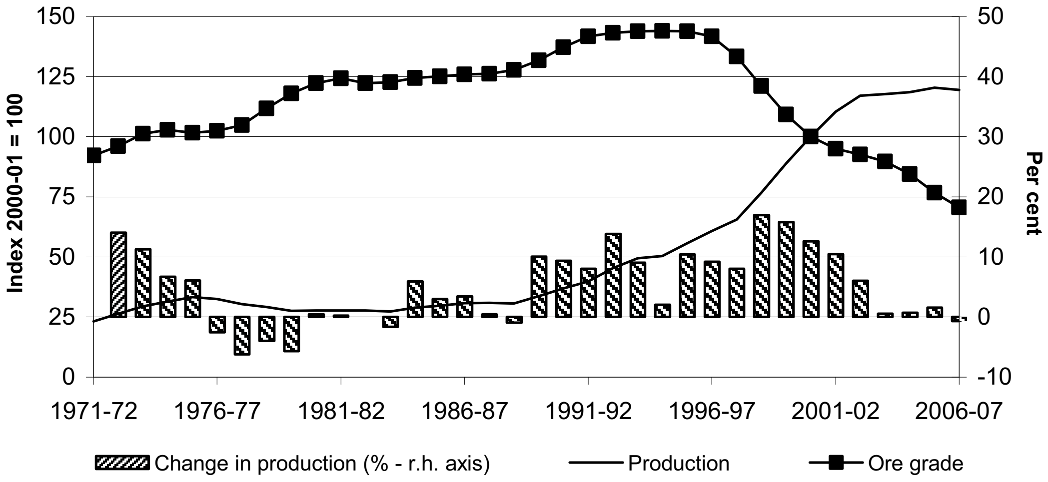


[a] 'Production' (gross output in constant prices) and 'Ore grade' are four-year moving averages. 'Ore grade' is the weighted average ore grade of nickel, bauxite and uranium.

Data sources: Mudd (2007); ABARE *(Australian Commodity Statistics* , various issues).

[8] This issue is explored further in chapter 5.

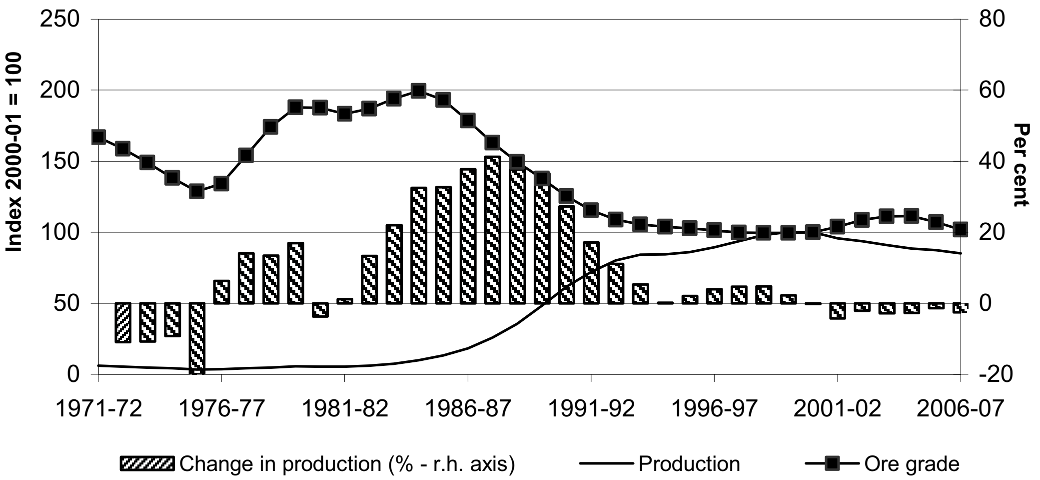
Figure 3.8 **Copper ore mining: production and ore grade, 1971-72 to 2006-07**



[a] 'Production' (gross output in constant prices) and 'Ore grade' are four-year moving averages.

Data sources: Mudd (2007); ABARE *(Australian Commodity Statistics,* various issues).

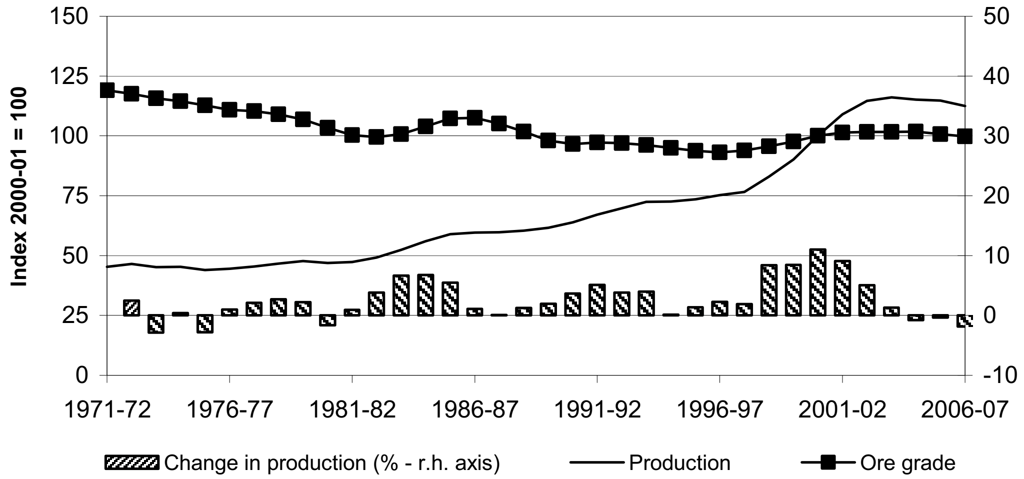
Figure 3.9 **Gold ore mining: production and ore grade, 1971-72 to 2006-07**



[a] 'Production' (gross output in constant prices) and 'Ore grade' are four-year moving averages.

Data sources: Mudd (2007); ABARE (*Australian Commodity Statistics,* various issues).

Figure 3.10 **Silver/Lead/Zinc ore mining: smoothed production and ore grade, 1971-72 to 2006-07**



[a] 'Production' (gross output in constant prices) and 'Ore grade' are four-year moving averages.

Data source: Mudd (2007); ABARE (*Australian Commodity Statistics*, various issues).

Other issues in metal ore depletion

For metal ore production, another way in which depletion can manifest itself is in relation to the minimum size that ore must be ground into in order to achieve mineral liberation.[9] A consequence of the deterioration of ore reserves is the need for finer grind sizes as remaining reserves are often fine-grained. For example, the metallurgical performance of the lead/zinc concentrator at Mt Isa Mines Limited declined dramatically during the 1980s because of declining ore quality, as the ore became both finer grained and contained increasing amounts of refractory pyrite (Young et al. 1997).

Notwithstanding further technological improvements in minerals processing, finer grained ores will increase the energy required to produce final output, and compound the effect of general declines in ore grades. Even where remaining reserves or deposits are not necessarily lower grade, some are nevertheless fine grained, and will likely require greater energy inputs to achieve mineral liberation (Norgate and Jahanshahi 2006). The greater energy use implies lower productivity for the mining process inclusive of the stage of generating concentrate of acceptable commercial quality.

[9] Mineral liberation refers to the particle size to which an ore must be crushed or ground to produce separate particles of either valuable mineral or gangue that can be removed from the ore (as concentrate or tailings respectively) with an acceptable efficiency by a commercial unit process.

3.4 Measuring the resource input in productivity estimates

Heterogeneity in the characteristics of the *in situ* deposits of resource input means that there is no obvious physical measure of resource input comparable to labour hours as the measure of labour input.[10] Similar difficulties occur with purchased capital inputs and are overcome by using expenditure measures. The purchase price of an item of capital equipment is used as a measure of the quantum of the capital stock and the flow of input is determined by allocating the stock over time using a depreciation rate. An analogous approach for resource input would require a purchase price for a deposit, which would be used to value the stock of resource, and an amortisation charge to allocate the use of this stock over time.

Unfortunately, extension of the method used for measuring the input from capital to the case of an *in situ* deposit is not straightforward. The payment for ownership of, or access to, a deposit is generally not a good indicator of the value of the resource stock. Substantial additional costs are often incurred by the mining company to explore and develop the deposit prior to production. Most importantly, the outcome of the exploration and development effort is uncertain. Thus, the degree to which a particular deposit can contribute to production is not well reflected in the amount spent on acquiring, exploring and developing the resource.

Furthermore, the resource stock does not contribute to production over time in a smooth way comparable to that of capital in the form of plant and equipment. First, there may be a long lag between expenditure on acquiring, exploring and developing an *in situ* deposit and its exploitation. Second, uneven quality of resource stock contained in the deposit can lead to substantial variation across time periods in its contribution to production, so that the amount of resource flow as an input to production is in some sense uneven during the period of exploitation. Thus, a constant amortization charge, equivalent to a constant depreciation rate for capital equipment, would not capture the contribution of the resource stock to production within each production period.

---

10 A standard response to the problems of deposit heterogeneity has been to measure *in situ* deposits of resource input using the concept of 'reserve', which measures the potential contribution of the deposit to the quantity of mining product. For example, a gold mine may be assessed as having a 'reserve' of 50 000 ounces of recoverable gold. The utilisation of the resource input is then calculated as depletion of the reserve. However, this confounds the measurement of input and output, and hence is not a meaningful measure of the contribution of the *in situ* deposit as the resource input to production.

While the flow of resource input into mining production is not observed, its contribution to the value of production can be inferred. In particular, the difference between the revenue received from mine output and the costs incurred for all other inputs, which is commonly referred to as the resource rent, puts an implicit price on missing elements in the production process. When mine output is sold into a competitive market by cost-minimising firms operating at their optimal outputs, differences in resource rent reflect differences in the value of the opportunity that is given up by exploiting the resource stock. In this sense differences in resource rent reflect differences in the quantity or quality of the resource input at any point in time.

It is tempting to conclude that production generating twice the resource rent involves twice the use of resource input. However, this treatment would rule out any possibility of capturing inefficient production through the measurement of productivity. If inefficient production involved more than the minimum resource input, the resource rent would not be affected and productivity should be lower. Simply equating differences in resource rents with differences in resource input is not appropriate for measuring productivity growth in mining.

A complete or comprehensive correction for changes in the contribution of natural resource inputs to mining requires detailed data on resource quality used in production. Information on average ore grades in Australia collected by Mudd (2007) and presented in section 3.3 provides the basis for a quantitative investigation of the extent to which these quality changes in resource inputs have contributed to changes in mining MFP. Similarly, detailed information on changes in oil and gas yields over time can also be used to examine the effect these changes have had on productivity in the oil and gas sector. In the remainder of this chapter we present estimates of the extent to which yield and ore grade changes have contributed to MFP changes in the mining industry since 1974-75. It is important to note however, that other aspects of resource depletion — deeper or more difficult deposits etc — may also be contributing to MFP changes in mining, but a lack of data precludes these effects from being measured.

Before considering how mining MFP estimates are affected by changes in yields there are a number of practical and definitional issues to consider.

Measuring 'yield' changes in oil and gas extraction and coal mining

In the case of oil and gas extraction, resource depletion generally manifests itself as a decline in the rate of flow of oil or gas from an individual well or field over time. Changes to the rate of oil and gas flow could be seen as synonymous with changes in the average grade of ore in metal ore mining. For example, lower production of oil or gas due to a decline in the natural pressure of a well or field over the course of a year is similar to a reduction in metal production in a metal ore mine due to a decline in the average grade of the metal ore that is extracted. Well or field level data can therefore be used to estimate the extent to which changes in oil or gas flows (both positive or negative) contribute to changes in output each year.[11]

In the case of coal mining there is no analogue to the concept of ore grade. However, there is a distinction in coal mining between the quantity of coal that is initially extracted — raw coal — and the quantity that is ultimately available for sale — saleable coal. Although it may not always be the case that changes in the saleable to raw coal ratio reflect changes in resource inputs due to depletion, the variable can be used as a proxy for general changes in the amount of effort that must be expended in mining coal due to the effects of cumulative production. For the purposes of this paper, changes in the ratio of saleable to raw coal are therefore treated as equivalent to a changes in the 'yield' of coal. As with metal ore grades, the ratio of saleable to raw coal can increase, decrease, or remain unchanged over time.[12]

Metal ore mining and the relevance of yield changes in MFP estimates

The output variable used in the majority of the metal ore mining industries covered in this report is the metal content of mine production. This reflects the fact that for most of the industries involved, the ABS survey results indicate that the majority of output is sold in the form of metal or metal concentrate, rather than in the form of metal-bearing ore.

The major exceptions are iron ore mining, bauxite mining and manganese ore mining, where the end product sold is largely metal-bearing ore. However, it is also the case that the outputs of these industries are not perfectly homogenous with respect to ore quality or metal content. For example, some iron ore is blended to improve the average quality of ore in order to meet customer specifications. To the extent this happens, greater costs will generally be incurred in producing final output. For the purposes of this report, however, it is assumed that, as the output variable used in MFP calculations is ore production, changes in the average grade of ore produced do not contribute to changes in MFP in these industries.

---

[11] In this context, care would need to be taken to ensure that changes in oil and gas flow rates due to abnormal events (breakdowns, natural disasters etc) are not attributed to 'depletion'.

[12] It may be the case, however, that increasing overburden ratios in coal mining have a much greater detrimental effect on coal mining productivity than the observed changes in the raw to saleable coal ratio. Further work needs to be undertaken to measure the extent that the coal to overburden ratio impacts on unit costs of extraction in coal mining to answer this question.

For the remaining metal ore mining industries the quantity measure of output is generally the metal content of ore production, and hence changes in the grade of ore over time are assumed to have a direct effect on conventional MFP estimates. As noted above however, changes in other characteristics of ore will also influence MFP to the extent that they alter the quantity of inputs used to process or prepare a unit of metal output. Such changes are not reflected in changes to average ore grades.

In general, the changes in 'yields' as defined above are only partial indicators of the overall change in resource inputs to mining as time goes by.

Methodology used to measure the effect of yield changes on MFP

The approach used here to estimate the effect of ore grade or yield changes on mining MFP is to make use of the fact that changes in yields have a direct effect on changes in the numerator of the MFP formula. That is, output (value added) is directly affected by changes in ore grades or yields through the equation:

$$\text{MFP} = \frac{\text{Output}}{\text{Inputs}} = \frac{\text{Value added}}{\text{Inputs}} = \frac{\text{Gross output} - \text{Intermediate inputs}}{\text{Inputs}}$$

where Gross output = Raw production * yield, so that

$$\text{MFP} = \frac{\text{Raw production * yield} - \text{Intermediate inputs}}{\text{Inputs}}$$

The change in MFP from one year to the next is simply the change in output (value added) that is not explained by changes in inputs. It is straightforward to account for that part of the output change that is known to have been caused by yield changes from one year to the next.[13] After removing the influence of yield changes, the residual is closer to the general interpretation of MFP — that is, the change in output that is not explained by changes in inputs. (The formula used to estimate the effect of yield changes on MFP is derived and explained in more detail in appendix C.)

[13] An alternative to adjusting the numerator in the MFP formula would be to introduce a new input to the MFP formula — natural resource inputs — such that deteriorations in yields due to cumulative extraction lead to a reduction in the total amount of resource input used, and vice versa. Under this approach, for example, the discovery and exploitation of new, higher yielding deposits would lead to a concomitant increase in resource inputs. The 'new input' approach to the issue would require estimating appropriate weights to apply to the growth in natural resource inputs each year so that they could be added to the appropriately weighted growth in existing labour and capital inputs. Although this approach is conceptually different to the direct approach used in this paper, the results should, in principle, be similar.

The effect of yield changes on MFP is estimated for each of the eight mining sub-divisions covered in this paper, using the yield variables as per table 3.1. Again, it is important to note that the influence of yield changes is only one possible type of resource input change that could be occurring in practice, and that for a number of metal-ore mining industries the ore grade issue is not relevant as the output measure used in MFP estimates is ore production, not the metallic content of ore production.

A composite yield index for the mining industry as a whole has also been derived in order to estimate the aggregate effect of yield changes on overall mining industry productivity. The composite yield index is a Tornqvist index based on the individual sub-sector yield indexes, and their relevant shares in the (annual) value of mining industry production. The 'services to mining' sector is included in the calculation of the composite yield index under the assumption that there is no change in the yield of this sector over time.

Table 3.1 **Yield variables used to measure depletion, by sub-sector**

Industry	*Yield variable or proxy*	*Data source*
Black coal mining	Saleable to raw coal ratio	Mudd (2007); ABARE (various issues)
Oil and gas extraction	Imputed yield	WADOIR (2008), VDPI (2008) , APPEA (2007) , ABARE (2007)
Iron ore mining	No adjustment – output measure is iron ore	Mudd (2007)
Other metal ores (inc bauxite)	Ore grade (no adjustment for tin, uranium, bauxite or manganese)	Mudd (2007)
Copper ore mining	Ore grade	Mudd (2007)
Gold ore mining	Ore grade	Mudd (2007)
Mineral sands mining	No data – no change assumed	
Silver, lead, zinc ore mining	Ore grade	Mudd (2007)
Services to mining[a]	No change	

[a] The 'Services to mining' sub-division is not included in our analysis of individual mining sectors, but it is accounted for when deriving the composite yield index used to measure the effect of yield changes on MFP at the aggregate mining industry level.

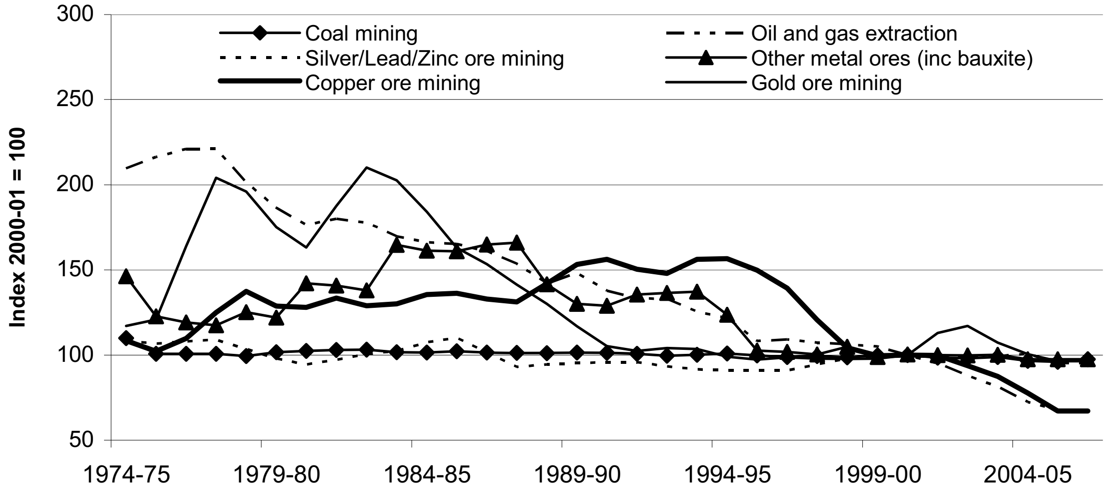
In the case of the oil and gas extraction sector, the imputed yield series is derived by calculating the year on year change in oil and gas production at each individual field (apart from fields in the Cooper- Eromanga basin, for which only aggregate data are available). The individual field changes are aggregated to produce the sector change in production each year due to yield changes. Changes in production due to the initiation of new wells or closure of old wells are excluded from the calculation on the grounds that these events generally do not take place at the beginning of the financial year, and hence do not reflect full-year results. We also remove the effect of changes in production in the Gippsland basin that were due to the gas explosion at the Longford refinery in October 1998.

The change in aggregate oil and gas production due to individual field yield changes is then expressed in percentage terms, and this forms the 'imputed yield' index for the oil and gas sector as a whole. As is the case in the metal-ore industries, the yield changes from one year to the next can be either positive, negative or zero.

Yield indexes

The estimated long-run yield indexes for the individual industries covered in this report are shown in figure 3.11, while the composite index used to estimate the effect of declining resource quality on the mining industry as a whole is shown in figure 3.12.

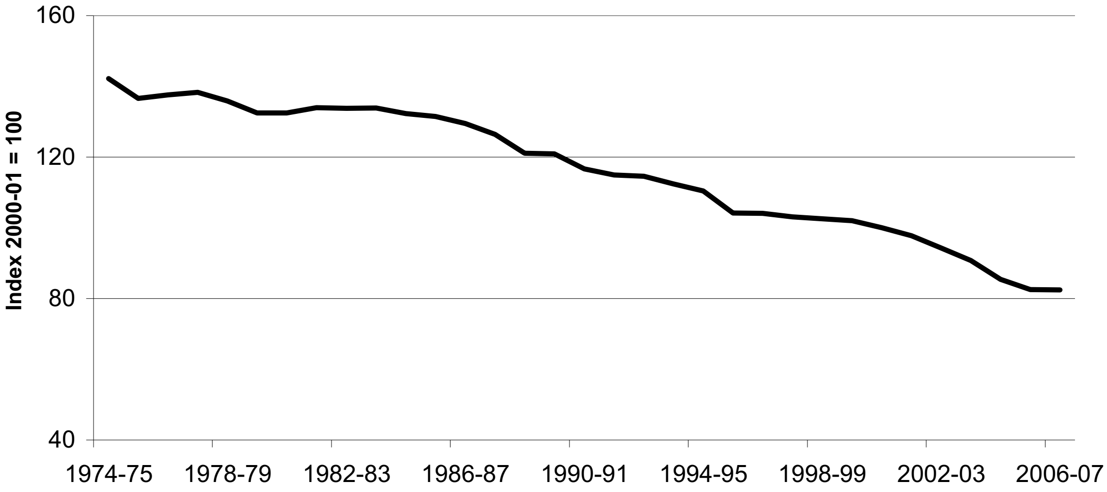
Figure 3.11 **Estimated yields in Australian mining, by industry[a]**



a No yield effects assumed for iron ore, bauxite, manganese or mineral sands for the reasons discussed above. Yield effects are assumed to be zero for oil and gas from 1968-69 to 1973-74 because this period reflects the start-up of production in the Gippsland basin. This 'start up' period is different from 'normal' production intensity, thus should not be considered in the depletion adjustment.

Data sources: Mudd (2007); ABARE (*Australian Commodity Statistics,* various issues).

Figure 3.12 **Estimated yield in Australian mining[a]**



[a] Reflects the composite effects of ore grade changes in metal ore mining, changes in the raw/saleable coal ratio, and changes in the rates of flow of oil and gas.

Data sources: Mudd (2007); ABARE (*Australian Commodity Statistics*, various issues); VDPI (2008); WADOIR (2008).

Other issues and assumptions

Changes to other inputs

The estimated effects on MFP due to yield changes are based on the assumption that the observed year on year changes to conventional inputs — that is, labour, capital and intermediate inputs — would not have been any different had yields not changed. For example, where yields have fallen from one year to the next, it is assumed that, had yields not fallen, inputs would have been exactly the same. In essence the assumption implies that, in the short run at least, variable costs of production are low relative to fixed costs. In this case the full effects of yield changes flow through to the MFP calculation. However, if it is the case that input requirements would have been significantly different had ore grades or yields not changed, then the full effect of any yield changes on MFP also requires an appropriate change be made to inputs. If, for example, yield declines also lead to a reduction in inputs, then the method used to estimate the effects of yield changes used in this paper will consistently overstate the effects, and vice versa.

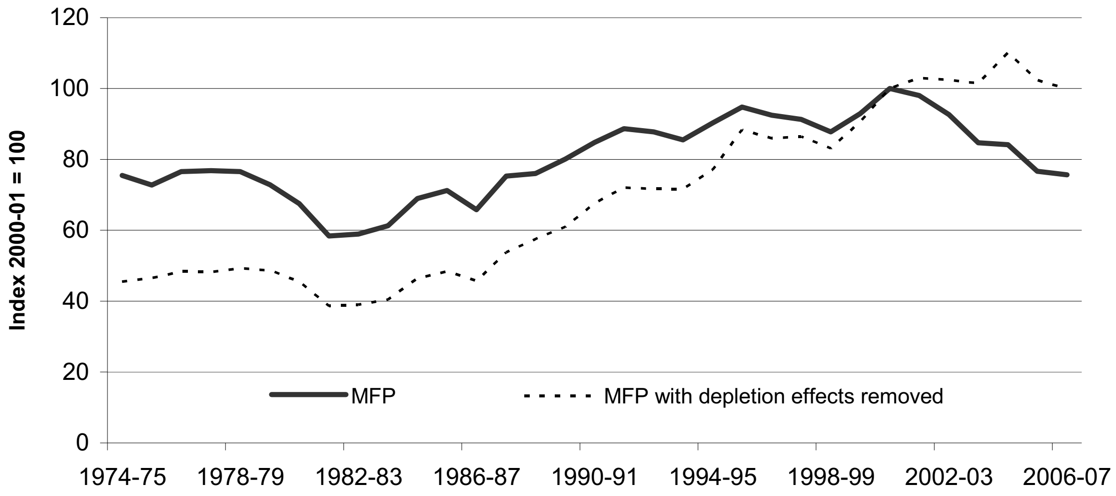
Where commodity production has fallen quickly and significantly — as has been the case since 2000-01 in the oil and gas sector in particular — it seems reasonable to assume that the change in total inputs observed from one year to the next over this period would not have been much different had depletion not occurred.

Variable costs in oil and gas extraction are low compared with fixed costs, which supports the argument that inputs would not likely have been much different had depletion not occurred. The high capital to labour ratio and fixed nature of capital in petroleum extraction also supports the view that inputs cannot be varied significantly in the short run. In this event the estimates of yield effects presented below, at least for the oil and gas sector, are likely to be reasonably accurate.

3.5 Results

The estimated effect of yield changes on MFP in the mining industry is shown in figure 3.13. The solid line shows mining MFP over the period from 1974-75 to 2006-07, while the dotted line shows annual movements in mining MFP once the effects of yield changes are removed. Hence, differences in the year on year changes in the two series illustrate the extent to which yield changes impact on MFP.

Figure 3.13 **Effect of yield changes on mining industry MFP**



Data sources: ABS (*Experimental Estimates of Industry Multifactor Productivity 2006-07*, Cat. no. 5260.0.55.002); PC (1999); Authors' estimates.

The long-term trends in yields are estimated to have had a significant adverse effect on the long-run rate of growth of mining MFP. By taking yield changes in the mining industry explicitly into account, the underlying rate of productivity growth in the sector is around 2.5 per cent per annum, compared with the standard MFP estimate over the period from 1974-75 to 2006-07 of 0.01 per cent.

Over the past 32 years, yield changes have occasionally had a positive effect on MFP changes from one year to the next, but in general the effects have been negative. Adverse movements in yields did occur during the early 1980s, but other factors appear to have been more important in explaining the sharp falls in MFP at that time.[14] In general, falling yields are estimated to have had strong adverse effects on growth in mining MFP throughout the 1980s and 1990s.

Yield changes also account for a large proportion of the marked decline in productivity in the mining industry between 2000-01 and 2006-07, particularly in the first few years of the period. For example, in the period from 2000-01 to 2003-04 mining industry MFP is estimated to have fallen by 15.3 per cent. Yield changes are estimated to have contributed negative 16.8 percentage points to this change, while 'other factors' are estimated to have contributed positive 3.0 percentage points. It also appears as if the general downward trend in yields accelerated after 2000-01, and hence the adverse effect of yield changes on MFP after 2000-01 was greater than might otherwise have been expected. As noted earlier, there has been a major decline in oil and gas production so far this decade, and this has contributed significantly to the overall decline in mining industry yield. The estimated effects of resource depletion on productivity at the mining sub-sector level are contained in appendix A.

Developments in 2007-08

As noted earlier, MFP in the mining industry is estimated to have fallen further in 2007-08, by around 8 per cent. It is not possible to estimate the extent to which resource depletion contributed to the decline in 2007-08 due to a lack of data. However, there is some evidence to suggest that there have been further reductions to flow rates in crude oil and condensate production, and to the extent this has happened, some of the decline in MFP will be due to depletion.

Implications and questions

A key question arising from the analysis of yield changes on mining MFP is whether the increase in the rate of yield decline seen between 2000-01 and 2006-07 is a permanent feature of mining, or whether it is a temporary phenomenon associated with the mining boom. That is, some part of the increase in resource depletion between 2000-01 and 2006-07 may have been due to behavioural changes by mining companies in response to the commodity price surge. For example, in an effort to maintain or increase production in the face of historically high output prices, mining companies may have exploited more marginal deposits, re-opened previously 'moth-balled' mines, run existing mines or capital equipment harder, or

[14] This includes the effects of a boom in new investment in the mining industry during the period, the consequences of which for MFP estimates are taken up in chapter 4.

used secondary or tertiary extraction techniques to increase production in the oil and gas sector. To the extent that this is the case and the consequence was faster resource depletion than might otherwise have been the case, then there is the possibility that some part of the recent decline in mining MFP due to yield declines post 2000-01 will be reversed once the mining boom is over. However, measuring the extent to which the observed yield declines in mining between 2000-01 and 2006-07 are due to behavioural changes by mining companies rather than a continuation of the observed longer term declines in ore grades and yields is difficult. (The broader issue of greater effort by producers in the face of a commodities price surge and the implications for measured productivity is addressed in chapter 5.)

