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Production and Technical Efficiency on Australian Dairy Farms

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Abstract
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1. Introduction

Dairy is one of Australia's most important agricultural industries with a farm gate value of production of $A3.7 billion in 2001 (ADIS, 2002). It is also the third largest dairy product exporter in the world, with export sales of processed milk and manufactured dairy products of $A3.25 billion in 2000-2001 (ADIS, 2002). Throughout the 1990s the gross value of the industry has expanded significantly, almost doubling, with an average annual growth of output and cow numbers of 5 and 4 per cent respectively (Kompas and Che, 2001). Although dairy production is well developed in every state, Victoria and New South Wales are dominant accounting for more than 76 per cent of milk output, 74 per cent of dairy farms and 75 per cent of cow numbers (ADC, 2003).

Results from an earlier research (Kompas and Che, 2001) on Australian dairy, using an index number approach to determine index values and growth rates in total factor productivity (TFP), showed significant productivity gains in the TFP index in the 1990s relative to the 1980s, but also clear evidence of a 'productivity slowdown' in the 1990s. However, a drawback of the index number approach is its inability to decompose changes in productivity due to technological advances from those that result from changes in efficiency or simply seasonal weather patterns that may affect outputs and inputs. Differences across states and regions are also impossible to quantify (given the base year index number approach), so that in many cases dairy farms in regions or states with relatively low rates of growth in TFP may in fact be operating in a highly efficient manner.

In this study, based on estimations of a stochastic production frontier and the associated inefficiency model, productivity levels are decomposed to allow for random effects and differences in levels of efficiency among dairy farms. The study concentrates on the main dairy regions in Australia, Victoria and New South Wales, the most dominant dairy suppliers in Australia. It combines annual farm survey with biannual farm surveys on technology use (for the years 1996, 1998 and 2000), carried out by the Australian Bureau of Agricultural and Resource Economics (ABARE). The main results provide estimates of the relative importance of inputs in dairy production, the quantitative effects of technology choice on farm efficiency, and overall farm profiles based on the efficiency rankings of dairy producers. The farm profiles give a good indication of the various farm characteristics that define dairy farms by efficiency levels.

Section 2 of the report provides a brief background on the dairy industry in Victoria and New South Wales. Section 3 outlines the model to be estimated and defines production and efficiency measures. Section 4 describes the data set and the relevant variables used in the estimations, including output, all input groups and the major technology variables. The farm surveys provide an unbalanced panel data set of 415 observations for 252 dairy farms in a biannual sequence for the years 1996, 1998 and 2000. Technology data for 2002 is not yet available. Section 5 sets out the econometric specification and presents the estimated results and section 6 provides a detailed discussion of all results, including a comparison of efficiency levels and a profile of Australian farms based on efficiency differences. Section 7 concludes. All references to earlier or related work on dairy efficiency are discussed in content.

2. Background

In the last two decades, the Australian dairy industry has developed strongly and accounts for an important share of dairy products in world markets. While seasonal conditions continue to have a large influence on yearly output, milk production in Australia has increased markedly. From 1980 to 2000 the industry (dominated by Victoria and New South Wales) has doubled annual milk output to now roughly 11 billion litres (ADC, 2001). The growth in output in Victoria and New South Wales has averaged 4.3 and 3.6 per cent per annum over the past twenty years (Kompas and Che, 2001). During the period of this study, 1996-2000, the average annual growth rate of output in these states is nearly 6 per cent.

2.1 Dairy farms in Victoria and New South Wales

Victoria and New South Wales have over 1.6 million dairy cows, accounting for roughly 75 per cent of total dairy cows in Australia. There are approximately 8,100 and 1,800 dairy farms located in Victoria and New South Wales, producing 6.8 and 1.4 billion litters of milk (ADC, 2001). The advantages of climate and natural conditions in these states allow production to be based mainly on year-round pasture grazing, although supplementary feeding with grains is becoming increasingly common, particularly in the last decade. Most dairy farming areas are located in high rainfall zones, where milk production depends on seasonal pastures. However, irrigation is important in northern Victoria and the Riverina in New South Wales. Most non-irrigated dairy production is located in the high rainfall coastal fringe areas. In 1999-2000, 61 per cent of Australian dairy farms were located in Victoria and 13 per cent in New South Wales (ADC, 2001).

