Economic Issues, Vol. 7, Part 2, 2002

Productivity Growth and Capacity Utilization in the Australian Gold Mining Industry: A Short-Run Cost Analysis

Bassim Shebeb[1]

ABSTRACT

This paper uses a stochastic short-run translog cost function to estimate productivity growth, adjusted for capacity utilisation effects, in the Australian gold mining industry over the time period 1968/69-1994/95. Productivity growth is measured and adjusted for the changes in capacity utilisation. It is found that a large portion of the cost-measure (observed) productivity growth may be attributed to technological change. Changes in capacity utilisation are found to have insignificant impacts on productivity growth in the Australian gold mining industry. Biases from technological change and capacity utilisation are also analysed. Technological change is found to be labour-saving and energy and intermediate inputs-using, but neutrality of capacity utilization cannot be rejected.

1. INTRODUCTION

THE AUSTRALIAN gold mining industry has expanded significantly over the last two decades, with gold production increasing from 17 tonnes in 1980 to 255 tonnes in 1995. Over the same time period, the value of Australian gold exports increased from A$90 million to A$5.2 billion. In recent years, gold mining has become Australia's second largest export industry, accounting for around 15 per cent of the value of Australian resource exports. However, despite such progress, this industry has not been subject to a rigorous economic investigation to measure and analyse its productivity growth, which is a key element in improving its competitiveness.

Productivity growth is realized by reductions in unit cost for a given level of output or increases in output for a given level of production inputs. Until recent years, most productivity studies were based on the assumption of instantaneous adjustment for all production inputs, which implies full utilisation (long-run equilibrium) of all inputs. If this strong assumption of full capacity utilisation is valid and constant returns to scale exist, the measured productivity growth reflects technological change. However, if full utilisation does not prevail, measured productivity growth is dependent on changing utilisation levels of production inputs in the short run. In other words, measured short run productivity growth reflects a combination of technological change and capacity utilisation change. To distinguish these components of productivity growth, measurement should be adjusted for the effect of capacity utilisation fluctuations.

Productivity studies such as Morrison (1985, 1988a, 1988b) have placed considerable emphasis on the adjustment of productivity growth for capacity utilisation. Since the Australian gold mining industry is export-oriented, it is directly affected by the volatility of the international demand for gold. To enhance their interpretability and use, productivity growth measures for this industry should be adjusted for short-run changes in capacity utilisation as a result of this demand volatility. The central aim of this paper is to measure and analyse productivity growth in the Australian gold mining industry over the last few decades, adjusted for changes in capacity (capital) utilisation.

2. Capacity utilisation measure and the adjustment of productivity

Capacity utilisation has been considered implicitly in many productivity studies by adjusting production inputs to account for their utilisation. However, there are various conceptual and data problems involved in the construction of these traditional measures of capacity utilisation. These problems are well documented in Morrison (1985, 1988a, 1988b) and Berndt and Hesse (1986) among others.

However, following Cassels (1937) and Morrison (1985, 1988a) a dual cost-based capacity utilisation measure (*CCU*) can be written in terms of short-run cost as: $CCU = \tilde{C}/C$ where $\tilde{C}$ is the short-run shadow cost and C is the observed short-run cost. That is, if the firm is under-utilising its inputs, more output can be produced at lower cost, since the shadow prices of the under-utilised inputs will be below their market price. This can be measured given that the shadow prices of production inputs are estimated.

In the rest of this section, the concept of the dual cost measure of productivity growth and its adjustment for capacity utilisation changes are presented, using a short-run cost function. The general form of a short-run total cost function with one quasi-fixed input (capital, K) can be written as:

$$C(P_i, Q, K, t) = V(P_i, Q, K, t) + k\,K \tag{1}$$

where:

V = total variable cost
P_i = the price of the ith variable input, i=1, 2, ..., n
Q = the observed output level
K = the level of the quasi-fixed input (capital)
t = time, representing the state of technology
k = the price of the quasi-fixed input.

