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.

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[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

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[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

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[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.

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[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

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[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).

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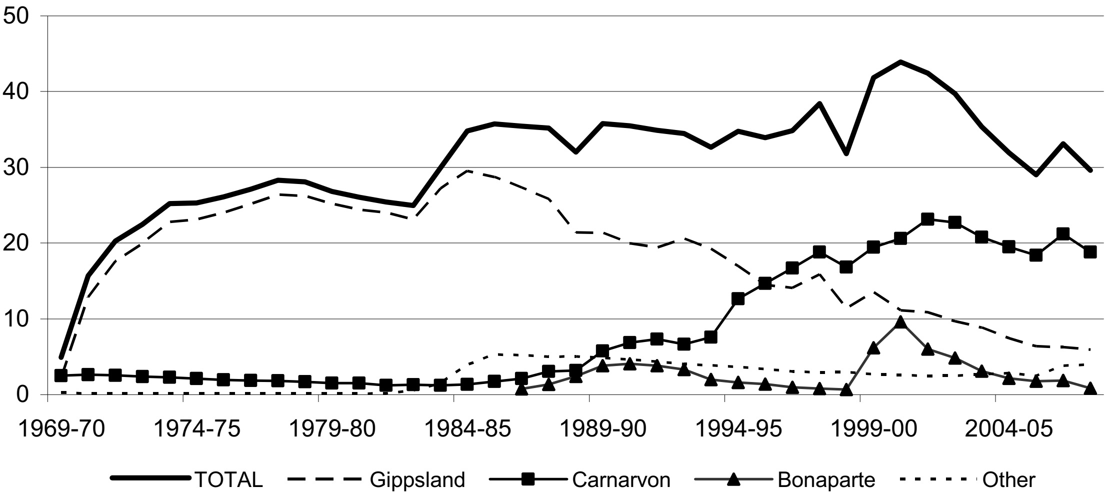
[6] The Hubbert Curve is most commonly applied to oil production, although in principle it should also apply to in-situ mineral commodities and other energy commodities like coal.

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

Billions of litres

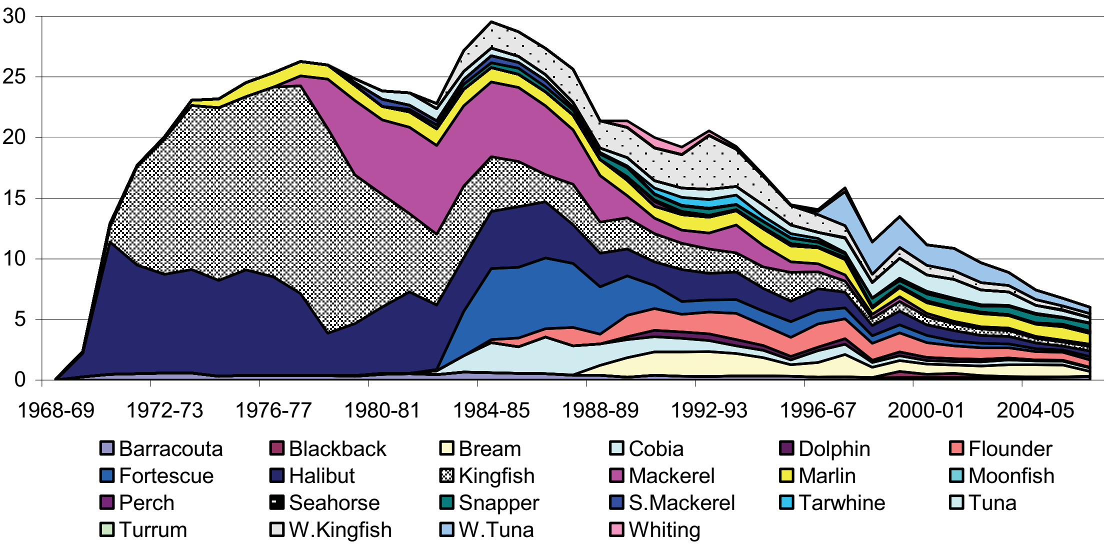


[a] Simple sum of crude oil, condensate and liquid petroleum gas (LPG). 'Other' represents all other production of crude oil, condensate or LPG in Australia.

