THE ECONOMIC RECORD, VOL. 70, NO. 209, JUNE 1994, 162–170

Comparing Like with Like in Productivity Studies: Apples, Oranges and Electricity*

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A methodology is developed to incorporate operating environment variables in the measurement of Total Factor Productivity. When no account is taken of operating environments, the Queensland Electricity Supply Industry (QESI) was found to be 13 per cent more productive than the New South Wales Electricity Supply Industry (NSWESI). However, when performance is adjusted for the relatively large area serviced by the QESI, the productivity advantage it has over the NSWESI expands to about 20 per cent.

I Introduction

Several recent studies have compared the performance of Australia's electricity industries and concluded that, despite significant gains made in recent years, there is scope for further productivity improvement. Lawrence, Swan and Zeitsch (1991a,b) compared the performance of Australia's State electricity industries and found wide disparities in performance. The Queensland Electricity Supply Industry (QESI) outperformed the other State electricity industries and, on average, was about 15 per cent more productive.

However, these studies can provide a misleading picture of the extent of productivity differences as they take no account of the effect on productivity of the environment utilities operate in. For example, an electric utility's per unit costs would rise the more sparsely settled is its distribution area. Similarly, higher sales per customer should enable a utility to lower the cost to supply, thereby reducing per unit input requirements which would increase productivity.

Lawrence, Swan and Zeitsch (1991a) attempted to account for the impact on productivity of the environment in which utilities operate. They estimated econometric models in which the productivity of each State's electricity supply industry was regressed against variables such as the scale of operations, the composition of sales, fuel quality, etc. This work represents the first attempt to incorporate quality variables into the measurement of the productivity of Australia's State electricity industries. However, the methodology used was largely *ad hoc* in that the role the environment variables play in electric utilities production functions was not specified *a priori*. This deficiency is overcome in the current study. A methodology is developed to account for the effect of these differences on measured productivity. The methodology is then applied to yield a more accurate comparison of the productivity performance of the QESI relative to the New South Wales Electricity Supply Industry (NSWESI).

* An earlier version of this paper was presented as a Contributed Paper to the Economics in Business and Government Conference, Gold Coast, 2 September 1992. The views expressed in this paper do not necessarily reflect those of the Industry Commission.

II Measuring the Relative Performance of Electric Utilities

The performance of an electric utility can be compared using a variety of measures including:

- technical performance measures such as availability factors, load factors, reserve plant margins, and capacity factors;
- quality measures such as the number of blackouts, time taken to repair faults, number of accidents, etc;
- financial measures such as the real or nominal rate of return on assets; and
- physical performance measures such as total factor productivity and the partial productivity of individual inputs.

All these measures play an important role in the management of an enterprise. They enable the identification of areas of poor performance and also facilitate valid performance comparisons through time. However, good management requires a summary measure that can be used to provide valid insights into the performance of an enterprise as a whole. Total factor productivity (TFP) is such a measure.

TFP measures output produced per unit of all inputs used. Because it takes account of the use of all inputs, it provides a complete assessment of how an organization is performing. On the other hand, partial measures, such as gigawatt hours per employee, can provide a misleading view of performance. For example, if performance is being judged in terms of labour productivity, managers will institute labour saving improvements. These improvements could involve increased use of other inputs such as contractors or labour saving capital and could result in reduced overall productivity. One way to avoid this counter-productive behaviour is to account for the use of all inputs.

While TFP is probably the best and most readily understood measure of the overall performance of an organization, its measurement is sensitive to differences in operating environments. Thus when undertaking a TFP analysis, it is important to compare like with like. Unless this is achieved, performance gaps may be due to differences in operating environments rather than to differences in technical performance.