In principle, there are a number of reasons to believe that the declines in ore grades and yields observed since 2000-01 are more consistent with the continuation of longer term trends, rather than a more temporary or transitory phenomenon. First, the mining industry price surge effectively started around 2003-04, rather than 2000-01. Hence, the extent to which behavioural changes in mining due to the price surge could have impacted on resource depletion and yields is largely limited to the period from 2004-05 onwards (an exception to this is oil and gas, discussed below). As shown in figure 3.13, the adverse effects of yield changes on mining MFP were occurring prior to the output price surge, and have slowed down in the last two years of the period despite commodity prices in the sector remaining very high in real terms.

On the other hand, the increase in prices for oil and gas did begin earlier — around 2000, and hence there has been a greater opportunity for behavioural changes to have played out in this sector. For example, higher prices in oil and gas from the late 1990s onwards may have encouraged greater use of secondary or tertiary production techniques than might otherwise have been the case. As a result, resource inputs to the sector would have been concomitantly greater over the period, contributing to the decline in MFP. Alternatively, the increase in oil prices in 2000-01 may have resulted in some oil and gas fields being kept operating when they would otherwise have been closed. In this event, some of the decline in MFP should correctly be seen as temporary or transitory, to be reversed at some point in the future when these wells are closed.

In general, however, it appears to be the case that the decline in oil and gas yields after 2001 was a continuation of ongoing declines in well pressures and flow rates at a very large number of individual oil and gas fields around Australia. There is little evidence to show that oil and gas producers deliberately attempted to speed up extraction of oil and gas in order to take advantage of higher prices, or that a significant number of oil and gas fields were kept in production solely because of the higher prices.

4 Understanding productivity in mining: purchased inputs

Key points

- Mining is a capital intensive industry with large sunk costs. While productive capacity is often fixed (particularly in the short term), annual production can vary significantly due to the natural characteristics of individual mines and wells.
- The fixity of productive capacity in the short term implies that permanent expansions to production can only come about with substantial new investment.
- There is a lag between investment in new capacity in mining and the associated output of around three years. Lags in the response of mining production to new capital investment mean that there can be a negative short-term relationship between capital investment in mining and mining MFP.
- Accounting for the lag between capital investment and output in mining explains a considerable amount of the year to year variability in mining MFP. After removing these effects, mining MFP is considerably less variable over time, although the trend rate of growth is unchanged.
- The lag between new investment and output accounts for around one third of the observed decline in mining MFP between 2000-01 and 2006-07, with the effects concentrated in the last three years of the period. A positive effect on multifactor productivity (MFP) would be expected over the next few years as production associated with recent capital investments comes on stream.

As discussed in the previous chapter, resource depletion plays a significant role in explaining changes in mining MFP. Another important reason that movements in mining MFP need to be interpreted carefully is that there are usually long lead times between investment in new capacity in the mining industry (whether in the form of new mines or mine expansions) and the corresponding production. This chapter examines the nature and extent of the relationship between investment in new capacity in mining and changes in MFP.

4.1 The structure of mining costs

The variety in activities, commodities and techniques of production in mining (chapter 2) means that there is not a unique, or even typical, set of input requirements. There are nevertheless some input characteristics that are of general relevance to the nature of productivity trends in the sector.

Mining is a capital intensive industry. Table 4.1 shows that capital inputs account for about half the total costs in mining production (or around 80 per cent of value added). The average for the economy as a whole is 21 per cent (or approximately 44 per cent of gross value added).

Labour inputs account for a relatively small share — approximately 12 per cent — of total costs (table 4.1 and figure 4.1) and around 23 per cent of value added in mining. In contrast, labour inputs in the economy as a whole are around 25 per cent of total costs, and around 52 per cent of gross value added. Mining employees are generally better paid than other workers however, which is partly a function of higher average skill levels among miners, and partly a function of the hazards and hardships of mine work, including remoteness. Apart from higher wages and salaries, mining companies also typically face higher on-costs associated with their employees, including accommodation costs for remotely located workers, and transport costs associated with moving mine workers to and from mine sites. The latter have risen considerably in recent times with the move among many mine operators to a 'fly-in, fly-out' approach to their on-site labour force.

There are also major differences in cost structures within the mining industry, with oil and gas producers in particular relying to an even greater degree on capital inputs compared with the other mining industries (figure 4.1). In general however, mining industries use more capital and less labour than the rest of the economy. The use of intermediate inputs in mining is also lower than the national average, mainly due to the very low use of these inputs in oil and gas extraction.

Table 4.1 **The cost structure of mining, 2004-05**

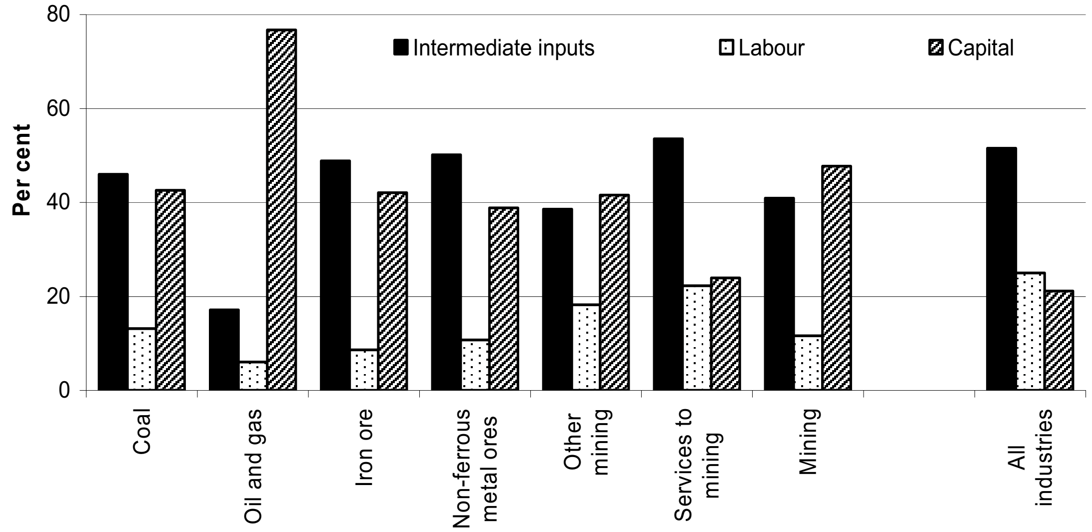
$million[a]

	Mining industry	Industries: Coal	Oil & gas	Iron ore	Non-ferrous metals	Other mining	Services to mining
Intermediates:							
Mining products	10 487	2908	1108	2032	3885	380	175
	(14)	(15)	(6)	(25)	(21)	(13)	(2)
- Services to mining	6814	1659	578	1579	2751	73	174
	(9)	(9)	(3)	(20)	(15)	(3)	(2)
Manufactured goods	8219	2503	779	816	2566	372	1184
	(11)	(13)	(4)	(10)	(14)	(13)	(13)
- Petroleum & coal products	2919	761	145	301	1091	140	482
	(4)	(4)	(1)	(4)	(6)	(5)	(5)
Energy	834	244	80	94	408	3	6
	(1)	(1)	(0)	(1)	(2)	(0)	(0)
Trade services	2643	785	338	306	543	149	522
	(3)	(4)	(2)	(4)	(3)	(5)	(6)
- Construction	544	199	89	115	44	25	73
	(1)	(1)	(0)	(1)	(0)	(1)	(1)
- Wholesale	1155	342	118	113	359	62	160
	(2)	(2)	(1)	(1)	(2)	(2)	(2)
Transport & storage	2467	1231	369	168	292	72	335
	(3)	(6)	(2)	(2)	(2)	(2)	(4)
Professional & other services	5745	1028	440	446	1261	134	2436
	(8)	(5)	(2)	(6)	(7)	(5)	(27)
- Banking	492	123	89	75	147	24	35
	(1)	(1)	(0)	(1)	(1)	(1)	(0)
- Other prop. services	1074	406	160	205	210	34	58
	(1)	(2)	(1)	(3)	(1)	(1)	(1)
Total intermediates	**30 858**	**8785**	**3144**	**3926**	**9114**	**1125**	**4764**
	(41)	(46)	(17)	(49)	(50)	(39)	(54)
Labour costs	**8767**	**2509**	**1107**	**690**	**1949**	**530**	**1982**
	(12)	(13)	(6)	(9)	(11)	(18)	(22)
Capital [b]	**36 003**	**8144**	**14 086**	**3383**	**7049**	**1211**	**2130**
	(48)	(43)	(77)	(42)	(39)	(42)	(24)
Production [c]	**75 524**	**19 135**	**18 361**	**8039**	**18 171**	**2917**	**8901**
	(100)	(100)	(100)	(100)	(100)	(100)	(100)

[a] Numbers in brackets are proportions of the value of production. [b] Defined as value added less labour costs. [c] Discrepancy in summation is due to indirect taxes.

Source: ABS (*Australian National Accounts: Input-Output Tables 2004-05*, Cat. no. 5209.0.55.001).

Figure 4.1 **Total cost shares in mining, by industry, 2004-05**



Data source: ABS (*Australian National Accounts: Input-Output Tables*, *2004-05,* Cat. no. 5209.0.55.001).

4.2 The nature of mining capital

As noted above, mining is a capital intensive industry, and the composition or mix of capital used in mining is also different to that of other sectors (figure 4.2). For one thing, the capital stock in mining includes exploration expenditure, which is a type of capital stock unique to mining. The ABS treats exploration expenditure as a capital input rather than an intermediate input on the basis that exploration activity, whether successful or not, is required to acquire new reserves (ABS 2006).

Of the remaining types of capital stock, mining also has a comparatively large share of construction capital. This reflects the large capital costs associated with the development and construction of open-cut and underground mines, and the high cost of off-shore drilling platforms in the oil and gas sector. Private infrastructure assets owned by mining companies such as roads, railways and port infrastructure, are also significant, and contribute to the large amount of non-dwelling construction capital used in the sector.

Table 4.2 **Net capital stock in selected industries, by capital type, in 2006-07**

$million (% of total)

	Machinery and equipment	*Non-dwelling construction*	*Computer software and other*	*Exploration*	*Total*
Mining	52.1 (23.8)	130.1 (59.4)	1.2 (0.5)	35.7 (16.3)	219.1
Agriculture, forestry & fishing	34.3 (40.5)	40.9 (48.3)	9.5 (11.2)	0.0 (0.0)	84.8
Manufacturing	72.9 (53.6)	60.4 (44.4)	2.6 (1.9)	0.0 (0.0)	135.9
Construction	17.6 (61.1)	10.4 (36.1)	0.8 (2.8)	0.0 (0.0)	28.8

Source: ABS (*Australian System of National Accounts 2007-08*, Cat. no. 5204.0, Table 88).

Variability in mining capital investment

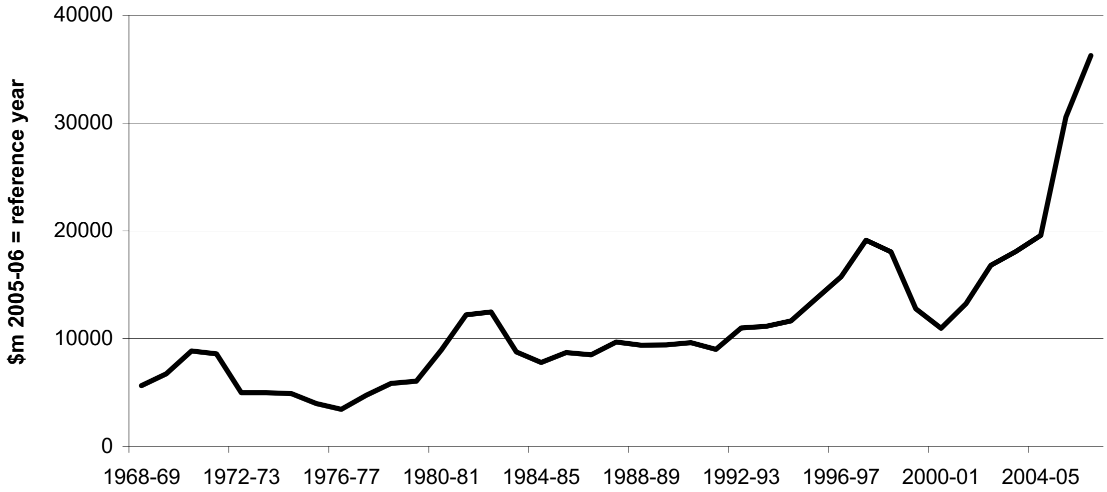
Annual investment in new capital in the mining industry also shows significant year to year variability, and there is clear evidence of cycles in investment behaviour over time (figure 4.2). For example, between 1968-69 and 2006-07 there appear to be four major investment cycles — peaking in the early 1970s, in the early 1980s, in the late 1990s, and an investment surge beginning around 2004-05 the peak of which is yet to be determined. As important as the investment surges may be, it is also important to note that each surge in new investment is accompanied by a significant drop-off in new investment following the peak. So while capital investment has risen dramatically since 2000-01, the increase is from a very low base. In fact, real mining capital investment in 2000-01 was below the levels reached in the early 1980s.

The specific nature of capital in mining

The nature of capital investment in the mining industry tends to be quite specific to the circumstances of individual mines. The way a mine is developed needs to take account of the characteristics of a deposit (for example, its depth, dispersion, distribution of ore grades and the nature and stability of surrounding material), the engineering and economic feasibility of different extraction techniques, associated plant and equipment requirements, infrastructure needs (access roads, power sources, transport systems, processing facilities, waste disposal areas), future rehabilitation requirements and so on.

Many, if not most, of the capital expenditures are sunk costs. Once incurred, they cannot be recovered by sale or transfer of the corresponding assets. However, there are sometimes opportunities for new mines that are being developed in close proximity to existing mines to take advantage of pre-existing capital, such as transport facilities and processing plants.

Figure 4.2 **Gross fixed capital formation in mining**
Chain volume measures with 2006-07 as the reference year



Data source: ABS (*Australian System of National Accounts 2007-08*, Cat. no. 5204.0, Table 91).

The technology chosen for use in an individual mine can also be considered largely fixed once the decision to build the mine in a particular way is locked in. In this event, major changes to market conditions after a mine is developed can have little effect on the way a mine operates, including its production capacity. While there are important technological advances in mining, major advances in technique or changes that entail different infrastructure requirements are more readily adopted when new mines are developed, rather than through retro-fitting existing mines.

The characteristics of mining that dictate the type and nature of new mine developments also apply to mine expansions and upgrades. The capacity and technology adopted in relation to mine expansions and upgrades tend be site specific, and projects are developed and built with a longer-term view in mind regarding production and production targets.

Capacity selection and utilisation

The circumstances of individual deposits also influence the scale of a project. Part of the pre-development phase of a new mine is to determine an optimal rate of extraction among feasible options and to set the scale of mine and associated infrastructure accordingly. For example, small but high-quality deposits may permit comparatively small-scale mining operations, while deposits of lower quality ore will generally demand larger-scale investments in order to extract larger volumes of material, and to transport and process it.

The 'Hotelling rule' and its various elaborations give some theoretical guidance on the optimal strategy for miners to extract non-renewable resources (chapter 3). These considerations suggest that the rate of production is set to maximise net returns over time and that the highest quality deposits are mined first. Given commodity prices, mining costs and interest rates, the rate of mining activity and the rate at which commodity outputs are produced from extracted material will essentially be determined by the quality of available deposits, where quality reflects not only ore grade but other characteristics.

In practice, of course, there is considerable uncertainty about the quantity and quality of resource reserves and uncertainty about the future course of prices over what can be long-life projects. Because many resource deposits are in remote locations, the availability of supporting infrastructure (and who pays for it) is also a vital cost issue.

The time scale for mine development is generally quite long — some mines taking decades to progress from initial resource discovery to full production. Once the decision is made to construct a new mine however, the length of time until production begins varies from mine to mine, although mine construction can be reasonably fast. It is also important to note that while production from a new mine can occur reasonably quickly after construction first begins, there may be a further lag until maximum production levels are reached. Typically, production starts at a low rate during the development phase and can take some years to work up to full capacity.

Fixed capital in the 'short' run

The characteristics of mining investment mean that capacity at individual mines tends to be fixed and fully utilised, once fully operational. Additional capacity can only be installed at high cost and with considerable time lag. Because of sunk costs, individual mines are often run at full capacity even if there is a downturn in prices, so long as variable costs are covered. On the other hand, some mines can and do record comparatively large changes in production from one year to the next. This occurs in both coal mining and metal ore mining, and can reflect natural factors and random events, as well as explicit management decisions to increase or decrease production.

In the oil and gas sector, the issue of production is largely determined by flow rates, which can vary substantially over time as a result of the natural characteristics of oil wells. Price and market conditions can induce managers to start or stop secondary or tertiary production, and this can temporarily alter the production profile of individual wells. Over the longer term however, production is largely determined by the natural characteristics of each oil and gas field.

In general, it seems reasonable to conclude that mines have limited capacity to expand production significantly in the short term, although clearly there is some capacity to boost (or cut) output in the very short term according to market and other conditions. For example, the length or number of production shifts can be changed, maintenance schedules can be adjusted, and machinery can be run harder or left idle until market or other conditions change once again. Decisions to permanently increase output at individual mines — say through mine expansions — involve longer-term commitments, and generally take a minimum of two to three years to achieve. They also involve the investment of significant amounts of new capital. At the same time, large and unexpected increases in output prices may make it feasible to revisit old or 'mothballed' mines, including the possibility of revisiting mine tailings as a source of short-term supply increases.[1]

4.3 Capital investment and MFP changes

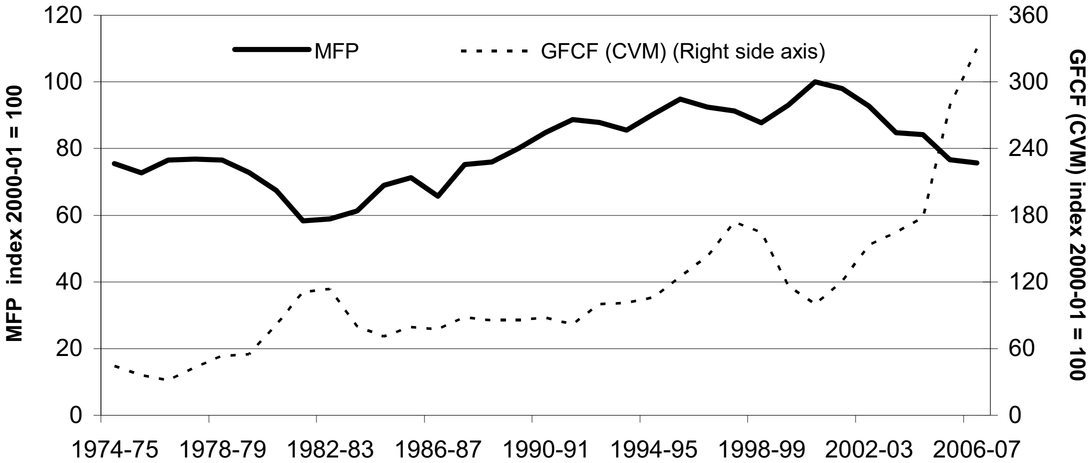
The importance of the nature and characteristics of capital used in mining can be seen more clearly when we consider the relationship between changes in capital investment in mining and changes in mining multifactor productivity (MFP). In general, there is an inverse relationship between changes in gross fixed capital formation (GFCF) and changes in mining MFP (figure 4.3). Increases in new capital investment are typically associated with lower or negative MFP growth in mining, and conversely. The most obvious explanation for the inverse relationship is that, while a surge in new capital investment leads to an immediate increase in capital inputs in mining, the corresponding output growth in the sector can be slower to eventuate because of lags between when investment takes place and when production from completed developments comes on stream. As a result, investment surges and declines can lead to short-term inverse changes in MFP.

Over the longer term we would not expect higher (or lower) capital investment to influence the rate of MFP growth except through the introduction of improved technology or management practices. Hence the observed inverse relationship between capital investment and MFP is likely to be a short-term or temporary phenomenon. Indeed, as is illustrated in figure 4.3, both capital investment and MFP have trended upwards over the longer term, albeit at different rates. Moreover, during a period when there was sustained but moderate growth in capital investment

[1] These issues and the implications for productivity estimates are explored in more detail in the next chapter.

— from the mid-1980s to the mid-1990s — mining MFP grew comparatively strongly.

Figure 4.3 **Mining MFP and gross fixed capital formation**



Data sources: ABS (*Australian System of National Accounts 2007-08,* Cat. no. 5204.0); ABS *(Experimental Estimates of Industry Multifactor Productivity 2007-08*, Cat. no. 5260.0.55.002).

The existence of lead times between when capital investment in new mining developments is initiated and when full production from these developments is reached is only likely to be notable from a productivity point of view during periods of abnormally high or low growth in new investment. During periods of comparatively steady growth in new investment, the effects of lags in production on MFP changes are likely to be small. However, when investment is rising or falling relatively quickly, the effects on MFP are likely to be larger.

The current period of booming capital investment in Australia is exactly the type of event that is likely to lead to substantial short-term, transitory effects on MFP. Gruen and Kennedy (2006) compare the current mining boom with a mining boom in the late 1970s to show that, in the former, production lagged the surge in investment by a number of years, but eventually grew strongly. They argue that a similar result will occur in the current boom, leading to an eventual turnaround in mining MFP. Similarly, Sibma and Cusworth (2006) conclude that lags and long lead times in capacity expansion account for much of the recent decline in mining industry productivity observed in Western Australia.

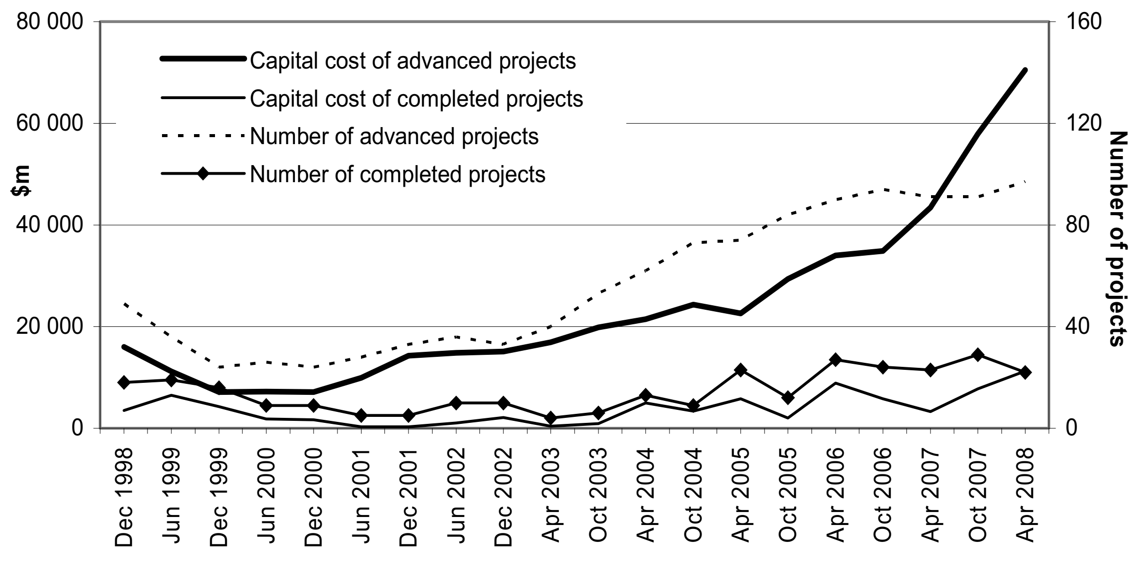
The remainder of this chapter contains a quantitative assessment of the effects on MFP of production lags associated with rapid changes in the rate of growth in new capital investment in mining. While the results presented are not intended to be definitive estimates of the effect of production lags on mining MFP, it is important that some attempt is made to put credible orders of magnitude around what is frequently referred to as a possible factor influencing mining MFP.

The surge in new investment

As discussed in chapter 2 and illustrated in figure 4.3 above, capital investment in mining is currently at historically high levels. Recently released data from the ABS indicate that capital investment in mining rose further in 2007-08, by around 28 per cent in nominal terms and by 22 per cent in real terms.

In line with the increase in capital investment, information released by the Australian Bureau of Agricultural and Resource Economics (ABARE) regarding the number of major mining projects under construction shows a significant increase in recent years in terms of both the number of new projects and the expected capital cost of those projects (figure 4.4).

Figure 4.4 **Number and capital cost of advanced mining projects and completed mining projects**



Data source: ABARE (*Australian Commodities 2008b* (2)).

The apparent blow-out in the capital cost of ‘advanced’ projects since 2006 is consistent with anecdotal evidence reported by mining companies regarding major increases in project costs due to shortages of specialised mining equipment and skilled labour brought about by the global mining boom.

Length of production lags in mining

In order to be able to measure the extent to which mining MFP is influenced by lags between capital investment and output, it is necessary to measure the length of the lags. Empirical analysis suggests a lag of three years between changes in capital investment in mining and changes in value added (output), although in statistical terms the relationship is not particularly strong (in part due to a lack of data).

There is other evidence, however, to support the view that the average production lag in mining is around three years. This includes detailed information published by ABARE regarding the number, capital cost, output capacity, and time between initiation and commissioning of all major new mining projects and developments in Australia since 1994 (see box 4.1). The ABARE data indicate an average time to commissioning of major mining developments of 2.1 years, although there can be large differences from project to project. For example, the new Ravensthorpe nickel mine took around 3.5 years between first appearance on the ABARE list to first production, while many smaller projects take less than one year to move from 'under construction' to 'completed'. Mine expansions also typically take less time to begin production than new mines (1.7 years on average versus 2.3 years), but expansions of some existing mines — such as large iron ore project expansions in the Pilbara region of Western Australia — can take much longer than many smaller, new projects.

In measuring the time taken between the 'commitment' phase of a new project and the commissioning of a project, it is important to note that there can be a considerably longer period of time between the initial discovery or identification of a new resource and the 'commitment' to develop the resource. Also, some amount of capital investment or cost will generally have been incurred in the activities that take place in the lead up to the 'commitment' to new projects. It is assumed, however, that the majority of capital costs involved in the development of new mining projects is expended during the period between the commitment to the new project and the completion of that project. It is also important to note that there is usually a further lag between initial production from a new development and 'full' production, although the length of this lag is less clear.

Based on the empirical data regarding changes in investment in mining and changes in output, and the information gleaned from the ABARE 'advanced projects' list regarding average project developments times, it is assumed for the purposes of this report that there is, on average, a lag of three years between investment in new productive capacity in mining and the associated output from that investment.

Box 4.1 Estimating production lags in mining

The Australian Bureau of Agricultural and Resource Economics (ABARE) has been compiling and publishing a list of major new mineral and energy projects under development in Australia since the late 1990s. The list contains details of major minerals and energy projects that are expected to be developed over the medium term. The state of progress of each project is recorded on the list, and this generally categorises projects as either ‘committed to’, ‘under construction’, or in a more preliminary state. The list also includes information on the expected capital expenditure of each project, and the new production capacity associated with each project. The list is currently published by ABARE on a bi-annual basis (generally released in the June and December editions of ABARE’s *Australian Commodities* journal) but has previously been published on an annual basis (ABARE 2008b). While the list is not intended to be a complete picture of every new development in the mining industry at a particular point in time (projects must meet minimum size requirements to appear on the list), all of the major new projects in Australian mining are covered.

By observing the entry and exit of individual projects from the list, estimates can be made of the average length of time it takes for mineral and energy projects to be constructed. In estimating the project completion times, only projects that are ‘committed to’ or ‘under construction’ are used, and projects are not counted if they fall off the list due to a change in status — for example, if projects move off the list because they are suspended or abandoned. For projects that are still under construction, the predicted project completion date is assumed to be the actual completion date. In all other cases the project length is determined by the entry of the project to the list, and the date of project completion.

The average project construction times reported below are weighted averages, where the weights are given by the amount of capital expenditure on each project. As there are very large differences in capital costs and productive capacity from project to project. Hence we give greater weight to projects with larger capacity (and potentially longer lead times), and less weight to smaller projects (that may have shorter lead times to full production). Capital expenditure is used as the weight variable rather than physical capacity or output on the basis that the latter is not always reported, and because it can sometimes be difficult to aggregate output quantities across different industries (gas production versus metal production etc). Also, expected output is often reported in the ABARE project lists in the form of a comparatively wide range, rather than as a precise figure.

Results

The estimated project construction times are presented in table 4.3. As expected, new mines tend to take longer to construct than mine expansions, with the difference being around six months.

(continued next page)

Box 4.1 **(continued)**

Table 4.3 **Average construction time of new mining projects[a]**

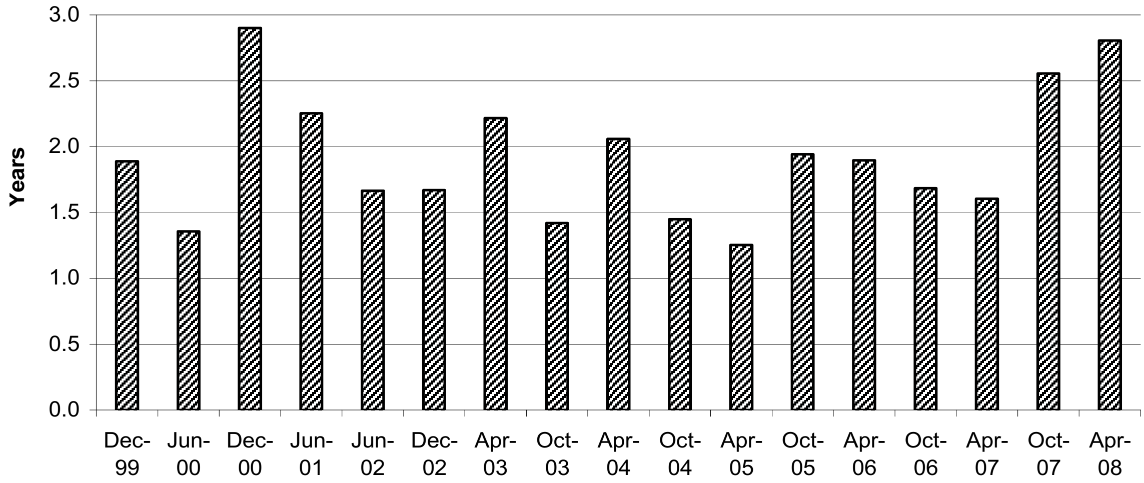
	Number of new projects	*Construction time in years*
All projects	341	2.1
New mines/developments	211	2.3
Mine expansions	130	1.7

a Based on project lists from December 1998 to April 2008.