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

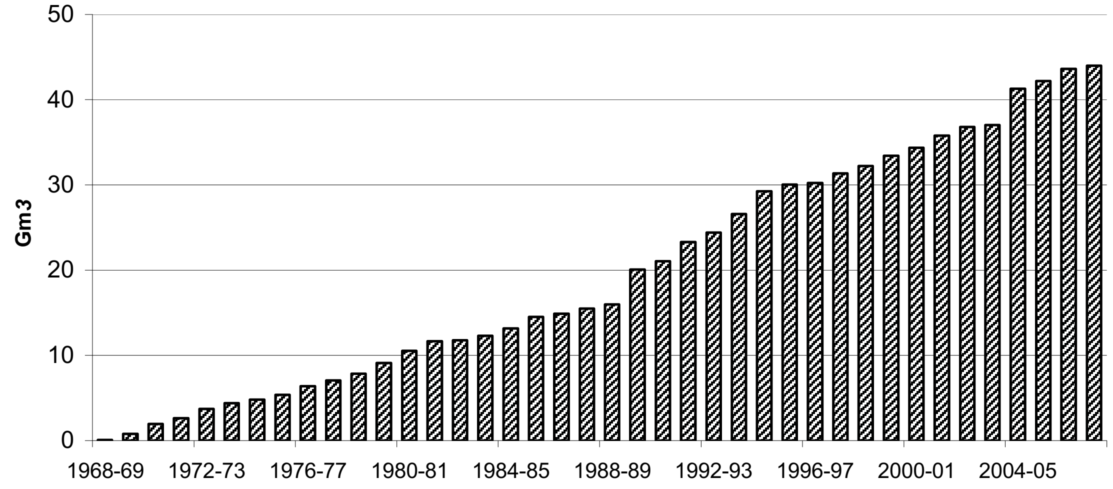
Figure 3.1 also helps to shed some light on the particularly rapid decline in oil and gas productivity since 2001. In the Gippsland basin oil production continued its long-term decline. Meanwhile, oil production in Carnarvon rose initially to peak in 2001-02, but then fell away quite quickly until 2005-06. 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

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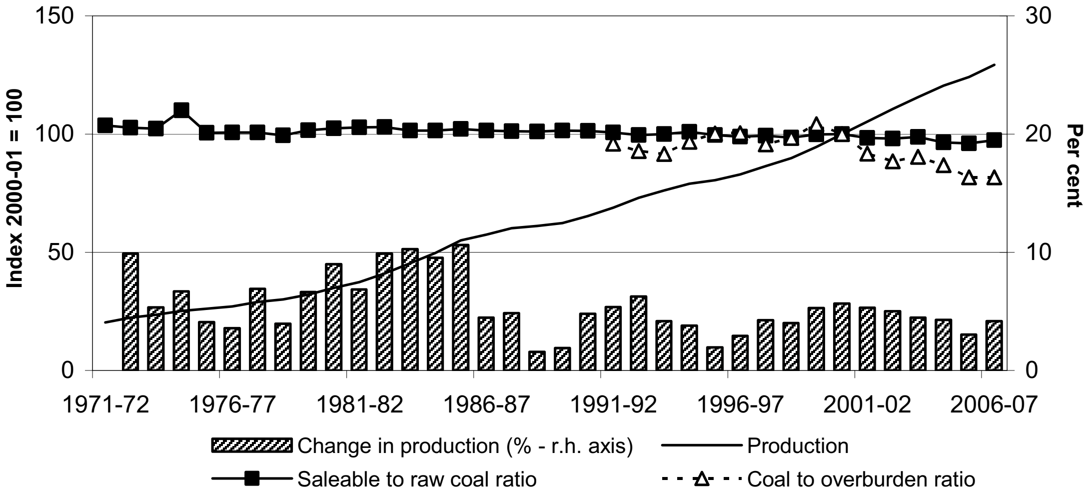
[7] Unfortunately, consistent and comprehensive national data on overburden production are not available, and time series data are limited to the past 14 years for Queensland only.

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.