It follows that the shadow price of capital and the short-run shadow cost can be defined as: $\tilde{k} = -\partial V(.)/\partial K$ and $\tilde{C}(P_i, Q, K, t) = V(P_i, Q, K, t) + \tilde{k}\,K$, respectively. Thus, the dual cost-based measure of capacity utilisation can be obtained as, Morrison (1988a):

$$CCU = \frac{\tilde{C}}{C} = \frac{V(P_i, Q, K, t) + \tilde{k}\,K}{V(P_i, Q, K, t) + kK}$$

$$= \frac{C + K(k - \tilde{k})}{C} = 1 - \frac{K(k + \partial V(.)/\partial K)}{C} = 1 - \varepsilon_{ck} \tag{2}$$

Where ε_{CK} is the elasticity of cost with respect to an increase in capital input.

From Equation (2), full capacity utilisation will be realised in the short-run if $\tilde{k} = k$, which implies a zero elasticity of cost with respect to the quasi-fixed input. In that case, the quasi-fixed input will have no impact on the short-run mix of variable inputs. However, if $\tilde{k} < (>)k, \tilde{C}(\bullet) < (>)C(\bullet) \Rightarrow \tilde{C}(\bullet)/C(\bullet) < (>)1$, this implies that the capital stock is under-utilised (over-utilised), thereby encouraging the firm to adjust its input combinations over the long-run.

Exploiting the relationship between the elasticity of cost with respect to the quasi-fixed[2] input and that with respect to output, *CCU* can also be derived using this relation:

$$\frac{d\ln C}{d\ln Q} = \frac{\partial \ln C}{\partial \ln Q} + \frac{\partial \ln C}{\partial \ln K}\frac{d\ln K}{d\ln Q} \tag{3}$$

Assuming homotheticity, the short-run elasticity of cost with respect to output can be expressed as:

$$\varepsilon_{CQ} = \eta(1-\varepsilon_{CK}) \tag{4}$$

where $\eta \equiv d\ln C/d\ln Q = d\ln K/d\ln Q$, and $1/\eta$ represents long-run returns to scale. Assuming that $\eta=1$, *CCU* can be expressed as:

$$CCU \equiv 1-\varepsilon_{CK} = \varepsilon_{CQ} \tag{5}$$

This relationship has an important role in adjusting the primal measure of productivity for the impacts of scale economies and changes in capacity utilisation.

The cost-measure of productivity growth is based on the cost function being at its lowest possible level, holding output and inputs prices fixed, can be obtained as:

$$\varepsilon_{Ct} = \frac{\partial \ln C}{\partial t} = \frac{dC/dt}{C} - \frac{dQ/dt}{Q} - \sum_i \frac{P_i X_i}{C}\frac{dP_i/dt}{P_i} \tag{6}$$

However, Morrison (1988a, 1989) shows that this cost measure of productivity needs to be adjusted for the impact of short-run input fixity as:

$$\varepsilon^{*}_{Ct} = \varepsilon_{Ct} + (1-\varepsilon_{CQ})\frac{d\ln Q}{dt} \tag{7}$$

Where ε^{*}_{Ct} is the cost measure of productivity adjusted for the short-run input fixity. Thus, with constant returns to scale and no input fixity, the measure of productivity collapses to the dual measure of technological change, ε_{Ct}.

Following Ohta (1975) the primal measure of the productivity growth rate (ε_{Qt}), defined as the rate of growth of output holding input levels constant, can be obtained using the dual cost approach as:

$$\varepsilon_{Qt} = -\frac{\partial \ln C}{\partial t} / \frac{\partial \ln C}{\partial \ln Q} = \frac{\varepsilon_{Ct} + (1-\varepsilon_{CQ})\frac{d\ln Q}{dt}}{(1-\varepsilon_{CK})} = -\frac{\varepsilon^{*}_{Ct}}{\varepsilon_{CQ}} \tag{8}$$

The treatment of capital stock as quasi-fixed input in the Australian gold mining industry is of particular interest since it is a capital-specific and capital-intensive industry. This suggests that variations in capital utilisation might have a significant impact on the economic performance of the industry. Moreover, since the Australian gold mining industry is export-oriented, it is subject to fluctuations in the international demand for gold. This implies that an unadjusted measure of productivity growth for short-run changes in capacity utilisation as a result of demand volatility would bias estimates of productivity growth.