Source: Authors' estimates using ABARE data (*Australian Commodities* , various issues).

The ABARE list can also be used to examine whether or not there has been any change in the average time taken to construct new projects in recent years. The evidence suggests that there has been an increase in the average length of projects in the last year or so (figure 4.5). For new projects appearing on the list in October 2007 and in April 2008, the average project length has risen by up to one year compared with projects started earlier this decade.

Figure 4.5 **Average construction time of new mineral and energy projects**



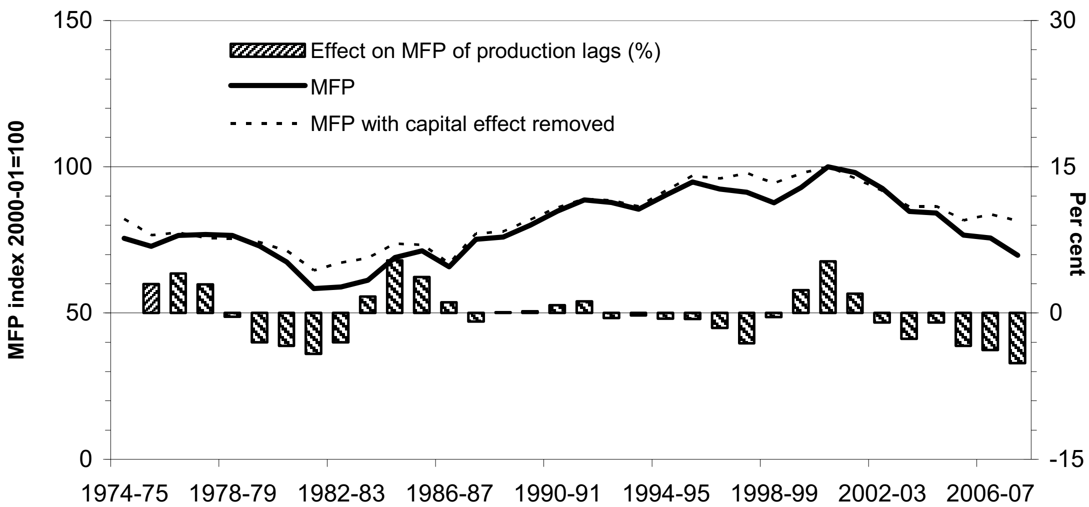
Data source: Authors' estimates using data from ABARE (*Australian Commodities,* various issues).

Adjusting capital inputs and measuring the effect on MFP

To estimate the size of the effects that production lags may be having on mining MFP we re-estimate the MFP series using a capital inputs index that is lagged three years, rather than using contemporaneous capital inputs.[2] By using a lagged capital services series we reduce the influence on mining MFP of the major cycles in investment by matching changes in productive capital capacity more closely to changes in output.

The results show that lags between capital investment and production have a significant effect on short-term changes in MFP (figure 4.6). The surge in capital investment in mining that occurred in the late 1970s led to MFP falling more rapidly than would otherwise have been the case, while the subsequent period of lower capital investment caused MFP to rise faster than it would otherwise have done. A similar result occurs in the late 1990s when capital investment surged and then fell, while the more recent surge in capital investment has again contributed to a decline in MFP growth. As expected, removing the influence of short-term changes in capital investment has little effect on the long-term trend rate of growth in mining MFP, while the variability of the series is lessened somewhat.

Figure 4.6 **Mining industry MFP and the effect of production lags**



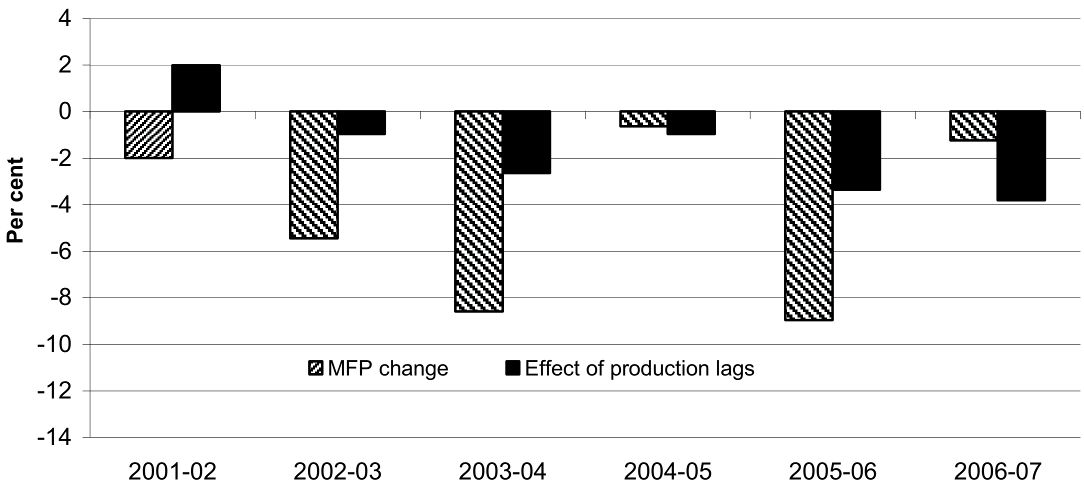
Data sources: ABS (*Experimental Estimates of Industry Multifactor Productivity 2006-07*, Cat. no. 5260.0.55.002); Authors' estimates.

2 Three years is chosen based on the empirical analysis and conclusions drawn from analysis of the ABARE data detailed above. While the ABARE data suggests a lag between two and three years, the longer lag is chosen in order to reflect the additional time a mine faces to 'ramp-up' to full production. The sensitivity of results to different selections of lag length is discussed below.

Effect of the capital surge on mining MFP from 2000-01 to 2006-07

Between 2000-01 and 2006-07 production lags are estimated to have had a substantial effect on the changes in mining MFP, although not all of the annual changes are negative. Figure 4.7 shows annual changes in mining MFP since 2000-01, along with estimates of the extent to which lags in the response of production to new capital investments contributed to the annual MFP changes. Hence, between 2002-03 and 2003-04 when mining MFP fell by around 8.5 per cent, production lags are estimated to have contributed around 2.5 percentage points to the decline, or just under one third of the total decline in MFP in that year.

Figure 4.7 **Annual changes in MFP and the contribution of production lags 2001-02 to 2006-07**



Sources: ABS (*Experimental Estimates of Industry Multifactor Productivity 2006-07*, Cat. no. 5260.0.55.002); Authors' estimates;

The effect of production lags on annual MFP changes is largest in more recent years, in line with the fact that capital investment is at record levels. Importantly, the slowdown in capital investment in the late 1990s/early 2000s actually had a positive effect on mining MFP in 2001-02. That is, the slowdown in capital investment prior to the recent boom meant that mining MFP was higher in 2001-2002 than it would otherwise have been. For the period from 2000-01 to 2006-07 as a whole, production lags accounted for an estimated 8.1 percentage points of the overall decline in MFP of 24.3 per cent, or around one third of the fall.[3]

[3] Estimates of the effect of capital lags on MFP at the mining sub-sector level are contained in appendix A.

Sensitivity of results to the length of the production lag

The sensitivity of mining MFP to the effects of production lags has been tested using shorter (two year) and longer (four year) lags. In both cases there was little change in the size of the effects on MFP compared with an assumed lag of three years. Using a two-year lag means that the adverse effects on MFP of the recent surge in capital investment are slightly smaller, while a four-year lag assumption has very little impact on the magnitude of the production lag effects.

Capital effects on mining MFP in 2007-08

Recently released data from the ABS indicate a decline in mining MFP in 2007-08 of 7.9 per cent. Based on the methodology described above, capital effects are estimated to have contributed around 5.1 percentage points to this decline. That is, after making allowance for production lags associated with the 22 per cent increase in real capital investment in 2007-08, the decline in mining MFP is 2.8 per cent. Perhaps more importantly, the results continue to show that a large share of the decline in mining MFP since 2004-05 has been due to the effects of the surge in capital investment in the sector, and the substantial lead times between investment and output in mining. If the lead times for new mining developments are matched to the changes in mining industry investment, the implication is that there should be a surge in mining industry output between 2008-09 and 2011-12 in response to the surge in capital investment from 2005-06 to 2007-08. This should have a strong positive effect on mining MFP over the next few years.

Questions and implications

Our results, while exploratory in nature, suggest that in environments where capital investment is changing quickly, MFP estimates are prone to potentially larger swings than might otherwise be the case. And while the short-term effects on MFP from investment surges or contractions are always, ultimately, offset by an associated production response, it is not always clear whether the final impact on MFP is positive or negative. The new developments may be inherently more productive than existing mines, meaning that the positive effects on aggregate MFP of new investments (once they are producing) may more than offset the negative effects on MFP of the initial investments. In general, there is no reason to expect that the short-term negative effects of a surge in investment will be symmetric with the longer-term positive effects on MFP, except in those cases where the productivity of new investments is exactly the same as the productivity of existing capacity.

A consequence of long lead times in the development of new mining capacity is that declines or increases in MFP may be attributed to changes in mining industry efficiency, when in fact the short-run changes are the result of the way inputs and output are measured.

Ideally the capital services estimates used in the formula for estimating MFP would be based on 'utilised' capital stock, rather than capital per se. In this case the issue of production lags would not arise. However, it seems unlikely that reliable or comprehensive capital utilisation estimates will ever be available, in which case the issue of production lags will continue to be of concern, particularly in periods of rapidly changing levels of capital investment.

Over the longer term production lags do not affect the trend rate of growth in MFP. However, the mining MFP series is shown to be more volatile over time because of production lags, and this is an important result in terms of how mining industry MFP changes are interpreted. Unless and until a capacity or utilisation-adjusted measure of capital services inputs is available, problems involved in measuring and interpreting short-term changes in mining MFP will persist.

5 Other factors influencing mining MFP

Key points

- Yield declines due to ongoing resource depletion and the effects of production lags in response to new capital investment are estimated to have contributed substantially to both longer-term and shorter-term movements in mining MFP. Failing to account for these factors when considering changes in mining MFP can lead to errors in interpretation.
- Recently released data indicate that mining industry MFP has fallen again in 2007-08, by just under 8 per cent. Production lags are estimated to explain just over 5 percentage points of this decline. While data limitations preclude an estimate of the extent to which resource depletion contributed to the decline, it is likely that reductions in oil and gas flow rates have occurred. In this case, resource depletion is likely to emerge as an important explanatory factor of the decline in mining MFP in 2007-08 as well.
- A number of other factors are likely to have influenced multifactor productivity (MFP) growth in mining in recent years, including the effect of increased effort by miners in response to record commodity prices, changes in technology, changes in work practices, infrastructure constraints, and ad hoc factors such as the weather. Although it is difficult to quantify the individual effects of most of these factors, it is estimated that these and other factors collectively made a net positive contribution to MFP in the mining industry between 2000-01 and 2006-07.

In chapters three and four the effects on mining MFP of resource depletion and capital investment surges were examined both qualitatively and quantitatively. The results suggested that both of these factors made substantial contributions to the decline in mining MFP between 2000-01 and 2006-07. This chapter reviews a range of other factors that influence productivity in the mining industry, and that may also have contributed to the recent decline in mining MFP. The focus of these reviews is qualitative.

The factors addressed in the chapter are the effects of increased effort to overcome short-run capacity constraints in response to price rises, advances (and failures) in new technology, changes in work practices, random events such as weather, and problems with infrastructure.

The chapter concludes with a review of the quantitative evidence regarding the key explanatory factors behind changes in mining MFP, with emphasis on the contributions of the various factors in explaining the recent decline in mining MFP.

5.1 Increased effort and changes in the quality of inputs

In chapter 3 it was shown that depletion has a powerful negative impact on MFP in mining. Depletion represents a decline in the quality of the unmeasured natural resource input essential to all mining operations. Implicitly, the intensity of use of other inputs compensates for the declining quality of the resource input. This is particularly likely to occur during periods of high prices as in recent years. The high prices make it profitable to continue to mine deposits that have reached such low quality that they might otherwise be abandoned. High prices can also impact on MFP through other indirect effects on the quantity and quality of inputs used in mining. Since changes in the quantity or quality of resource inputs are not generally taken into account when measuring inputs, the result of such changes is apportioned to the residual — that is, to productivity.

Demand-driven fluctuations in the price of mining products are common and often large. It is still most profitable to exploit the highest quality deposits as these yield the greatest differences between price and production cost, even after allowing for the implicit value of the resource input as measured by the discounted value of the resource rent along the optimal depletion path. However, when prices rise unexpectedly there is also an incentive to exploit lower quality deposits. This includes re-opening 'mothballed' mines, and exploiting mine 'tailings'. The critical constraint is being able to get the mined product to market while prices are high.

Some evidence of the extent to which high prices are encouraging the exploitation of lower quality deposits can be found in the form of industry and other reports of old mines being reopened in order to take advantage of the current period of higher prices. For example, in the coal industry the Elouera coal mine in NSW was re-opened, while in iron ore mining the Koolan Island and Frances Creek mines were re-opened. In gold mining, significant depletion has led to the re-working (and in the case of some mines re-re-working) of old mines to extract pockets of remaining reserves, generally in response to the recent higher prices. According to industry analysts, the decline in aggregate gold production in Australia in recent years is due to the deliberate strategy of miners to temporarily target lower grade ores while output prices are high[1]. There are also reports of a significant number of old nickel mines having been reopened since 2001 due to high prices, including the Redross, Long-Victor, Miitel, Wannaway and Mariners mines. The Pillara lead and zinc mine at Lennard shelf was also reopened in response to higher prices, and a tailing re-processing operation was undertaken at the Hellyer zinc mine in Tasmania.[2]

Targeting lower quality resources may not be the only response to higher prices that has the potential to adversely affect mining MFP. In the short term to overcome the constraints imposed by shortages of specialist equipment and long construction lead times, miners may increase the effort they apply to extract output, and in so doing be forced to employ a less than optimal combination of inputs. This can lead to a decline in measured MFP.

During booms demand for mining inputs generally increases, leading to shortages and delays in obtaining key inputs. Anecdotally, this has become a problem in coal mining where waiting times for new draglines have increased from 18-24 months to over 30 months (BHPB Interim Report 2006), necessitating the use of lower 'quality' inputs such as trucks and shovels to remove overburden (figures 5.1 and 5.2).

Skilled labour shortages are also pushing out waiting times for key mining activities, including maintenance and repairs to machinery.

To the extent that mining companies have been unable to use the least cost combinations of inputs due to the mining boom, or have been subject to greater delays in completing maintenance and other key mining activities, the net effect of the boom on measured productivity is likely to be negative.

---

1 Analysts reviewing the reduction in Australian gold production during 2006 described the decline as one 'consequence' of higher gold prices, which induced a move by producers to treat lower grade ores (The Age, 27 November 2006). Moreover, according to the analysts, mining lower grade gold ores in response to the higher prices was a 'perfectly reasonable and rational response'.

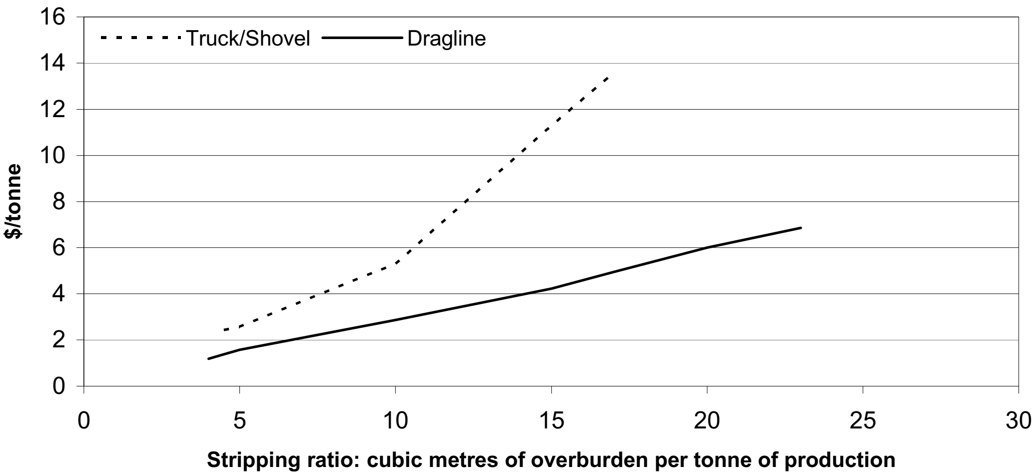
2 Many of these 're-opened' mines have since 're-closed' since the economic downturn at the end of 2008. The effects of these re-closures and of the downturn in general are discussed in section 6.3 in chapter 6.

Figure 5.1 **Dragline versus trucks and shovels**

An illustrated example[a]

[a] The large crane-like machine in the background is a dragline, designed to strip and remove overburden. The alternative is shown in the foreground: a truck being loaded with an electric shovel.

Figure 5.2 **Cost comparison in overburden removal technologies**



Data source: From Hartman and Mutmansky (2002).

Productivity versus profitability

In making the case that unexpectedly high output prices could be leading to less efficient production — either through the deliberate targeting of poorer quality resources, or the deliberate use of more costly or less efficient technologies and inputs — it is not intended to imply that this is a problem or negative outcome for the industry. On the contrary, it is expected that high output prices would induce an increase in production, and that this would generally only be achievable at a higher cost. Profitability, ultimately, is the goal of mining companies, rather than the maximisation of productivity.

5.2 Technology changes

Technology is a critical, long-run factor influencing productivity, and plays a major role in offsetting the effects of resource depletion. In a review of the debate regarding the long-term supply of minerals, Tilton (2003) describes the long-run availability of mineral commodities as, 'a race between the cost-increasing effects of depletion, and the cost-decreasing effects of new technology'.

There have been major technological advances in Australian mining since the 1960s. Some examples include the expansion of open-cut mining, the development of longwall operations in underground coal mining, and greater automation and scale of plant and equipment. Australia, with a long history of underground mining, has also employed innovations in hard-rock mining, such as block-caving and sublevel-caving technologies. [3]

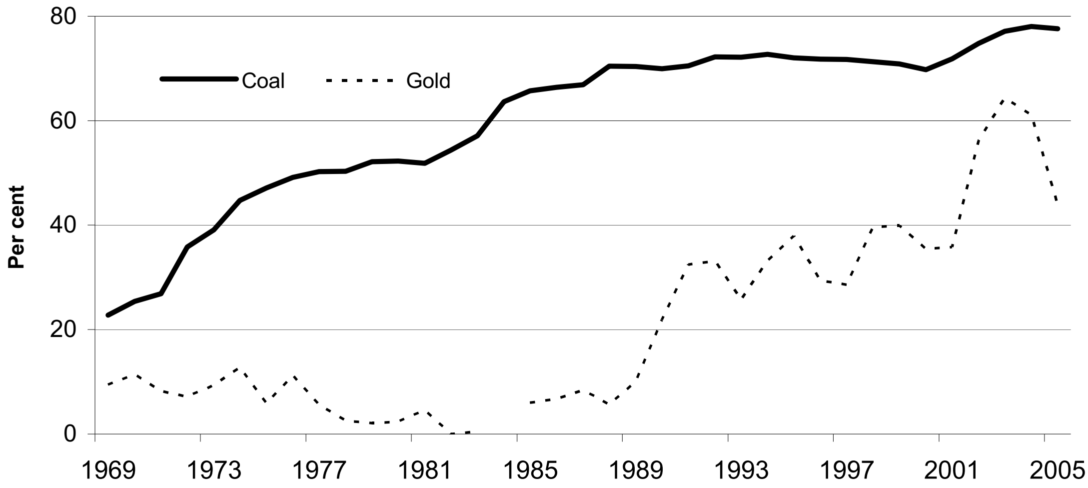
The shift to open-cut methods in coal mining reflects its generally lower costs of production and greater flexibility in varying output with less of the hazards associated with underground mining (Hartman and Mutmansky 2002). In gold and copper ore mining, a shift to open-cut operations also became economic following the discovery of carbon-in-pulp and solvent extraction-electrowinning methods of ore extraction, which enabled metal to be produced from lower grades of ore. Other mining industries have also experienced an increase in the number of open-cut operations, especially those that target multiple products (figure 5.3).

In oil and gas production, developments in drilling technology saw 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 wells in deeper and deeper water (see figure 5.4).

---

[3] For a description of longwall mining and more detail regarding trends and developments in coal mining technology (see Pinnock 1997).

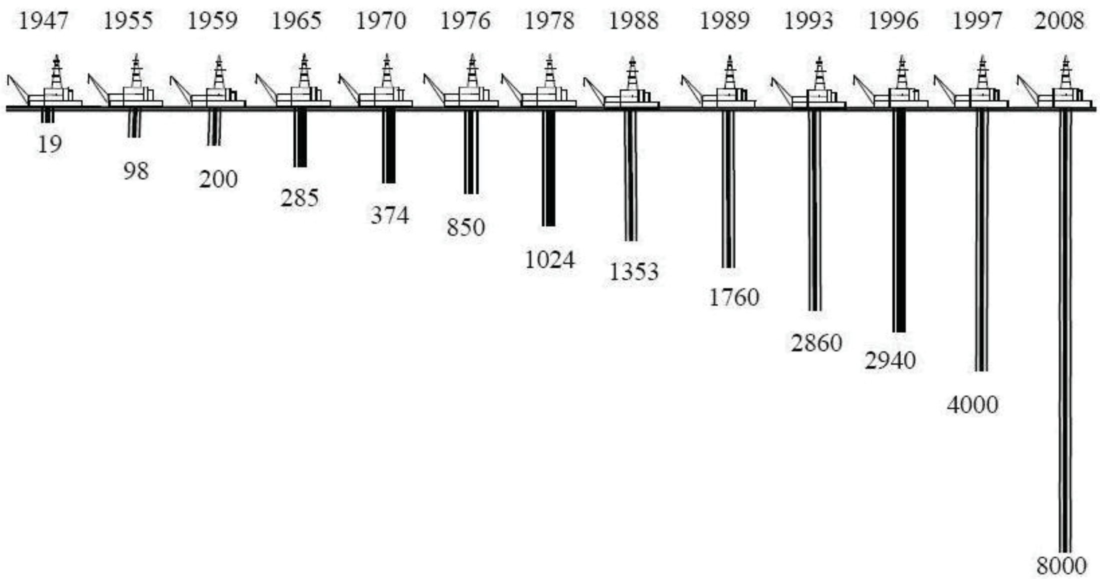
Figure 5.3 **Open-cut share of total mine production**
Gold and black coal



[a] The gold data represent a minimum of gold produced by open-cut mines. The proportion, especially in more recent years is likely to be higher.

Data source: Mudd (2007).

Figure 5.4 **Progress in deep offshore drilling technology** [a]



[a] Depth of water is given in feet.

Data sources: Bohi (1998) (in turn adapted from various Shell briefing notes). The data for 2008 added from Phillips (2008).

In relation to ore processing there have been a number of key technology changes, including the development and use of heap-leaching technologies which allow metal to be extracted from comparatively low-grade ore, and hydrometallurgical extraction processes such as electrowinning and pressure acid leach technologies in base metals production. In both cases the new technologies have allowed economic extraction of metals from relatively low grade ores (Hogan et al. 2002).

There have also been major advances in the technology used to explore and identify mineral resources in the first place. Off-shore oil and gas exploration and production has been significantly enhanced through the development and use of three-dimensional seismic reflection surveys. In metals production, developments in aeromagnetic and gravimetric survey technology have contributed to some major discoveries, including Olympic Dam in 1975 (Hogan et al. 2002). Airborne surveys in general have lowered the cost of much exploration activity, and overcome difficulties in access and environmental impacts for exploration.

Recent developments in mining technology and their effect on productivity

It is difficult to gauge the extent to which changes in technology may have influenced recent developments in mining MFP. There was a surge in the proportion of coal produced in open-cut mines after the year 2000, which should in principle have added to productivity growth. The general increase in gold production from open-cut mines following the development of new ore-processing technologies should also have acted to boost productivity, although the open-cut share of gold production did fall quickly between 2003 and 2005.

Perhaps most notable during the period of interest was the implementation of High Pressure Acid Leach (HPAL) techniques in nickel mining to extract nickel from more difficult laterite deposits. Despite considerable enthusiasm and investment in a number of HPAL mines in the late 1990s — early 2000s, the technology was an expensive failure (FD Capital 2007).

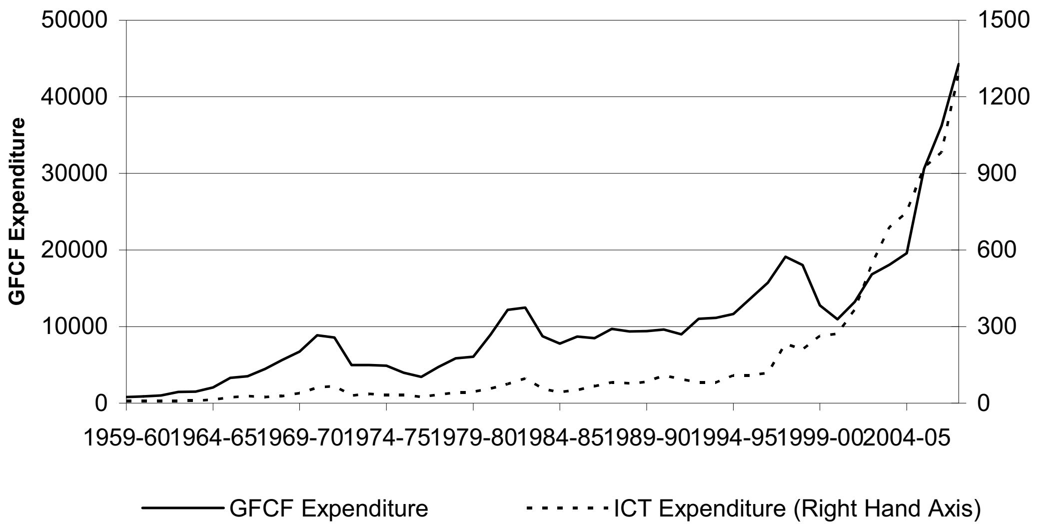
There have also been difficulties with some longwall underground mining operations in the coal sector, particularly adapting technologies developed in the United States to Australian conditions. Although some of these issues have now been overcome, the uniqueness of many Australian deposits means that longwall technology sometimes has to be adapted, and this can lead to productivity problems as new ideas and methods are trialled and assessed. According to the CRC for Mining:

> 'most Australian longwall equipment is significantly underutilised by international standards' (quote from CRCMining website, May 2008).

Information and communications technology (ICT) expenditure in the mining industry has also surged with the record levels of investment in the recent period (see figure 5.5). ICT has played an important role in all stages of mining activity, especially in the field of exploration and three-dimensional seismic surveys (Neal et al. 2007). Improved ICT technology has allowed mining services companies to undertake activities previously performed by miners (leaving them to specialise in mining alone). ICT investment has also led to the automation of many mining processes, facilitated more accurate targeting of ore bodies (via GPS) and improved communication between different stages of the mining process. ICT penetration in the mining industry was found to be greater than that of the market sector as a whole in 2000-01 and with record levels of investment in ICT, and this trend is unlikely to have been reversed. Of interest, however, is that ICT investment takes longer to be fully utilised in the mining industry compared to the rest of the market sector, with investment taking on average four years to yield results (PC 2004). The associated productivity benefit of increased take-up of ICT technology within the mining industry will likely explain some of the 'other factors' productivity growth identified at the beginning of the chapter.

Figure 5.5 **Gross fixed capital formation and ICT investment in the mining industry[a]**

Chain volume measure with a reference year of 2005-06



[a] ICT Expenditure defined as expenditure on computers and peripherals, computer software, electronics and electrical equipment.