There are two ways like comparisons can be achieved. The first involves selecting a benchmarking partner with similar operating characteristics. In some cases this is not possible, thus the second method adjusts measured performance for differences in operating environments. To show how this latter method can be applied, the productivity performance of the QESI is compared with that achieved by the NSWESI. Various measures are provided in Box 1 to enable the two systems to be compared. These include a measure of the capacity of each system's distribution and transmission network. While it is understood that there is no standard formula for quantifying transmission and distribution capacity, the formula used in this study—megawatt kilometres (MWk) as defined in Box 1—is a reasonable empirical approximation for a wide range of lines operating in Queensland and New South Wales. Furthermore, the Queensland and New South Wales transmission and distribution systems are planned and designed to similar criteria for the comparable parts of the network and thus deliver a comparable quality of service. Thus, the measure of transmission and distribution capacity developed in this paper provides a valid basis for comparing the two systems.

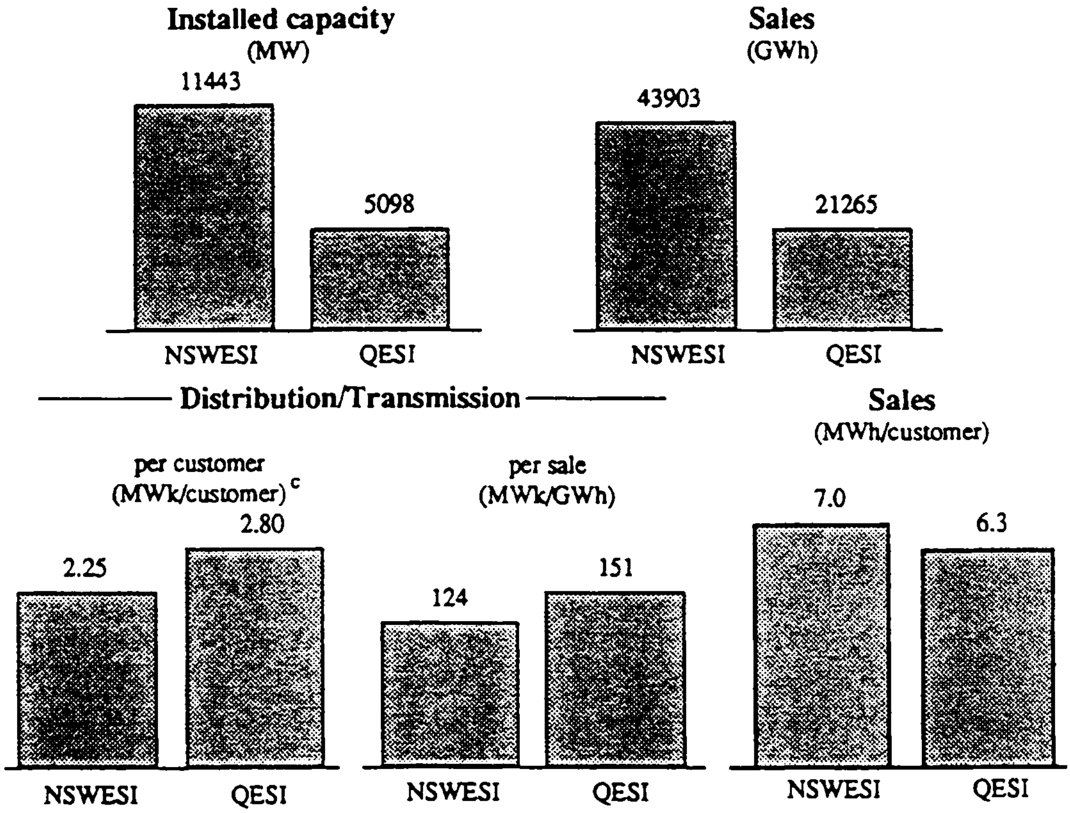
As shown in Box 1, there are significant differences between the two systems. The NSWESI is almost double the size of the QESI in terms of installed capacity and sales. It also sells more per customer than does the QESI. In addition, the QESI's service area is less densely settled than is the NSWESI's service area as reflected in the QESI's higher MWk per customer and MWk per GWh figures. Consequently, more capital per GWh of sales is required to distribute electricity in the QESI than is required in the NSWESI. Thus per GWh of sales, the QESI has about 20 per cent more transmission and distribution capacity than does the NSWESI. Consequently, per GWh of sales it requires relatively more manpower and more distribution and transmission capital. These added input requirements would reduce the QESI's productivity because, as conventionally measured, the QESI's output measure will not reflect the greater relative distance electricity is transmitted in the QESI.