3. Econometric framework

A translog short-run (variable) cost function[3] is used to estimate an adjusted measure of productivity growth for short-run changes in capacity utilisation in the Australian gold mining industry. Variable cost may be defined as a function of prices of the variable inputs (labour (L), energy (E), and intermediate inputs (M)) and the quantities of the quasi-fixed input (capital stock) in addition to the observed level of output. Following Brown and Christensen (1981) a short-run translog cost function may be specified as:

$$\begin{aligned}\ln V = {} & \beta_C + \beta_Q \ln Q + \sum_i \beta_i \ln P_i + \beta_K \ln K + \beta_t t \\ & + \frac{1}{2}\left\{\beta_{QQ}(\ln Q)^2 + \sum_i \sum_j \beta_{ij} \ln P_i \ln P_j + \beta_{KK}(\ln K)^2 + \beta_{tt} t^2\right\} \\ & + \sum_i \beta_{Qi} \ln Q \ln P_i + \sum_i \beta_{Ki} \ln K \ln P_i + \beta_{QK} \ln Q \ln K \\ & + \sum_i \beta_{ti} t \ln P_i + \beta_{tk} t \ln K + \beta_{tQ} t \ln Q \end{aligned} \tag{9}$$

Where V, K, Q, t, and P_i for $i = L$, E, and M are defined as above.

It follows that the factor share equations (Si) can be derived using Shephard's Lemma as:

$$\frac{\partial \ln V(.)}{\partial \ln P_i} = S_i = \beta_i + \sum_j \beta_{ij} \ln P_j + \beta_{Ki} \ln K + \beta_{Qi} \ln Q + \beta_{ti} t \tag{10}$$

Certain restrictions are needed for this cost function to satisfy linear homogeneity in variable input prices for a given level of 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 (sufficient) restrictions:

$$\sum_i \beta_i = 1, \text{ and } \sum_j \beta_{ji} = \sum_i \beta_{ij} = \sum_i \beta_{ti} = \sum_i \beta_{Ki} = \sum_i \beta_{Qi} = 0 \tag{11}$$

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

$$\beta_{QQ} + \beta_{QK} = 0,\ \beta_{KQ} + \beta_{KK} = 0,\ \beta_{tQ} + \beta_{tK} = 0, \text{ and } \beta_{Qi} + \beta_{Ki} = 0 \qquad \forall_i \tag{12}$$

Non-neutral technological change is incorporated in this model. Thus, an estimate of the bias in technological change, β_{ti} can be obtained by differentiating the i^{th} input cost share equation with respect to technology (t):

$$\frac{\partial^2 V(\cdot)}{\partial \ln P_i \partial t} = \frac{\partial S_i(\cdot)}{\partial t} = \beta_{ti} \tag{13}$$

Recent economic performance studies have drawn some attention to the measurement and analysis of this type of bias, which shows the impact of having one extra unit of the fixed input on the demand (cost share) for (of) the i^{th} variable input. This definition implies that the bias in capacity utilisation can be derived as:

$$\frac{\partial \ln V(\cdot)}{\partial \ln P_i \partial \ln K} = \frac{\partial S_i(\cdot)}{\partial \ln K} = \beta_{Ki} \tag{14}$$

That is, if adding an extra unit of the fixed-input, capital (K), reduces (increases or does not change) the demand for the i^{th} variable input, then the bias in capacity utilisation is said to be i^{th}-input saving (using or neutral) if $\beta K_i <(> \text{ or } =)\ 0$.

4. Data

In order to estimate dual cost-based measures of productivity adjusted for capacity utilisation changes, price indices of variable input, output, and quasi-fixed input are required. 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 1994/95 to construct aggregate industry-level indices of output, capital stock, and inputs (labour, energy, and the intermediate inputs) and their prices (1989/90=100) as:

Output (Q)

The output of gold mining industry is defined as the real value of production. This study uses the gold price index to obtain the real value (constant price) of industry output including any change in inventories.[4]

Capital Input (K)

The data on capital may be divided into three main groups: (1) capital expenditure on new buildings, mine development and other construction; (2) capital expenditure on new plant, machinery and equipment; and (3) expenditure on land and other fixed assets. An aggregated capital stock incorporating these three capital components is constructed using the implicit price deflator of private gross fixed capital expenditure by type of asset to obtain estimates of real (constant price) investment, and thus in the construction of the capital stocks.