Victoria is the most important producer of dairy products in Australia. In 1999-2000, 63.3 per cent of milk and about 85 per cent of dairy exports came from Victoria, valued at $A1.55 billion. Exports are mainly in the form of bulk commodities of skim milk powder, butter and cheese (ADC, 2003). Dairy herds in Victoria are mainly pasture fed, and temperate climatic conditions allow for year-round grazing on permanent pasture. Supplementary feeding of grain is used as an aid to pasture management. Dairying takes place in the higher rainfall areas of the state (more than 700mm per year), namely the southwest, the northeast and Gippsland regions, and in the irrigation areas of Northern Victoria and Central Gippsland. Production and milk yield per cow have increased substantially since 1985. In 1999-2000 the average milk yield was roughly 4,500 litres per cow. The temperate climate in this area enables the production of milk using pasture grown under natural rainfall in the south west, most of Gippsland and the river valleys of the North East, or with irrigation water in the Murray, Goulburn and MacAlister irrigation systems. The typical Victorian dairy farm is a family operated and managed enterprise, milking about 150 cows on 80 to 100 hectares producing about 750,000 litres of milk per annum (ADC, 2003).

For the most part, milk producers in New South Wales are located near major regional centres and close to the state's primary production areas. About half of the milk produced in this state is consumed as fresh milk. Although herd size in Victoria (250 cows per herd) is slightly larger than in New South Wales (200 cows per herd), average farm size in Victoria is smaller than in New South Wales, or 170 compared to 260 hectares (ADIS, 2000 and ABARE, 2000). During 1996-2000, there has been considerable structural adjustment in Victoria and New South Wales. The long-term trend indicates a movement toward larger farms both in terms of area and herd size. On average (per year) the number of dairy farms has decreased at a rate of around 2 per cent a year, but dairy cow numbers have increased at 4 to 5 per cent and total milk production by approximately 6 per cent a year (ADC, 2001).

2.2 Dairy regions in Victoria and New South Wales

Based on production systems and natural conditions in New South Wales and Victoria, dairy producers are divided into dairy regions (see figure 1) by ABARE. The three regions in Victoria are Region 21, northern Victoria (Goulburn-Murray); Region 22, southern Victoria; and Region 23, Gippsland Victoria. The three regions in New South Wales are defined by Region 11, north coast New South Wales; Region 12, central and south coast; and Region 13, the irrigation districts of New South Wales (Riverina).

Region 21 (Goulburn-Murray) in Victoria includes the irrigated areas of the Goulburn and Murray Valleys, where production is based almost entirely on irrigated grazing. Farm areas are generally small relative to those in other dairying regions. Region 22 (southern Victoria) in Victoria includes the southwest areas of Victoria where production is mainly pasture based, with temperate climatic conditions and rainfall mostly occurring in winter and spring. Region 23 in Victoria includes the Gippsland area. This is a temperate, relatively high rainfall area with rainfall mainly occurring in the winter and spring. Production is based mainly on grazing. Few farms have irrigation.

Region 11 (north coast) and Region 12 (central and south coast) in New South Wales include the coastal areas of New South Wales, the adjacent tablelands, the Hunter and Lachlan Valleys and scattered inland dairy farms. Production is mainly pasture based but there is some irrigation in the south and drier inland areas. Region 13 (Riverina) in New South Wales includes the Murrumbidgee Irrigation Area and Murray Valley areas. Production is mainly based on irrigated grazing.

