Capacity Utilisation and Productivity Change in the Australian Metals Mining Industry

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Paper Presented at the 41st Annual Conference of the Australian Agricultural and Resource Economics Society, Surfers Paradise, Gold Coast, Queensland 20-25 January 1997

Abstract

In this paper multifactor productivity of the Australian metals mining industry is analysed for the years 1969-70 to 1993-94. Particular attention is paid to account for changing capacity utilisation and for returns to scale in the industry, using a cost-theory based approach. The translog cost function is employed to provide estimates of productivity growth, returns to scale and the index of capacity utilisation in the industry. The main findings are: (1) capacity utilisation in the mining industry is found to have increased over time (2) the annual average multifactor productivity growth rate in the metals mining industry has declined over time (3) an increasing long-run and short-run returns to scale are existed, however, the annual average short-run returns to scale is declining, implying that the industry has realised most of the efficiency gains associated with expanding capacity. Overall, the study suggests that the mining industry has grown sizeably, but that productivity gains are diminishing over time. Reasons for this are hypothesised and include taking on less-productive mining sites, facing new higher costs, overutilisation of the exist capacity, and realising lesser returns to scale with additional industry expansion.

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Introduction

The metals mining industry of Australia has grown rapidly in recent decades and has become a major contributor to export earnings. The industry has employed highly capital-intensive methods as it has grown. Some of the largest single pieces of capital equipment in the world (drag lines, ore-carrying trucks and ore-carrying trains) can be found in operation. Despite the changes that have occurred within the industry, there has been little reported research on productivity growth in mining. This paper presents research undertaken on productivity growth in recent decades in the Australian metals mining industry (whose main sectors include gold, iron ore, copper, nickel, silver, lead, and zinc).

Several questions have emerged with respect to productivity growth in the mining sector in Australia. Firstly, studies of mining in other countries have shown that the rate of productivity growth has been declining over time. An important question for Australia and the mining industry is whether a similar phenomenon has occurred in this country. Secondly, the highly capital-intensive nature of the Australian mining industry suggests that technological change will tend to be overstated if proper account is not taken of returns to scale and capacity utilisation effects. An important question is the extent to which productivity might be overstated. Thirdly, the mining sector has faced considerable constraints to development in recent decades in Australia, including additional resource rental payments, additional environmental restrictions and increased uncertainty concerning mining rights and associated compensation. This paper does not include an attempt to measure the impact of these changes on productivity, but is part of a research effort which will include analysis of these factors on mining industry growth in the future.

The specific focus in this paper is on measuring productivity growth in the metals mining industry after allowing for returns to scale and changes in capacity utilisation. A cost-theory based measures of productivity change and capacity utilisation are employed. Aggregate annual data for the Australian metals mining industry are used. The approach employed is based upon studies of productivity growth reported for

other countries. These studies have placed considerable emphasis on accounting for capacity utilisation and returns to scale when measuring productivity growth. Since the early 1980s, the measured rate of productivity growth in the Australian metals mining industry has declined when proper account is taken of these effects.

This paper is organised as follows. Firstly, a brief theoretical foundation to the cost-based measure of capacity utilisation is developed. The next contains an overview of the translog cost function and the associated hypotheses. Emphasis is placed on showing how estimates of multifactor productivity and capacity utilisation can be derived. The estimates and implied rates of productivity growth are then presented. The broader implications of the results and concluding comments are in final part.

Analytics of Productivity Growth, Returns to Scale and Capacity Utilisation

In order to simplify the analysis that follows later in this paper, a diagrammatic exposition of the relationship between productivity growth, returns to scale and capacity utilisation is now presented. The model is drawn from cost-based theory and presumes the usual relationships between inputs and outputs for an industry.

Take an industry made up of identical firms whose input-output coefficients do not vary across firms at any level of output. Cost and production theory suggests that a reasonable representation of the industry, presumed to be realising increasing returns to scale, is as in Figure 1. The downward slope on the long-run average cost (LRAC) implies that returns to scale are increasing, but declining with additional output.