The perpetual inventory method is employed in estimating capital stock by adding up capital expenditures for each individual capital component separately with adjustment for changes in prices and depreciation rates[5] over the time period 1968/69 to 1993/94. Using the capital-output ratio in the Australian mining industry, the capital stocks in 1967/68 are estimated for the Australian gold mining industry, ABS (Catalogue no, 1342.0: table 10).[6]

Labour (L)

Labour input is derived by aggregating two types of labour (administrative and production workers) weighted by their cost shares in total wages and then, an average price for labour is obtained by $P_L = \sum_{i=1}^{n} w_{i,t} / L_t$ and $L_t = \sum_{i=1}^{n} \frac{w_{i,t}}{\sum_{i=1}^{n} w_{i,t}} L_{i,t}$, where w_i is total wages paid to the i^{th}

labour class and L_i is total number of workers in the i^{th} labour class.

Energy input (E)
The energy input includes both electricity and fuels. However, quantity data are not available for these two components for most of the time period covered by this study. So, no direct price index for energy can be calculated. Therefore, the electricity price index and the fuel price index were employed to obtain the real cost (constant price) of energy input from which an average price for the energy input was derived.

Intermediate inputs (M)
Intermediate inputs represent variable inputs other than labour and energy. Since this production factor includes various intermediate inputs, the implicit overall GDP deflator is used as the most appropriate price deflator for this input.

5. Empirical results

A system of equations including translog restricted cost function and input-share equations[7] was used to obtain estimates of observed productivity and adjusted productivity growth rates for capacity utilisation in the Australian gold mining industry. Imposing the required restrictions (equations 11 and 12) reduces the number of independent parameters to be estimated from twenty-seven to sixteen. The remaining parameters can be calculated by exploiting the model restrictions.

The parameters of the estimated model are reported in Table 1. Most of the estimated parameters are significantly different from zero at the 0.05 level of significance. The insignificant coefficients of $\ln(K)\ln(P_L)$ and $\ln(K)\ln(P_E)$ may indicate that price of labour and energy has no significant impact in determining the shadow price of capital for this industry. The insignificant coefficient of $t.\ln(P_E)$ shows that price of energy also had no impact on the rate of technological change.[8] In other words, the growth rate of technological change in the Australian gold mining industry has not been affected significantly by the change in energy prices.

The hypothesis of Hicks neutrality of technological change (H$_0$: $\beta_{ti} = 0, \forall_i$) and neutrality of capacity utilisation (H$_0$: $\beta_{Ki} = 0, \ \forall_i$) were then tested. These tests were carried out using the Wald-test, the statistic of which is asymptotically distributed as a chi-square (χ^2) random variable under the null hypothesis with degrees of freedom (df) equal to the difference between the number of free parameters estimated in the unconstrained and constrained models under investigation. The test results show that the hypothesis test of Hicks neutral technological change can be rejected at the 0.01 significance level. This implies that technological change rotates the isoquant and changes the marginal rates of substitution between inputs, which leads to a change in the cost shares of inputs over time. The direction of the input-specific bias of technological change in the Australian gold mining industry can be summarised as labour-saving, and energy- and intermediate inputs-using.

This implies that the pure technological change in this industry tends to increase the share cost of energy and materials inputs over time. This may also indicate that the mining and processing technologies employed by the Australian gold mining industry are mostly inefficient with respect to energy and material usage.

Neutrality of capacity utilisation ($\beta_{Ki} = 0, \ \forall_i$) implies that increasing the stock of the quasi-fixed input (capital) has no impact on the cost shares of the variable inputs. On the other hand, if increasing the capital stock reduces (increases) the cost share of the i^{th} variable input, then capacity utilisation is i^{th}-input-saving (i^{th}-input-using). Referring to the test results, the hypothesis of neutrality of capacity utilisation cannot be rejected at a significance level less than 0.72.