Given the significant differences between the two systems, if reliable productivity comparisons are to be made between the QESI and the NSWESI then either:

- the added input requirements associated with transmitting and distributing electricity over greater distances per customer must be deducted from the QESI's input use; or
- an output measure must be developed which incorporates the distance electricity is transmitted.

Box 1

The Two Systems at a Glance: 1989–90



a *Source:* Swan Consultants (Canberra) Electric utility database.
b MW = megawatts, GWh = gigawatts hours, MWk = megawatt kilometres.
c Megawatt kilometres are calculated using the formula: MWk = $(v^{1.4} K)/20$; where V is the voltage of the line in kilovolts and K is the length of the line in circuit kilometres.

We adopt the former approach. The exercise begins by first calculating a measure of the relative productivity of the two systems.

There are a variety of ways that productivity can be measured. But it is generally accepted that TFP provides the best indicator of how productive a firm is at any point in time. Conventional measures of TFP have enabled comparisons to be made of rates of change of productivity between organizations but have not enabled comparisons to be made of differences in the absolute levels of productivity. This is due to the failure of conventional TFP measures to satisfy a number of important technical properties. However, comparisons need to be made not only of growth rates of productivity but also of absolute levels—a utility can take little comfort from a similar productivity growth rate to those of its partners if its productivity in absolute terms is inferior.

Caves, Christensen and Diewert (1982) overcame these deficiencies by creating the Multilateral Translog TFP index. Lawrence, Swan and Zeitsch (1991a,b) used this technique to compare the productivity performance of the electricity supply industries in each of the five mainland Australian States for the period 1975–76 to 1989–

90. The technique was also used by Swan Consultants (Canberra) (1991) to compare the productivity of investor-owned electric utilities in the United States with an aggregate of Australia's five mainland Australian State electricity industries.

The multilateral TFP index methodology provides an ideal method of benchmarking an organization's productivity performance. It represents a significant advance over earlier productivity studies in that it enables total productivity levels as well as growth rates in productivity to be compared across firms. Lawrence, Swan and Zeitsch (1991a,b) outline the merits of this index.

The multilateral translog TFP index is given by;

$$
\begin{aligned}
&\mathrm{Log}\ (\mathrm{TFP}_m/\mathrm{TFP}_n) = \\
&\textstyle\sum_i (R_{im} + \bar{R}_i)(\log Y_{im} - \overline{\log Y_i})/2 - \\
&\textstyle\sum_i (R_{in} + \bar{R}_i)(\log Y_{in} - \overline{\log Y_i})/2 - \\
&\textstyle\sum_j (S_{jm} + \bar{S}_j)(\log X_{jm} - \overline{\log X_j})/2 + \\
&\textstyle\sum_j (S_{jn} + \bar{S}_j)(\log X_{jn} - \overline{\log X_j})/2 \qquad (1)
\end{aligned}
$$

where m and n are any two observations in a data set consisting of stacked time-series and cross-section, i is an output, j is an input, R_{im} (S_{jm}) is the revenue (cost) share of output i (input j), $\bar{R}_i$ $(\bar{S}_j)$ is the revenue (cost) share averaged over all observations and $\overline{\log Y_i}$ $(\overline{\log X_j})$ is the average of the log of output i (input j). Equation (1) expresses the multilateral translog TFP index as the log of the ratio of the TFP levels of observations m and n. To calculate the index for multiple observations the data are stacked and the formula applied to each adjacent pair of observations. To convert this to a conventional index the antilog of the expression is taken, one observation's TFP level is set equal to 1.0 and multiplied by the ratio of TFP levels to obtain the index for the second observation. This is then multiplied by the ratio of TFP levels between the second and third observations in the stacked data set to obtain the index value for the third observation and so on throughout the stacked data set. Using equation (1), comparisons between any two observations m and n will be both base-system and base-year independent and the resulting index values will be independent of the order in which the data are stacked. This index can also be interpreted as comparing each observation in the different utilities to a hypothetical utility with output vector equal to the geometric mean of Y_i, input vector equal to the geometric mean of X_j, revenue shares $\bar{R}_i$ and cost shares $\bar{S}_j$.

