

# The efficiency of the Australian dairy processing industry<sup>†</sup>

Hristos Doucouliagos and Phillip Hone\*

In this article we analyse trends in the economic performance of the dairy processing industry and evaluate the link between these trends and the deregulation of the industry. Using Stochastic Frontier Analysis to derive Malmquist total factor productivity estimates, we show that the industry exhibits a relatively high level of technical efficiency. Victoria, the major producing state, has been effectively on the frontier over the period studied. In recent years, the rapid expansion in capital investment that has attended the shift towards deregulation, has been accompanied by an apparent slowdown in both productivity growth and technical progress. There is also evidence of a convergence in productivity levels across states.

## 1. Introduction

The Australian dairy processing industry has traditionally been one of Australia's more regulated industries. State regulations have influenced most decisions concerning the production, distribution and sale of wholemilk products while many aspects of the production and sale of manufactured milk products such as cheese and butter, have been controlled by Federal regulations. (See Industry Commission (1991) for background on the development of these policies and ADC (1997) and McCredie (1996) for details on the current regulatory position.) The nature of the state regulations and the inherent differences in the dairy farming industries in each state have resulted in an industry that differs markedly between states. Victoria is by far the largest producer of wholemilk and manufactured milk products, followed by New South Wales and Queensland. While the industries in Victoria and Tasmania are heavily dependent on manufactured milk products and exports, the other states are more focused on the production of

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<sup>†</sup>The authors gratefully acknowledge the comments and assistance provided by two anonymous referees.

\*Hristos Doucouliagos and Phillip Hone, School of Economics, Deakin University, Burwood, 3125.

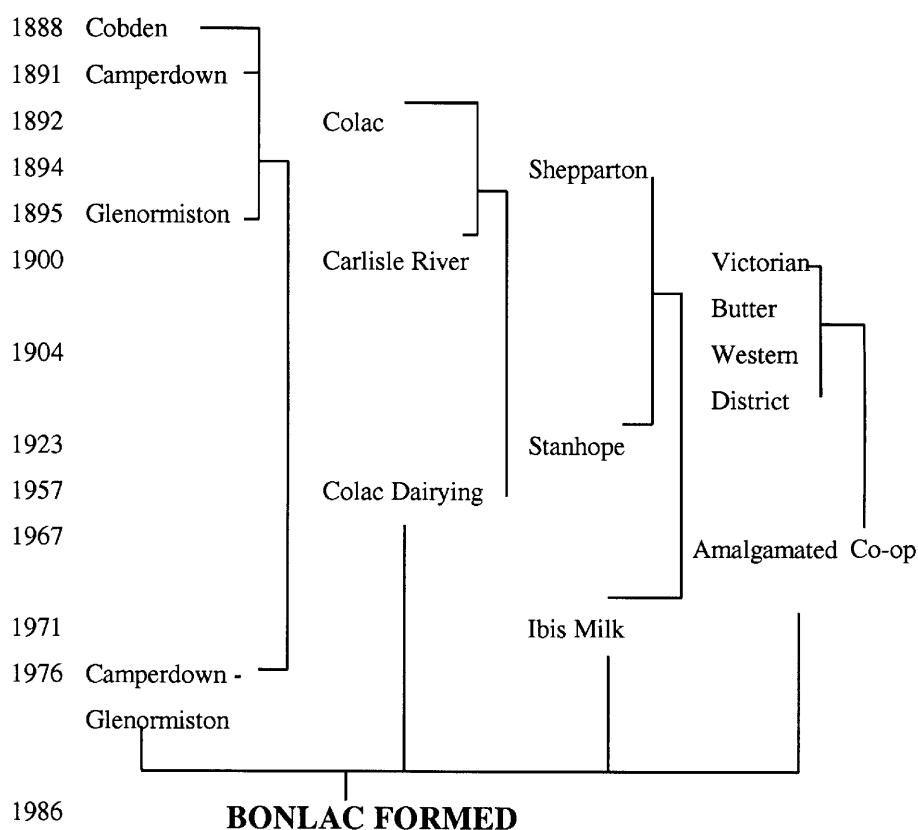
wholemilk products and local state markets. To date there has been little trade in wholemilk or raw milk between states.