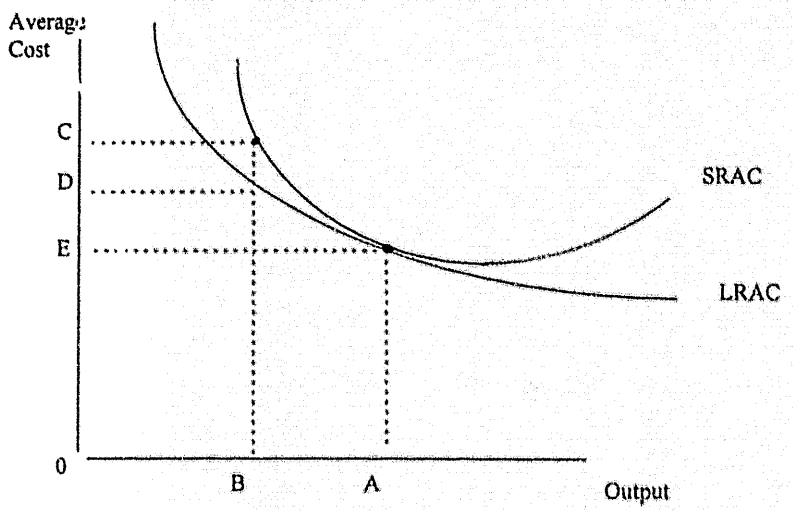

Figure 1. Cost-Theory Based Model of Industry Productivity Allowing for Non-Constant Returns to Scale and Capacity Utilisation

The short-run average cost (SRAC) curve is tangential to the LRAC at A. When the industry is operating at A, the industry is fully utilising its capacity in an economic sense. At this level of output, short-run cost equals long-run cost and no scope exists for further cost reduction by changing the capacity or the capacity utilisation of the industry. In other words, at A the industry has the potential capacity for producing that level of output. More commonly, however, industries operate at levels of output other than A. For example, if operating at output level B, SRAC exceeds LRAC by the amount CD per unit of output. This difference can be attributed to the capacity utilisation of the industry in the short run being less than fully utilised.

Take it that an industry is operating at level of output B, and moves from B to A without any technological change. Short-run cost per unit will decline by CE and this would translate into a measured gain in multifactor productivity that is proportional to the overall cost reduction. Two possible effects underlie the decline in costs associated with the movement from B to A: (1) the efficiency gain (cost reduction) associated with better utilising plant capacity and (2) the efficiency gain associated with realising

returns to scale. If the mov from B to A involves no change in plant capacity, all of the efficiency gains CE can be attributed to better utilising plant capacity. If the move from B to A involves expanding industrial plant capacity by BA, then DE will represent the cost savings from the returns to scale effect. The remainder CD will represent the cost savings from better utilising capacity.

Note that in Figure 1 the level of technology in the industry is assumed fixed. Without technological change, any measured productivity change would be attributable to scale and capacity utilisation effects. The simple analysis of Figure 1 highlights that measured productivity change, based on measured cost reduction through time, might be the result of changing capacity and capacity utilisation in the industry rather than technological change. Now introduce technological change, as in Figure 2. In this case the SRAC curves and LRAC curves shift as a result of the change in technology.

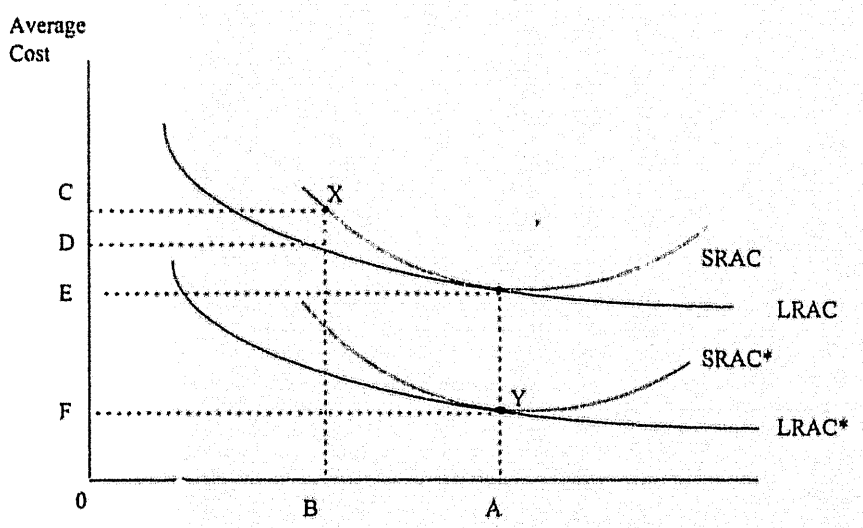

Figure 2. Cost-theory Based Model of Industry Productivity Allowing for Non-Constant Returns to Scale, Capacity Utilisation, and Technological Change

I ake it that the industry moves from X to Y in Figure 2. There are three sources of potential cost reduction: (1) the technological change effect, EF (2) the returns to

scale effect, DE and (3) the capacity utilisation effect, CD. The overall gain in productivity that would be measured by the overall cost reduction CF could now be ascribed to these three sources. To generalise the simplified analysis above we need to consider all combinations of levels of A and B, including moving from one point where capacity is not fully utilised to another point where it is also not fully utilised. That was not illustrated diagrammatically for ease of exposition.