The multilateral translog TFP index given by (1) can be given a strong economic interpretation in that it corresponds to a flexible translog production structure if firms are both profit maximizing and cost minimizing. However, these conditions are unlikely to be fulfilled in the government enterprise sector although recent reforms have given more emphasis to minimizing costs. An alternative interpretation of productivity measurement is the test or axiomatic approach outlined by Diewert (1993). This approach simply requires the index formula used to satisfy a number of desirable properties and it produces a unique productivity measure, the Fisher index. The translog productivity index is a close approximation to the corresponding Fisher index. As Diewert (1993, p. 42) notes 'the test approach does not depend on any assumptions about optimising behaviour on the part of producers (assumptions which may or may not be satisfied)'.

Following Lawrence, Swan and Zeitsch (1991a,b) a one-output, four-input multilateral TFP analysis was undertaken covering the period 1975–76 to 1989–90. Output was measured as GWh of electricity sold. Inputs incorporated into the analysis include:

- fuel—measured in terajoules;
- labour—measured in terms of the number of operation and maintenance personnel employed by the electric department;
- capital—measured in terms of the annual user charge in constant dollars; and
- other costs—measured in constant dollars.

Data on output, fuel, labour and other costs were obtained from the statistical tables published in Electricity Supply Association of Australia (various years). Data on gross investment levels and the value of work in progress were used to form capital annual user charges using the methodology of Swan (1990).

The multilateral TFP indexes are graphed in Figure 1 where it can be seen that up to about 1982–83 the NSWESI was more productive than the QESI. However, reflecting the major management initiatives introduced by the QESI, the situation was reversed in the second half of the study period. This also coincided with the development of a large degree of excess capacity in the NSWESI as several power stations were built in anticipation of increased demand associated with mineral processing developments which did not eventuate. It was only by the late 1980s that the NSWESI had made progress on rationalizing its generating capacity. By 1989–90 the QESI had opened up a productivity gap of 13 per cent over the NSWESI.

The productivity figures given in Figure 1 implicitly assume both systems operate in similar environments. However, as indicated in Box 1, the QESI has a much more sparsely settled network and required more transmission and distribution capital to achieve each sale. Consequently, its aggregate input use would be inflated. Thus even if it were as technically efficient as some other utility, its TFP would be lower because of these added input requirements. In addition, other factors such as the level of sales per customer, may affect performance. To provide a more accurate assessment of the extent of productivity improvements possible it is necessary to adjust for operating environment characteristics beyond the control of management. This would leave a productivity gap which should reflect differences in management performance, excess capacity levels and work practices, all of which can be influenced by the enterprise itself.

To adjust measured TFP for operating environment factors beyond the control of management, an econometric model was estimated and used to predict input use given different assumptions about the environment the two systems operate in. Christensen *et al.* (1985) used a similar technique to adjust measured productivity in the United States postal system for changes in the number of delivery points in the postal network. They estimated Diewert's (1974) factor requirement function and this model can be adapted to adjust measured productivity in electricity supply for differences in environmental factors. Thus, Diewert's factor requirement function for the QESI was specified as;

$$I = f(Y, NC, NS, T) \qquad (2)$$

where I is an aggregate index of inputs used by the QESI, Y is an index of sales of electricity, NC is the number of the QESI's customers, NS is the size of the distribution and transmission system and T is a time trend introduced to represent structural improvements made by the QESI. In this case the aggregate input index used was the Caves, Christensen and Diewert (1982) multilateral input index for Queensland formed from the inputs of fuel, labour, capital and other costs.