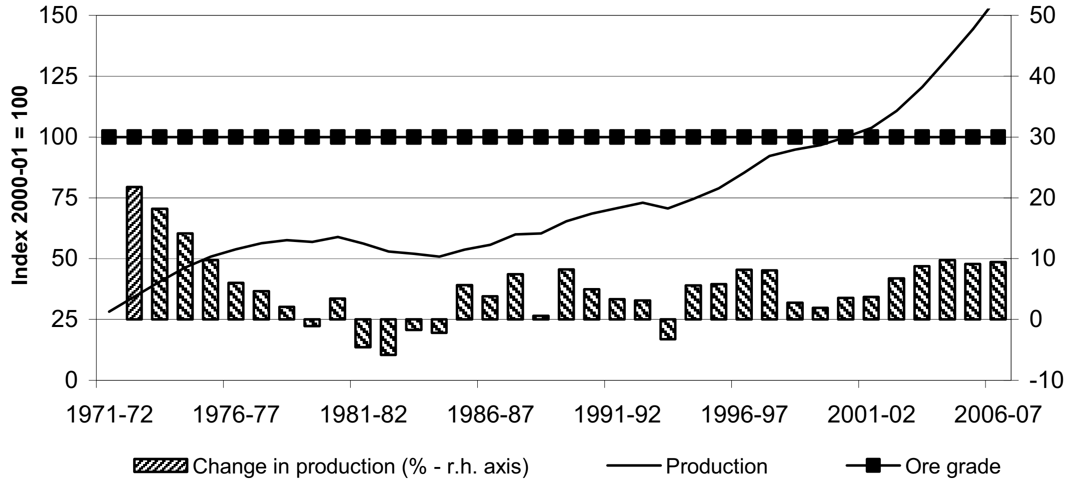
Data sources: Mudd (2007); ABARE (*Australian Commodity Statistics*, 2007).

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)

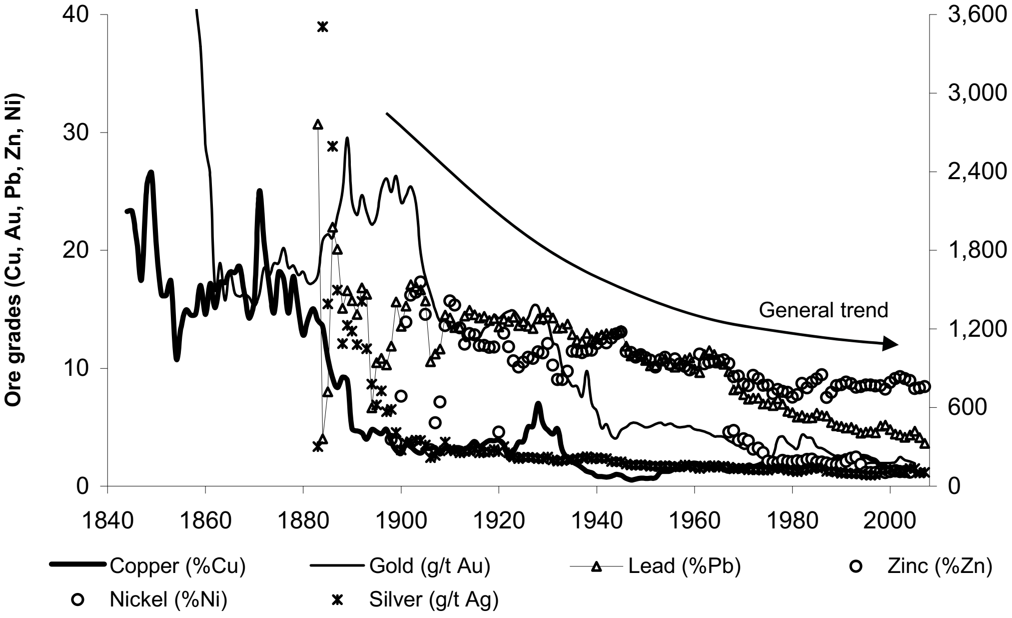
Nonetheless, Mudd contends that the issue of concern in iron ore mining is not so much the grade of as-mined iron ore, but the level of impurities and overall smelting characteristics of the ore. Like coal, most iron ore projects now include plants for improving the quality of iron ore in order to maintain 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**