Over the last 15 years both Federal and State regulations have been steadily rolled back. The effect of this deregulation has been to increase the exposure of dairy processors and dairy farmers to market forces. At the same time the nature of these market forces has also undergone considerable change with a general trend towards reduced production subsidies in Europe and Northern America (Telford, Gleeson and Ashton 1997). The most visible outcome of this amalgam of changes in the industry has been successive rounds of mergers and take-overs, rationalisation of production and marketing arrangements and extensive new investment programs. These actions, which have been evident in all states, represent the responses of the industry to the threats and opportunities created by the changes in their market and regulatory environments by improving the overall efficiency of the industry's production and marketing efforts.

One of the outcomes of these changes has been to create an industry dominated in production terms by two large players with a large number of smaller speciality producers. Murray Goulburn and Bonlac, both dairy farmer co-operatives based in Victoria, account for nearly half of all raw milk intake in Australia (Hill 1996). These firms developed through a process of mergers and take-overs spread over many years. For example, the history of Bonlac is illustrated in figure 1. The mergers between four firms (Ibis, Amalgamated, Colac and Camperdown-Glenormiston) in 1986 to create Bonlac in its current form, resulted in a firm of substantial size with a major market share in some product categories. These changes have provided the firm with an opportunity to realise any economies of size that may exist in production and marketing and offered the potential to improve the overall efficiency of the firm.

In this article we analyse the nature and extent of changes in the efficiency of the industry. In so doing we provide empirical evidence on how this industry has coped with and taken advantage of the changes in both their regulatory environment and the international market place. Stochastic Frontier Analysis (SFA) is used to derive estimates of technical efficiency in the Australian dairy processing industry, for the 1969–96 period. Estimates are made of changes in technical efficiency, technical progress and total factor productivity growth by applying the Malmquist procedure to results derived from the estimated SFA model. The proposition that the performance of the dairy processing industry in the competing Australian States is converging is also explored.

This article is laid out as follows. The methodology adopted and the data used are discussed in the next section. Then the efficiency scores calculated from the SFA approach are discussed. Technical change, change in technical



#### Significant Subsequent Acquisitions

1986	Unilac Dairy	1999	United Milk Tasmania
	Murrumbidgee Dairy		
1987	Drouin Butter		
1988	Midland Milk		
1994	Primary Products Div., National Dairies		

**Figure 1** Evolution of Bonlac Foods Ltd

Source: Bonlac Foods Limited, *Annual Report*, various editions

efficiency and total factor productivity are reported in the following section and the convergence hypothesis is explored in the penultimate section. In the final section, conclusions are drawn and suggestions are made for further research.

## 2. Methodology and data

The Data Envelopment Analysis (DEA) and SFA approaches are alternative statistical techniques that are both widely used for evaluating efficiency in a production sense. DEA is a linear programming based approach to determining which Decision Making Units (DMUs) are best practice (are on the frontier). However, this approach is sensitive to sample size and consequently has not been used in this study. We estimate and report results based on the SFA approach. This involves the parametric estimation of a hypothetical least cost frontier that is used to compare the performance of DMUs. In this article, the DMU is taken to be the key dairy processing States: Victoria, New South Wales, Tasmania, Queensland, South Australia and Western Australia, for the period 1969 to 1996.<sup>1</sup>

While the SFA approach is less sensitive to the numbers of DMUs, it is not without limitations. The two major problems with the SFA approach are that it is necessary to specify both the functional form of the underlying production function and the distribution of the error term representing the technical inefficiency component. Our SFA estimates are based on the translog functional form because of both its flexibility and its consistency with the data set.

The resulting stochastic production function is given by:

$$\begin{aligned} \ln(Q_{it}) = & \beta_0 + \beta_1 \ln(K_{it}) + \beta_2 \ln(L_{it}) + \beta_3 \ln(M_{it}) + \beta_4 \ln(E_{it}) + \beta_5(t) \\ & + 1/2[\beta_6 \ln(K_{it})^2 + \beta_7 \ln(L_{it})^2 + \beta_8 \ln(M_{it})^2 + \beta_9 \ln(E_{it})^2 \\ & + \beta_{10}(t)^2] + \beta_{11} \ln(K_{it}) \ln(L_{it}) + \beta_{12} \ln(L_{it}) \ln(M_{it}) \\ & + \beta_{13} \ln(K_{it}) \ln(M_{it}) + \beta_{14} \ln(K_{it}) \ln(E_{it}) + \beta_{15} \ln(L_{it}) \ln(E_{it}) \\ & + \beta_{16} \ln(E_{it}) \ln(M_{it}) + \beta_{17} \ln(K_{it})t + \beta_{18} \ln(L_{it})t + \beta_{19} \ln(M_{it})t \\ & + \beta_{20} \ln(E_{it})t + (V_{it} - U_{it}) \end{aligned} \quad (1)$$