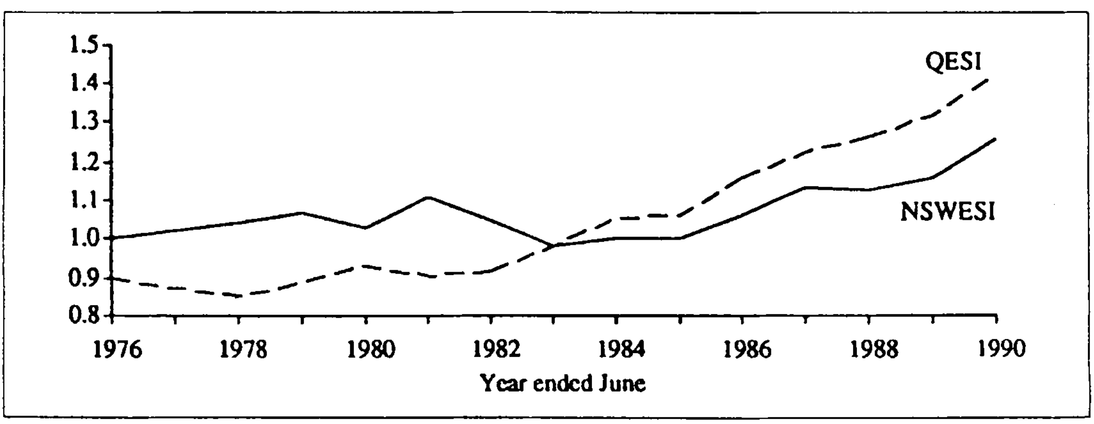
Following Christensen *et al.* (1985, p. IX-3) a logarithmic form of equation (2) is specified. Specifically, the model estimated is given by;

$$\ell nI = \sum_{i=1}^{2} \alpha_{0i} \cdot D_i + \sum_{i=1}^{2} \beta_{0i} \cdot D_i \cdot T + \varepsilon_y \cdot \ell nY + \varepsilon_{nc} \cdot \ell nNC + \varepsilon_{ns} \cdot \ell nNS + u \qquad (3)$$

where D_i are dummy variables included in the model to test for differential rates and levels of structural change which can take the form of improved technical performance or better organizational structures. From Figure 1 there appears

FIGURE 1

The Relative Performance of the QESI and the NSWESI: 1975–76 to 1989–90



to be a change in the trend rate of TFP growth around 1981–82. Before this TFP growth appeared relatively flat while it increased steadily afterwards. This coincided with a number of reforms and new management initatives. Thus D_1 takes the value one in the period 1975–76 to 1981–82 and is zero otherwise. D_2 takes the value one in the period 1982–83 to 1989–90 and is zero in other periods. The parameters ε_y, ε_{nc} and ε_{ns} measure the elasticities of total input use with respect to output, customers and network size, respectively.

When estimating this model difficulty was encountered in isolating the separate influence on input use of the size of the system (as measured by GWh generated), the number of customers and the network size. The number of customers and output generated are highly correlated. Consequently, it was not possible to separately identify the effects of these variables on costs while also including the network size variable. As a result, the models tested included only the output and network size variables. It is recognized that the estimated output coefficients in the model will capture more than just the influence on costs of system output. The elasticity of cost with respect to system output is capturing the effects on costs of both system size and customer numbers.

There were insufficient degress of freedom available to permit the inclusion of second-order and interactive terms in equation (3) along with the dummy variable terms. Including second-order and interactive terms is desirable to permit a flexible approximation to a general factor requirements function. However, including these terms in a simplified version of equation (3) without the dummy variables revealed a high degree of multicollinearity. It was decided to opt for the factor requirements function given by equation (3) which permits concentration on the key variables and allows us to examine whether there have been fundamental shifts in management efficiency without introducing more complexity than the relatively small data set can handle.