Table 1: Translog short-run cost function estimates, Australian gold mining industry

Variable	*Coefficient*	*t-statistic*
Intercept	14.9703	15.0757
$\ln(P_L)$	0.7186	23.3174
$\ln(P_E)$	0.0870	4.1328
$\ln(Q)$	0.8513	6.1505
$\ln(K)$	4.4361	12.0327
$\ln(K)\ln(Q)$	0.3061	5.6182
$\ln(P_L)\ln(P_L)$	0.1000	3.2570
$\ln(P_E)\ln(P_E)$	0.0878	3.2880
$\ln(P_E)\ln(P_L)$	-0.0476	-2.4676
$\ln(K)\ln(P_L)$	0.0156	0.6704
$\ln(K)\ln(P_E)$	0.0117	0.6634
t	-0.7818	-8.5946
t^2	0.0405	9.2465
$t.\ln(P_L)$	-0.0243	-14.4962
$t.\ln(P_E)$	0.0007	0.6310
$t.\ln(K)$	-0.2400	-10.4274
R-squared		
V-Equation	0.9952	
S_L-Equation	0.9586	
S_E-Equation	0.1676	

Next, estimates of productivity measures were analysed to show the impact of technological change, scale economies, and capacity utilisation on productivity growth in the Australian gold mining industry. First, capacity utilisation and the growth rate of technological change were calculated using the estimated parameters of the short-run cost function from Table 1 and historical data. Then, primal measure of productivity was estimated using the two-step adjustment process shown in Equations (7 and 8).

Table 2 reports these estimated measures of productivity. In the first column of Table 2, estimates of the cost-measure of productivity are reported. The adjusted cost-measure and the primal measure of productivity growth rates are reported in the next two columns, respectively. By examining the adjusted cost-measure of productivity growth for the changes in capacity utilisation, it appears that variations in capacity (capital) utilisation were insignificant in percentage terms.

Table 2: Cost-measure of productivity and adjusted productivity growth rates, the Australian gold mining industry

Time	*Cost-measure of productivity* $-\varepsilon_{Ct}$	*Adjusted cost-measure of productivity* $-\varepsilon^*_{Ct}$	*Adjusted primal measure of productivity* $\varepsilon_{Qt} = -\frac{\varepsilon^*_{Ct}}{\varepsilon_{CQ}}$
	Annual growth		
1968/69	0.6100	NA	NA
1969/70	0.6488	0.6458	0.6521
1970/71	0.4737	0.4793	0.4842
1971/72	0.3401	0.3442	0.3476
1972/73	0.4290	0.4246	0.4282
1973/74	0.4537	0.4520	0.4552
1974/75	0.4513	0.4507	0.4534
1975/76	0.5500	0.5472	0.5503
1976/77	0.4337	0.4350	0.4368
1977/78	0.3209	0.3221	0.3233
1978/79	0.3528	0.3520	0.3530
1979/80	0.2158	0.2168	0.2173
1980/81	0.4094	0.4084	0.4089
1981/82	0.2964	0.2970	0.2973
1982/83	0.2471	0.2474	0.2477
1983/84	0.2665	0.2665	0.2667
1984/85	0.2548	0.2550	0.2551
1985/86	0.1609	0.1611	0.1612
1986/87	0.0734	0.0735	0.0735
1987/88	0.0493	0.0494	0.0494
1988/89	0.0123	0.0123	0.0123
1989/90	-0.1098	-0.1098	-0.1098
1990/91	-0.1597	-0.1597	-0.1597
1991/92	-0.1768	-0.1768	-0.1768
1992/93	-0.1948	-0.1947	-0.1947
1993/94	-0.2011	-0.2011	-0.2010
1994/95	-0.2015	-0.2015	-0.2014
Time period	Average growth		
1969/70-1994/95	0.2075	0.2076	0.2088
1969/70-1973/74	0.4691	0.4692	0.4735
1974/75-1979/80	0.3874	0.3873	0.3890
1980/81-1988/89	0.1967	0.1967	0.1969
1989/90-1994/95	-0.1740	-0.1739	-0.1739