3. Summary of theoretical framework

Stochastic production frontiers were first developed by Aigner, Lovell and Schmidt (1977) and Meeusen and Van den Broeck (1977).[1] The specification allows for a non-negative random component in the error term to generate a measure of technical inefficiency, or the ratio of actual to expected maximum output, given inputs and the existing technology. The idea can be readily applied to panel data. Indexing (dairy) firms by *i*, the specification can be expressed formally by

$$Y_{it} = f(X_{it}, \beta, t)e^{v_{it} - u_{it}} \tag{1}$$

for financial year *t*, Y_{it} output (or the gross value of dairy product), X_{it} a vector of inputs and β a vector of parameters to be estimated. The mapping between inputs and output forms the basis of a production function and the estimated values of β indicate the relative importance of each input to production. As usual, the error term v_{it} is assumed to be independently and identically distributed as $N(0, \sigma_v^2)$ and captures random variation in output due to factors beyond the control of farms, such as normal variations in the weather.

[1] Recently, there has been widespread application of stochastic production frontiers to assess firm inefficiencies in various agricultural and industrial settings (see, for example, Battese and Coelli, 1992, Coelli and Battese, 1996 and Kong, Marks and Wan, 1999).

The error term u_{it} captures technical inefficiency in production, assumed to be firm-specific, non-negative random variables, independently distributed as non-negative truncations (at zero). A higher value for u implies an increase in technical inefficiency. If u is zero the farm is perfectly technically efficient. Following Battese and Coelli (1995),

$$u_{it} = \delta_0 + z_{it}\delta \quad (2)$$

defines an inefficiency distribution parameter for z_{it} a vector of firm-specific effects that determine technical inefficiency and δ is a vector of parameters to be estimated. Firm-specific effects for a dairy farm could include the size of farm, type of dairy shed, feeding concentration and so on. Input variables may be included in both equations (4.1) and (4.2) as long as technical inefficiency effects are stochastic, say for random variable ϖ_{it}, assumed to be normally distributed (see Battese and Coelli, 1995).

The technical efficiency (TE) of the ith firm in the tth period can be defined as

$$TE_{it} = \frac{E(Y_{it} | u_{it}, X_{it})}{E(Y_{it} | u_{it} = 0, X_{it})} = e^{-u_{it}} \quad (3)$$

for E the usual expectations operator. The measure of technical efficiency is thus based on the conditional expectation of equation (3), given the values of (v_{it} - u_{it}) evaluated at the maximum likelihood estimates of the parameters in the model, where the expected maximum value of Y_{it} is conditional on u_{it} = 0 (see Battese and Coelli, 1988). All estimates are obtained through maximum likelihood procedures, where the maximum likelihood function is based on a joint density function for the composite error term (v_{it} - u_{it}). In this case, efficiency can be calculated for each farm per year by

$$E[\exp(u_i) : v_i + u_i] = \frac{1 - \phi(\alpha_a + \gamma(v_i + u_i) / \sigma_a}{1 - \phi(\gamma(v_i + u_i) / \sigma_a)} \exp[\gamma(v_i + u_i) + \sigma_a^2 / 2] \quad (4)$$

for $\sigma_a = \sqrt{\gamma(1-\gamma)\sigma^2}$, $\sigma^2 \equiv \sigma_u^2 + \sigma_v^2$, $\gamma \equiv \sigma_u^2 / \sigma^2$ and $\phi(.)$ the density function of a standard normal random variable (Battese and Coelli, 1988). A value of gamma closer to zero implies that much of the variation is due to random stochastic effects, whereas a value of gamma closer to one implies mainly differences in technical efficiency among farms.

4. Database and variable summary

The unbalanced panel data set used in this study was extracted from ABARE farm annual surveys and ABARE biannual technology surveys in 1996, 1998 and 2000 for New South Wales and Victoria. It consists of 415 observations for 252 farms. Two groups of variables are needed in order to obtain estimated results: one group for the frontier production function and one for the technical inefficiency model. Definitions of all variables are contained in table 1 and table 2 provides summary statistics.