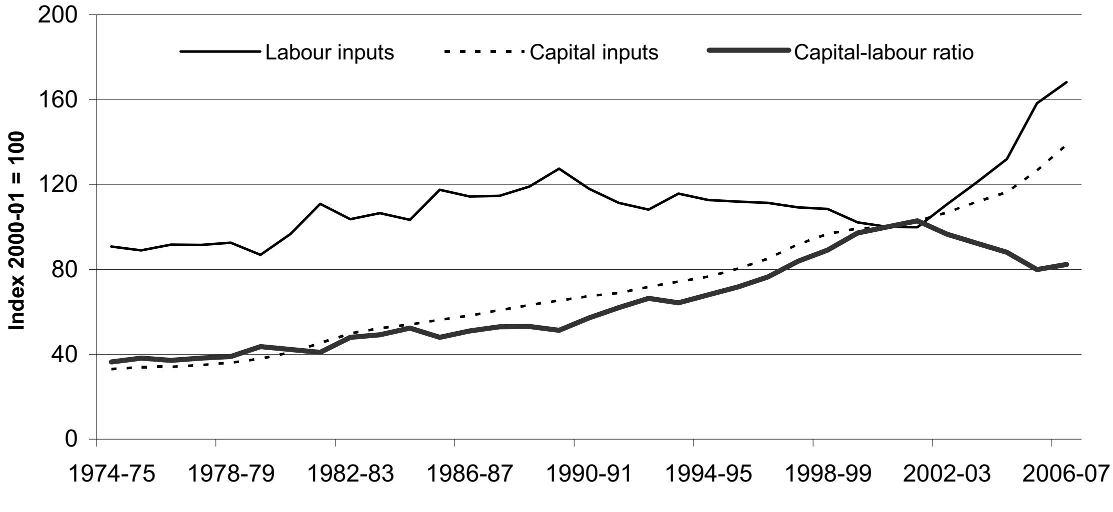
Data source: ABS (*Australian System of National Accounts 2007-08,* Cat. no. 5204.0).

5.3 Work practices

Changes in work arrangements and management practices have also had an important influence on mining productivity over the longer term. In a capital-intensive industry, work arrangements can have a crucial influence on capacity utilisation. This was particularly apparent in a number of mining industries, especially coal, during the 1990s. Lower commodity prices had squeezed profitability, placing pressure on regulatory arrangements, wages and employment conditions (Heiler and Pickersgill 2001). Large scale retrenchments and restructuring took place within the industry in the 1990s, and this led to a decrease in labour inputs and an increase in the ratio of capital to labour in mining (figure 5.6).

Among full-time employees (the dominant form of labour used in mining), working hours grew strongly in the 1980s and 1990s, and by 1997 mining recorded both the longest hours profile of any industry and the most rapid increase in weekly hours (Heiler and Pickersgill 2001, p. 23). The introduction of 12-hour shifts was a key factor in labour and capital utilisation in mining, and by the end of the 1990s it was estimated that around one half of all production and maintenance employees were working 12-hour shifts (Heiler and Pickersgill 2001, p. 30).[4]

Figure 5.6 **Labour inputs and the capital to labour ratio in mining**



Data source: ABS (*Experimental Estimates of Industry Multifactor Productivity 2006-07*, Cat. no. 260.0.55.002)

[4] Possible adverse consequences for productivity associated with changed labour arrangements in mining, including long daily hours, inadequate recovery time between shifts, night work and long commuting times are mentioned in Heiler and Pickersgill (2001) and discussed in more detail in Heiler, Pickersgill and Briggs (2000, pp. 37-44).

An early example of labour rationalisation leading to improved utilisation of capital (capital-deepening) and subsequent productivity growth was the case of the Robe River iron ore mine (Schmitz 2005). A sudden change was made to workplace practices at the mine in 1986 aimed at ending 'status quo' work practices, and yielded a sharp increase in labour productivity and a more modest (yet significant) increase in production (figure 5.7).

Figure 5.7 **Robe River iron ore mine: labour productivity and production, 1973-74 to 1990-91**

Data source: Schmitz (2005).

In more recent years a major change to labour use in mining has been the rise in long-distance commuting in the form of 'fly-in, fly-out' mining (see box 5.1). However, additional costs have been incurred by mining companies to attract labour to mining (such as wage premiums, and the transport costs associated with 'fly-in, fly-out' operations), which may have had a detrimental effect on productivity as firms cannot use the desired roster pattern, but must rely on patterns that are more attractive to labour.

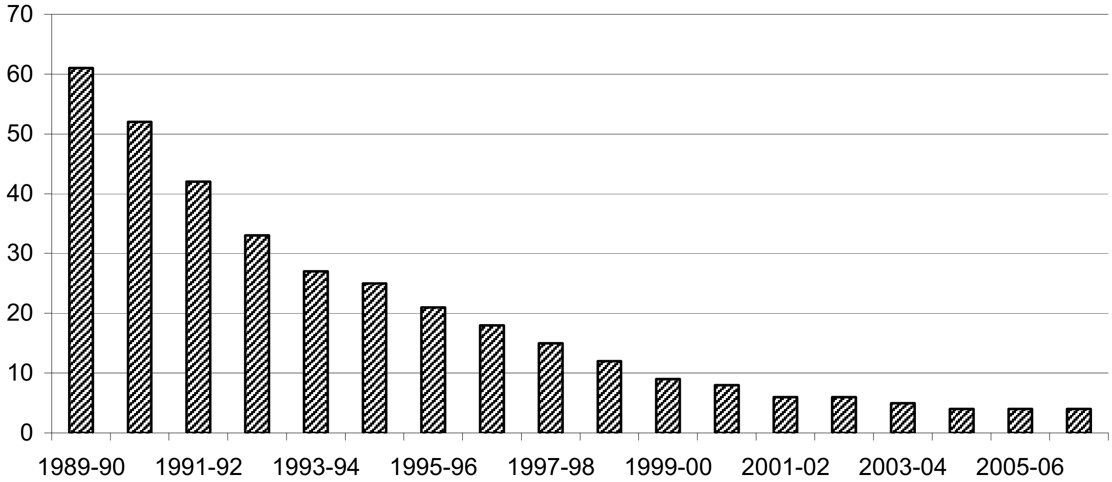
Safety

A positive development in the Australian mining industry has been the decline in the lost time injury frequency rate (LTIFR), a measure of the number of lost time injuries[5] per million hours worked (figure 5.8)

[5] A lost time injury is one where an injury results in a minimum of one full shift's absence.

The extent to which the decline in lost time injury rates has had a positive effect on mining MFP is not well documented. The decline in LTIFR, especially in recent years, has been the result of changes to a 12 hour roster system, which in turn generally provides for longer periods of time off. It is this longer time off that promotes recovery and reduces fatigue, which are major causes of injuries in the mining industry (AMMA 2004). It would be expected that a reduction in the number of time-lost injuries per million hours worked would have a positive effect on productivity, if for no other reason than the number of shutdowns at mine-sites due to injuries has declined, reducing the amount of idle capital and the potential for lost production.

Figure 5.8 **Lost time injury frequency rate[a]**



[a] LTIFR = The number of lost time injuries per one million hours of work.

Data sources: Minerals Council of Australia, (*Safety Performance Report of the Australian Minerals Industry,* 2007); Minerals Council of Australia, (*Safety & Health Performance Report of the Australian Minerals Industry,* 1999).

Box 5.1 **Fly-in, fly-out operations**

Fly-in, fly-out (FIFO) operations are where the workforce does not reside permanently on the mine site or in a nearby township, but instead are flown in and out of the mine site on a roster basis. FIFO operations are prevalent in the more remote mines and newer mines in Western Australia. Approximately 47 per cent of mines in Western Australia were using FIFO to meet their labour requirements in 2000. FIFO has been more attractive to mining companies in order to overcome labour shortages and poor perceptions of living permanently in remote areas.

A question that arises out of this relatively new labour supply mechanism is how it affects productivity. A study by the Centre for Social Responsibility in Mining in 2003 found that FIFO operations have a higher rate of turnover compared to residential counterparts. As a result of this, the study suggests that FIFO operations face lower operational efficiency and greater opportunity costs of jobs needing to be filled. The increased use of FIFO means that revenues generated in remote areas that go to wages are not being spent in those areas, as well as anecdotal evidence of social impacts, especially with regard to disruption of family life.

There are exceptions to this rule, and a critical factor seems to be the roster schedule used at FIFO sites. Those mines that give a longer time-off ratio appear to have lower turnover, and fewer of the problems listed above. Regardless, as companies increasingly rely on FIFO, there is an expectation that there will be a corresponding effect on labour productivity and MFP in general.

Source: Beach, Brereton and Cliff (2003), Chamber of Minerals and Energy Western Australia (2005)

5.4 Poor weather

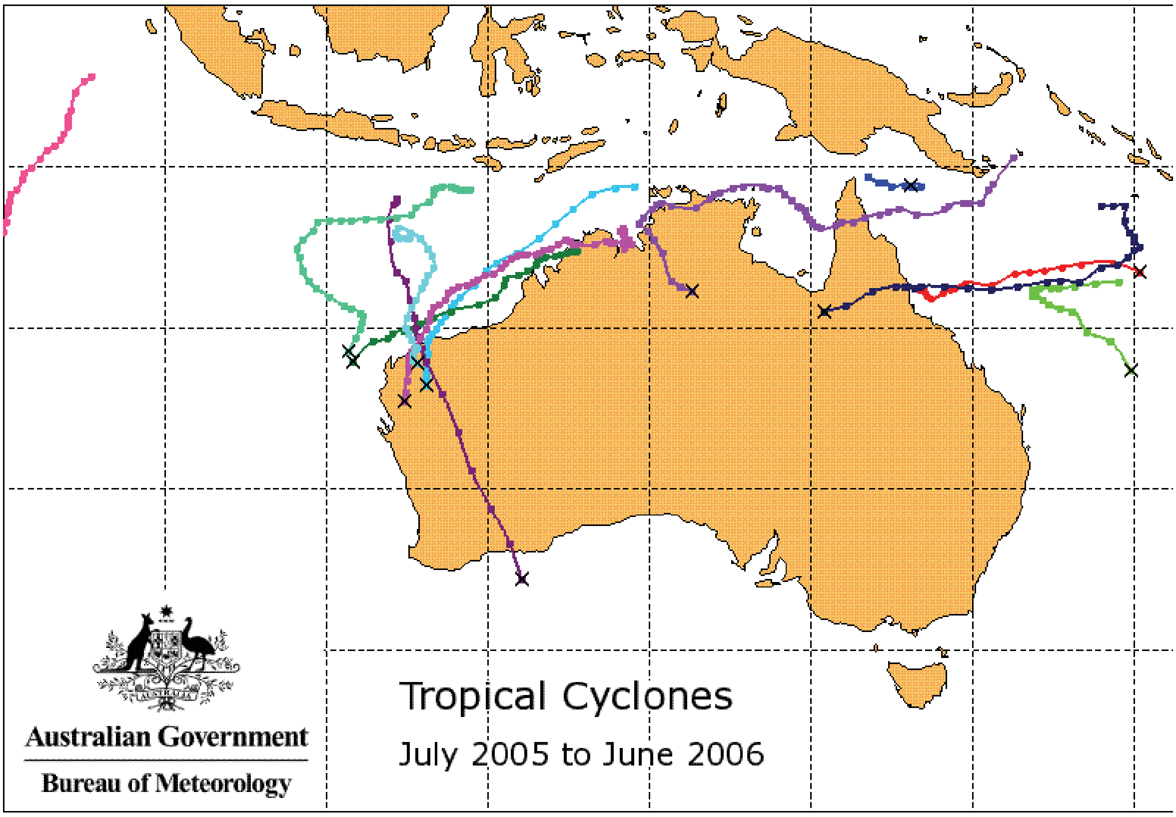
The weather can also have a significant impact on mining operations, and hence on measured productivity. Underground mines can become flooded and require elaborate pumping systems in order to remove water. Open-cut pits can become minor lakes under heavy rainfall, with pumping and evaporation required to remove water. Poor weather can also hamper loading and shipping operations that, when combined with long vessel queues, can result in disaster, such as the stranding of the Pasha Bulk bulk carrier off the coast of Newcastle in 2007. If production time lost to bad weather events cannot be recouped, there will be negative flow-on effects to measured productivity.

Conversely, a lack of rain can also lead to problems in mining operations. While mines do not account for a large proportion of water use in Australia (around 3 per cent), water inputs are vital for operation. For example, water is used for dust suppression and washing of raw coal in coal mining, to liquify concentrate in copper mining, and in gravity separation to sort metal ores and to filter impurities in metal ore mining.

Over a long enough time period however, it is likely that the effect of weather on productivity calculations would tend to average out. The question in relation to the downturn in mining MFP between 2000-01 and 2006-07 is whether adverse climatic events were worse or more frequent compared with the preceding period?

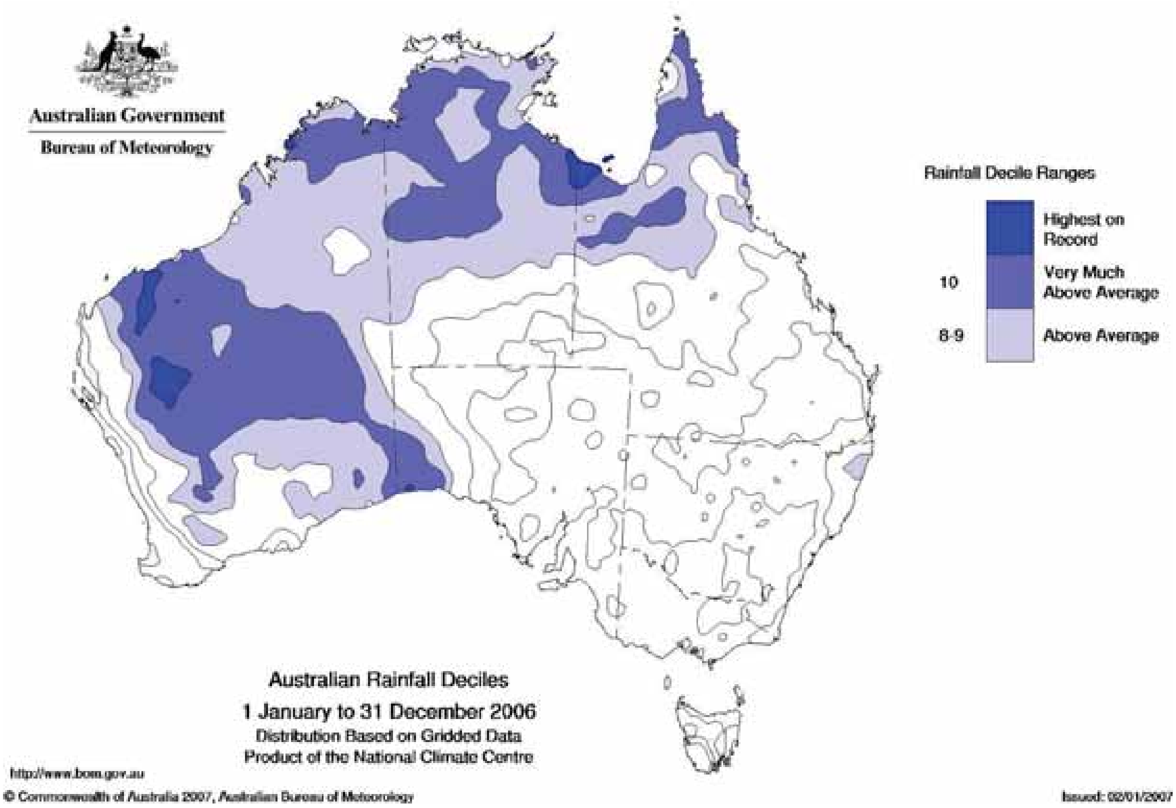
From a mining productivity perspective some significant climate events over the 2000-01 to 2006-07 period were heavy cyclonic activity in northern Australia, and very dry to drought conditions in many parts of southern Australia. For example, cyclonic activity around the Pilbara region in north western Australia was exceptionally bad in early 2006, leading to flooding of many iron ore open cut mines and the Telfer gold mine pit. Oil and gas extraction in the North-West Shelf was also adversely affected by the severe weather, with 13 per cent of annual production lost in 2005-06 (ABARE 2006). The severe rain caused by tropical cyclones (figure 5.9), many of which crossed the coast and proceeded through the Pilbara region, had a significant impact on mining activities, and probably impacted on productivity in the 2005-06 financial year (figure 5.10).

Figure 5.9 **Tropical cyclone activity 2005-06**



Data source: Bureau of Meteorology (accessed 2008): Tropical Cyclone Information

Figure 5.10 **Rainfall deciles — high rainfall areas, 2006**



Data source: Bureau of Meteorology Annual Australian Climate Statement 2006 (modified by PC).

In contrast to northern Australia, prolonged dry to drought conditions for most of this decade to date are impacting adversely on some mines. For example, the Cadia Hill copper-gold mine in New South Wales is having to develop new infrastructure to source water, while the Tarong coal mine in Queensland reduced output and employment in 2007 as a result of water shortages. Continued conditions of lower rainfall in southern Australia will put further pressure on mine economics, and may adversely affect productivity.

5.5 Infrastructure constraints

The final factor considered as a possible contributor to the major reduction in mining industry productivity between 2000-01 and 2006-07 are problems with export infrastructure.

Infrastructure in mining primarily refers to the network of public, private and third-party owned transport links that allow mine production to be moved to its final destination or port-of-exit. As the export-orientated mining industry has become larger (both in terms of value and volume of production) capacity constraints on transport supply chains have become more apparent, especially with respect to coal mining, and to a lesser degree with iron ore mining.

The rail and port infrastructure associated with coal exports has achieved a degree of notoriety in recent years as supply chains have become more congested. A review of the capacity of Queensland's Goonyella Coal Chain commissioned by the Queensland Government and the Queensland Resources Council in late May 2007 found that the current bottleneck to increased exports of coal was rail operations (O'Donnell 2008). A number of recommendations were made regarding ways in which the capacity and overall efficiency of the supply chain could be improved, including with respect to the rail transport component. In response to the review, the Queensland Government approved an additional $113 million investment from Queensland Rail to purchase 510 (additional) new coal wagons (Department of Resources, Energy and Tourism 2008).

The rail 'bottleneck' identified in the May 2007 review is consistent with an earlier finding by ABARE in a study of Australia's export infrastructure published in 2006. The authors found that despite improvements in regulatory arrangements in Queensland, 'mine capacity continues to exceed system capacity, with mines such as Blair Athol ramped back because of system constraints' (ABARE 2006, p. 368).

The congestion in east coast coal handling systems resulted in the implementation of queue management schemes, where coal companies in loose coalition allocated rail network quota between them as a short-term measure to provide surety regarding export capacity. While such schemes were only envisioned as temporary as improved rail and port infrastructure was constructed, and put in place in 2003, they are still in effect today (although it has been suspended on occasion). The scheme has also led to apparent inefficiencies, whereby companies that did not fill their quota were not always able to reallocate unused quota to other companies, resulting in the chains occasionally being *under*utilised. It is reasonable to assume that uncertainty and congestion on transport links would have a negative effect on coal mining productivity, although it is difficult to estimate the extent to which this is the case.

The authors of the ABARE report cautioned, however, that (supply system) capacity usage is also a function of mine throughput and the overall demand for commodities, and that the existence of capacity rationing systems does not *always* imply that mine production is being held back because of post-mine capacity constraints. The example they use to illustrate the point is that of coal exports out of the Port of Newcastle, where from January to May 2006 the annualised outloading rate was 81.7 million tonnes — significantly below system capacity, and 'possibly representing constraints on mine capacity' (ABARE 2006).

With respect to iron ore, the recent decision to grant third-party access to the Goldsworthy, Robe River and Hammersely lines may affect productivity is but the impact is beyond the scope of this paper. What is of interest is the degree of congestion now being experienced on the Pilbara supply chains as a result of rapid mine expansion projects in north-west Australia. This too could have productivity implications, if not now, then at some point in the future.

5.6 Putting the pieces together

Chapter 3 contained a review of the important role played by natural resource inputs in mining, and the problems that arise in interpreting productivity changes when changes in the quality or quantity of resource inputs are not taken into account. Using detailed information regarding changes in the quality of resource inputs arising from changes in ore grades, oil and gas flow rates, and the ratio of saleable to raw coal, it was found that declining resource quality contributes significantly to the rate of productivity growth in mining over the longer term. After accounting for the measured declines in resource quality, MFP growth in mining is large and significant, and above the longer-term growth rates in other sectors and the market sector as a whole (table 5.1).

Table 5.1 **Average annual growth in MFP, 1974-75 to 2006-07**

	Per cent
Mining	0.01
Mining with depletion effects removed	2.5
Mining with depletion and capital effects removed	2.3
Manufacturing	1.3
Agriculture	1.8
Market sector	1.1

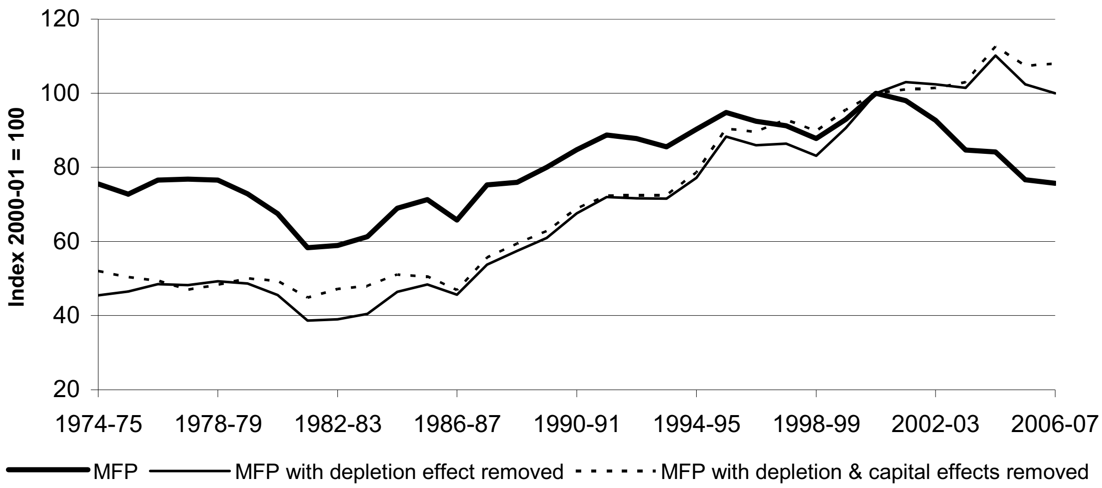
Sources: Authors' estimates; ABS (*Experimental Estimates of Industry Multifactor Productivity 2006-07*, Cat. no. 5260.0.55.002)

The other key factor influencing productivity in mining and for which quantitative estimates have been made in this paper is the issue of lags between investment in new or expanded mine capacity and full production from these investments. Mining has a history of new capital investment occurring in cycles or surges, and the surges can have immediate adverse consequence for measured productivity due to lags in output responses. Chapter 4 contained estimates of the size of these effects, and showed that improved measurement of capital services inputs in mining MFP calculations removes a significant degree of variability in the measured MFP data series.

By subtracting from MFP the influence of these two factors — that is, the effects of yield declines and production lags — the balance or remainder is a measure of the extent to which mining output is not explained by changes in conventionally measured inputs – that is, labour and capital. It is this component of the original MFP estimate that is a measure of the influence of 'other' factors on MFP, including such things as technology changes, changes in work practices, changes in effort or input combinations due to unexpected output price changes, and ad hoc factors like poor weather.

When added together, the effects of resource depletion and production lags are estimated to explain a large part of both longer-term and shorter-term changes in mining MFP (figure 5.11).

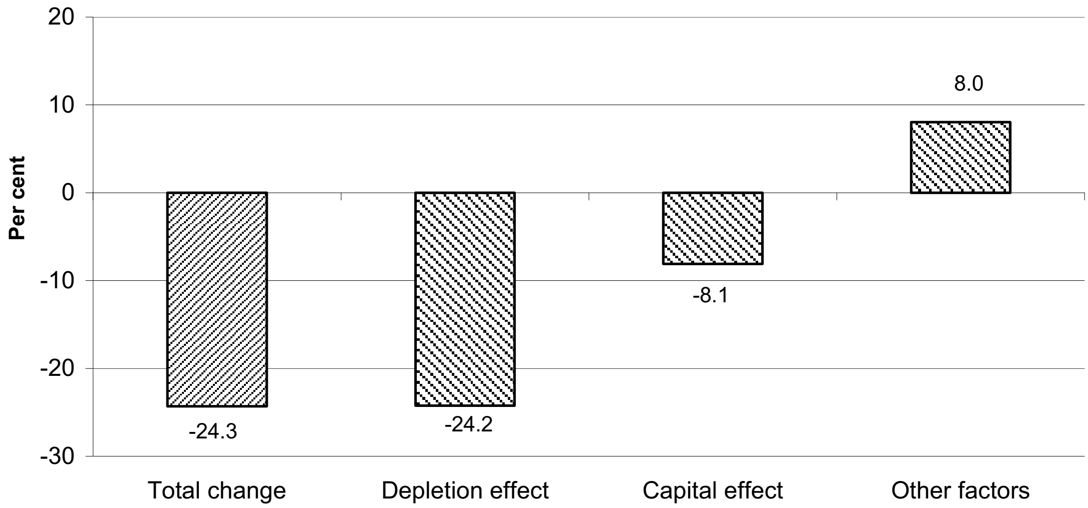
Figure 5.11 **Impact of yield declines and production lags on mining MFP**



Data sources: Authors estimates, ABS (*Experimental Estimates of Industry Multifactor Productivity 2006-07*, Cat. no. 5260.0.55.002)

In particular, the large decline in mining MFP in the late 1970s is much less apparent once yield changes and the capital investment surge that occurred at that time are taken into account. And in relation to the key issue motivating this study in the first place — the sharp and sustained decline in mining MFP between 2000-01 and 2006-07 — yield declines since 2000-01 and the surge in capital spending from around 2004-05 onwards are estimated to have contributed just over (negative) 33 percentage points to the total decline in MFP of around 24.3 per cent (figure 5.12).

Figure 5.12 **Contributions to the decline in mining MFP between 2000-01 and 2006-07**



Data sources: Authors' estimates, ABS (*Experimental Estimates of Industry Multifactor Productivity*, 2006-07, Cat. no. 5260.0.55.002).

As noted in earlier chapters, recently released data from the ABS indicate that mining industry MFP has fallen again in 2007-08, by just under 8 per cent. Production lags are estimated to explain just over 5 percentage points of the decline. Unfortunately, data limitations mean that we cannot estimate the extent to which resource depletion contributed to the decline. However, it seems likely that the decline in aggregate production of crude oil and condensate in 2007-08 reflects on-going reductions in oil and gas flow rates in some fields. To the extent this turns out to be the case, resource depletion is likely to emerge as an important explanatory factor of the decline in mining MFP in 2007-08 as well.

Positive effects on mining productivity

The implications of the quantitative assessments of yield effects and the surge in capital spending is that 'other factors' have contributed a positive amount (8.0 percentage points) to productivity growth in the mining industry between 2000-01 and 2006-07. Given that a number of the 'other' factors considered earlier are more likely than not to have made an adverse contribution to mining MFP since 2001 — for example, poor weather, infrastructure constraints, and shortages of skilled labour and machinery — the implication is that there must have been strong positive contributions to productivity growth in recent years from other sources, particularly technology.

An international perspective

In the long term, another mature mining nation, Canada, has experienced slow mining MFP growth. A study by the Canada-based Centre for the Study of Living Standards (CSLS) found that mining MFP growth in Canada over the period 1973 to 2000 was negative 2.2 per cent (Arsenault and Sharp 2008). Over the more recent period, Canada has experienced a more severe decline in MFP, negative 5.5 per cent over the period 2000 to 2006 (Arsenault and Sharp 2008). In explanation of this trend, the authors of the study state:

> Since 2000 and especially since 2004, increasing commodity prices have allowed the exploitation of reserves yielding much lower productivity levels. Through a compositional effect, this has led to increasingly negative labour productivity and MFP growth… Because the falling productivity of the sector is both the result of a rapid increase of its labour force and of the sudden increase in the exploitation of the oil sands, we may expect future labour productivity performance to be better (even if still negative) as the sector adjusts to its new reality and as the rate of increase in the oil sands share of total production levels falls off… Yet, if oil prices remain high, extraction activities in deeper oil sand deposits might grow significantly and continue to put downward pressure on the sector's productivity growth. (Arsenault and Sharp 2008)

The Canadian experience is one brought about by compositional changes in the industry, which is unlike the events that have occurred in Australia. Nonetheless, the response of mining poorer quality natural resources in response to higher prices is common, and has played a part in the declining productivity in the mining industry of both nations.

6 The big picture: mining, productivity and prosperity

Key points

- The decline in mining industry productivity after 2000 has been a major drag on national productivity growth. In 2005-06 a decline of nearly 9 per cent in mining industry MFP reduced market sector MFP by close to 1 percentage point.
- After removing the influence of resource depletion effects and capital investment effects in the mining industry, market sector MFP growth between 2000-01 and 2006-07 is estimated to be around 8 per cent higher.
- While conventionally measured multifactor productivity (MFP) growth in mining has been poor in recent years, higher world prices for many mineral and energy commodities generated record profit levels in much of the industry, and record levels of new investment. The mining boom led to a sharp increase in Australia's terms of trade, and an increase in the real exchange rate. The higher terms of trade contributed to an increase in the real incomes of Australians in recent years, even though growth in real output (production) was comparatively poor.
- The broader effects of the mining boom on income and economic activity are regionally concentrated in line with the geographic pattern of mining activity. Mining is more important to the economies of Western Australia and Queensland, and the effects of the boom in terms of income and employment growth are more apparent in these states.
- The expectation has been that mining MFP would begin to improve in 2008-09 as production associated with the surge in labour and capital investment in the sector between 2004-05 and 2006-07 began to come on-stream. However, this projection is now in question due to falling commodity prices, and decisions by many mining companies to cut production and postpone new investment.
- If mineral and energy commodity prices do indeed remain comparatively low over the next few years, then it is likely that mining companies will focus heavily on trying to reduce production costs. To the extent this occurs, it will have a positive effect on mining MFP, and reinforce the expected rebound in MFP (albeit possibly further delayed) as production associated with the recent surge in capital investment comes on-stream.