where the subscripts  $i$  and  $t$  denote the state and time period respectively,  $Q$  is output,  $K$  is aggregate capital stock,  $L$  is the labour input,  $M$  is the milk input,  $E$  is energy used and  $t$  is a linear time trend.  $V$  denotes a random error term and  $U$  represents the term associated with technical inefficiency.

The second problem noted above was to specify the distribution of the technical inefficiency term ( $U_{it}$ ). Various distributional assumptions can be made. Here we used the half-normal and the truncated normal, but present only the results associated with the half-normal because likelihood ratio tests indicated that this specification was preferred.<sup>2</sup>

<sup>1</sup> The dairy processing industry is negligible in the ACT and the Northern Territory.

<sup>2</sup> The full set of results are available from the authors.

A third problem arises in that in order to estimate total factor productivity, it is necessary to impose constant returns to scale on the stochastic production frontier. This is necessary because, changes in output-to-input ratios can arise from both changes in scale as well as technical change (see Coelli *et al.* 1998).

The stochastic production frontier with constant returns to scale imposed is given by:

$$\begin{aligned} \ln(Q_{it}/K_{it}) = & \beta_0 + \beta_2 \ln(L_{it}/K_{it}) + \beta_3 \ln(M_{it}/K_{it}) + \beta_4 \ln(E_{it}/K_{it}) + \beta_5(t) \\ & + 1/2[\beta_7 \ln(L_{it}/K_{it})^2 + \beta_8 \ln(M_{it}/K_{it})^2 + \beta_9 \ln(E_{it}/K_{it})^2 \\ & + \beta_{10}(t)^2] + \beta_{12} \ln(L_{it}/K_{it}) \ln(M_{it}/K_{it}) \\ & + \beta_{15} \ln(L_{it}/K_{it}) \ln(E_{it}/K_{it}) + \beta_{16} \ln(E_{it}/K_{it}) \ln(M_{it}/K_{it}) \\ & + \beta_{18} \ln(L_{it}/K_{it})t + \beta_{19} \ln(M_{it}/K_{it})t + \beta_{20} \ln(E_{it}/K_{it})t \\ & + (V_{it} - U_{it}) \end{aligned} \quad (2)$$

This means that there are six fewer parameters to be estimated. The remaining coefficients can be recovered from the estimated function. The parameter estimates of the stochastic frontier are presented in the Appendix.<sup>3</sup>

In this study we apply the SFA approach to panel data to derive interstate comparisons at a point in time, as well as over time. The estimated frontiers are likely to shift over time. The Malmquist procedure is applied to levels of inputs and outputs derived from the SFA model to estimate this shift in the frontier by deriving intertemporal and interstate distance functions. The use of panel data means that it is possible to trace movements in technical efficiency, productivity and technical progress over time, as well as to compare efficiency across different states.<sup>4</sup>

The analysis presented in this article is based on the measurement of the relationships between a single composite measure of output and four inputs (labour, raw milk, energy and total capital stock). The data have been compiled principally from published Australian Bureau of Statistics (ABS) and Australian Bureau of Agricultural and Resources Economics (ABARE) statistics and in some cases from unpublished sources. A full discussion of

<sup>3</sup> Multicollinearity is a common problem with translog functional form. However, most of the variables in the estimated stochastic frontier had statistically significant coefficients. Note that the production function satisfied the conditions necessary for a well behaved production system (first and second order conditions). The program FRONTIER 4.1 was used to estimate the stochastic production function (see Coelli 1996).