The main point of the above analysis was to illustrate that measured productivity growth can be decomposed into the three effects. Also very important is that failing to account for the returns to scale and capacity utilisation effects will tend to bias measured rates of productivity growth. The challenge taken on in this paper is to attempt to measure productivity growth in the Australian metals mining industry while accounting for capacity utilisation and returns to scale effects.

Cost-Based Capacity Utilisation

Over the past two decades, capacity utilisation has been shown to be one of the most important factors influencing estimated rates of productivity growth. The measure of capacity utilisation is constructed as an index using the ratio of the actual output to the capacity "non-observed" output. This measure has been employed in analysing different economic phenomena. For example, Fahrer and Simon (1995) have employed the measure of capacity output in their analysis and predictions of investment and employment in Australian industries. They stated that " ... *Similarly in the mining and wholesale and retail trade sectors capital is currently underutilised. However, in these sectors the amount of labour currently employed is greater than necessary, given the degree of capital utilisation; this means that the potential for employment growth as the capital stock is more full employed may be limited*". Capacity utilisation has also been considered implicitly in many productivity studies by adjusting production inputs to account for their utilisation. However, there are different conceptual and data problems involved in the construction of these traditional measures of capacity utilisation. These

problems are well documented, see Morrison (1985, and 1988a,b) and Berndt and Hesse (1986).

Berndt and Morrison (1981) conclude "*we hope that applied researchers in the future will devote greater attention and care to the economic theory underlying the concept of capacity....which can then be interpreted more clearly.*" Thus, an estimate of the capacity utilisation that is based on economic theory is needed to provide more reliable and rigorous dynamic explanations of economic performance. Capacity utilisation (CU) measures are usually employed to assess how different levels of output can be achieved in the short-run compared with desired levels of firm or industry capacity. These measures are mostly based on constructing an index of the ratio of the actual output (Q) to the full capacity level of output (Q^*)[1]; $CU= Q/Q^*$. There are two basic approaches to constructing this index of capacity utilisation: (1) traditional "ad-hoc", (2) cost-theory based. The traditional approach has no strong economic theoretical basis, especially with respect to defining the full capacity output (Q^*).

On the other hand, the cost-theory based measure of capacity utilisation depends on the determination of the optimal steady state level of output (Q^*) given the technology, prices, availability and constraints of the inputs of production. The economic full capacity is defined to be that level of output at which the short-run and the long-run total average cost are tangent to one another. This cost-based definition of determining the steady state output was originally presented by Cassels (1937) and followed by Klein (1960). It has been extended and developed, however, by Morrison (1985, 1988a,b and 1989) and many others[2]. This approach takes explicitly into account the fixity of different inputs that may occur in the short-run production process and determines the economic optimal firm's responses under these fixity. The main economic variable underlying the cost-based measure of capacity utilisation is the degree of fixity of the scarce production factors. Thus, input fixity is the key factor which causes the capacity not to be fully utilised in the short run. This implies that a

[1] The full capacity output (Q^*) represents that level of output that the firm is looking to produce in the steady state (long-run) for a given set of inputs (X).
[2] Hulten (1986), Berndt and Hesse (1986).

measure of capacity utilisation can be based on a short-run specification of cost structures which reflect underlying production relationships. Following Cassels (1937), a cost-based capacity utilisation measure (CCU) can be written in terms of short-run cost as follows: $CCU = \tilde{C}/C$, where $\tilde{C}$ is the shadow cost and C is the observed cost, Morrison (1985, 1988a). That is, if the firm is underutilising its inputs, more output can be produced at lower cost, since the shadow price of the underutilised input will be below their market price.

In the rest of this section, the concept of the cost-based capacity utilisation is presented. Using the short-run cost function inputs fixity can be explicitly treated. That is, if the general form of the total short-run cost function is written as:

(1) $C(P_i, Q, X_j, t) = V(P_i, Q, X_j, t) + \Sigma_j P_j X_j$,

Where:
P_i = the price of the ith variable input, i=1, 2, ..., n
Q = the observed output level
X_j = the level of the ith quasi-fixed input, j=1, 2, ..., m
t = time, representing the state of technology
P_j = the price of the jth quasi-fixed input

The shadow price of the jth quasi-fixed input is defined as $\tilde{P}_j = \partial V/\partial X_j$, so that the shadow cost can be written as:

(2) $\tilde{C}(P_i, Q, X_j, t) = V(P_i, Q, X_j, t) + \sum_j \tilde{P}_j X_j$.