Following a surge in market sector productivity during the 1990s, Australia's productivity growth has slowed this decade to below the long-term average rate. This chapter reviews the extent to which developments in the mining industry have contributed to slower aggregate productivity growth, and argues that the key productivity measurement issues raised in chapters 3 and 4 — resource depletion effects and capital investment effects — have played an important role.

Notwithstanding the lower aggregate productivity growth outcome this decade, measures of national income and expenditure have been comparatively strong, and this is partly the result of the strength in mining commodity prices leading to higher profitability in the sector, a higher terms of trade, and a stronger Australian dollar. This chapter also reviews the broader relationship between the mining boom and national prosperity so far this decade.

The market outlook for mining changed fundamentally, however, in mid-to-late 2008, as the prices of some mineral and energy commodities fell substantially and as the global financial market crisis unravelled. This chapter also examines the possible consequences for mining productivity of these events.

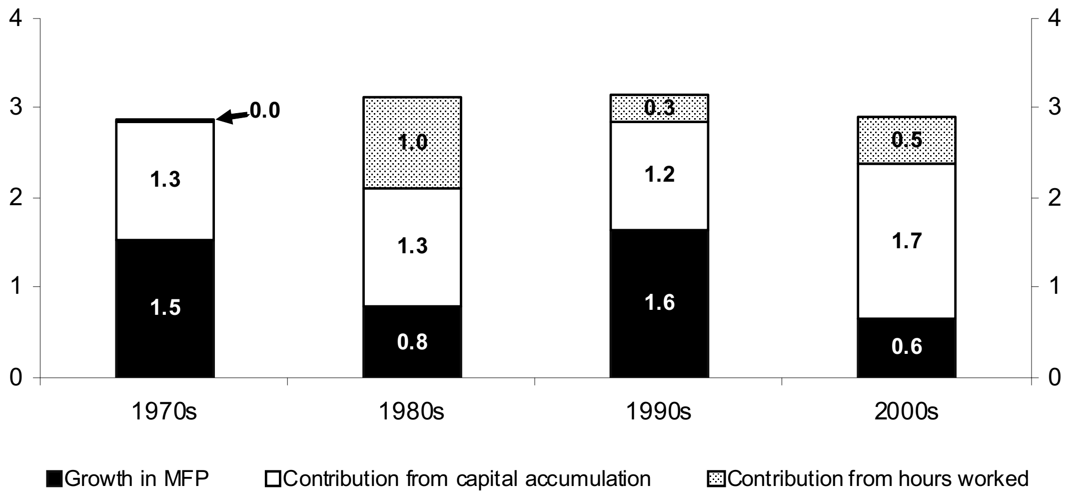
6.1 The contribution of the mining industry to Australia's productivity growth

Figure 6.1 shows the contributions to growth in the market sector output over the last four decades from growth in hours worked, capital accumulation and growth in productivity. While output growth has varied only slightly over the period — between an annual average rate of 2.9 and 3.2 per cent per year — MFP has varied considerably, with a very noticable decline in productivity growth from 1.6 per cent over the 1990s to 0.6 per cent over the seven years of the current decade for which data are available.

While productivity growth in all sectors has slowed so far this decade, the agricultural and mining industries stand out – recording negative productivity growth over the period since 2000. The developments in agriculture and mining explain more than half of the fall in Australia's productivity growth below the long-term average growth rate (figure 6.2). As noted in chapter 1, the collapse in MFP in the mining industry in 2005-06 reduced market sector MFP by almost 1 percentage point, while in 2006-07 a widespread drought in Australia subtracted 1.3 percentage points from market sector multifactor productivity.

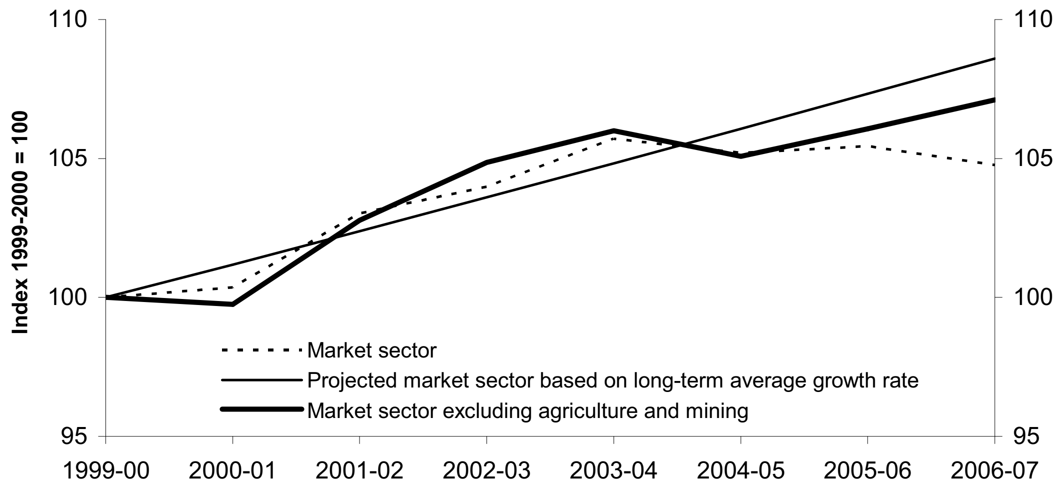
Figure 6.1 **Contributions to market sector output growth**

Annual average change, percentage points



Data source: ABS (*Australian System of National Accounts 2006-07*, Cat. no. 5204.0)

Figure 6.2 **Multifactor productivity**

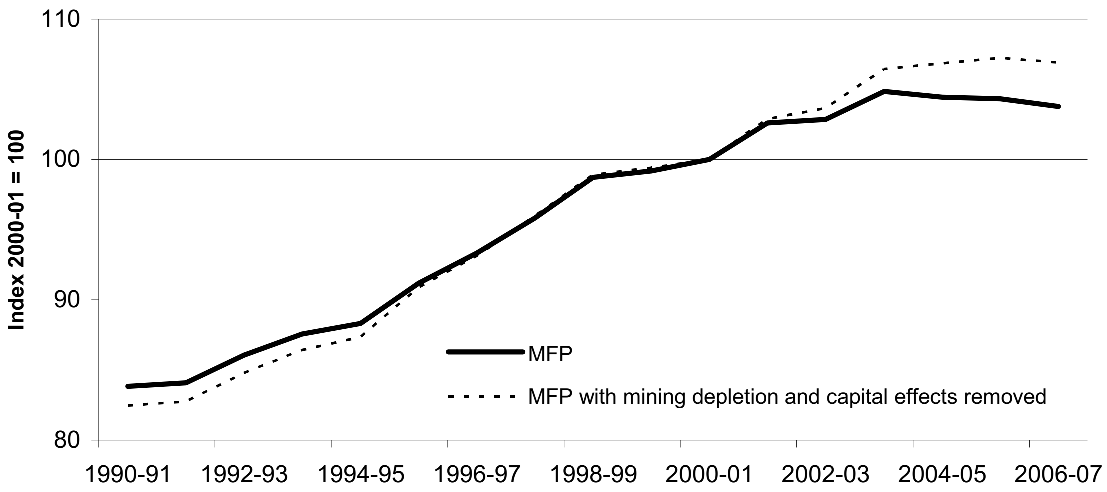


Data sources: Authors' estimates; ABS (*Australian System of National Accounts 2006-07*, Cat. no. 5204.0).

But it is also the case that much of the decline in mining industry productivity between 2000-01 and 2006-07 was the result of the temporary effects of production lags associated with a massive increase in new capital investment, and the effects of ongoing declines in the quality of natural resource inputs used in mining.

After removing the influence of these factors on mining MFP and re-estimating market sector MFP, a significant proportion of the slowdown in MFP growth in recent years can be explained by developments in the mining industry alone (figure 6.3). That is, difficulties associated with the measurement and interpretation of productivity in the mining industry are found to play an important role in explaining the slowdown in overall productivity growth in Australia so far this decade.

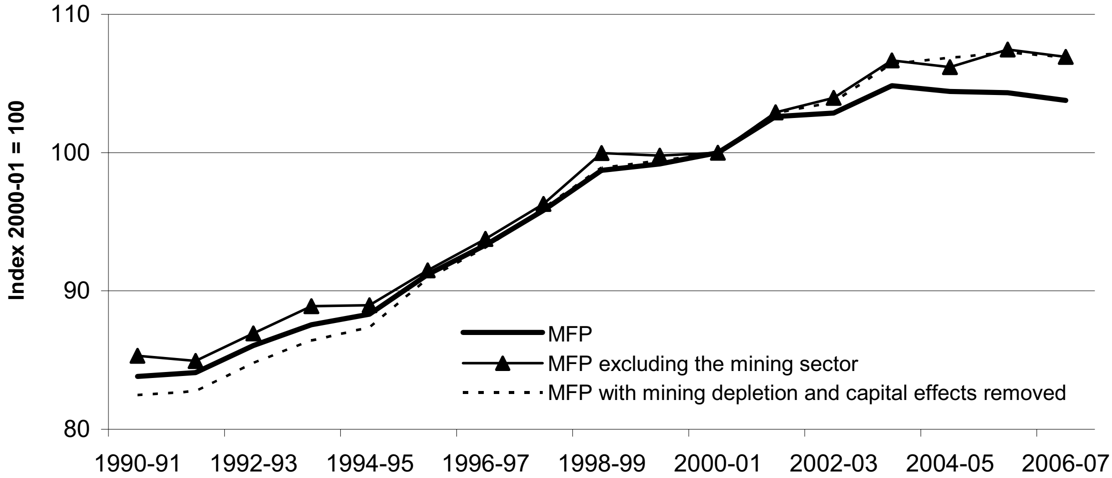
Figure 6.3 **MFP in the market sector: original and adjusted for mining industry developments**



Data sources: Authors estimates; ABS (*Australian System of National Accounts 2006-07*, Cat. no. 5204.0)

The impact on market sector MFP of accounting for the effects of resource depletion and the recent capital investment surge in mining is very similar to the effect of removing mining from the calcuation of market sector MFP in the first place (figure 6.4). That is, after removing the effects on mining MFP of resource depletion and capital effects, mining MFP grew by approximately the same amount as the rest of the market sector between 2000-01 and 2006-07 (approximately 8 per cent).

Figure 6.4 **MFP in the market sector: original, excluding mining, and adjusted for mining industry developments**



Data sources: Authors estimates; ABS (*Australian System of National Accounts 2006-07*, Cat. no. 5204.0).

6.2 The mining boom and national prosperity

The increase in mining industry commodity prices has been a major contributor to an on-going improvement in Australia's overall 'terms of trade' — the ratio of export prices to import prices.[1] By the end of June 2008 the terms of trade had reached a level above that seen during the energy crisis of the mid-1970s, and approaching the level reached during the wool-price boom associated with the Korean War (figure 6.5).

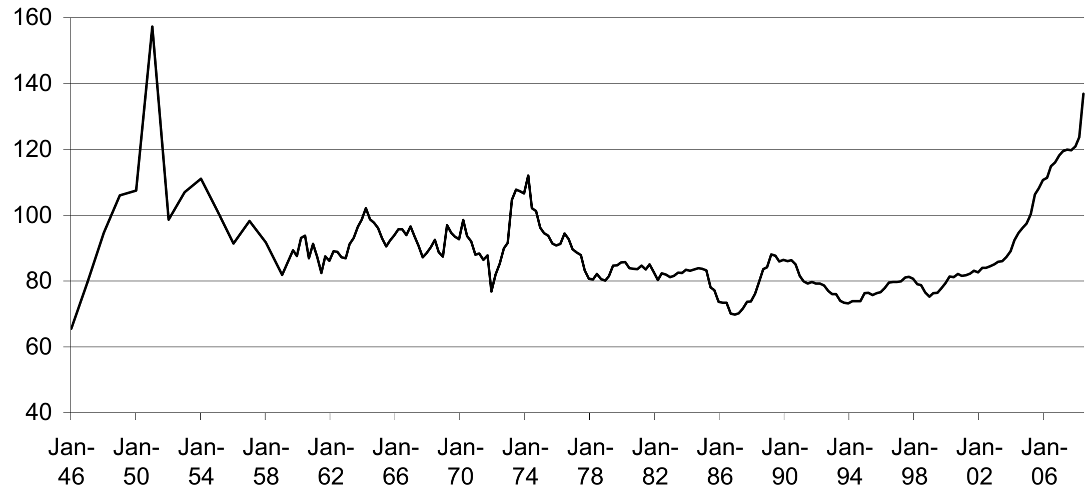
The increase in Australia's terms of trade is important because it has provided a substantial boost to national incomes, spending and activity. In general, an improved terms of trade increases Australia's real income by allowing greater quantities of imports to be purchased for the same quantity of exports.[2] Figure 6.6 shows the extent to which the terms of trade has contributed to the average income growth of Australians over the past four decades, along with the contributions of changes in labour utilisation, and labour productivity. So far this decade, the

[1] Significant declines in the prices of Australian imports, particularly manufactured goods, have also played a part.

[2] The converse, of course, is that a decline in the terms of trade reduces the real income of Australians. What is important for longer-term economic welfare is whether or not an increase in the terms of trade is sustained. Recent declines in the spot market prices of crude oil and a number of metals may be a precursor to the end of the long-running increase in the terms of trade.

improvement in the terms of trade has contributed a substantial increase in real income.

Figure 6.5 **Terms of trade, 1946 to 2006-07**



Data sources: Gruen and Kennedy (2006), ABS (*Australian National Accounts: National Income, Expenditure and Product* 2008 Cat. no. 5206.0, table 1).

Figure 6.6 **Contributions to income growth – the importance of the terms of trade**

Contributions to annual average growth in real gross domestic income per capita, percentage points per year

Data source: Commission calculations based on ABS (*Australian System of National Accounts 2006-07*, Cat. no. 5204.0) Labour utilisation is hours worked per capita, while Labour productivity is output per hour worked. Changes in labour productivity reflect both MFP growth and capital deepening — increases in outputs due to increases in the stock of capital.

However, some of the profits associated with the resources boom are payable to foreign owners of Australian mining industry assets, and hence not all of the increased income associated with the mining boom necessarily flows through to the rest of the economy (see Reserve Bank 2005). A measure which takes account of income payable to non-residents and income received from overseas is Gross National Income (GNI). Growth in GNI is lower than growth in gross domestic income (GDI) as income payable to non-residents is greater than income received from residents living abroad, nevertheless growth in GNI has been strong with the contribution of the terms of trade effect (net of the net income effect) remaining very strong (figure 6.7).

Figure 6.7 **Contributions to gross national income**

Contributions to annual average growth in real gross national income per capita, percentage points per year

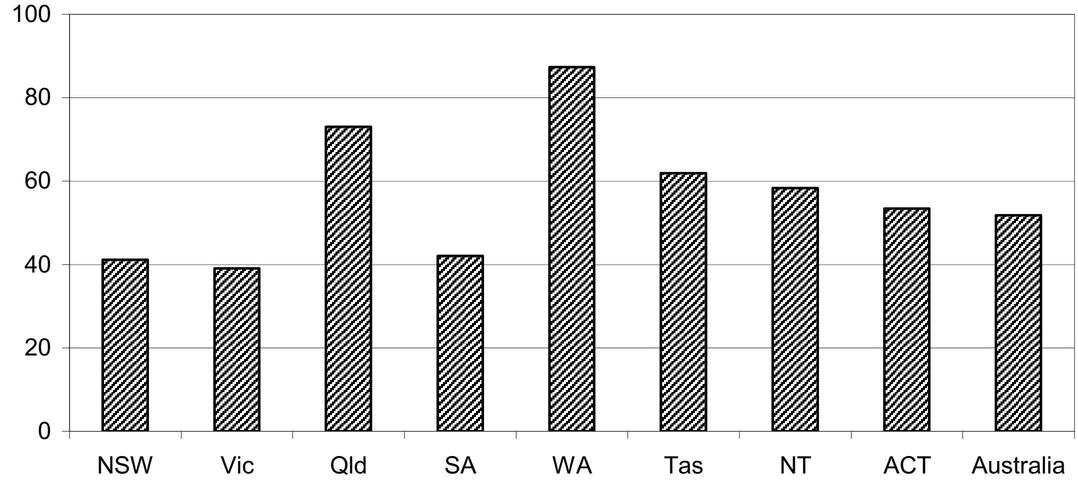
Data source: Commission calculations based on ABS (*Australian System of National Accounts 2006-07*, Cat. no. 5204). Labour utilisation is hours worked per capita, while Labour productivity is output per hour worked. Changes in labour productivity reflect both multifactor productivity growth and capital deepening - increases in outputs due to increases in the stock of capital. The net income effect refers to the contribution made by the change in gross national income due to the difference between primary income flows payable to non-residents and foreign income payable to residents.

Impact of the resources boom on downstream industries

The mining boom has also had significant real effects on economic activity in other areas of the national economy. The direct effects of the boom include stronger demand for inputs, including construction, equipment and infrastructure. As noted in chapter 2 and chapter 4, mining industry spending on new capital equipment has increased dramatically over the last couple of years, and spending on other inputs has also grown strongly (see table 2.1 and figure 4.3).

The impact of the mining boom on downstream industries is particularly important in the states of Western Australia and Queensland. As shown in chapter 2, the mining industry represents a comparatively large proportion of overall economic activity in these regions (see figure 2.1), and the change in gross state product between 2000-01 and 2006-07 is considerably larger in these states (figure 6.8).[3]

Figure 6.8 **Percentage change in gross state product[a] between 2000-01 and 2006-07**



[a] In current prices.

Data source: ABS (*Australian National Accounts: State Accounts 2006-07*, Cat. no. 5220.0)

A recent paper by Ye (2006) uses a general equilibrium model to simulate the flow-on effects of the iron ore boom on the Western Australian economy. The author finds that the surge in iron ore exports and the development of new iron ore projects is having the greatest stimulatory effects on the industries most closely related to construction activity — that is, energy supply and other services to mining. In relation to employment, more than 80 per cent of the new jobs created as a result of the iron ore boom are expected to be generated *outside* the iron ore sector, particularly in service industries (Ye 2006).

6.3 Impact of global economic developments and falling commodity prices

The expectation was that mining MFP would begin to improve in 2008-09 as production associated with the surge in labour and capital investment in the sector

[3] For a more detailed discussion of the impact of the mining boom on state and regional economic activity (see Garton 2008).

between 2004-05 and 2006-07 began to come on-stream. In September 2008 for example, the Australian Government forecasting agency ABARE was predicting a substantial (7 per cent) increase in mining industry output in 2008-09, after a long period of comparative sluggish output growth (ABARE 2008a).

However, these projections are now in question due to the substantial decline in world prices of a number of mineral and energy commodities. There is anecdotal evidence to suggest that overall output growth in the sector will be revised downwards in 2008-09, due to both the closure of existing mines, and cut-backs to production at others. Mine closures are likely to have a positive effect on MFP as mines with higher average costs of production will generally be closed first. On the other hand, cut-backs in output at existing mines may lead to lower MFP if they lead to temporarily idle capital.

There is a substantial amount of new productive capacity in mining that is expected to come on-stream in 2008-09. The decline in commodity prices may have an impact on the speed and extent to which the new mines and mine expansions reach full capacity. This may delay the anticipated rebound in MFP as production lags associated with the surge in capital investment that started in 2004-05 begin to unwind.

As noted in chapter five, a commodity price boom can lead to lower productivity (albeit occuring at the same time as high profitability) because higher prices render less efficient mines and mining practices economically viable. In boom times the primary focus of mining operations is usually on increasing output, albeit at a higher unit cost of production. The converse tends to hold in downturns, as (in an effort to maintain profitability) less efficient mines and mining practices are wound back in order to reduce unit costs.

If mineral and energy commodity prices do indeed remain comparatively low over the next few years, then it is likely that mining companies will focus heavily on trying to reduce production costs. To the extent this occurs, it will have a positive effect on mining MFP, and reinforce the expected rebound (albeit possibly further delayed) in MFP as production associated with the recent surge in capital investment comes on-stream.

A Sub-sector results

A.1 Background

This appendix contains estimates of multifactor productivity (MFP) in each of the eight mining sub-sectors covered in the study, along with estimates of the extent to which resource depletion and capital investment effects contribute to MFP changes over time.

The eight sub-sectors covered in the study and their shares of total mining industry value added in 2006-07 are shown in table A.1.

Table A.1 **Shares of total mining industry value added in 2006-07**

	$million	*Per cent*
1. Coal mining	16 364	22.8
2. Oil and gas extraction	22 420	31.2
3. Iron ore mining	11 208	15.6
4. Copper ore mining	3 699	5.2
5. Gold ore mining	2 629	3.7
6. Mineral sand mining	373	0.5
7. Silver-lead-zinc ore mining	4 339	6.0
8. Metal ore mining nec [a]	5 141	7.2
The industries not covered in this study are:		
Other mining	2034	2.8
Services to mining	3563	5.0
Total	71 770	100.0

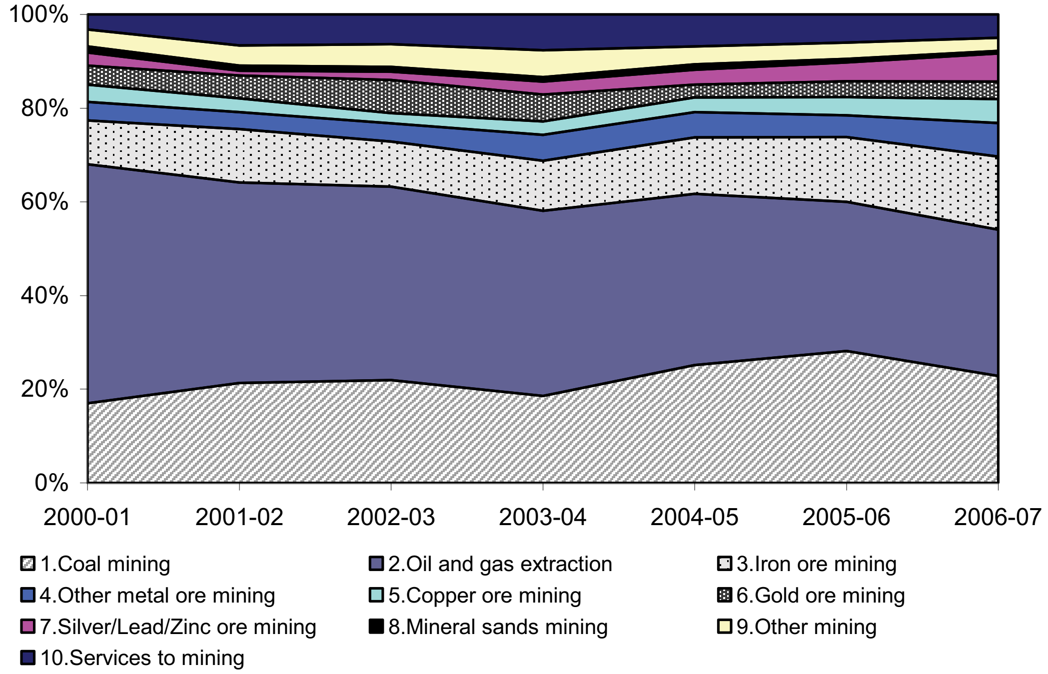
[a] Bauxite mining and nickel ore mining results are included in 'Metal ore mining nec'.

Source: ABS (*Mining Operations, Australia 2006-07*, Cat. no. 8415.0).

Changes in production and relative prices between 2000-01 and 2006-07 have led to changes in sub-sector shares of total mining output (figure A.1). Despite record prices in recent years, lower production of crude oil has caused a significant decline in the relative importance of the oil and gas sector. In contrast, increases in production and record prices for iron ore have resulted in a major new investment phase in iron ore mining, and an increase in the share of total mining output accounted for by this sub-sector.

The rest of this appendix outlines MFP changes on an industry by industry basis, with particular reference to developments in MFP growth since 2000-01.

Figure A.1 **Changes in industry shares of total output, 2000-01 to 2006-07[a]**



[a] Shares of industry value added in current price terms.

Data source: ABS (*Mining Operations, Australia 2006-07*, Cat. no. 8415.0)

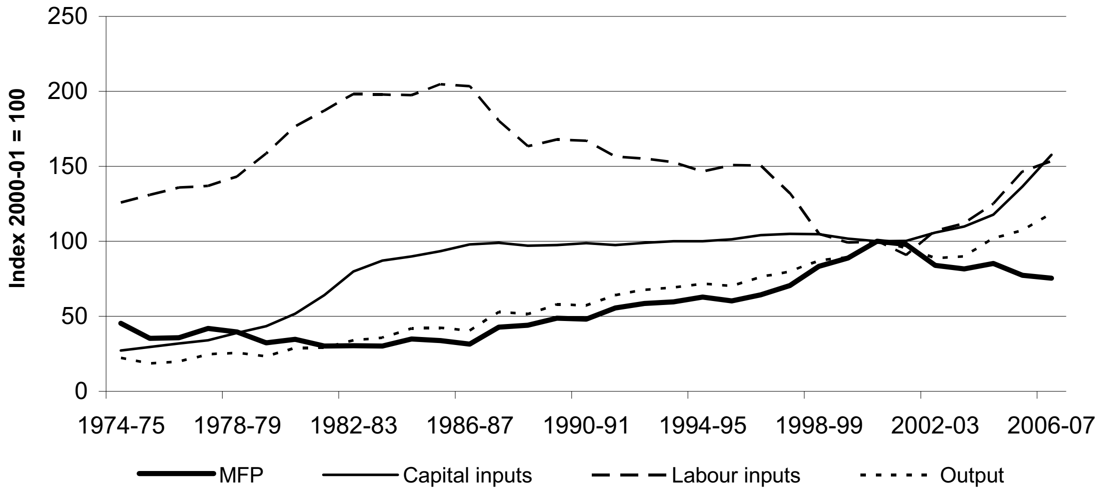
A.2 Coal mining

Coal mining has been a prominent feature of the mining landscape in Australia for over two centuries. Coal was first noted in Australia throughout the 1790s, and the first mineral exports from Australia were shipments of black coal sent to India in 1799 (Mudd 2007).

Until recent times the majority of Australian coal production served as an input to domestic industries, both as a source of fuel and as an input to steel making. From the mid-1960s, however, coal exports began to increase, and by the mid-1970s the quantity of coal exported from Australia exceeded the quantity sold domestically for the first time. Since then exports have continued to grow in volume and value terms relative to domestic sales, and now represent around three quarters of total production. The black coal industry accounted for 22.8 per cent of mining value added in 2006-07.

Measured MFP within the industry has declined in recent years following a steady improvement in productivity through the 1980s (figure A.2). The decline in recent years is a result of the substantial increase in inputs within the industry, with a comparatively modest increase in output. Coal production was particularly poor in 2002-03 as low prices encouraged some miners to scale-back production, and in 2005-06 as poor weather, difficulties with maintenance, and the closure of some depleted mines acted to constrain production growth.

Figure A.2 **Coal mining: Inputs, outputs and MFP**

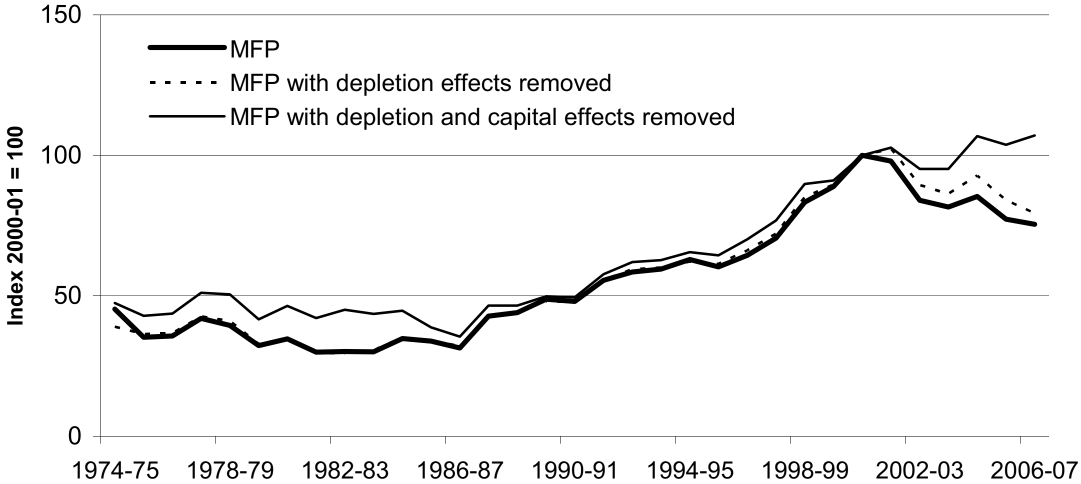


Data source: Authors estimates.

A decline in the saleable to raw coal ratio is estimated to have made a small contribution to the decline in MFP between 2000-01 and 2006-07 (figure A.3). It is also possible that an increase in overburden production in coal mining during the period contributed to the decline in MFP (figure A.4). However, further work needs to be done in order to quantify the effect on production costs of changes in the coal to overburden ratio.