<sup>4</sup> Technical details and the formula used in the Malmquist procedure can be found in several texts, such as Fare *et al.* (1992), Fare *et al.* (1994), and Piesse, Thirtle and Turk (1996).

the construction of the data base, as well as all the sources, is available from the authors.<sup>5</sup>

Output was measured as real turnover, by deflating the industry's turnover by the (unpublished) price index of articles produced by the dairy processing industries (ASIC Group 212). This price deflator is not available for each state separately, so that the same deflator was used for each state.<sup>6</sup> The labour input used is number of workers employed in each year and in each state. (These unpublished data were provided by the ABS.)

Energy is measured as the total number of petajoules used by the industry in each state. (This is unpublished data supplied by ABARE.)

The primary raw material is milk intake. Since there is limited inter-state trade in wholemilk, it has been assumed that wholemilk production in each state enters as the raw milk input into the dairy processing industry of that state.

In addition to the labour, energy and milk inputs, a single capital stock input is included in the efficiency analysis. This variable covers the stock of buildings and the stock of plant and equipment. The capital stock series was constructed using the perpetual inventory method (see Australian Bureau of Statistics (Catalogue No. 5221) and the Bureau of Industry Economics (1985)). Capital stock was estimated assuming that: (a) depreciation is taken to be on the basis of straight line; (b) prices for assets used in dairy products manufacturing are proxied by the implicit price deflator for asset prices in general; and (c) asset lives are taken from those used by the Bureau of Industry Economics (1985) for the 'other food products' group. These asset lives are 17 years for owned plant and equipment and forty years for owned buildings and structures.

Trends in the capital stock series are potentially very important in this study. The data in table 1 reflect a very rapid expansion in capital investment in most states since the mid-1980s. This investment, which has occurred in all states except Tasmania, may be a reflection of the response of firms to opportunities and threats created by the deregulatory process.

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<sup>5</sup> Over the period studied the classification of industry groups was changed by the ABS. These classifications *do not* affect the data for the dairy processing industry.

<sup>6</sup> This deflator is satisfactory for all states except Victoria and Tasmania. Quality changes have been particularly important to the industry in these two states where most milk is used for manufactured dairy products. These products have undergone substantial quality adjustments over time as evidenced by a trend towards more branded and promoted products. To the extent to which this quality adjustment has not been adequately corrected for in the index, the result could be a downward bias in the measured efficiency of the industry in these two states relative to the other states.

**Table 1** Australian dairy processing industry, average real capital stock, annual percentage rates of change, 1969–96

Region	1969–96	1969–85	1986–96
Australia	1.06	0.80	3.37
New South Wales	−0.46	−1.35	1.56
Victoria	0.49	0.36	2.32
Queensland	1.50	1.77	2.28
South Australia	−0.67	−1.21	1.78
Western Australia	0.91	1.37	2.96
Tasmania	−3.77	−1.48	−6.65

The state data are an aggregation of individual plants of the firms operating in each state. Since the firm and plant level data are not available, it is necessary to use the state data. This is a common problem and the use of state-level data is consistent with the assumption of a representative firm for each state. Nevertheless, the use of state data enables the comparison of the efficiency of the industry across the different states, as well as the industry in each state over time. This in itself is important, as it is reasonable to expect that developments at the firm level will be reflected at the State level. The use of aggregate state-level data is also supported by the regional nature of the industry. This regional characteristic is sustained by climatic differences between states that drive the nature and scale of the dairy farming sector and state-specific regulations under which the industry operates. These regulations result in common characteristics in the operating environment for firms within a state and potential differences between states. For example, given the differences in the relative importance of manufacturing milk production between states, the regulations governing the wholemilk and manufacturing sectors are potentially different in terms of their overall impact on factory operations.

### 3. Efficiency levels<sup>7</sup>

In this analysis we concentrate on efficiency on the production side of operations and we use three indicators of efficiency. Technical efficiency shows the extent to which the firms have maximised outputs for a given level

<sup>7</sup> All the calculations were made using the program DEAP, see Coelli (1996).