It follows that the level of CCU can be determined by the difference between $\tilde{C}(\cdot)$ and $C(\cdot)$. Full capacity utilisation, in other words, will be recognised in the short-run if $\tilde{P}_j = P_j$. However, if $\tilde{P}_j <(>) P_j$, $\tilde{C}(\cdot) <(>) C(\cdot) \Rightarrow \tilde{C}(\cdot)/C(\cdot) <(>) 1$, implies that the jth input is underutilised (overutilised) which will encourage the firm to adjust its input combination over the long-run, Morrison (1985).

Morrison (1985, and 1988a) has shown that CCU can be derived by exploiting the relationship between the elasticity of cost with respect to the quasi-fixed[3] input and that

[3] It is assumed that producers are facing a quasi-fixed input (capital) that may adjusted partially in the short-run. However, its full adjustment is reached on the long-run. Adjustment costs and/or adjustment process, change in quality of the output and inputs have not considered in this paper due to their irrelevant or to the data constraints.

with respect to the output. That is, under cons[illegible] returns to scale, the elasticity of long-run cost with respect to output, η, can be [illegible] as:

$$(3) \quad \eta = \frac{d \ln C}{d \ln Q} = \frac{\partial \ln C}{\partial \ln Q} + \sum_j \frac{\partial \ln C}{\partial \ln X_j} = \zeta_{CQ} + \sum_j \zeta_{CX_j} = 1$$

$$\Rightarrow \zeta_{CQ} = 1 - \sum_j \zeta_{CX_j} = CCU$$

Where:

$$\zeta_{CQ} = \frac{\partial \ln C}{\partial \ln Q}$$

$$\zeta_{CX_j} = \frac{\partial \ln C}{\partial \ln X_j}$$

However, if the underlying technology is homothetic and non-constant returns to scale exist, then this cost-based capacity utilisation can be presented as follows:

$$(4) \quad CCU = 1 - \sum_j \zeta_{CX_j} = \frac{\zeta_{CQ}}{\eta},$$

where: $\eta = \frac{d \ln C}{d \ln Q} = \frac{d \ln X_j}{d \ln Q}$, and $1/\eta$ is the long-run return to scale.

It has been also shown that the measure of cost-based capacity utilisation plays an important role in adjusting the dual measure of multifactor productivity change for input fixity in the short-run. Following Ohta (1975) and Morrison (1988, and 1989) the adjustment of MFP for short-run subequilibrium and return to scale (for a homothetic technology) can be obtained by equation 3 and 4 respectively,

$$(5) \quad MFP^C = -\frac{\partial \ln C}{\partial t} / \zeta_{CQ} = -\zeta^*_{CT} / (1 - \sum_j \zeta_{CX_j}),$$

where:

MFP^C: Multifactor productivity growth adjusted for capacity utilisation.

ζ^*_{CT} is the corrected measure ζ_{CT} for short - run inputs fixity, under constant returns to scale.

$$(6) \qquad MFP^{CR} = -\frac{\partial \ln C}{\partial t} / \zeta_{CQ} = -\zeta_{CT}^{**} / \eta(1 - \sum_j \zeta_{CX_j}),$$

where

MFP^{CR}: Multifactor productivity growth adjusted for capacity utilisation and non - constant returns to scale.

ζ_{CT}^{**} is the corrected measure of ζ_{CT} for capacity utilisationand non - constant returns to scale.

Econometric Framework

Following Berndt and Hesse (1986), we employ the translog short-run (variable) cost function to estimate capacity utilisation in the Australian metals mining industry. This can be defined as a function of the prices of the variable inputs (labour (L), energy (E), and non-ore intermediate inputs (M)[4]) and the quantities of the quasi-fixed input (capital stock[5]) in addition to the observed level of output. The modified version to the short-run translog cost function introduced by Brown and Christensen (1981) is hypothesised as follows[6]:

$$(7) \qquad \ln VC = \beta_C + \beta_Q \ln Q + \sum_i \beta_i \ln P_i + \beta_K \ln K + \beta_T T$$

$$+ \frac{1}{2}\{ \beta_{QQ}(\ln Q)^2 + \sum_i \sum_j \beta_{ij} \ln P_i \ln P_j + \beta_{KK}(\ln K)^2 + \beta_{TT} T^2 \}$$