One should note that the unadjusted and the adjusted cost-measures of productivity growth presented in Table 2 differ slightly. Since the level of capacity utilisation was close to unity, the adjustment for short-run sub-equilibrium had an insignificant impact on productivity growth in the Australian gold mining industry. On the other hand, these two measures differ significantly from the primal measure of productivity. This can be seen clearly if a comparison between the estimates of primal productivity and the unadjusted cost-measure of productivity growth is made. Another important point is while productivity growth declined on average over the time period 1969/70-1994/95, great deal of productivity growth did occur in the late 1960s and the early 1970s.

After 1989/90, the Australian gold mining industry experienced a negative productivity growth owing to negative technological change. The negative technological change over the time period 1989/90-1994/95 indicates that the cost of production increased on average of 0.17 per cent a year. Therefore, the large negative technological change could not be offset by changes in capacity utilisation.

Overall, looking at any of the productivity measures presented in Table 2, the Australian gold mining industry experienced a positive average growth over the time period 1969/70 to 1989/90. From 1969/70-1973/74, however, the average growth of productivity measures is about 0.47% a year, which is the highest average growth of productivity over the entire time period (1969/70-1994/95). The lowest average growth is reported over the time period 1989/90-1994/95. This reflects the recent significant productivity slowdown. This slowdown, however, is driven by the negative technological change that started in the early 1990s. Hence, it can be seen from the estimates of the annual growth of productivity measures that the negative technological change has a large impact on the downward shift of the average annual growth of productivity.

6. Summary and Concluding Comments

This paper has been concerned with measuring and analysing the contribution of technological change, scale economies, and capacity utilisation to productivity growth in the Australian gold mining industry. In order to meet these objectives, a short-run cost specification of the underlying technology is employed. Comparing the estimates of the unadjusted and adjusted productivity growth rates, the slowdown of productivity growth over the time period 1968/69 to 1994/95 was largely due to an increase in average cost associated with the declining rate of technological change.

The findings of this paper are consistent with ABARE's (1990, no.2: p443) analysis. That is, the Australian gold mining industry was expected to become increasingly dominated by smaller number of large producers reflecting the higher capital requirements for open cut mining at greater depth and the increasing cost of processing deeper sulphide ores rather than shallow oxide ores. However, given that the Australian gold mining industry is export-oriented, an increase in production cost would have a significant impact in its international competitive position in world gold market.

Given the declining rate of productivity growth uncovered in this industry, a cost comparison between the Australian gold mining industry and its major competitors seems to be a critical requirement before any policy-oriented decision can be drawn. The cost inefficiency should also be isolated from the technological change before these policy decisions are drawn.

To avoid any misinterpretation of current productivity estimates, a comparison with that of its competitors is another requirement before a policy decision is recommended.

ENDNOTES

1. Department of Economics and Finance, College of Business Administration, University of Bahrain, P.O. Box 32038, Kingdom of Bahrain. I gratefully acknowledge the extremely helpful comments made on earlier versions of the paper from anonymous referees and from Dr. Wendy Bailey.

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

3. It is sufficient to state that all the standard properties of the unrestricted cost function are maintained for the short-run (restricted) cost function as well. In particular, Shephard's lemma and the properties of the input demand functions are maintained, Diewert (1985).

4. See ABARE, Australian Commodity Statistics (1996: p.283, Table 291)

5. For a detailed presentation to this method, see ABS (Occasional Paper no. 1985/3). A constant exponential rate of depreciation is assumed; $\delta t = \delta$. For a justification of this assumption, see Hulten and Wykoff (1981a, 1981b). The depreciation rates are assumed to be 10 per cent for plant, machinery and equipment, 5 per cent for dwellings and other buildings and constructions, and 2 per cent for other fixed assets.

6. For full discussion of the user cost of capital, see Jorgenson (1995).

7. Since the input-share equations sum to unity, the singularity of the system is handled by dropping the intermediate inputs share cost equation.