**Table 2** Australian dairy processing industry, technical efficiency levels, 1970–96

Year/State	Technical efficiency scores
1970	
New South Wales	0.90
Victoria	0.95
Queensland	0.87
South Australia	0.94
Western Australia	0.95
Tasmania	0.92
1975	
New South Wales	0.95
Victoria	0.95
Queensland	0.96
South Australia	0.87
Western Australia	0.89
Tasmania	0.87
1980	
New South Wales	0.95
Victoria	0.96
Queensland	0.95
South Australia	0.90
Western Australia	0.97
Tasmania	0.95
1985	
New South Wales	0.96
Victoria	0.95
Queensland	0.95
South Australia	0.91
Western Australia	0.96
Tasmania	0.91
1990	
New South Wales	0.93
Victoria	0.94
Queensland	0.87
South Australia	0.94
Western Australia	0.85
Tasmania	0.91
1996	
New South Wales	0.93
Victoria	0.94
Queensland	0.83
South Australia	0.86
Western Australia	0.91
Tasmania	0.97



of inputs or alternatively, the extent to which they have minimised inputs for a given level of output. It reflects the proximity of the DMU to the production frontier. Technical progress indicates the extent to which the hypothetical frontiers confronting the DMUs are shifting out over time. The final indicator is total factor productivity (TFP). It is an overall measure of the relationship between inputs and outputs. Changes in this index can reflect the combined impact of changes in technical efficiency and technical progress. TFP growth may also reflect cost reductions due to DMUs realising economies of size (scale efficiency) or improvements in cost efficiency associated with changes in factor mix decisions (allocative efficiency).

Estimates of the level of technical efficiency of the DMUs based on the SFA approach are presented in table 2 for six of the years studied. Note that in this table the entries for each year are relative to the estimated frontier. However, the frontier in 1996 is different to that of 1970. The efficiency scores help to rank the states relative to the frontier as it existed in a particular year. A score of 1 for a DMU would indicate that that state is estimated to be part of the theoretical best practice frontier for that year.

The dairy processing sector appears to be reasonably technically efficient overall. The Victorian industry was effectively operating on frontier throughout the period studied, while the industries in the other states also achieved high levels of technical efficiency in most years. The comparatively poor performers in terms of technical efficiency were Queensland and, in recent years, South Australia. The lowest score in table 1 was 0.83 for Queensland in 1996. This implies that the adoption of the most appropriate technology for the scale of operation in that state could have expanded output by around 17 per cent in this worst case year.

#### **4. Change in efficiency, technical change and total factor productivity**

Like most industries, the dairy processing industry faces strong incentives to innovative and to invest in new technology. The estimates in table 2 provide little information on trends in efficiency in each state. For example, although we have found that Victoria was effectively operating on the frontier throughout the period studied, we have no measure of the extent to which this frontier has been moving over time. The movements in technical progress, technical efficiency and TFP derived by applying the Malmquist TFP procedure to estimates derived from the SFA model are presented in table 3. Note that the figures presented in table 3 are geometric means for each state over the 1969 to 1996 period and the measure of TFP is defined as the product of technical progress plus the change in pure technical efficiency.

**Table 3** Australian dairy processing industry Malmquist indices of efficiency and total factor productivity, 1969–96

State	Change in technical progress	Technical efficiency change	Total factor productivity change
New South Wales	1.029	1.000	1.029
Victoria	1.015	0.999	1.014
Queensland	1.029	0.996	1.025
South Australia	1.035	0.996	1.032
Western Australia	1.024	0.999	1.022
Tasmania	1.023	1.002	1.025
Average	1.026	0.999	1.024

Given the high levels of technical efficiency in the industry, growth in total factor productivity is likely to be driven by changes in technical progress. As expected, there is no evidence of technical regress in any of the periods. The data on technical progress in table 3 suggest that the frontier has been moving out at a rate of around 2.5 per cent a year with the most rapid progress in South Australia, New South Wales and Queensland, over the entire period studied. The Malmquist pure technical efficiency change scores are consistent with the notion that the technical efficiency scores of each state have not trended substantially up or down over time. The overall TFP change data suggest that the industry has achieved a moderate productivity growth rate of just over 2 per cent a year, with New South Wales and South Australia recording the best average performance.

The relatively modest TFP change rates for Victoria, the leading producer state, are consistent with the results in table 2. That is, although Victoria is on the technical efficiency frontier in each year, in terms of TFP, it is tending to fall behind the smaller production states.