$$+ \sum_i \beta_{Qi} \ln P_i \ln Q + \sum_i \beta_{Ki} \ln P_i \ln K + \beta_{QK} \ln Q \ln K$$

$$+ \sum_i \beta_{Ti} T \ln P_i + \beta_{TK} T \ln K + \beta_{TQ} T \ln Q$$

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[4] The choice of the KLES production function has been encouraged by the limited information in the ore input and its price. Some studies, however, did used the resource tax as an approximate for the ore price, Smith and other (1976). Stollery (1985) used a KLE production function in his application to the Canadian mining. However, it is more appropriate to include as much as possible production factors in measuring an economic performance indicator.

[5] It is worth noting that the capital utilisation and capacity utilisation are two different measures of the economic performance. However, since the only quasi-fixed input in our model is capital stock, it follows that both these measures coincide.

[6] In this paper constant returns to scale is not imposed

Where:
VC = total variable cost of the metals mining industry
P_i = price index of the ith variable input, and
i=Labor(L), Energy(E), and non-ore intermediate inputs (M).
K = quantity index of capital stock
Q = aggregate real output index
T = technology index (time trend)

As noted by Brown and Christensen (1981), the factor share equations (S_i) can be derived using Shephard's lemma as follows.

$$(8) \quad \frac{\partial \ln VC}{\partial \ln Pi} = S_i = \beta_i + \sum_j \beta_{ij} \ln P_j + \beta_{Ki} \ln K + \beta_{Qi} \ln Q + \beta_{Ti} \ln T$$

Certain restrictions are needed for this cost function to satisfy linear homogeneity in variable input prices for a given output, capital stock, and technology, as required of a well-behaved cost function. Thus, symmetry is imposed so that $\beta_{ij} = \beta_{ji}$ and the following restrictions are sufficient:

(9) $\Sigma_i \beta_i = 1$,

(10) $\Sigma_j \beta_{ji} = \Sigma_i \beta_{ij} = \Sigma_i \beta_{Ti} = \Sigma_i \beta_{Ki} = \Sigma_i \beta_{Qi} = 0$

It is assumed that the underlying technology homogenous of a constant degree in output and the fixed input (capital) which it requires the following restrictions:

(11) $\beta_Q + \beta_K = \eta$

(12) $\beta_{QQ} + \beta_{QK} = 0$.

(13) $\beta_{Qi} + \beta_{Ki} = 0, \forall_i$

(14) $\beta_{TQ} + \beta_{TK} = 0$.

The translog cost function as specified in equations (7-14) is utilised to estimate the adjusted multifactor productivity growth and the components of the short-run return to scale (capacity utilisation and long-run returns to scale). Following an empirical study by Shebeb et al. (1996) non-neutral technical change is also adapted in this study.

A system of equations including the translog restricted cost function and the input-share equations is utilised to obtain estimates of cost-based capacity utilisation and both adjusted multifactor productivity growth rates (MFP^C and MFP^{CR}) in the Australian metals mining industry. The singularity of the system[7] is handled by dropping the non-ore intermediate inputs-share equation. The system is estimated using multivariate regression, Zellner's method. Imposing the restrictions (9-14) reduces the number of independent parameters from twenty-seven to sixteen that need to be estimated. The remaining parameters can be computed by exploiting the model restrictions.

Data

In order to estimate cost-based capacity utilisation and the adjusted index of MFP in the Australian metals mining industry, indices of prices of inputs and output and of quantities of output and the quasi-fixed inputs are required[8]. Unfortunately, very few indices have been published by ABS. The aggregate industry level of inputs (labour, energy, and the non-ore intermediate inputs) and their prices (1989/90=100) are constructed as follows:

Output: Output[9] of the metals mining industry is referred to as the real value of concentrated ore. Unfortunately there is no implicit or explicit price index to the output of any individual mining industry. However, this study has made use of the implicit GDP deflator of mining sector (ASIC B) as the closest price index to that of the metals mining industry[10] to obtain the industry's output at constant price.

Capital Stock: The data set on new capital investments is divided into three main groups; capital expenditure on new buildings, mine development and other constructions; capital expenditure on new plant, machinery and equipment; and the expenditure on land and other fixed assets. Over the time period from 1968\69 to

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[7] Since the input-share equations sum to unity

[8] Data for all inputs and output are obtained from ABS (Catalogue no. 8414.0, 8402.0 and 10.19 for the time period from 1968/69 to 1993/94.)