The specification of changes in the structure of costs given in equation (3) is still relatively rich in that both the average level of productivity and the rate of productivity growth can differ between periods. Also, as outlined by Christensen *et al.* (1985, p. IX-6), various restricted versions of equation (3) can be estimated to test hypotheses including the existence of constant returns to scale. This hypothesis was tested and could not be rejected. It should be noted that this hypothesis refers to constant returns to scale within the range of observations for the QESI. Its acceptance does not necessarily imply there will be constant returns between large systems and small systems.

Various hypotheses concerning the level of technology and rates of growth of technology were tested assuming constant returns to scale prevail. The various tests undertaken are set out in Box 2 and test statistics for these hypotheses are given in Table 1. With constant returns to scale imposed, all restrictions on the level of technology and rate of technical change were rejected indicating that they were significantly different between the two subperiods.

The parameter estimates of the factor requirements function with constant returns to scale imposed are given in Table 2. The estimated model fits the data well as indicated by the R-square of 0.99. Constant returns to scale is imposed in the model and the elasticity of cost with respect to output is estimated at 0.73. This elasticity probably also captures the effect on costs of customer numbers. The elasticity of cost with respect to size of the distribution and transmission network is 0.27.

The QESI's estimated factor requirements function was used to estimate QESI's input requirements assuming it had a distribution area as densely settled as in New South Wales (Figure 2).[1] In 1989–90, for example, this involved an 18 per cent reduction in the size of the QESI network which was calculated to reduce QESI's input requirements by 6 per cent.

The adjusted input series was used to recalculate the QESI's multilateral TFP. With this adjustment, the QESI was found to be about 20 per cent more productive than the NSWESI (Figure 3). Thus, if no account is taken of the effect of the operating environment faced by the QESI we would be under-estimating significantly the productivity gap that exists between the QESI and the NSWESI.

III Conclusions

Operating environments have a significant effect on the productivity performance of State

[1] It is recognized that a more densely settled distribution area would mainly reduce the need for transmission and distribution infrastructure thus concentrating input reductions on capital and labour rather than proportionately reducing all four inputs as assumed here. However, in 1989–90 capital and labour accounted for around three quarters of the QESI's total costs.

BOX 2

Restrictions on the Parameters of the Factor Requirement Function Needed to Test Various Hypotheses

H_1; Constant Returns to Scale ($\varepsilon_y + \varepsilon_{nd} = 1$);

H_2; Constant Returns to Scale and a common rate of structural change in all periods ($\beta_{01} = \beta_{02}$, $\varepsilon_y + \varepsilon_{nd} = 1$);

H_3; Constant Returns to Scale plus zero rates of structural change ($\beta_{01} = \beta_{02} = 0$, $\varepsilon_y + \varepsilon_{nd} = 1$)

H_4; Constant Returns to Scale and the level of technology are the same in all periods; ($\alpha_{01} = \alpha_{02}$, $\beta_{01} = \beta_{02} = 0$; $\varepsilon_y + \varepsilon_{nd} = 1$); and

H_5; Constant returns to scale and the rate of structural change is zero in the first period. ($\beta_{01} = 0$, $\varepsilon_y + \varepsilon_{nd} = 1$)

TABLE 1

Test Statistics Associated with Alternative Model Specifications

Hypothesis tested	F test statistic	Number of degrees of freedom	Critical F value at the 5 per cent level of significance
H_1: constant returns to scale	1.06	1, 9	5.12
H_2: constant rate of structural progress given H_1	23.06	1, 10	4.96
H_3: rate of structural change is zero given H_1	134.69	2, 10	4.10
H_4: level of structural change is the same in all periods given H_1	96.66	3, 10	3.71
H_5: level of structural change is zero in the period 1975–76 to 1981–82 given H_1	8.44	1, 10	4.96

TABLE 2

Estimated Parameters of the QESI's Factor Requirements Function with Constant Returns to Scale Imposed