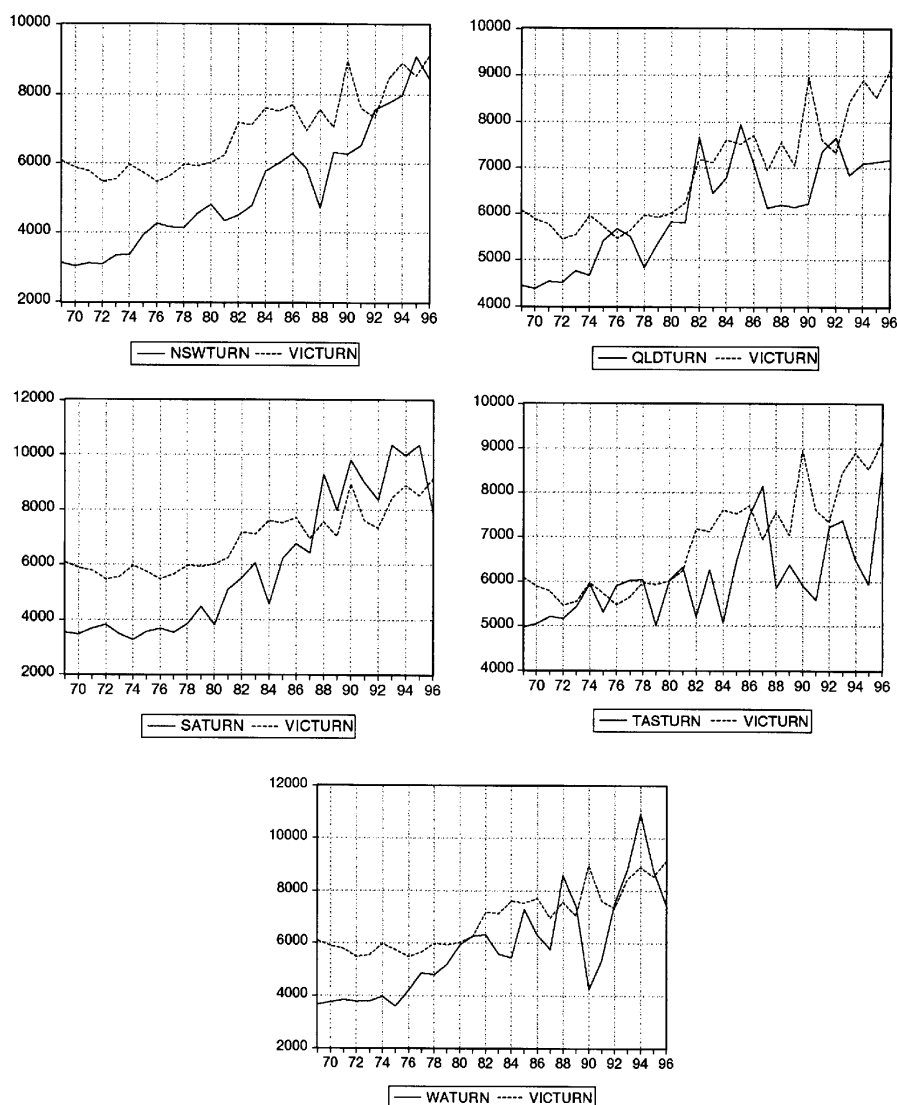
Given that substantial changes have occurred to the regulatory environment of the industry, it is relevant to investigate whether the partial deregulation of the Australian dairy processing industry has had any impact on efficiency and total factor productivity. In table 4, the state-level efficiency scores are separated into five distinct time periods, 1970–75, 1976–80, 1981–85, 1986–90 and 1991–96. The last two periods capture the impact of both the partial deregulation of the industry as well as a severe recession.

Some interesting patterns emerge from table 4. First, there is no evidence that TFP growth has increased since the mid-1980s. In fact, the industries in all states have recorded very low TFP growth rates in the 1990s, with only New South Wales and Western Australia averaging greater than 1 per cent per annum over the period 1991–96. Over the same period the Victorian industry effectively recorded a zero rate of growth in TFP.