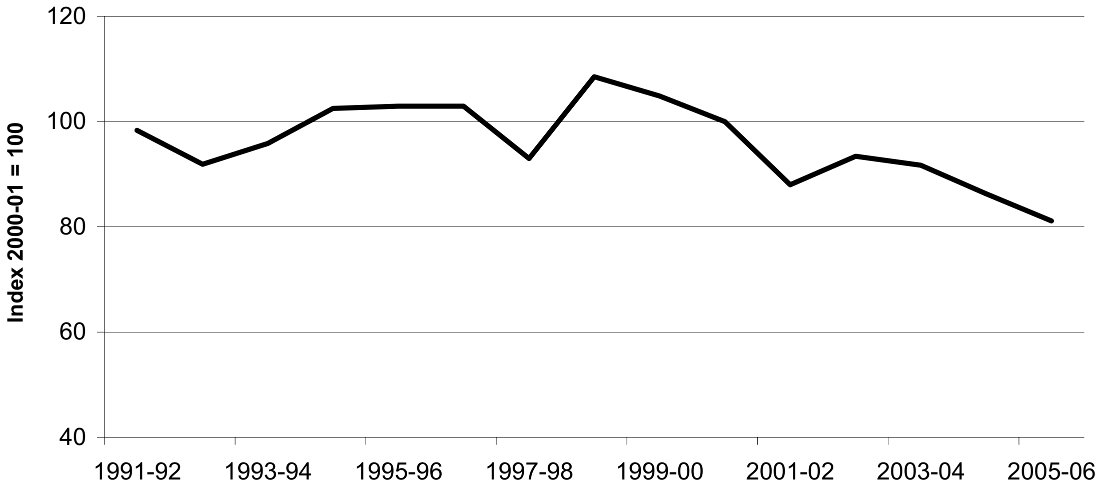
The effect of production lags has been significant in coal mining, with an investment surge from 2004-05, the scale of which is sufficient by itself to counter all of the productivity decline from 2000-01 onwards. As noted in chapter 4, the substantial lead time involved in most new mining developments means that a surge in new investment can lead to a temporary decline in MFP as inputs increase without an accompanying increase in output. Once the new coal mines and mine expansions currently under construction reach full production, there is likely to be an associated improvement in MFP.

Figure A.3 **Coal mining MFP: Impact of resource depletion and capital effects**



Data source: Authors' estimates.

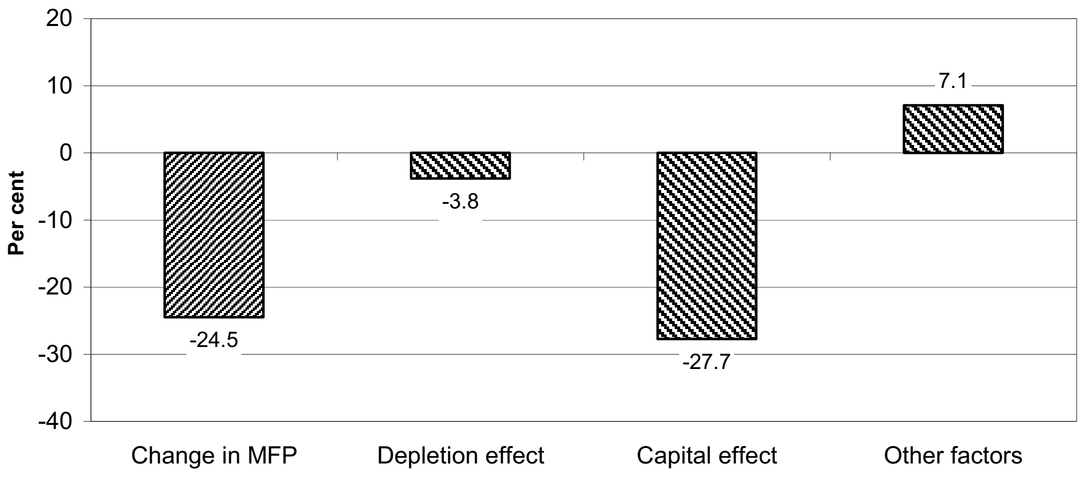
Figure A.4 **Ratio of coal to overburden production, 1991-92 to 2006-07**



Data source: Mudd (2007).

Once the effects of yield changes and the capital investment surge are taken into account, MFP in the coal mining sector is estimated to have grown by around 7 per cent over the period from 2000-01 to 2006-07, rather than to have fallen by nearly 25 per cent (figure A.5). As the majority of the decline in coal mining MFP is caused by the recent surge in capital investment, the decline is likely to be a temporary phenomenon that will be reversed as new productive capacity comes on-stream. Nevertheless, coal mining MFP growth does appear to have slowed so far this decade compared with the previous decade.

Figure A.5 **Coal mining: Contributions to MFP changes, 2000-01 to 2006-07**



Data source: Authors' estimates.

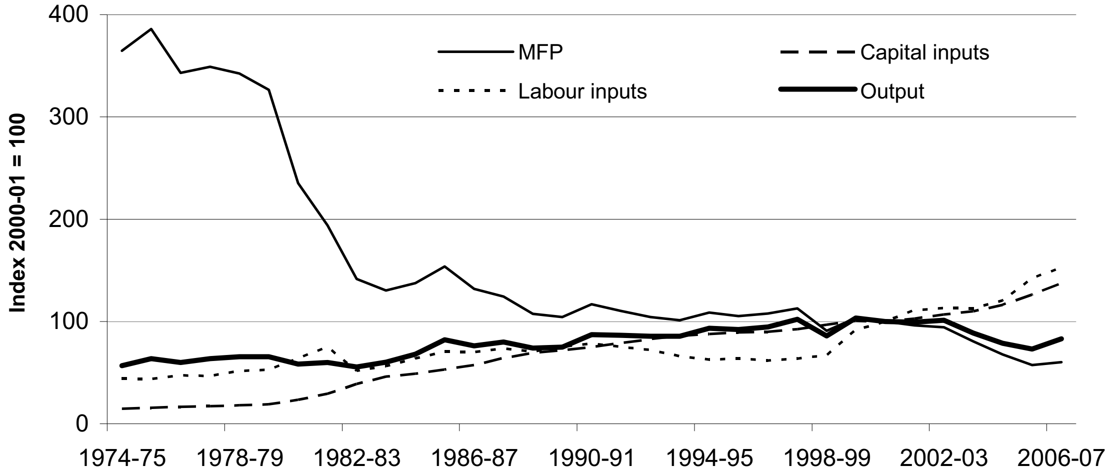
A.3 Oil and gas extraction

Oil and gas production in Australia is a relative newcomer to the mining scene. First commercial production began on Barrow Island in the mid-1950s, but the main petroleum extraction came with the development of the Gippsland basin in the Bass Strait in the late 1960s. Since then, major production of hydrocarbons has occurred in the Gippsland, Carnarvon and Bonaparte basins.

The oil and gas industry is currently one of the largest sub-sectors in the mining industry, contributing 31.2 per cent of mining value added in 2006-07. As such, developments in the sector have a significant impact on the sector as a whole.

A key development in the oil and gas sector is the decline in productivity since 2001, which coincides with the peak of Australian crude oil production. The effects of cumulative extraction from existing fields (outlined in chapter 3) combined with a surge in new capital and labour inputs has led to a sharp decline in MFP that has had a large negative effect on MFP in the mining industry as a whole (figure A.6).

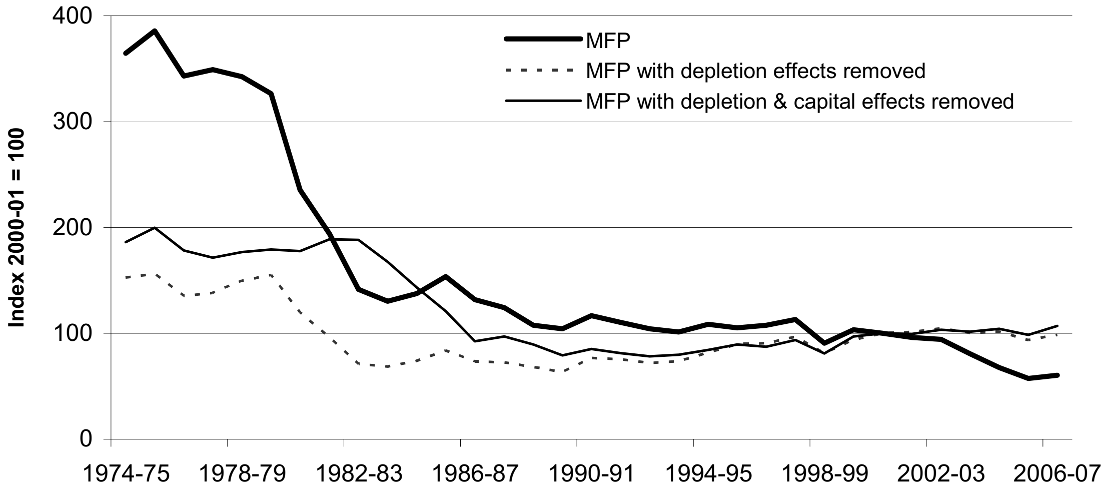
Figure A.6 **Oil and gas extraction: Inputs, output and MFP**



Data source: Authors' estimates.

After removing the influence of lower flow rates (of oil and gas production) due to the maturing of existing fields, a significant proportion of the long-term decline in MFP in oil and gas extraction is explained. Similarly, long lead times in new production capacity are found to be significant factors explaining shorter-term movements in MFP (figure A.7).

Figure A.7 **Oil and gas extraction MFP: Impact of resource depletion and capital effects**



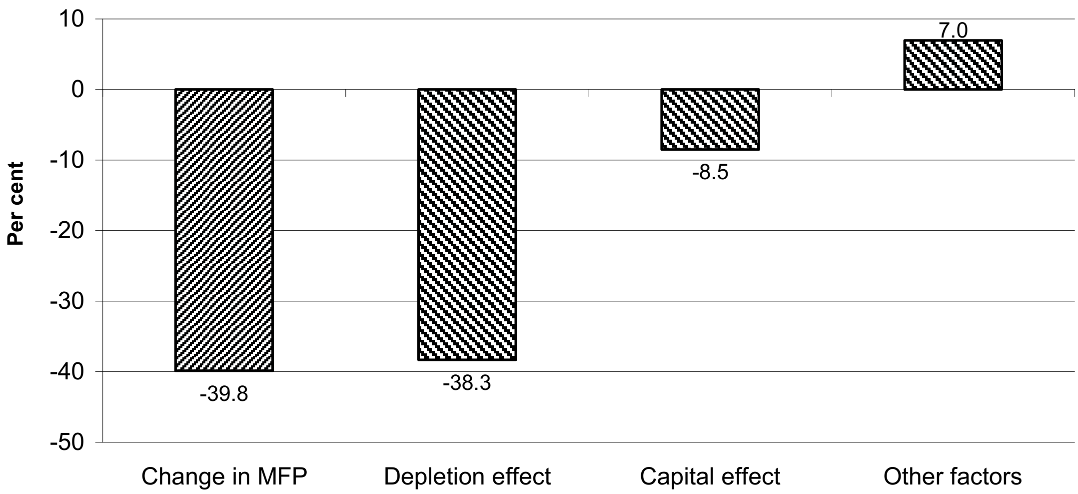
Data source: Authors' estimates.

In contrast to the case of coal mining, the decline in MFP in oil and gas extraction between 2000-01 and 2006-07 is largely explained by yield declines associated with the maturing of existing oil and gas fields (figure A.8). Long lead times in new production capacity are estimated to have contributed negative eight percentage points to the change in MFP over the period, meaning that 'Other factors' contributed a positive amount to MFP growth of around the same magnitude. The negative effects of the recent surge in capital investment in the sector are likely to be temporary, and should be offset over the next few years as new production comes on stream.

While the bulk of the observed depletion is caused by dwindling yields of crude and condensate, there is little in the way of depletion in natural gas. Should demand for gas continue to increase, then depletion effects on productivity should decline as the industry shifts to the (comparatively) more abundant resource.

In terms of recent developments, the sector is continuing its 'geographic shift' away from the Gippsland basin and towards the Carnarvon and Bonaparte basins to exploit new fields with an increased emphasis on the production of natural gas. Improvements in drilling technology have aided this by facilitating access to deeper resource deposits, and through the use of directional drilling to target more complex geological formations. The trend towards the exploitation of deeper deposits, especially for liquid hydrocarbons, is likely to continue.

Figure A.8 **Oil and gas extraction: Contributions to MFP changes, 2000-01 to 2006-07**



Data source: Authors' estimates.

A.4 Iron ore mining

Like the oil and gas sector, the Australian iron ore sector developed comparatively recently, with production growing extremely rapidly from the mid-1960s to the early 1970s. After a comparative lull in production growth in the 1970s and early 1980s, iron ore production began to grow strongly once again, and has continued to grow to the present day. The vast majority of the increase in iron ore production since the late 1960s has been exported, with little change in the quantity used domestically. As a result, iron ore has become a major export industry for Australia, earning just over $16 billion in export revenue in 2006-07 — or 7.5 per cent of the total value of goods and services exports. Over one half of iron ore exports were sold to China in 2006, up from just 18 per cent of total exports in 1999 (ABARE 2007).

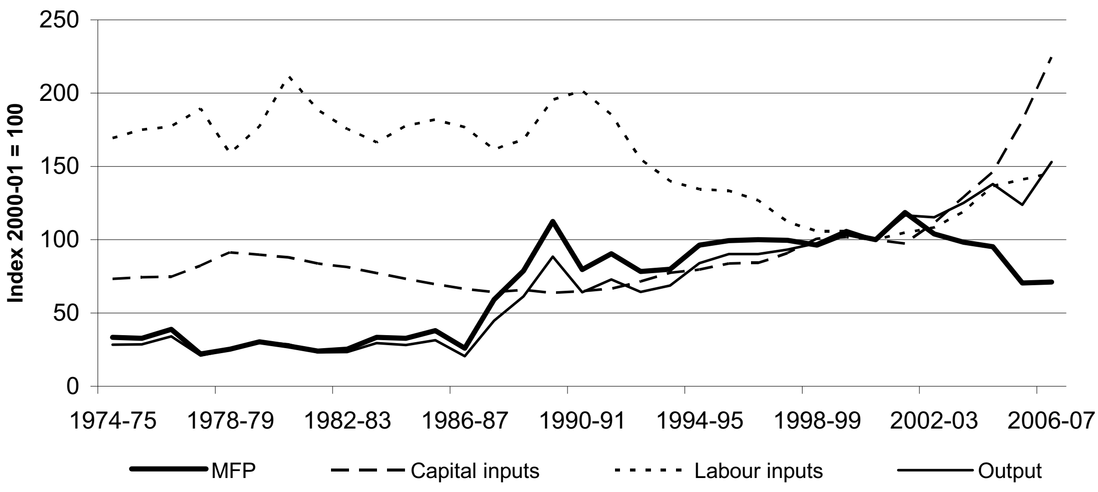
Iron ore production in Australia is currently dominated by two major companies — BHP Billiton and Rio Tinto. Together the two companies accounted for around 92 per cent of production in 2006-07, although recent high prices have encouraged new entrants to the industry. Nearly all iron ore is produced in the Pilbara region of Western Australia.

Iron ore is currently the third largest mining sub-sector in Australia in terms of value added, and is likely to continue to increase its size and importance. According to Mudd (2007, p. 47) Australia holds some of the largest and highest quality deposits of iron ore in the world.

Although there are significant periods of little or no growth in measured productivity in the iron ore sector over the past 32 years, there is nevertheless a strong upward trend (figure A.9). As a result, the average rate of MFP growth over the period is a healthy 3.2 per cent per year, even taking the poor productivity performance over the last six years into account. The period of strong MFP growth between the mid-1980s and the late 1990s is characterised by a substantial increase in the capital to labour ratio in the sector (figure A.9).

Given the substantial reserves of high quality iron ore Australia currently holds relative to production, it would seem unlikely that resource depletion could have played any significant role in explaining trends in MFP growth in the sector since the late 1960s. However, changes in the average grade of iron ore (which, as noted in chapter 3, do not contribute to MFP changes in this sector because the final output is in the form of ore rather than metal derived from ore) are only one possible adverse effect that depletion of reserves over time through cumulative production could be having on measured productivity. For example, Mudd (2007) argues that, as with coal, changes in the amount of waste material that is produced in extracting iron ore could have been occurring over time. Increases in overburden or waste rock production can clearly lead to higher costs of production, putting downward pressure on productivity. In the case of iron ore however, there is little data available to indicate whether or not there has been any significant change in average waste material production in iron ore mining in recent decades.

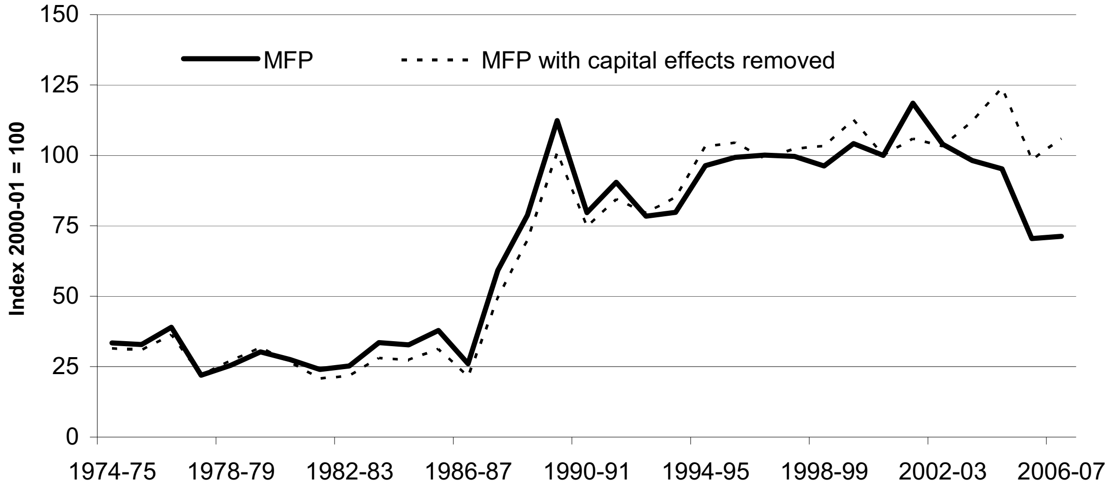
Figure A.9 **Iron ore mining: Inputs, outputs and MFP**



Data source: Authors' estimates.

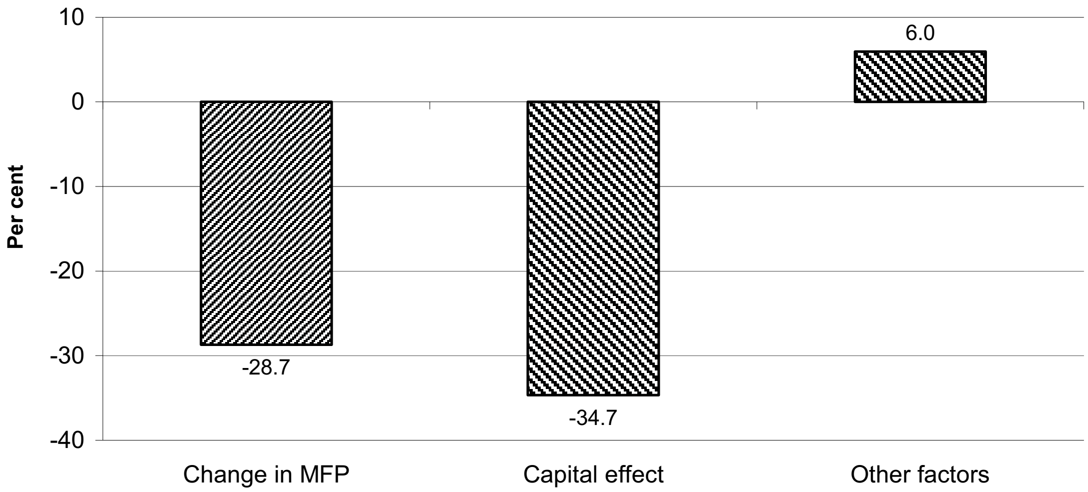
As noted in chapter 3, measured productivity in iron ore mining is not affected by changes in the average grade of ore (although changes in the average iron ore grade have been small), as the output variable is in the form of ore itself (this is in contrast to some of the other metal ore mining industries where the output from mining is measured in the form of metal concentrate or metal per se, rather than 'ore'). However, measured productivity in the iron ore sector is subject to the issue of long lead times associated with investment in new capacity. After accounting for production lags associated with the recent surge in new capital spending in the iron ore sector, measured productivity is found to be significantly higher (figure A.10). In fact, productivity in iron ore mining between 2000-01 and 2006-07 is found to have grown by around 6 per cent, rather than to have fallen by nearly 30 percent. once the effects of the recent capital investment surge in the sector are taken into account (figure A.11). This is despite the fact that iron ore production has also been hampered by very poor weather conditions over the past couple of years, which would almost certainly have contributed adversely to measured productivity.

Figure A.10 **Iron ore mining MFP: Impact of capital effects**



Data source: Authors' estimates.

Figure A.11 **Iron ore mining: Contributions to MFP changes, 2000-01 to 2006-07**



Data source: Authors' estimates.

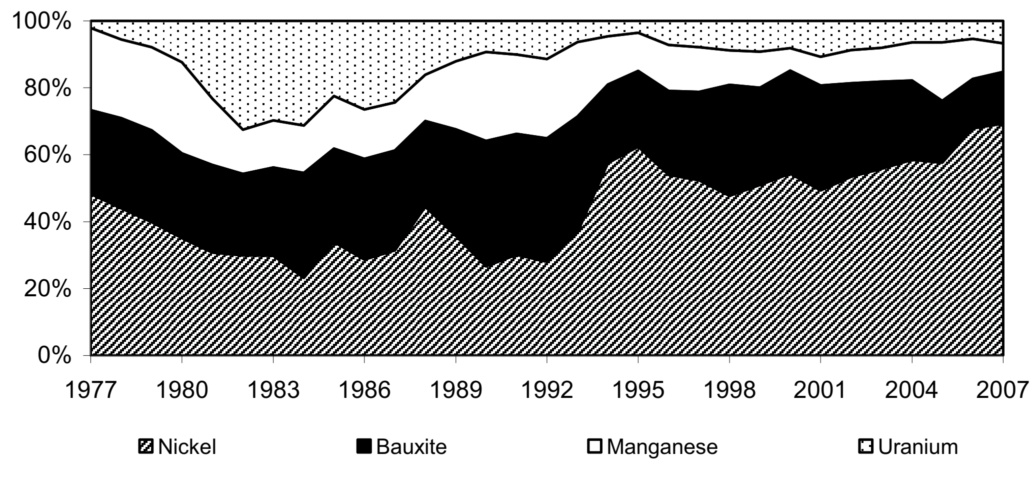
A.5 Other metal ore mining

The ABS classifies several mining operations to the 'Other minerals not elsewhere classified' category. This category encompasses a multitude of non-ferrous minerals, including bauxite, manganese, tin, nickel, tungsten, uranium and lithium.

In Australia's case, the main other metal ores are bauxite and nickel, with manganese and uranium to a lesser extent. These minerals do not have any common purpose, and as such, have price and quantity dynamics that differ. In terms of value added, the 'Other metal ores' category accounted for around 7.2 per cent of the mining sector in 2006-07.

The most notable trend within the category is the increasing importance of nickel over the past 20 years (figure A.12). While nickel production has been increasing over the more recent period (from 169 kilotonnes in 2000 to 185 kilotonnes in 2007), its share of the gross value of production within this category rose substantially due to growth in the price of nickel (up from $14 000 per tonne in 2000 to around $46 000 per tonne in 2007).

Figure A.12 **Gross value of production shares within 'Other metal ore' mining**

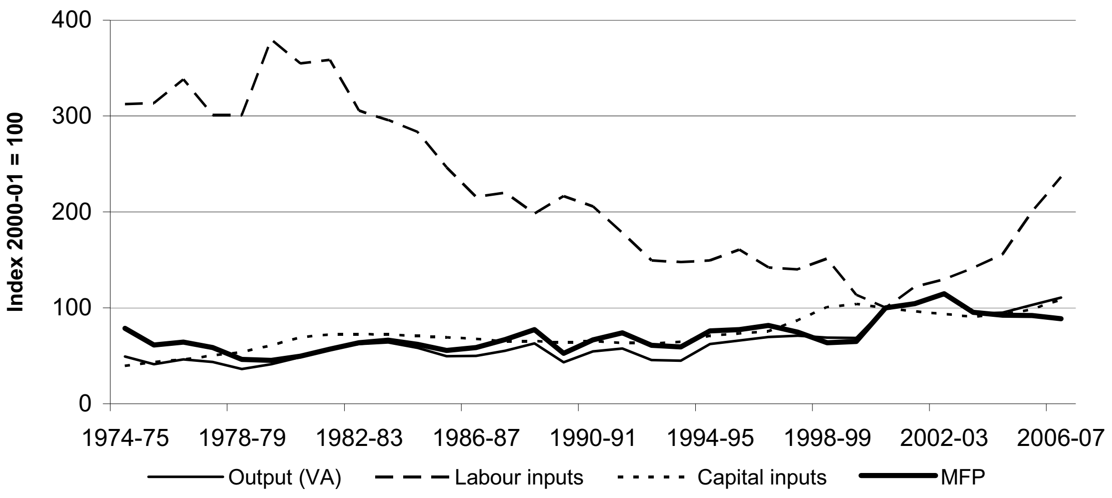


Data source: Authors' estimates using data from ABARE (*Australian Commodity Statistics* 2007).

Productivity trends

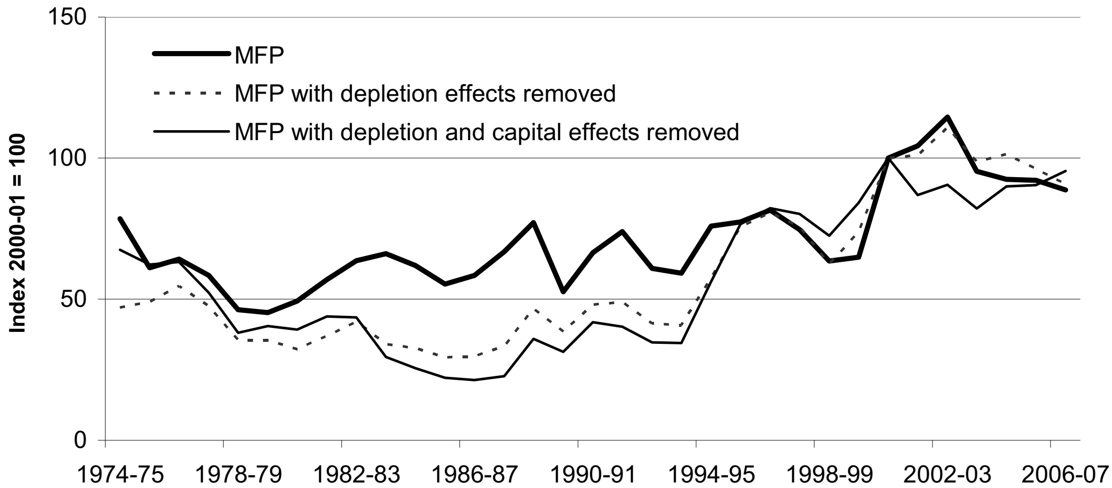
Over the longer term, productivity growth in the ‘other metal ores’ sector has been comparatively strong, with a compound annual growth rate of MFP over the period from 1974-75 to 2006-07 of 1.8 per cent (figure A.13). Until recent times the growth in MFP was due to capital deepening (an increase in the amount of capital per unit of labour), but the capital to labour ratio has fallen dramatically since 2000-01, and MFP has fallen a little. Unlike other mining sectors, depletion in the form of lower ore grades has not been a major factor influencing productivity trends over the longer term, and has played little role in explaining MFP trends in the sector since 2000-01 (figures A.14 and A.15). This is partly a reflection of the fact that productivity in the bauxite and manganese sectors is not affected by ore grade changes as ‘ore’ is generally the final output. Hence, only changes in the average ore grades of nickel, tin and uranium are taken into account when estimating the effect of ore grade changes on MFP. This is not to say that other aspects of resource depletion — deeper or more difficult deposits etc — have not contributed to productivity changes in this sector, but a lack of data precludes the effect of these factors from being measured.

Figure A.13 **Other metal ore mining: Inputs, outputs and MFP**



Data source: Authors’ estimates.

Figure A.14 **Other metal ore mining MFP: Impact of resource depletion and capital effects[a]**

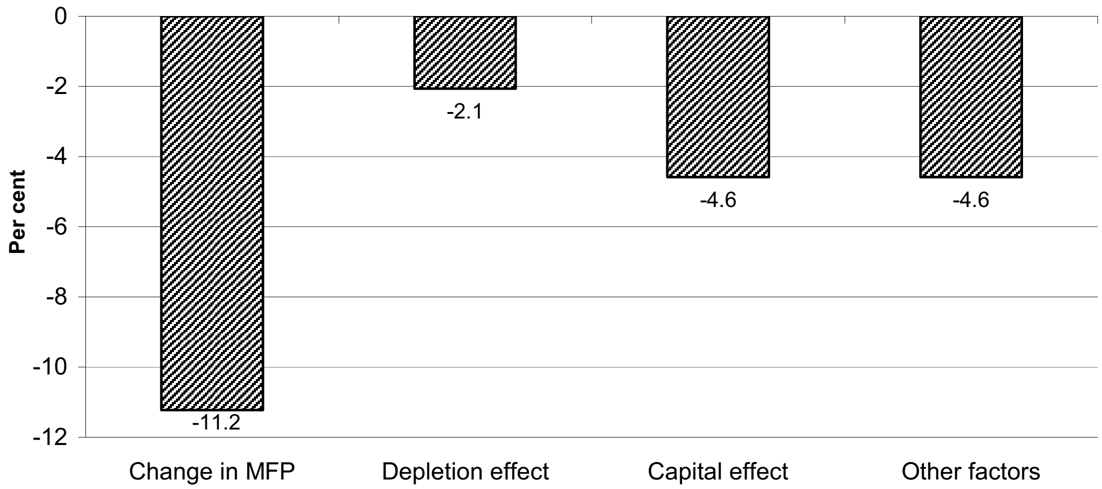


[a] Resource depletion is calculated on the ore grades of manganese, bauxite, nickel and uranium oxide.