[9] Inventories have been considered in output measurements.

[10] A precise price index for each individual mining industry is under construction as part of Shebeb's Ph.D. thesis.

1993\94, the average annual capital stock-output ratio in the Australia mining industries was .7, .9 and 1.6 for equipment, construction and total capital stock respectively. Based on these ratios an estimate benchmark for capital stocks in 1967/68 has computed individually. The new capital investments in 1968\69 has been assumed that it has increased by 20% and 40% of that in 1967\68 for equipment and construction respectively. This assumption has based on a carefully analysis of the investment trends over the time period from 1968\69 to 1993\94. Then, an aggregated capital stock incorporating these three capital components is constructed. The implicit price deflator of private gross fixed capital expenditure by type of asset is utilised to obtain estimates of real investment and in the construction of the capital stocks, ABS (Catalogue No.5204.0). The perpetual inventory method is employed in accounting for individual capital stock[11] separately with adjustment for the change in prices and depreciation rates[12].

Labour: The labour input, quantity and price are derived by aggregating the two types of labour, administrative and production workers, weighted by their shares in total wages. The labour quantities (L_t) and price (P_L) are, then, calculated.

Energy Input: The energy input includes both electricity and fuels. However, the quantity data are not available for these two components for most of the time period covered by this study. It follows that no direct price index for energy can be calculated. The electricity price index for manufacturing-industries-use and the fuel price index for farm-use were employed to obtain the real cost of energy inputs individually. An aggregated price of energy inputs then is derived.

Non-ore intermediate inputs: This category represents variable inputs other than labour, and energy. Since the input (M) includes various intermediate inputs, the implicit overall GDP deflator was used as the most appropriate deflator for this input[13].

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[11] For a detailed discussion in this method, see ABS (Occasional Paper no. 1985/3).

[12] A constant exponential rate of depreciation is assumed; $\delta_i=\delta$. For a justification of this assumption, see Hulten and Wykoff (1981a, 1981b). The depreciation rates are assumed to be 10% for plant, machinery and equipment, 5% for dwellings and other buildings and constructions, and 2% for other fixed assets.

[13] This deflator has been exploited in most productivity studies.

Empirical Results

Various Wald tests were conducted in order to establish the validity of the restriction of the hypothesised model. These tests reveal information about the underlying production technology in the Australian metals mining industry. The translog cost function as presented above represents a production technology which is homogenous of degree ($1/\eta$) with non-neutral technical change. Test results for the different restrictions to the underlying technology show that the null hypotheses of constant returns to scale, H_0: $\beta_Q+\beta_K=1$ is rejected at a significance level of 7.2%. An earlier study by Shebeb al (1996) has also suggested the presence of increasing returns to scale. This test indicates that the partial derivative of cost with respect to output could not be equal to unity not only due to the input fixity but also to the existence of non-constant returns to scale. It follows that the cost-based measure of MFP multifactor productivity needs to be adjusted for the impacts of the capacity utilisation effect, due to input fixity, and the non-constant returns to scale effect, as presented above in equation 6.

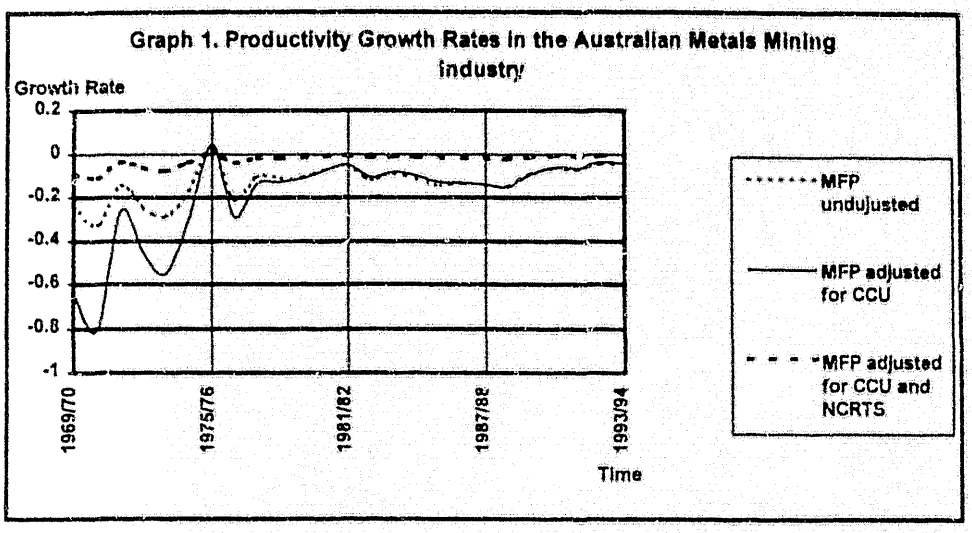
Neutrality of technological change, H_0: $\beta_{it}=0\ \forall\ i$, was rejected at less than .01% significant level. It thus that the estimates of multifactor productivity were based on the results of the hypothesis tests presented above. That is, they were based on a cost function of a homogenous of a constant degree of the underlying production technology with no prior restrictions involving neutrality of technological change.