**Table 4** Australian dairy processing industry, Malmquist indices, sub-periods

Malmquist indices, Australian dairy processing industry, sub-periods State	Technical efficiency change	Technical progress	Total factor productivity change
1970–75			
New South Wales	1.002	1.040	1.042
Victoria	0.996	1.026	1.022
Queensland	1.008	1.029	1.038
South Australia	0.986	1.045	1.030
Western Australia	0.991	1.030	1.021
Tasmania	0.991	1.059	1.050
1976–80			
New South Wales	1.000	1.038	1.038
Victoria	1.003	1.028	1.031
Queensland	0.996	1.038	1.034
South Australia	1.006	1.047	1.053
Western Australia	1.018	1.040	1.059
Tasmania	1.018	1.050	1.068
1981–85			
New South Wales	1.001	1.028	1.030
Victoria	0.997	1.023	1.020
Queensland	1.000	1.039	1.039
South Australia	1.003	1.038	1.041
Western Australia	0.998	1.029	1.028
Tasmania	0.992	1.039	1.031
1986–90			
New South Wales	0.993	1.023	1.016
Victoria	0.999	1.006	1.005
Queensland	0.983	1.025	1.008
South Australia	1.006	1.029	1.035
Western Australia	0.975	1.014	0.988
Tasmania	1.000	1.009	1.009
1991–96			
New South Wales	1.001	1.017	1.019
Victoria	0.999	0.995	0.994
Queensland	0.992	1.016	1.008
South Australia	0.985	1.020	1.005
Western Australia	1.012	1.007	1.019
Tasmania	1.010	0.964	0.974

Second, while the pattern of low growth rates in TFP in the 1990s is also reflected in the technical progress data, the reduction in growth rates is generally less pronounced than was the case for TFP. This supports the notion that lower technical efficiency scores are driving the recent apparent reductions in TFP.



**Figure 2** Bivariate time series graphs of real turnover per hour employed in the Australian dairy processing industry

### 5. Convergence in the dairy processing industry

As all firms in Australia face common pressures from overseas competition and the deregulation of the industry in Australia, it could be expected there would be a tendency towards the convergence of the economic performance of the industry across all states. The TFP and technical efficiency data

**Table 5** Unit root tests on log difference in real turnover per hour worked, 1969–96

Bivariate variables	PP test statistic
NSW and Victoria	−4.36 <sup>b</sup>
SA and Victoria	−3.40 <sup>a</sup>
TAS and Victoria	−4.63 <sup>b</sup>
QLD and Victoria	−3.48 <sup>a</sup>
WA and Victoria	−3.55 <sup>a</sup>

Notes: <sup>a,b</sup> statistically significant at the 10 and 1 per cent levels, respectively.

examined above do seem to support this hypothesis. That is, although Victoria was a frontier state in terms of technical efficiency throughout the study period, firms in Victoria have apparently tended to achieve lower TFP growth than firms in some of the other states.

As a further test of this proposition, the bivariate procedure recommended by Bernard and Durlauf (1995, 1996), and recently applied by Greasley and Oxley (1997), was employed. The convergence hypothesis is typically applied to international comparisons of per capita GDP. The convergence hypothesis, however, makes more sense within a national industry such as the dairy manufacturing sector, where essentially similar competitive pressures are exerted on firms, across the different states.<sup>8</sup> The Bernard and Durlauf test involves testing for unit roots in the difference of the two variables being compared. The variables of interest here are the log of real turnover for state *i* and the log of real turnover for state *j*. The unit root tests are conducted on the difference between these two variables. Real turnover per hour employed is chosen here, as it is common to use output to labour ratios when making international and national comparisons. If the differenced series contains a unit root, then convergence is not indicated. Both Phillips-Perron (PP) and Augmented Dickey Fuller (ADF) tests were conducted, we present only the results of the PP procedure.

The time series graphs are shown in figure 2 and the unit root tests are presented in table 5. All the tests were conducted with the inclusion of a constant and a time trend. The coefficients on the time trend and constant were statistically significant.

The statistically significant values for the PP statistic reported in table 5 suggest that a unit root does not exist. That is, the unit root tests lead to acceptance of the convergence hypothesis. This evidence supports the hypothesis that the dairy processing industry in all Australian states is converging, when performance is measured in terms of real turnover per hour employed.

<sup>8</sup> Although there are state differences in regulation, the industry as a whole has come under similar pressures from overseas competitors and moves towards deregulation.