Data source: Authors' estimates.

Accounting for the effects of long lead times in response to investment in new capacity changes the year to year movements in productivity in recent years, but does not change the conclusion that there has been a slight decline in MFP in the 'Other metal ores' sector over the period (figure A.15).

Figure A.15 **Other metal ore mining: Contributions to MFP changes, 2000-01 to 2006-07**



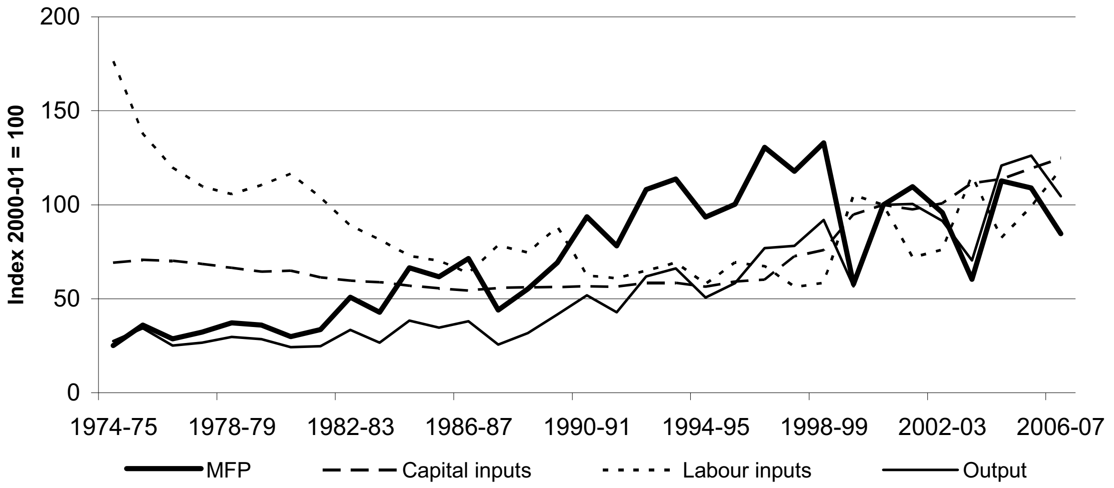
Data source: Authors' estimates.

A.6 Copper ore mining

Copper mining has been performed on an industrial scale in Australia since the 1840s, preceding the original gold mining boom in the mid-nineteenth century by almost a decade. In more recent times, copper has been produced from larger mines as a co-product or by-product with other minerals. The consequences for the accuracy of measured MFP in the copper ore mining sector are unclear. The ABS data on which the MFP estimates for copper ore mining are based suggest that the majority of Australian copper ore production is accounted for by the businesses covered in this classification. As a result, the MFP numbers are likely to be reasonably accurate. On the other hand, the ABS data for 'copper ore mining' exhibit large year to year changes in inputs, output and MFP, and this makes interpreting changes in MFP more difficult. Some of the year to year variability could be the result of individual mining enterprises moving into or out of the survey, or from one industry classification to another as a result of changes in their enterprise mix. As a consequence, the focus in relation to copper ore mining is on general trends in MFP rather than shorter term movements.

With these limitations in mind, it appears to be the case that productivity in copper ore mining grew comparatively strongly from the early 1970s to the late 1990s. Since 1998-99 however, MFP has fallen, on average, and become much more variable from year to year (figure A.16).

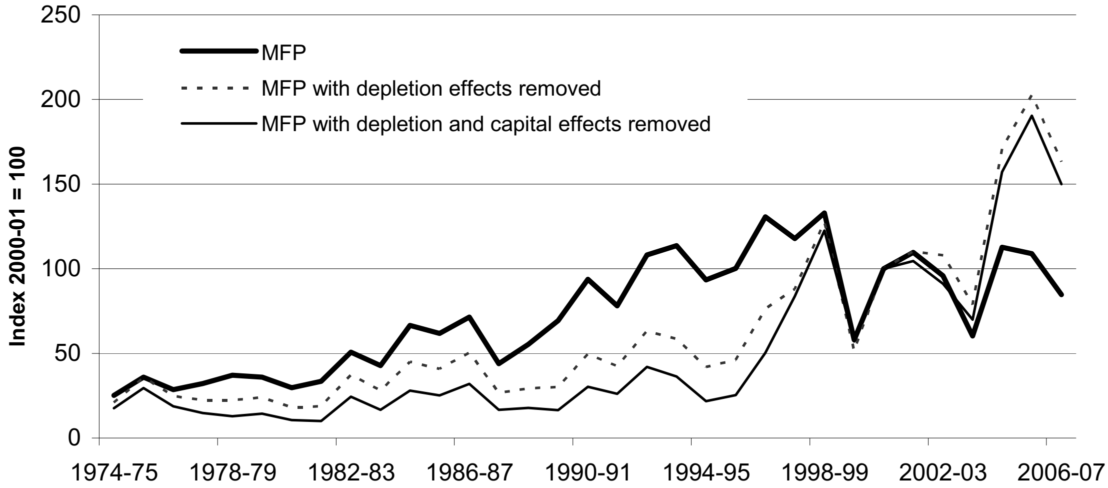
Figure A.16 **Copper ore mining: Inputs, outputs and MFP**



Data source: Authors' estimates.

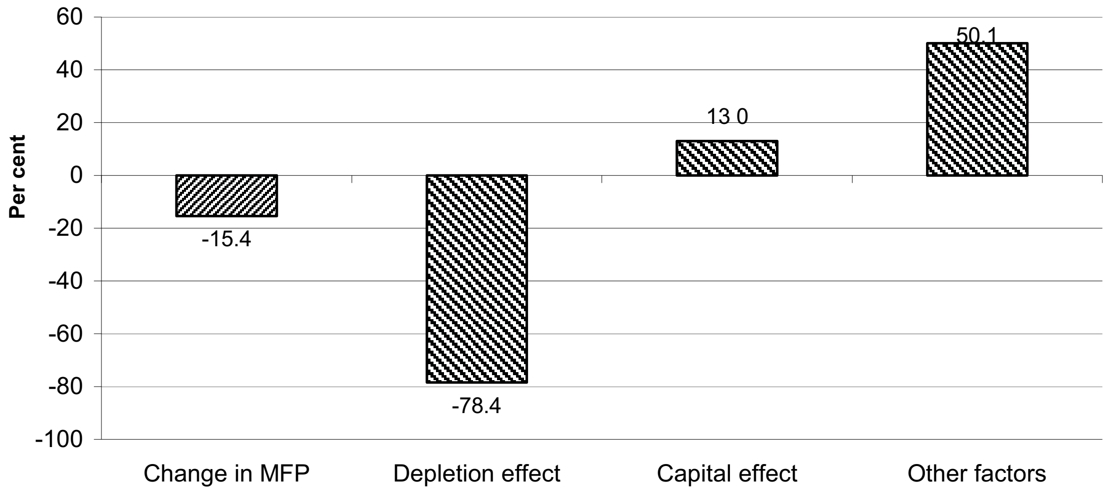
It is estimated that improvements in average ore grades made a significant contribution to the strong increase in copper ore mining MFP during the 1980s and 1990s (figure A.17). From the mid-1990s onwards however, the average grade of copper ore began to fall consistently, contributing to a slowdown in measured productivity growth. Between 2000-01 and 2006-07, the decline in the average grade of copper ore was estimated to have added negative 80 percentage points to the change in MFP. In contrast to many of the other mining industries, new investment in the copper ore mining sector has been comparatively weak in recent years, despite higher output prices. In fact, a slowdown in the rate of growth in new investment in recent years is estimated to have temporarily added around 13 percentage points to MFP growth in the sector. After accounting for the effects of resource depletion and the temporary effects of the capital investment slowdown, 'other factors' are estimated to have made a substantial positive contribution (around 50 percentage points) to the change in MFP in copper ore mining during the period (figure A.17 and A.18).

Figure A.17 **Copper ore mining: Impact of resource depletion and capital effects**



Data source: Authors' estimates.

Figure A.18 **Copper ore mining: Contributions to MFP changes — 2000-01 to 2006-07**



Data source: Authors' estimates.

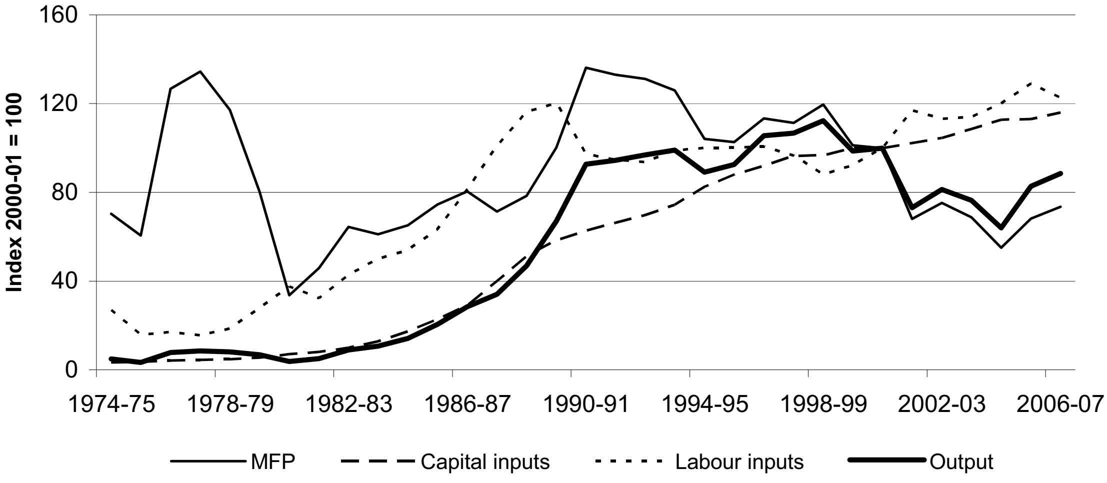
A.7 Gold ore mining

Gold came to prominence in Australia during the first gold boom in the 1850s, making the sector one of the oldest in the mining industry (Close 2004). Easily extractable alluvial gold lured thousands of people from around the world to Australia where the goldfields in Victoria and New South Wales boomed. A second gold boom followed in the 1890s, when large deposits of gold bearing ore were found in Western Australia. Following this second gold boom, production declined and remained low through until the 1970s (with the exception of a small 'mini-boom' during the second world war). The reason behind this slump in production was primarily depletion: the remaining available gold was of such low concentration that extraction was at best uneconomical and at worst impossible. New technology allowed a significant increase in production, but further depletion is now presenting the greatest problem to both production and productivity in the gold mining sector.

In terms of its contribution to the mining sector, gold ore mining is now one of the smaller industries, accounting for just 3.7 per cent of mining value added in 2006-07.

As seen in figure A.19, gold mining productivity in the 1970s was characterised by significant swings. The low production, low input characteristics of gold mining during this period make the MFP series highly sensitive to small changes in output, thus the high volatility of the MFP series should be considered with caution.

Figure A.19 **Gold ore mining: Inputs, outputs and MFP**

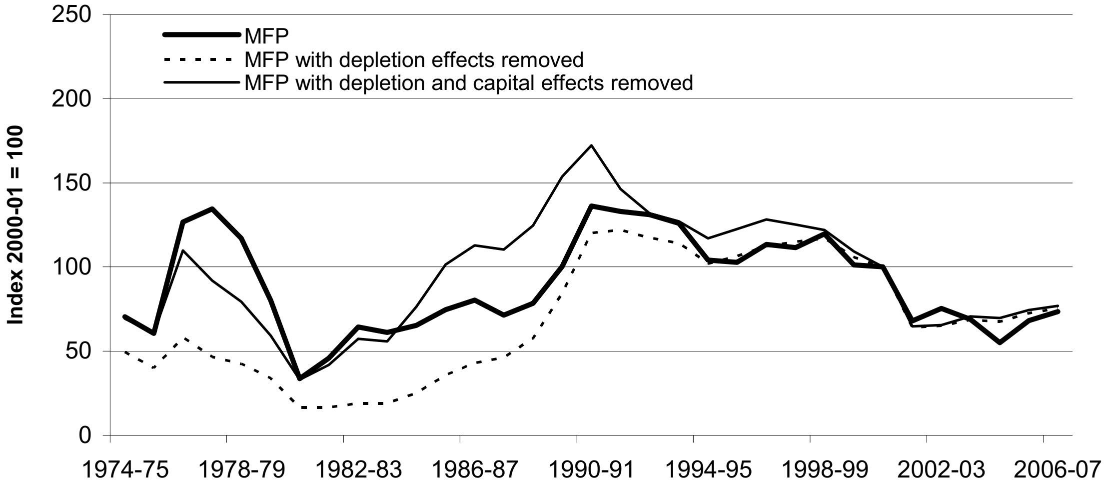


Data source: Authors' estimates.

Gold production and gold productivity increased substantially during the 1980s with the adoption of the carbon in pulp technology, which allowed production from lower concentration ore bodies, and with the discovery of new, large deposits. After peaking in 1990-91 however, MFP in gold ore mining began to trend downward as production growth first slowed and then reversed. The average grade of gold ore has been largely unchanged since 1990-91 however, meaning that the decline in MFP must have been caused by other factors.

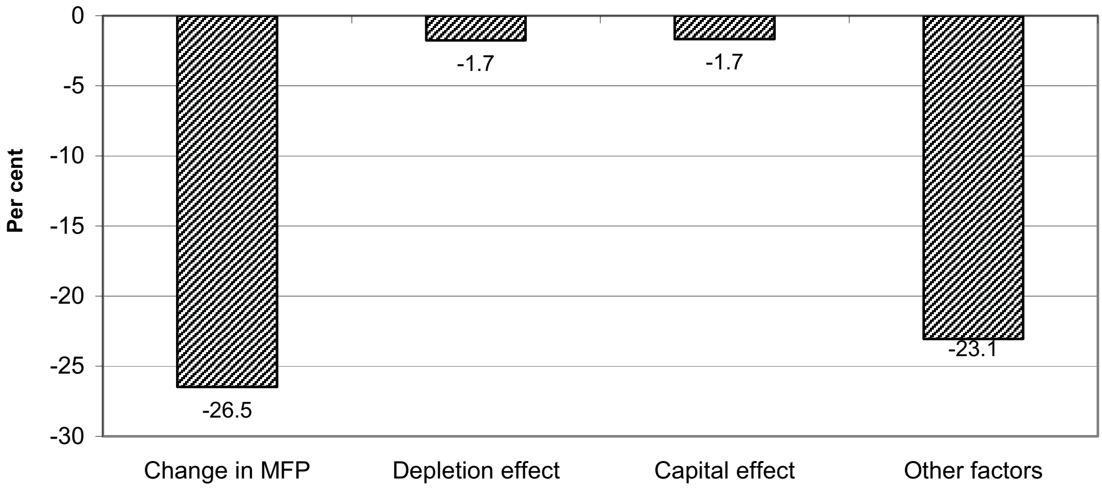
Unlike many other mining industries, recent changes in MFP in gold ore mining are *not* due to the (temporary) effects of investment in new capacity leading output changes (figures A.20 and A.21).

Figure A.20 **Gold ore mining MFP: Impact of resource depletion and capital effects**



Data source: Authors' estimates.

Figure A.21 **Gold ore mining: Contributions to MFP changes, 2000-01 to 2006-07**



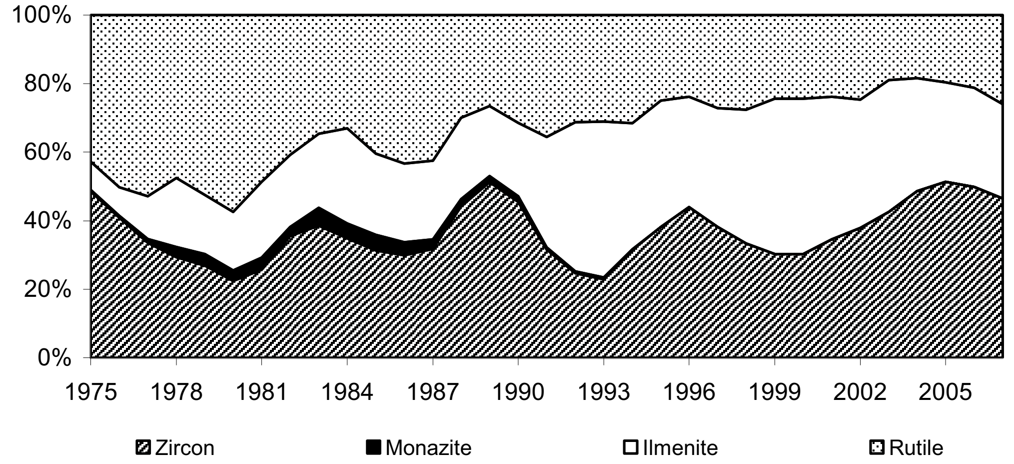
Data source: Authors' estimates.

A.8 Mineral sands mining

Heavy mineral sands — mainly ilmenite, rutile and zircon — have been mined in Australia since the 1930s. Ilmenite and rutile contain titanium dioxide, which is used to make pigment for paint and concentrates. Ilmenite is also converted into synthetic rutile. Zircon has a wide range of diverse uses. Mineral sands are mined in

New South Wales, Queensland, Victoria and West Australia. The gross value of production of mineral sands commodities is distributed roughly evenly between the three main commodities (figure A.22)

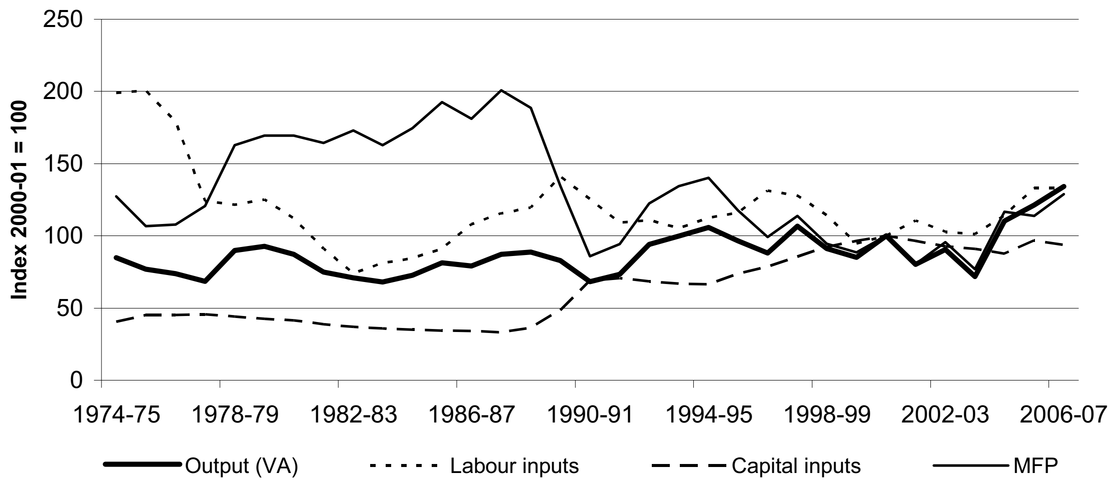
Figure A.22 **Gross value of production shares within mineral sands mining, 1974-75 to 2006-07**



Data sources: Authors' estimates using data from ABARE (*Australian Commodity Statistics* 2007); ABARE (*Australian Mineral Statistics* June 2008).

The mineral sands sector is one of the smaller mining industries, accounting for less than 1 per cent of mining value added in 2006-07 (figure A.23).

Figure A.23 **Mineral sand mining: Inputs, outputs and MFP**

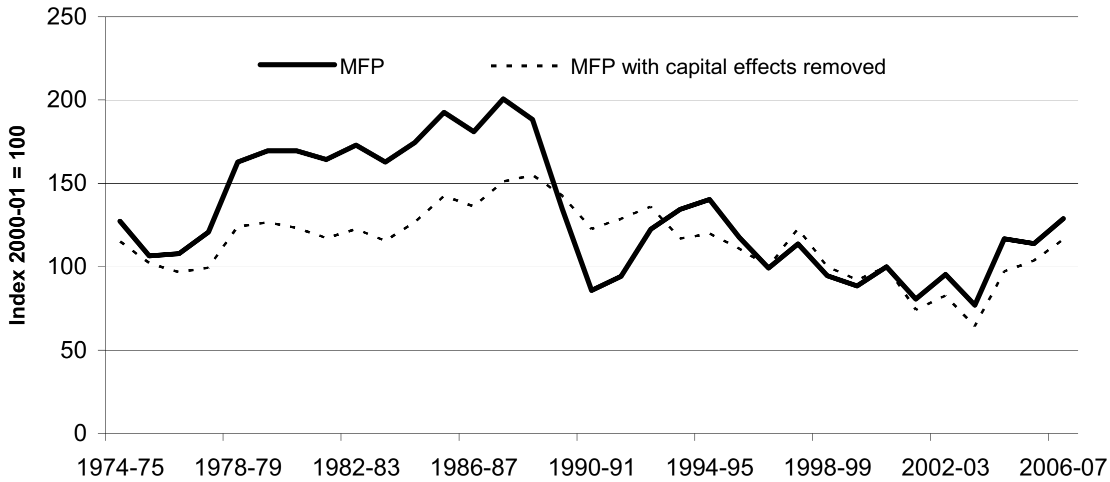


Data source: Authors' estimates.

As a comparatively small mining industry, caveats regarding the accuracy of MFP estimates based on disaggregated ABS mining statistics are particularly relevant for the mineral sands industry — hence the focus is on broad trends over time, rather than year on year changes.

A notable feature of measured MFP in the mineral sands sector is the sharp decline in measured productivity in the late 1980s/early 1990s, which was the result of capital deepening and a decline in output. However, a major contributor to the decline in MFP was the effect of a surge in new investment in the sector from 1988-89 to 1990-91 (figure A.24). After removing the effects of investment cycles, MFP in the sector is much less variable over time, and the sharp decline and recovery in MFP is no longer apparent. The sector is nevertheless characterised by a long period of declining MFP however, which runs from the late 1980s to 2003-04, at which point MFP rebounds on the back of strong growth in production.

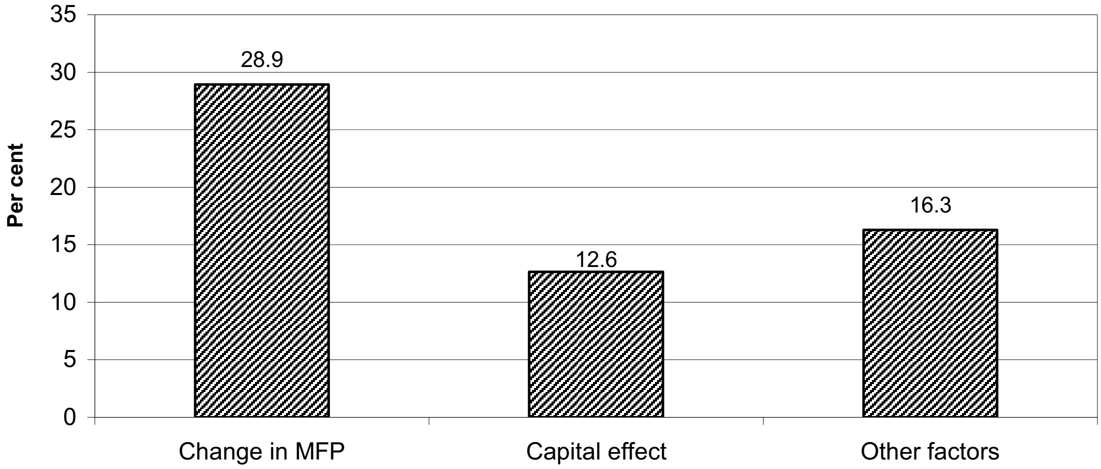
Figure A.24 **Mineral sands mining: Impact of resource depletion and capital effects**



Data source: Authors' estimates.

Apart from a major increase in new investment in the sector in 2005-06, the period from 2000-01 to 2006-7 was characterised by fairly sluggish investment in new capacity. This is consistent with the fact that prices for mineral sands commodities have fallen (in real terms) since 2001-02, rather than risen. As was the case for copper ore mining, a slowdown in new investment made a positive contribution to the change in MFP between 2000-01 and 2006-07 (figure A.25).

Figure A.25 **Mineral sands mining: Contributions to MFP changes, 2000-01 to 2006-07**



Data source: Authors' estimates.

Data on the extent of resource depletion in mineral sands mining is patchy and generally unavailable, particularly in relation to changes in the average grade of ore over time. Hence, no attempt has been made to measure the extent to which ore grade changes may have contributed to changes in MFP in the sector over time.

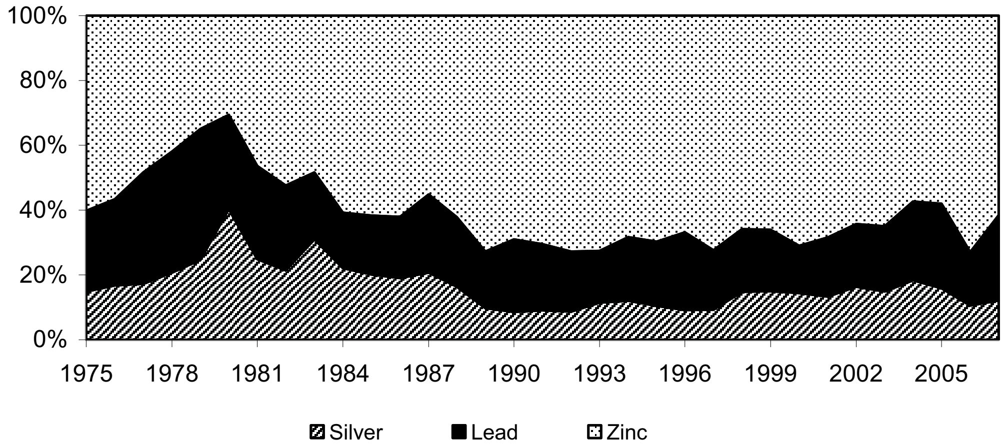
However, anecdotal and other evidence supports the theory that depletion is having a detrimental effect on mineral sands mining productivity. Lee (2001) states that declining ore grades and more complex mineralogy are increasing the cost and effort that must go into mine design. In addition, while exploration has found more reserves of zircon and ilmenite, Australia's reserves of rutile have remained relatively static.

A.9 Silver-lead-zinc ore mining

Silver, lead and zinc are typically mined as co-products from silver-lead-zinc ores, copper-zinc-lead ores, or lead-zinc-copper-silver-gold ores. Lead and silver mining have a long history in Australia, commencing as a major industry with the mining at Broken Hill in 1883. The other well known silver-lead-zinc project is Mount Isa in northern Queensland. Silver is used primarily in jewellery and film, lead for a variety of purposes, and zinc mainly for anti-rust coatings.

In the early years of silver-lead-zinc mining, zinc was considered a useless by-product, and was generally discharged into tailings dumps. Now it is the most important mineral by GVP share, especially in recent years as the price has increased dramatically (figure A.26). Conversely, lead's significance has diminished through time. This should not be confused, however, with the lead concentrate that is sintered as part of the production process (to crude lead) with a high silver content. Strong growth in zinc and lead prices in recent years has led to an increase in the share of total mining value added that is accounted for by the silver-lead-zinc sector.

Figure A.26 **Gross value of production shares within silver-lead-zinc ore mining**

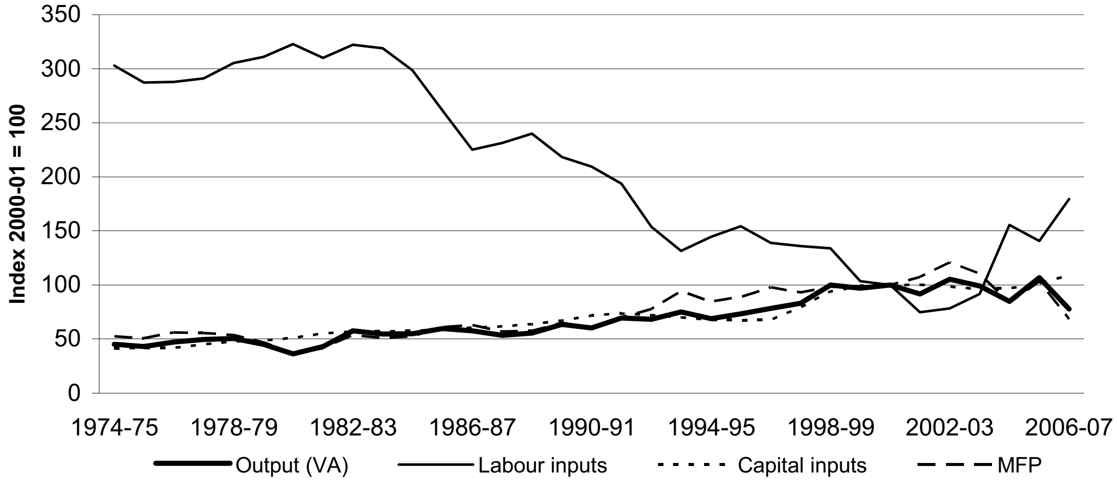


Data source: Authors' estimates using data from ABARE (*Australian Commodity Statistics* 2007).