The estimated restricted cost function is reported in Table 1. The estimated variable cost function satisfies most of the regularity conditions. In addition, monotonicity of the cost function in input prices, and that of output are satisfied. Monotonicity in input prices requires the cost-share equations to be greater than zero; $S_i>0$, and the necessary and sufficient condition for the monotonicity in output is that the partial derivative of the cost function with respect to output is non-negative. It follows that $\partial lnVC/\partial lnQ+\partial lnVC/\partial lnK<1$ when all variable-input prices, capital stock and output are indexed to one and t indexed to zero. The quasi-concavity condition for the estimated translog cost function with respect to variable-input prices is also checked.

Most of the estimated parameters of the cost function are significantly different from zero at less than the five per cent level of significance. In particular, the estimated parameters of disembodied technical change measure are highly significant. It shows that the cost in mining industry increase over time in a diminishing rate. This implies that the yearly measure of the technical change is negative over the time periods 1969\70-1993\94 except that in 1975/76 as illustrated in graph 1.

Table 1
Estimated Restricted Cost Function:
Australian Metals Mining Industry

Coefficient	Estimates	t-Statistic	Prob.
β_C	4.8857	28.2182	0.0000
β_L	0.5321	44.9241	0.0000
β_E	0.0413	3.3179	0.0015
β_Q	-0.7182	-2.2423	0.0285
β_K	0.8567	2.2130	0.0306
β_{KQ}	0.4381	0.6486	0.5190
β_{LL}	-0.0428	-1.4875	0.1420
β_{EE}	0.0137	0.6134	0.5418
β_{KL}	-0.0394	-1.6460	0.1048
β_{KE}	0.0417	2.1343	0.0368
β_{TK}	-0.0372	-2.0931	0.0404
β_{TL}	-0.0113	-21.0837	0.0000
β_{TE}	0.0031	5.6996	0.0000
β_T	0.2422	12.5988	0.0000
β_{TT}	-0.0073	-4.8577	0.0000
β_{EL}	-0.0196	-1.0563	0.2949



In Graph 1, the difference between the adjusted and unadjusted MFP growth rates in the Australian metals mining industry shows clearly the significant impacts of accounting for input fixity and non-constant returns to scale on productivity measurement. Considering the impact of input fixity alone, Graph 1 shows that the unadjusted growth rate of MFP in the Australian Metals mining industry is underestimated prior to early 1980s due to the existence of underutilised capacity. This over (under-) estimate of MFP growth rate is a consequence of the capacity over (under-) utilisation over the time period covered in this study. Thus, adjusting the technical change for the impact of inputs-fixity results in a higher average annual growth rate if capacity under utilisation occurs. That is, the capacity utilisation effect is a significant factor in the measurement of productivity growth. It follows that taking into account the impact of both the non-constant returns to scale and capacity utilisation should provide a more accurate measure of "true" MFP growth rate.

Cost-based capacity utilisation index is calculated based on estimation of the translog cost function, Tabel 1. Also from the results of Table 1, the parameters of non-neutrality of technical change suggest that technical change in the Australian metals

mining industry is biased toward labour-saving, non-ore intermediate input and energy-using[14] technology.

Table 2 reports the average capacity utilisation index, short-run return to scale and the unadjusted and adjusted productivity growth rates. The average CCU index, Table 2, suggests that capacity was underutilised over the time period before 1983/84 and overutilised for the period of time starting mid-1980s. This finding, capacity overutilisation, may suggests that the demand for metals minerals becomes greater than the Australian economic-capacity output since mid 1980s.