## 6. Conclusion

The Australian dairy processing industry has undergone significant changes over the last 30 years. Both the State and Federal governments have substantially reduced their direct regulatory controls over the industry, increasingly exposing firms to an international market place where production subsidies are being reduced in most major producing countries. In this article we have studied how the firm level responses to these changes have been reflected in efficiency of the industry.

Before considering the results, several limitations of the analysis should be noted. First, there are obviously other inputs, such as the managerial input, into the dairy processing process which have not been incorporated into this analysis. Second, by necessity, it is assumed that the quality of inputs is the same across all firms, which may not be the case. Third, the use of state data means that there is the danger of aggregation bias.

Given these qualifications we conclude that the evidence strongly indicates that the industry has been operating at high levels of technical efficiency throughout the study period and has achieved modest technical progress. However, our results do not provide conclusive evidence of an increase in the overall efficiency of the production system that has been associated with the period of most rapid regulatory change, post-1986. Moreover, they show that although there has been growth in the productivity levels achieved by the industry in Victoria, the lead that this state has had over the other states in terms of the efficiency of their production system has been falling over time.

In the most recent years it appears that the TFP performance of Victoria may have been at least matched by firms in the other states. Given that deregulation has occurred across states and the general outcome has been greater exposure to the underlying market pressures, this convergence of productivity levels is at least partial evidence in support of the notion that deregulation has encouraged improved performance in the industry. It shows that as the distortions and differences between states in terms of regulations have been reduced, the other states are moving closer to the benchmark performer in this industry.

The absence of strong evidence to support the notion that deregulation has increased efficiency could reflect one of two conflicting outcomes. First, it could show that deregulation has not aided efficiency. Deregulation may have created uncertainty and market pressures with which the industry has been unable to cope. The alternative hypothesis is that it is still too early to pass judgement on the issue. The rates of capital investment portrayed in table 1 reflect enormous changes in the industry and these changes may take years to have their full impact on the technical efficiency and TFP scores.

It is noticeable from table 1 that firms have increased their commitment to the industry in the post-deregulation period. Such commitments, in the form of marked increases in capital expenditure across all states except Tasmania, can be interpreted as suggesting that the industry participants expect gains over time as a result of deregulation. These expectations would be consistent with the hypothesis that it may be too early to assess the overall impact of deregulation. In addition, during the 1990s the industry increasingly focused on product quality, variety and branding. All these changes suggest the need for further analysis in the future as the impact of deregulation works through the system.

While the results presented here have focused on efficiency comparisons within Australia, it is clear that as protection falls in the industry, the valid comparisons will be with the efficiency of the key overseas competitors. Future research needs to focus on these international comparisons, as the ability of the dairy manufacturing sector to at least match the performance of the other major players in the international market place will be a key determinant of the profitability of both the dairy processing and dairy farming sectors. There is also a need to carry out comparative efficiency analysis at the firm rather than state industry level. However, given the highly concentrated nature of the dairy manufacturing industry, the feasibility of firm level analysis is constrained by issues of confidentiality and data availability.

## Appendix

**Table A1** Australian dairy processing industry, stochastic production frontier, half-normal distribution

Variable	Coefficient ( <i>t</i> -statistic)
$\beta_0$	-2.772 (-0.491)
$\beta_2$ (LABOUR)	2.583 (1.687)
$\beta_3$ (MILK)	1.535 (1.102)
$\beta_4$ (ENERGY)	1.216 (0.955)
$\beta_5$ (TIME)	0.115 (2.784)
$\beta_7$ (LABOUR SQR)	-0.306 (-1.117)
$\beta_8$ (MILK SQR)	0.781 (2.003)
$\beta_9$ (ENERGY SQR)	0.239 (1.510)
$\beta_{10}$ (TIME SQR)	-0.002 (-4.315)
$\beta_{12}$ (LABOUR *MILK)	-0.617 (-2.863)
$\beta_{15}$ (LABOUR *ENERGY)	-0.017 (-0.107)
$\beta_{16}$ (MILK * ENERGY)	0.022 (0.159)
$\beta_{18}$ (LABOUR * TIME)	-0.020 (-2.657)
$\beta_{19}$ (MILK * TIME)	-0.036 (-5.090)
$\beta_{20}$ (ENERGY*TIME)	-0.008 (-2.045)
$\gamma$	0.618 (2.308)

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