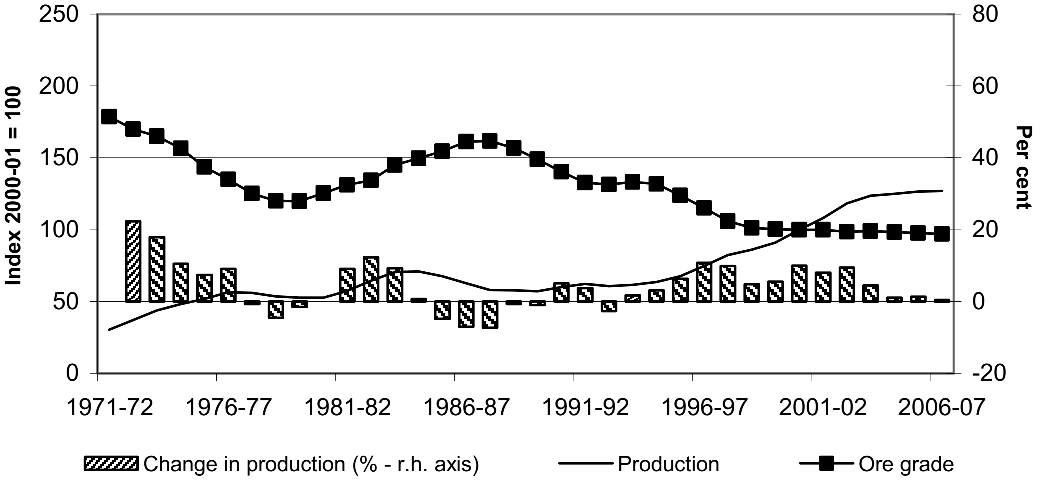
Data source: Adapted from Mudd (2007, p. 119).

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).

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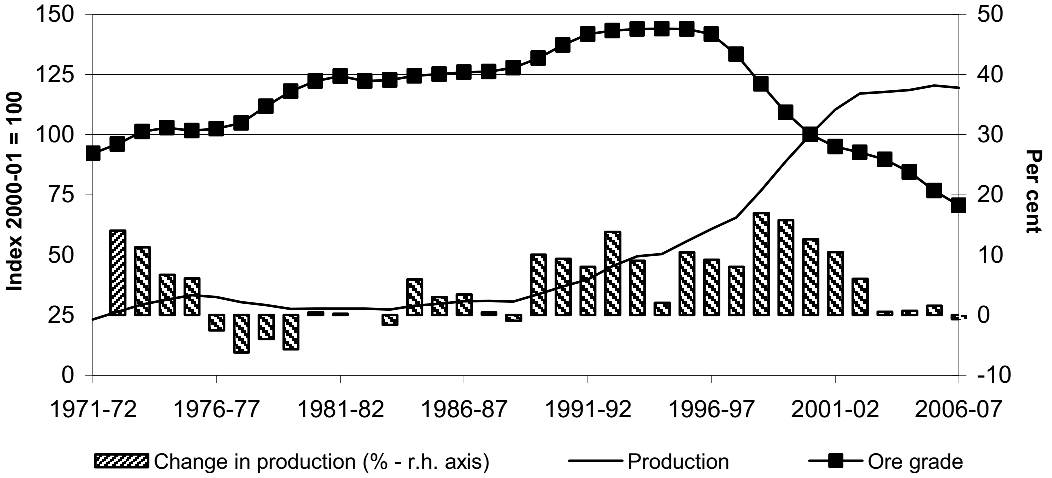
[8] This issue is explored further in chapter 5.

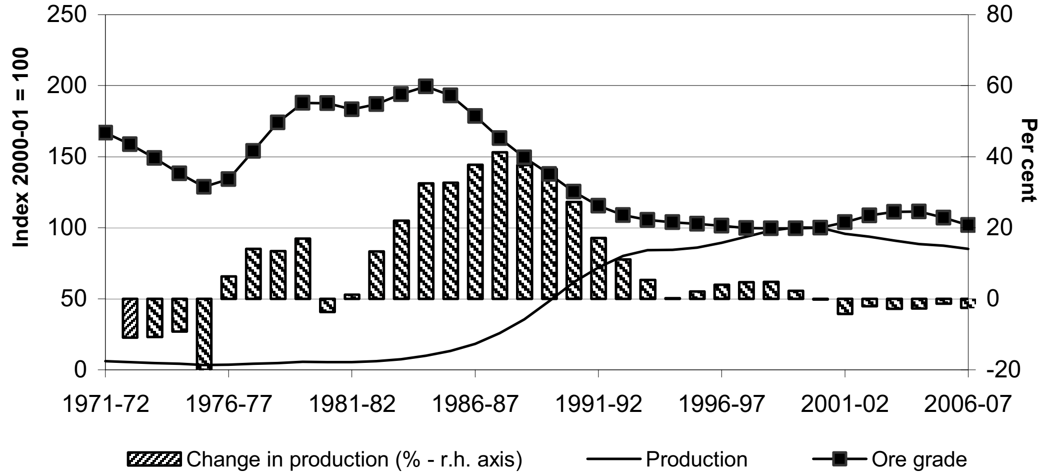
Figure 3.8 Copper ore mining: production and ore grade, 1971-72 to 2006-07