Table 2
Estimated Capacity Utilisation, Short-run Return to Scale and Annual Average Productivity Growth Rates[a] in the Australian Metals Mining (1969\70-1993\94)

TIME/ INDICATOR[b]	CCU Index	SRTS index	-CT** % per year	MFP[C] % per year	MFP[CR] % per year
1969\70-1972\73	0.47	4.79	0.01	5.10	0.69
1973\74-1982\83	0.84	2.43	1.90	5.11	0.69
1983\84-1993\94	1.08	1.31	0.39	0.35	0.05
1969\70-1993\94	0.89	2.32	0.81	2.55	0.35

a Computed as annual compound rate b CT** refers to ζ^{**}_{CT} in equation 6
SRTS is the short-run returns to scale

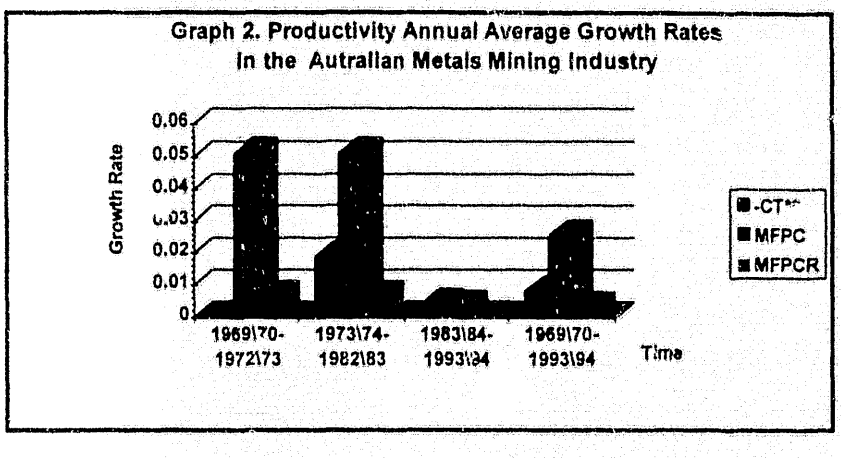
Table 2 also shows that higher average growth rate of technological change in the Australian metals mining has occurred over the time period of mid 1970s to mid 1980s than that of 1990s.

The estimates of average annual growth rate of the unadjusted and adjusted MFP growth rates are somewhat surprising, since they are higher than those of mining industries in other countries. For example, Stollery (1985) reports that the annual average of the MFP growth rate over the time period 1966-1970 and 1971-1979 in the Canadian mining industry was -.07 and -.01 respectively, (p53: table 4).

The slowdown in productivity growth rate of the Australian metals mining industry over the last decade, however, can be explained by exploiting the relationship

[14] Its relatively small coefficient implies, however, that the increase in energy usage was not significant. Shebeb et (1996) have also reported that technical change in Australian mining industries was energy-neutral to it insignificant increase.

between capacity utilisation and productivity growth, equation 6. Since the capital stock can not be adjusted in the short-run it becomes overutilised, and the shadow value of capital, the cost of having an extra unit of capital stock, becomes higher than the market price of capital. This implies that the cost of production is higher than for the optimal level of capital. As a result the annual average productivity growth rate is lower in these years. The declining magnitude of the short-run scale economies also has its impact on MFP growth as it is shown in Table 2. Graph 2 shows clearly the differences between the adjusted and unadjusted productivity growth rates.



Concluding Remarks and Further Research

This paper has been concerned with decomposing and analysing the contributions of economies of scale and capacity utilisation to productivity growth. Various hypotheses were tested in order to obtain a well-estimated cost function for the Australian metals mining industry.

Estimates of the cost function reveal strong evidence on the significance of the contribution of scale economies and capacity utilisation to productivity growth in the Australian metals mining industry. Technological change appeared to be biased; energy-neutral, labour-saving, and non-ore intermediate inputs-using. However, there are some limitations to the results of this study. This is due to the unavailability of some output

and inputs price indices. The possible existence of technical inefficiency is another reservation to the results of this study[15]. The relative high annual average (positive) productivity growth rate of this industry suggests the need to conduct further productivity analysis at a more disaggregated industry level[16].

These and other deficiencies, mentioned above, will be addressed in future research. The implications of different governmental policies on the economic performance of the Australian mining industries will also be investigated. A simulation based on a model of the adjusted productivity growth will be constructed to obtain an estimate to the consequence of selected polices on the mining industry. An interstate comparison of MFP growth rate, biased technological change, technical efficiency, scale economies, and capacity utilisation of the Australian mining will also be considered.

[15] However, the stochastic cost frontier approach will be exploited to estimate technical efficiency and to obtain an adjusted measure to technological change, Lovell and Schmidt (1988).
[16] A commodity level mining industry (four digit ASIC) will be considered in further research.

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