As with the 'other metal ores' sub-sector, it appears as though trends in MFP in the silver-lead-zinc sector have been affected by changes in the amount of labour inputs (figure A.27). It should also be noted that silver-lead-zinc mining has not suffered as severe productivity declines as other parts of the mining industry. Moreover, over the period for which data are available, MFP growth in the sector has been comparatively strong, averaging 0.8 per cent per year.

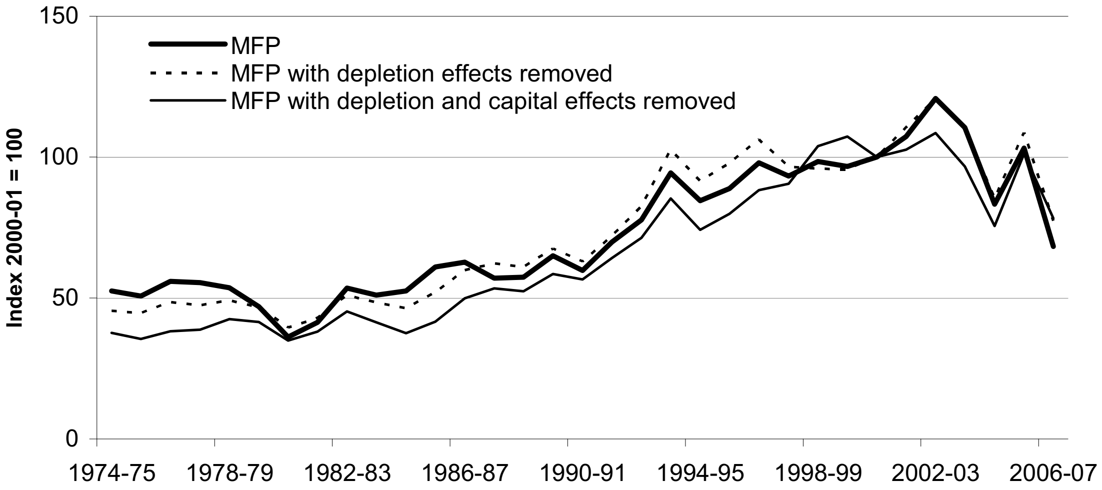
The effects of depletion and lagged capital investment have not, however, been as significant in the silver-lead-zinc mining sector compared to other mining commodities (figure A.28).

Figure A.27 **Silver-lead-zinc ore mining: Inputs, outputs and MFP**



Data source: Authors' estimates.

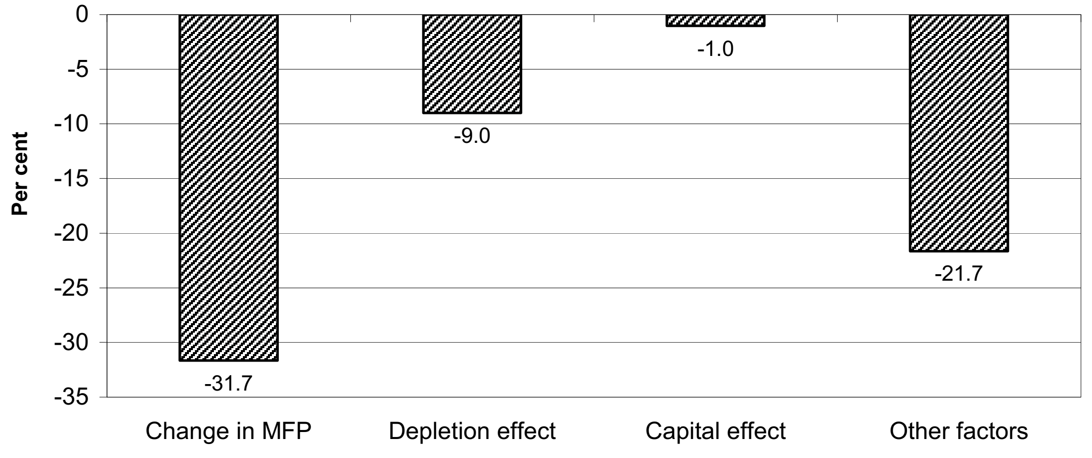
Figure A.28 **Silver-lead-zinc ore mining: Depletion and lagged capital effects**



Data source: Authors' estimates.

One of Australia's older mining industries, silver-lead-zinc mining has seen declining ore grades in recent decades, albeit to different degrees for different metals (see section 3.3 in chapter 3). While zinc has not had a noticeable decline in average ore grade over the past forty years, both silver and lead ore grades have been falling, on average, over the period. Nevertheless, the effect of declining ore grades in silver-lead-zinc mining does not contribute significantly to the longer term trend in MFP in the sector, and does not appear to be a major factor influencing MFP changes after 2000-01. While prices for silver, lead and zinc have, on average, risen significantly in 2005-06 and 2006-07, there has not been a dramatic increase in new investment in the sector. Hence the issue of long lead times in new mining developments does not appear to be a significant factor in explaining recent movements in MFP in the sector either (figure A.29).

Figure A.29 **Silver-lead-zinc ore mining: Contributions to MFP changes, 2000-01 to 2006-07**



Data source: Authors' estimates.

B Methodology and data

B.1 Introduction

Estimates of multifactor productivity for eight mining sub-industries presented in this report are generated using an updated version of a model developed by Gretton and Fisher (1997). The model is based on the neoclassical growth model formulated by Swan (1956) and Solow (1956), and is concerned with tracing out the growth in output relative to the growth in inputs to production, thereby identifying productivity improvements associated with the use of those inputs.

This appendix contains a brief description of the model used to estimate multifactor productivity, and a description of the data and data sources.

B.2 The basic model

A standard approach to studying the productivity of labour and capital in production begins with an aggregate production function of the form:

$$Y = Af(K, L) \qquad \text{(B1)}$$

where Y is output measured in terms of value added and K and L are measures of capital and labour inputs, f is a constant returns to scale function of factor inputs K and L that defines the level of output in year t, given the conditions and technology in the base period, and A is a productivity shift term reflecting influences such as technical change, unmeasured changes in the quality of labour and capital and the intensity with which capital and labour are used.

For any industry, (B1) can be written in percentage changes as:

$$y = a + s_k k + (1 - s_k)l \qquad \text{(B2)}$$

where y, a, k and l are the percentage changes in Y, A, K, and L, respectively, and s_k is the elasticity of Y with respect to K. Assuming:

- constant returns to scale (since s_k plus $(1\text{-}s_k)$ sum to one); and

- capital and labour are paid according to their marginal products, s_k is the capital share in the value of output.

Multifactor productivity (MFP) is equivalent to '*a*' in equation B2, and is therefore defined to be:

$$MFP = y - s_k k - (1 - s_k)l$$

Additional technical details about the growth model and its application to the estimation of capital inputs can be found in Gretton and Fisher (1997, appendixes C and D).

B.3 Data sources

As noted by Gretton and Fisher (1997), the information necessary to undertake an analysis of productivity growth in the various sub-divisions or classes within the mining industry is not available from a single source, although much of the required data are available from Australian Bureau of Statistics publications 8415.0 and 8414.0. Another important source of the data used to prepare the productivity estimates reported in this study is the Australian Bureau of Agricultural and Resource Economics (ABARE), particularly their annual compendium of statistics – *Australian Commodity Statistics*.

A difference between the earlier analysis of productivity in key industries within the mining industry conducted by the Productivity Commission is that estimates are only reported for eight sub-divisions or classes within the mining industry rather than nine. Changes to the ABS survey reporting mean that separate productivity estimates are no longer available for 'Bauxite mining' (ANZIC class 1312). In this study, the category 'Other metal ore mining' now incorporates the bauxite mining sector.

As with the earlier study, there are a number of industry classifications within the mining industry as a whole that are not covered in this study. The most important of these in terms of output shares is 'Services to mining', which generally accounts for around 6 per cent of mining industry value added. Services to mining differs from the other mining classes in that a significant component of output is exploration and exploration support activities, as opposed to mining per se. The other sectors that are not considered in this study are 'Construction materials', which includes sand and gravel mining, and 'Mining nec', which includes salt mining and non-metallic mineral mining. Collectively the latter two sectors account for around 3 per cent of mining value added.

The key variables and parameters used in the construction of the MFP series for each subdivision or class are as follows:

Gross output at current prices by mining industry is measured as the value of sales plus increase in stocks of finished goods plus other operating revenue of mining industry production units (or establishments). Gross output is net of the indirect taxes that are included in measures valued at market prices, and is generally preferred to market price measures for productivity studies. The components of gross output at current prices by mining industry were obtained from ABS mining industry statistics (see ABS Cat. nos. 8414.0 and 8415.0).

Gross output at average 1989-90 prices for each mining industry was provided by the ABS for the years 1985-86 to 1994-95. For 1984-85 and earlier, gross output at 1989-90 reference prices was derived by deflating current price data using industry specific implicit output-price (current-period weighted) deflator information referenced to 1989-90 and provided by the ABS. For 1995-96 to 2006-07, gross output at constant prices was derived by deflating current price estimates using an implicit price deflator obtained by dividing current price gross output by the quantity of output, where quantity of output was equal to measured commodity production for each mining industry, as sourced from ABARE (*Australian Commodity Statistics* — various issues). For industries comprising multiple sub-industries (for example, the oil and gas sector), the quantity of output was estimated using a divisia index of the individual outputs with weights based on gross value of production shares.

Purchases of material and services at current prices by mining industry were estimated from cost information obtained from the annual mining industry census plus business expenses (including land tax, rates and payroll tax, travelling expenses, accounting and legal expenses, insurance premiums, advertising and bank charges) derived from industry of enterprise statistics (see ABS Cat. nos. 8414.0 and 8415.0). Information on business expenses was available for the years 1990-91 to 1994-95 for the industries black coal mining, oil and gas extraction and metallic mineral mining. The series were completed by allocating the relevant data across establishment industries and across years on the basis of relative wages and salaries.

Purchases of materials and services at average 1989-90 prices were obtained from the ABS for the years 1985-86 to 1994-95. For 1984-85 and earlier years, purchases at 1989-90 reference prices were derived using implicit input-price deflator information provided by the ABS. Separate price information was available for the input categories: purchases of materials, electricity and fuels, and other goods for resale; charges for processing or other commission work, and payments to mining contractors; outward freight and cartage and motor vehicle running expenses; rent, leasing and hiring expenses, and changes in stocks of materials and other supplies.

Business expenses information was deflated using the implicit price deflator for gross domestic product. For the period from 1995-96 to 2006-07, purchases at 1989-90 reference prices were obtained by deflating current price estimates using an index of mining input prices published by the ABS (Cat. no. 6427.0, Table 21 Coal mining: materials used).

Value added (at current prices) was estimated directly as the difference between gross output at current prices and purchases of materials and services at current prices.

Value added (at constant prices) was calculated directly as the difference between gross output at constant prices and purchases of materials and services at constant prices.

Employment is used as the measure of labour inputs in the current study.[1] It is measured as the number of working proprietors and employees on the payroll, including those working at separately located administrative offices and ancillary units at 30 June. The number of persons employed was obtained from the ABS census of mining (see ABS Cat. nos. 8414.0 and 8415.0).

Capital capacity is estimated using a generalised perpetual inventory method (PIM). The detailed estimation method (ie the generalised logistical method) is described in Gretton and Fisher (1997, Appendix C). The method uses annual expenditure on machinery and equipment (including motor vehicles and other plant and machinery) and non-dwelling construction (including buildings, other structures and mine development) by industry, and obtained on an annual basis from ABS Cat. nos. 8414.0 and 8415.0). For more details regarding the PIM and the specific assumptions used regarding asset lives and the asset retirement function see Productivity Commission (1999).

Indexes of capital-good prices for machinery and equipment and non-dwelling construction were used to convert current price investment to constant 1989–90 prices, and were obtained from ABS Cat. no. 5206.0, National Income, Expenditure and Product (as extracted from the ABS dX data base system, August, 2008).

Separate measures of capital capacity of equipment and construction were estimated. These estimates were weighted together to form a composite measure of capital capacity for each industry using average relative rental prices, where the rental price is defined, without time or industry subscripts, as:

[1] Labour inputs for productivity studies are conventionally measured by the number of hours worked by persons employed in each industry. For individual mining industries, hours worked information is not available.

$$p = q(r + \delta) - \dot{q} \tag{B5}$$

where p is the rental price of capital, q is the expected price of a unit of capital, r is the nominal rate of return, δ is the rate of depreciation and $\dot{q}$ is the expected change in the price of the capital good over the period. In this framework, the expected rental price of a unit of capital for production in a period is equal to the depreciation in the value of the asset over the period due to its use in production, returns to management net of depreciation, less any revaluation of the nominal value of the asset due to inflation or other price changes.

The expected value is first approximated by reference to actual flows in any one year (that is, the ex post rental price). To avoid negative average relative rental price weights due to large annual fluctuations in the fortunes of mining industries, the rental price values were averaged over the period 1968-69 to 2006-07. This longer term averaging in turn, avoids measuring capital as a negative input to production when period-specific rental prices are negative.

Labour and capital input shares by mining industry are used to weight labour and capital inputs together for the calculation of multifactor productivity. The individual shares are estimated by dividing the relevant current price series by the level of value added at current prices. The cost of labour was estimated as wages and salaries from the industry census plus superannuation and workers compensation payments by industry of enterprise. Information on superannuation payments was available for the years 1990-91 to 1994-95 for the industries black coal mining, oil and gas extraction and metallic mineral mining. The series were completed by allocating the relevant data across establishment industries and across years on the basis of relative wages and salaries. Payments to capital including depreciation (ie gross operating surplus) were estimated by deducting payments to labour from value added at current prices.

C Estimating the contribution of yield changes to mining MFP

This appendix contains a description of the methodology used to derive estimates of the extent to which changes in 'yield' – ore grades in metal mining, the saleable to raw coal ratio in coal mining, and the implicit rate of oil and gas flow in oil and gas extraction – contribute to year on year changes in multifactor productivity (MFP).

It is assumed that the contribution of yield changes to MFP can be calculated directly by measuring the extent to which gross output changes are attributable to changes in yield alone. For example, if the average ore grade in a metal mining industry falls from one year to the next, the contribution of the yield decline to the change in gross output can be measured directly. However, the output measure used in MFP studies is real value added (gross output less intermediate inputs), and hence the effect of a yield change on value added is also influenced by the relative size of intermediate inputs. As a result, the calculation of the extent to which yield changes contribute to MFP changes involves first estimating the extent to which yield changes influence changes in value added.

The formula used to measure the extent to which yield changes affect MFP is derived below. Note that yield effects are estimated separately for each of the eight mining subdivisions or classes analysed in this study, as well as for the ABS mining industry classification as a whole. Each parameter therefore has two subscripts: *i*, indicating mining subdivision or class, or the mining industry as a whole; and *t*,., designating the time period measured in fiscal years. Thus for $i \in \{1,2,...,9\}$ where 1 represents coal mining, 2 oil and gas extraction and so on with 9 representing the ABS classification in its entirety. The time subscript runs from 1974-75 to 2006-07.

Define Y_{it} as gross output (that is, metal content in metal ore mining, saleable coal in coal mining, crude, condensate, LPG, and LNG in the oil and gas extraction sector) of industry *i* at time *t*, which is equal to $s_{it}\gamma_{it}$, where:

s_{it} = Raw production (for example, ore production in metal mining, raw coal production in coal mining, and the amount of time spent extracting oil & gas in the oil and gas sector) for industry *i* at time *t*.

γ_{it} = Yield (ore grade/saleable to raw coal ratio/oil & gas flow rate) for industry i at time t.

J_{it} = Intermediate inputs for industry i at time t.

I_{it} = Labour and capital inputs of industry i at time t.

VA_{it} = Value added $= Y_{it} - J_{it}$

$MFP_{it} = \frac{Y_{it} - J_{it}}{I_{it}} \equiv \left[\frac{s_{it}\gamma_{it} - J_{it}}{I_{it}}\right]$ = Multifactor productivity of industry i in period t.

We define multifactor productivity exclusive of resource depletion (yield) effects to be:

$$M\hat{F}P_{it} = \frac{s_{it} - J_{it}}{I_{it}}$$

that is, set $\gamma_{it} = 1$ for all t to represent no depletion effect.

Therefore,

$$\frac{M\hat{F}P_{it}}{MFP_{it}} = \frac{(s_{it} - J_{it})}{(s_{it}\gamma_{it} - J_{it})}$$

$$M\hat{F}P_{it} = MFP_{it} \cdot \frac{(s_{it} - J_{it})}{(s_{it}\gamma_{it} - J_{it})}$$

$$or,$$

$$M\hat{F}P_{it} = MFP_{it} \cdot \frac{(Y_{it} - J_{it}\gamma_{it})}{(Y_{it} - J_{it})\gamma_{it}}$$

Hence, changes in the ratio $\frac{Y_{it} - J_{it}\gamma_{it}}{(Y_{it} - J_{it})\gamma_{it}}$ over time indicate the extent to which MFP changes over time as a consequence of changes in average yields. Decreases in the average yield over time imply that $\frac{Y_{it} - J_{it}\gamma_{it}}{(Y_{it} - J_{it})\gamma_{it}}$ will be increasing over time (ceteris paribus), and $M\hat{F}P_{it}$ growth will be greater than MFP_{it} growth, and conversely.

References

Arsenault, J. and Sharpe, A. 2008, ‘An Analysis of the Causes of Weak Labour Productivity Growth in Canada since 2000’, *International Productivity Monitor*, vol. 18, Spring issue, pp: 14–39, Centre for the Study of Living Standards Ottawa, Canada.

Australian Bureau of Agricultural and Resource Economics (ABARE) 2006, *Australian Commodity Statistics*, Canberra.

—— 2007, *Australian Commodity Statistics,* Canberra.

—— 2008a, *Australian Commodities Statistics*, vol. 15, no. 1, March quarter, Canberra.

—— 2008b, *Australian Commodities Statistics*, vol. 15, no. 2, June quarter, Canberra.

—— 2008c, *Energy in Australia,* Canberra.

Australian Bureau of Statistics (ABS) 2006, *Australian System of National Accounts: Concepts Sources and Methods*, Cat. no. 5216.0, Canberra.

Australian Mines and Metals Association (AMMA), 2004, *Mine Safety Review 2004 Submission*, Sydney, http://www.amma.org.au/publications/AMMAsubmission_minesafetyreview2004.pdf (accessed 2 December 2008).

Australian Petroleum Production and Exploration Association (APPEA), 2007, *Key Statistics 2007,* http://www.appea.com.au (accessed 2 September 2008).

Beach, R., Brereton, D. and Cliff, D. 2003, *Workforce Turnover in FIFO Mining Operations in Australia: An Exploratory Study*, The Centre for Social Responsibility in Mining, Sustainable Minerals Institute, University of Queensland, http://www.csrm.uq.edu.au/docs/TURN_FINAL.pdf (accessed on 25 July 2008).

BHPB 2006, *BHP Billiton Interim Results*,**.** http://www.bhpbilliton.com/bbContentRepository/Reports/PPADecember05.pdf (accessed 15 July 2008).

Bohi, D.R. 1998, ‘Changing Productivity in U.S. Petroleum Exploration and Development’, Discussion Paper 98-38, *Resources for the Future*, June, Washington.

Chamber of Minerals and Energy Western Australia 2005, *Fly In/Fly Out: A Sustainability Perspective*, http://www.cmewa.com.au (accessed on 5 November 2008).

Close, S.E. 2004, *The Great Gold Renaissance: The Untold Story of the Modern Australian Gold Boom 1982-2002,* Surbiton Associates Pty Ltd.

CRCMining 2008, ‘Coal production program notes’, http://www.crcmining.com.au/dynamic_page.php?page_reset=1&page_id=147, (accessed 1 September 2008).

DCITA (Department of Communications, Information Technology and the Arts), 2006**,** *Forecasting productivity growth: 2004 to 2024*, Occasional Economic paper, March.

Department of Resources, Energy and Tourism, 2008, Australia’s Coal Infrastructure Developments, http://www.ret.gov.au/resources/mining/australian_mineral_commodities/Pages/australias_coal_infrastructure_developments.aspx, (accessed 29 October 2008).

Devarajan, S. and Fisher, A.C. 1981, ‘Hotelling's “Economics of Exhaustible Resources” Fifty Years Later’, *Journal of Economic Literature*, XIX, March, pp: 65–73.

Fairhead, L., Curtotti, R., Rumley, C. and Melanie, J. 2006, *Australia Coal Exports: Outlook to 2025 and the role of Infrastructure*, ABARE Research Report 06.15, Canberra, October.

FD Capital 2007, *The Nickel Sector: Metal and Equity Review*, Fox-Davies Capital, London, http://www.fox-davies.com (accessed 1 September 2008).

Fisher, B.S. and Rose, R. 2006, ‘Export infrastructure and access: key issues and progress’, *Australian Commodities Statistics*, vol. 13, no. 2, June quarter, pp: 366–97.

Fox, K.J., Grafton, R.Q., Kompas, T. and Che, T.N. 2006, ‘Capacity reduction, quota trading and productivity: the case of a fishery’, *The Australian Journal of Agricultural and Resource Economics*, vol. 50, no. 2, June, pp: 189-206.

Garton, P. 2008, ‘The resources boom and the two-speed economy’, *Economic Roundup*, Issue 3, pp: 17-29.

Grafton, Q., Kirkley, J., Kompas, T. and Squires, D. 2006, *Economics for Fisheries Management*, Ashgate Publishing Ltd.

Gretton, P. and Fisher, B. 1997, *Productivity Growth and Australian Manufacturing Industry*, Industry Commission Staff Research Paper, AGPS, Canberra.

Gruen, D. and Kennedy, S. 2006. *Reflections on the Global Economy and the Australian Mining Boom*, Keynote address to the Australian Business Economists forecasting conference, 11 October.

Hartman, H.L. and Murmansky, J.M. 2002, *Introductory Mining Engineering*, John Wiley and Sons, New Jersey, United States of America.

Heiler, K. and Pickersgill, R. 2001, 'Shiftwork and Rostering Arrangements in the Australian Mining Industry: An Overview of Key Trends', *Australian Bulletin of Labour*, vol. 27, no. 1, March.

——, —— and Briggs, C. 2000, *Working Time arrangements in the Australian Mining Industry: trends and implications with particular reference to OH&S*, October, ILO Geneva.

Hogan, L., Harman, J., Maritz, A., Thorpe, L., Simms, A., Berry, P. and Copeland, A. 2002, 'Mineral Exploration in Australia: Trends, Economic Impacts and Policy Issues', A*BARE eReport 02.1*, Canberra, December.

Hotelling, H. 1931, 'The Economics of Exhaustible Resources', *The Journal of Political Economy,* vol. XXXIX, pp. 137–175.

Kokic, P., Davidson, A. and Boero Rodriguez, V. 2006, *Australian Grains Industry: Factors Influencing Productivity Growth*, ABARE Research Report 06.22 Prepared for the Grains Research and Development Corporation, Canberra, November.

Lasserre, P. and Ouellette, P. 1988, 'On measuring and comparing total factor productivities in extractive and non-extractive sectors, *Canadian Journal of Economics*, vol. XXI, no. 4, November.

Lee, G. 2001, *Mineral Sands — Some Aspects of Evaluation, Resource Estimation and Reporting*, Mineral Resource and Ore Reserve Estimation — The AusIMM Guide to good Practice (Ed. Edwards, A.C.), The Australian Institute of Mining and Metallurgy, pp: 315–321, Melbourne.

Managi, S., Opaluch, J.J., Jin, D., and Grigalunas, T.A. 2005, 'Stochastic frontier analysis of total factor productivity in the offshore oil and gas industry', *Ecological Economics,* vol. 60*,* pp. 204–215.

Mudd, G.M. 2007, *The Sustainability of Mining in Australia: Key Production Trends and Their Environmental Implications for the Future*, Research Report No. RR5, Department of Civil Engineering, Monash University and Mineral Policy Institute, October.

Neal, H.W., Bell, M.R.G., Hansen, C.A. and Siegfried II, R.W. 2007, *Oil and Gas Technology Development*, Topic Paper 26 of the National Petroleum Council Global Oil and Gas Study, http://www.npc.org (accessed 1 July 2008).

Norgate T. and Jahanshahi, S. 2006, *Energy and Greenhouse Gas Implications of Deteriorating Quality Ore Reserves*, CSIRO paper presented at the 5th Australian Conference on Life Cycle Assessment, Melbourne, 22-24 November.

O'Donnell, S. 2008, Goonyella Coal Chain Capacity Review — Second and Final Report. http://www.transport.qld.gov.au/resources/file/ebe0d705af5833c/Pdf_goonyella_coal_chain_capacity_review_final_full.pdf (accessed on 30 October 2008)

OECD 2002, *Structural Change and Growth: Trends and Policy Implications*, http://www.oecd.org/dataoecd/43/13/2087106.pdf (accessed on 1 September 2008).

Parham, D. 2005, 'Is Australia's Productivity Surge Over?', *Agenda*, vol. 12, no. 3, pp: 253–266.

—— and Wong, M-H. 2006, 'How strong is Australia's productivity performance?', Paper presented at the Productivity Perspectives Conference, 23 March, Canberra.

Pinnock, M. 1997, Productivity in Australian Coal Mines: How are we meeting the challenges?, *The Australian Coal Review*, July, http://www.australiancoal.csiro.au/pdfs/Pinnock.pdf (accessed on 3 November 2008.

Phillips, D. 2008, 'Cost of Offshore Drilling Rising as Fast as Oil Prices', http://www.industry.bnet.com/energy/100029/cost-of-offshore-drilling-rising-as-fast-as-oil-prices/ (accessed on 5 November 2008).

Productivity Commission (PC) 1999, 'Statistical Annex to Supplement to Inquiry Report: Modelling the Regional Impacts of National Competition Policy Reforms', *Impact of Competition Policy Reforms on Rural and Regional Australia*, Canberra, September.

—— 2004, *ICT Use and Productivity: A Synthesis from Studies of Australian Firms*, Commission Research Paper, Canberra.

Powell, T. 2008, *Discovering Australia's Future Petroleum Resources: The strategic geoscience information role of Government*, STIR Science Services, Canberra.

Raggatt, H.G. 1968, *Mountains of Ore: Mining and Minerals in Australia*. Lansdowne Press, Melbourne, Victoria.

Rawlings, C. D. 1997, 'Coal — the technological challenge', Paper presented to the Australian Academy of Technological Sciences and Engineering, Academy Symposium, November, http://www.atse.org.au. (accessed on 1 September 2008).

Reserve Bank of Australia, 2005, 'Commodity prices and the terms of trade', *Reserve Bank Bulletin*, April.

—— 2007, 'The recent rise in commodity prices: a long run perspective', *Reserve Bank Bulletin*, April 2007.

Rodriguez, X.A., and Arias, C. 2008, ‘The effects of resource depletion on coal mining productivity’, *Energy Economics,* vol. 30, pp: 397–408.

Schmitz, J.A. 2005. ‘What Determines Productivity? Lessons from the Dramatic Recovery of the U.S. and Canadian Iron Ore Industries following their Early 1980s Crisis’, *Journal of Political Economy*, vol. 113, no. 3, pp: 582–625.

Sibma, K. and Cusworth, N. 2006, ‘Western Australia’s Productivity Paradox’, *Western Australian Economic Summary*, no. 3, WA Department of Treasury and Finance, pp: 54–74.

Solow, R.M. 1956, ‘A Contribution to the Theory of Economic Growth’, *Quarterly Journal of Economics*, no. 70, pp: 65–94.

Stollery, K.R. 1985, ‘Productivity change in Canadian mining 1957-1979’, *Applied Economics,* vol. 17, pp: 543–558.

Swan, T.W. 1956, ‘Economic Growth and Capital Accumulation’, *Economic Record*, no. 32, pp: 332–361.

Tilton, J.E. 2003, ‘Assessing the Threat of Mineral Depletion’, *Minerals and Energy*, vol. 18, no.1 , pp: 33–42.

Tilton, J.E. and Landsberg, H.H. 1997, ‘Innovation, Productivity Growth, and the Survival of the U.S. Copper Industry’, Discussion Paper 97-41, *Resources for the Future*, September, Washington.

Victorian Department of Primary Industry (VDPI), 2008, *Production Data for the Gippsland Basin,* unpublished.

Wedge, T.A. 1973, ‘The effect of Changing Ore Grade on the Rates of Change in the Productivity of Canadian Mining Industries’, *The Canadian Mining and Metallurgical Bulletin*, vol. 66(), pp: 64–66.

WADOIR (Western Australia Department of Industry and Resources) 2008, *Production Data for the Carnarvon Basin*, unpublished.

Wilkinson, R. 2000, *Where God Never Trod*, Christopher Beck Books, Windsor, Australia.

Ye, Q. 2006, *Commodity Booms and their Impacts on the Western Australian Economy: The Iron Ore Case*, Economics Discussion/Working Paper No. 06-18, The University of Western Australia, Department of Economics.

Young, D. 1991, ‘Productivity and metal mining: evidence from copper-mining firms’, *Applied Economics*, vol. 23, pp: 1853–1859.

Young, M.F., Pease, J.D., Johnson, N.W. and Munro, P.D. 1997, ‘Developments in Milling Practice at the Lead/zinc Concentrator of Mount Isa Mines Limited from 1990’, AusIMM Sixth Mill Operators Conference, Madang, Papua New Guinea.