[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).

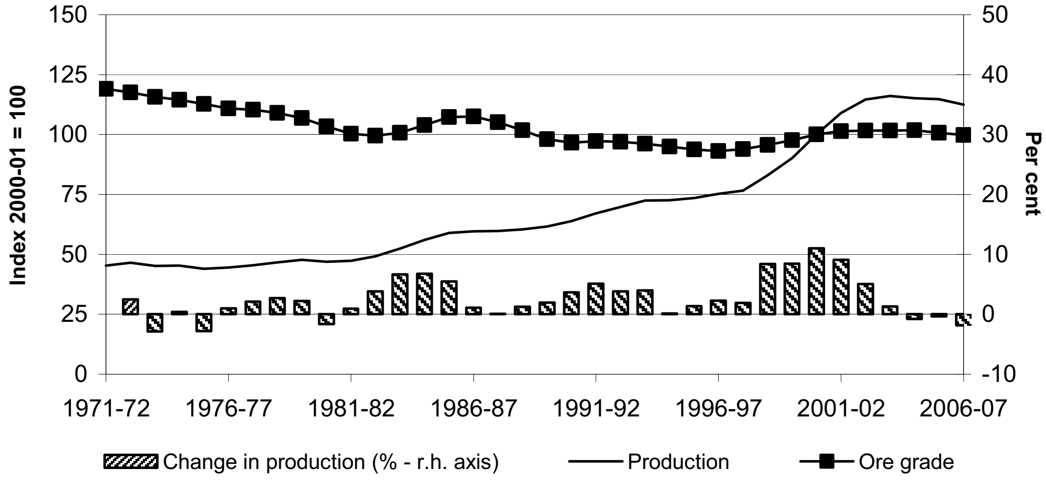
Figure 3.9 Gold ore mining: production and ore grade, 1971-72 to 2006-07



[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.

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[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.

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[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.

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[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

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

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.)

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[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.

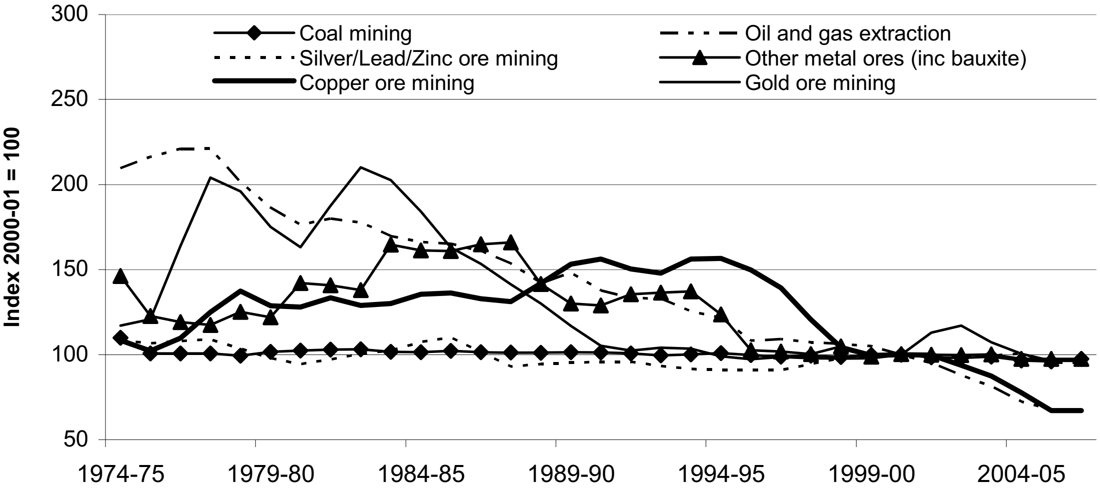
In the case of the oil and gas extraction sector, the imputed yield series is derived by calculating the year on year change in oil and gas production at each individual field (apart from fields in the Cooper- Eromanga basin, for which only aggregate data are available). The individual field changes 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.