8. That is $\partial^2 \ln C / \partial t \ \partial \ln P_E \approx 0$.

REFERENCES

Australian Bureau of Agricultural and Resource Economics (ABARE) (1989-1993) *Agriculture and Resources Quarterly*, various issues.

Australian Bureau of Agricultural and Resource Economics (ABARE) (1994-1996) *Australian Commodities: Forecasts and Issues*, various issues.

Australian Bureau of Statistics (ABS) (1985) 'Estimates of Depreciation and Capital Stock', *Occasional Paper*,1985/3.

Australian Bureau of Statistics (ABS) (1968/69-1994/95) 'Australian Mining Industry', Catalogues no. 8414.0, 8402.0, and 10.19.

Berndt E R (1991) *The Practice of Econometrics: Classic and Contemporary*, Massachusetts: Addison-Wesley Publishing Company, Berndt E R and Morrison C J (1981) 'Capacity Utilisation Measures: Underlying Economic Theory and Alternative Approach', *American Economic Review*, 71 (2), May, 48-57.

Berndt E R and Hesse D (1986) 'Measuring and Assessing Capacity Utilisation in the Manufacturing Sectors of Nine OECD Countries', *European Economic Review*, 30, 961-989.

Brown R S and Christensen L R (1981) 'Estimating Elasticities of Substitution in a Model of Partial Static Equilibrium: An Application to U.S. Agriculture 1947 to 1974' in Berndt E R and Fields B C (eds.) *Modelling and Measuring Natural Resource Substitution*, Cambridge, Mass.: M.I.T. Press.

Cassels J M (1937) 'Excess Capacity and Monopolistic Competition', *Quarterly Journal of Economics*, 51 (May), 426-443.

Diewert W E (1985) 'The Measurement of Economic Benefits of Infrastructure Services', *Discussion Paper*, No.85-11, Department of Economics, University of British Colombia.

Hulten C R (1986) 'Short Run and Long Run Cost Functions and the Measurement of Efficiency Change', *Journal of Econometrics*, 33 (1/2), October/November, 31-50.

Hulten C R and Wykoff F C(1981a) 'The Estimation of Economic Depreciation Using Vintage Asset Prices: An Application of Box-Cox Power Transformation', *Journal of Econometrics*, 15, No.3, August, 367-396.

Hulten C R and Wykoff F C (1981b) 'The Estimation of Economic Depreciation', in C. R. Hulten (ed.), *Depreciation, Inflation and the Taxation of Income from Capital*, Washington, D.C.: The Urban Institute.

Jorgenson D W (1995) (ed.) *Productivity*, Cambridge, Mass.: MIT Press.

Klein L R (1960) 'Some Theoretical Issues in the Measurement of Capacity', *Econometrica*, April, 28, 272-286.

Morrison C J (1985) 'Primal and Dual Capacity Utilisation: An Application to Productivity Measurement in the U.S. Automobile Industry', *Journal of Business and Economic Statistics*, 3 (4), October, 312-324.

Morrison C J (1988a) 'Capacity Utilisation and Productivity Measurement: An Application to the U.S Automobile Industry' in A. Dogramaci (ed.) *Studies in Productivity Analysis*, Boston: Kluwer Nijhoff Press.

Morrison, C J (1988b) 'Quasi-Fixed Inputs in U.S. and Japanese Manufacturing: A Generalized Leontief Restricted Cost Function Approach', *Review of Economics and Statistics*, 70 (2), May, 275-287.

Morrison C J (1989) 'Unraveling the Productivity Growth Slowdown in the U.S., Canada, and Japan: The Effects of Subequilibrium, Scale Economies and Markups', *National Bureau of Economic Research Working Paper*, No. 2993, June.

Ohta M (1975) 'A Note on the Duality Between Production and Cost Functions: Rate of Returns to Scale and Rate of technological Progress', *Economic Studies Quarterly*, No.25, 63-65.

Shebeb B, Longmire J and Campbell H F (1996) 'Multi-factor Productivity and Biased Technological Change in the Australian Mining Industry', *Book of Abstracts*, the 25th Annual Conference of Economists, Australian National University, Canberra, Australia, 22-26 September.