Parameter	Parameter estimate	Standard error
α_{01}	−11.242	0.429
α_{01}	−10.988	0.443
β_{01}	−0.014	0.004
β_{02}	−0.046	0.003
ε_y	0.734	0.082
ε_{nd}	0.266	0.082
R-square	0.99	
Durbin Watson Statistic	2.45	
Number of observations	15	

electricity industries. We have demonstrated how operating environment variables can be formally incorporated into a TFP study. The methodology has been applied to the standardization of one characteristic, network density, between the Queensland and NSW electricity supply industries. The preliminary results indicate that the gap between the QESI, generally regarded as Austral-

FIGURE 2

Input Use by the QESI (index: actual input use = 1.0 in 1975–76)

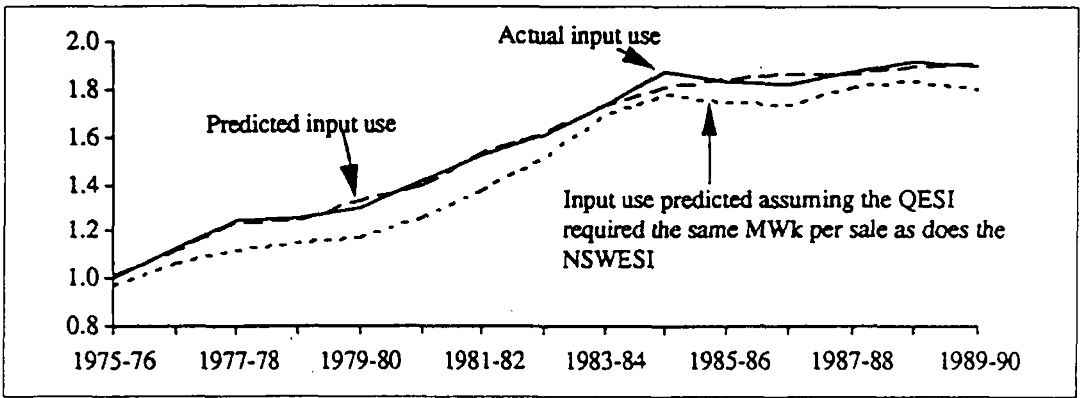
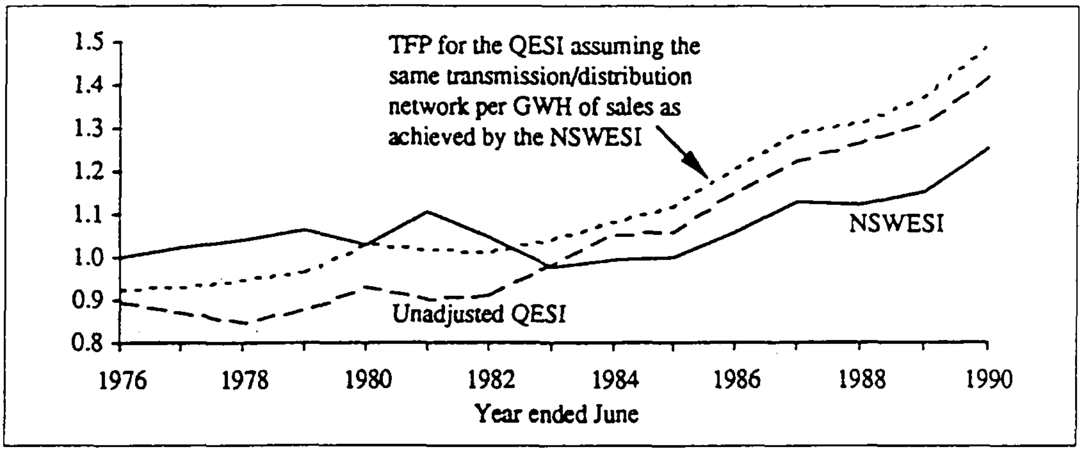


FIGURE 3

The Adjusted Productivity Performance of the QESI and the NSWESI: 1975–76 to 1989–90



ia's leading electricity system in terms of efficiency and management initiatives, and the largest system (the NSWESI) is wider than previously estimated once similar network densities are allowed for.

In future work it is hoped to extend this adjustment technique to more operating environment characteristics and more electricity systems.

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