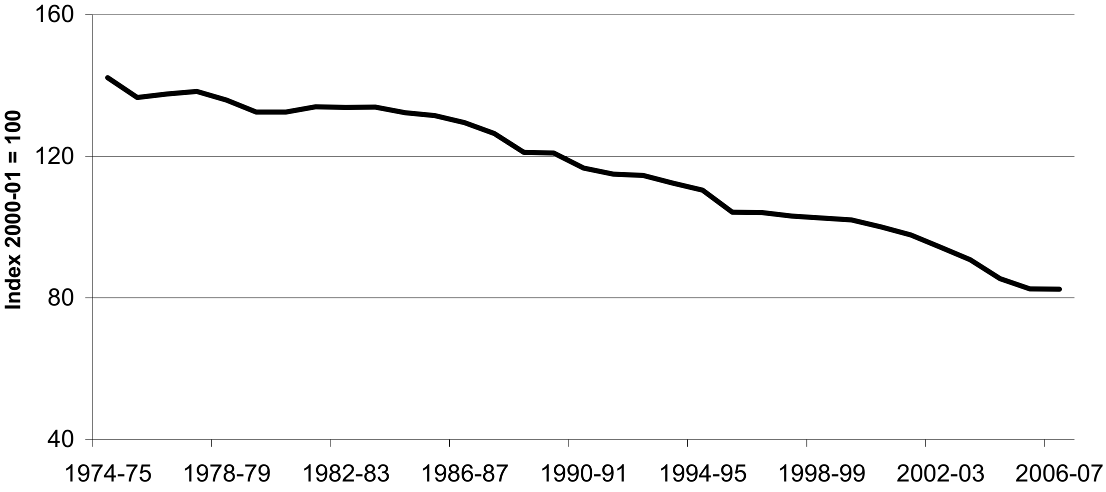
Figure 3.11 **Estimated yields in Australian mining, by industry**[a]



[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.

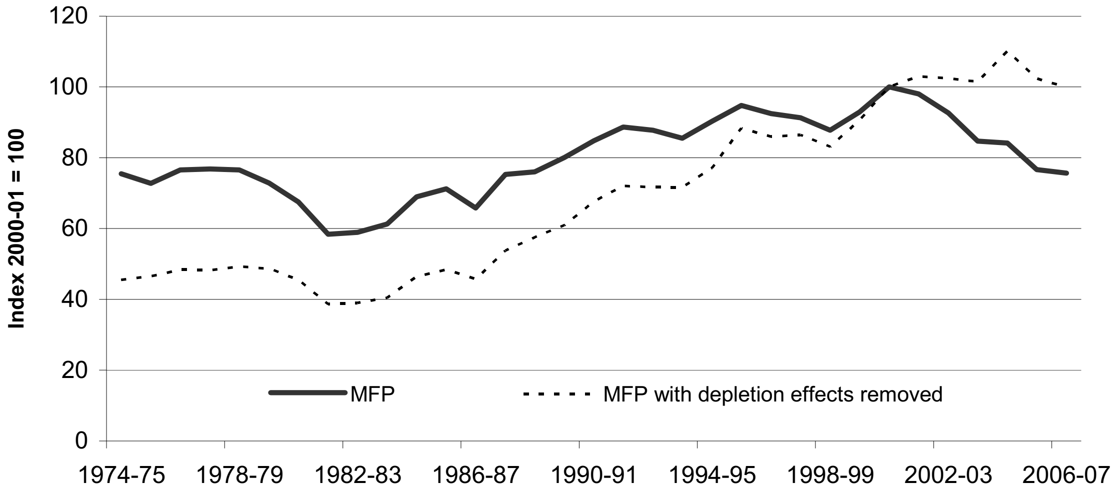
Where commodity production has fallen quickly and significantly — as has been the case since 2000-01 in the oil and gas sector in particular — it seems reasonable to assume that the change in total inputs observed from one year to the next over this period would not have been much different had depletion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

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[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.