4.1 Variables in the frontier production function

In the frontier production function, equation (1), the variable used for real output (Y) is farm income from milk produced (total litres of milk produced during the year) and cattle sold. Although Australian dairy is now largely deregulated, to avoid complications between 'market' and 'manufacturing' milk, total gross milk income is calculated at the manufacturing price.

Input variables consist of six major components: livestock capital, land area, labour, fodder expenditures, materials and services and asset and structure capital. Livestock capital (*KLI)* measures the total number of dairy cattle on hand as of June 30th of each year. Land (*LAN*) is farm area operated as of June 30th of each year including land owned plus land leased. Fodder (*VFOD*) is the total value of expenditures on fodder and purchases of non-tree and vine crops. Labour (*LAB*) consists of weeks worked for the owner-operator, family labour and hired labour. Materials and services (*MAT*) are the total expenditures on fertiliser, fuel, crop chemicals, livestock materials, seed, dairy supplies and other materials and rates (including rates paid for drainage and water delivery), administrative costs, repairs, insurance, contracts and other services. Capital (*K*) measures the value of plant and structure capital including the value of the dairy shed and irrigation system, depreciation adjusted. All values, for output and inputs where appropriate, are in constant prices indexed by base year 1996.

4.2 Variables in the technical inefficiency model

The technology survey conducted by ABARE consists of many measured applications of farm technology, from the use of a computer and the Internet to the type of dairy shed. In a number of cases specific technology variables estimated as insignificant determinants of efficiency. Of those remaining (table 1), the key drivers of farm efficiency tested in equation (2) include farm size (*SIZE*) or the number of cows or the area utilised by the milking herd; the type of dairy shed technology, classified as walk-through, swingover (*SWING*), herringbone (*HERRING*), and rotary (*ROTARY*)[2]; feeding concentration (*FEED*) measured as total grain per cow; the effluent system (*EFFLU*) as one that recycles versus a ponding system; the land's productive capacity, with the average land value per hectare as a proxy[3]; the number of operators, the number of bails (*BAIL*); the year of build for the dairy shed[4]; and the proportion of total area that is irrigated (*IRRI*). The summary statistics for variables are indicated in table 2.

5. Econometric specification and estimated results

Based on the theoretical framework (section 4) this section details the econometric specification of the stochastic production frontier and inefficiency model.

5.1 Econometric specification

Generalized likelihood ratio tests are used to help confirm the functional form (e.g., general translog, linearly homogeneous, CES) and specification. The correct critical values for the test statistic from a mixed χ-squared distribution (at the 5 per cent level

[2] Where farms have more than one dairy shed the last dairy shed built was chosen. Where more than one dairy shed was built in one year the dairy shed with the largest throughput (cows milked in peak season) was chosen.

[3] It should be noted that in some regions, such as Region 12 and Region 23 for example, nonagricultural factors may have stronger influences on land values than productive capacity. Also, the average percentage of income contributed from milk and cattle sales in the total observations is very high (at 94 per cent) since only dairy farms which have a value of at least 80 per cent of income from milk and cattle sales are included in the data set.

[4] The number of bails occasionally increases for farms that remain in the survey over time without the year of dairy shed build changing in the data set, that is upgrades occur but the age of the basic shed remains unchanged in some cases.

of significance) are drawn from Kodde and Palm (1986). Likelihood ratio tests (see table 3) indicate that equation (1) is best specified by a production function in log-linear Cobb-Douglas form, or

$$\begin{aligned}\ln Y_{it} = \beta_0 + \beta_1 \ln(KLI)_{it} + \beta_2 \ln(LAB)_{it} + \beta_3 \ln(LAN)_{it} + \beta_4 \ln(VFD)_{it} + \\ \beta_5 \ln(MAT)_{it} + \beta_5 \ln(K)_{it} + \beta_6 D_{V98} + v_{it} - u_{it}\end{aligned} \tag{5}$$

for the *i*th farm at time *t*, and where *Y, KLI, LAB, LAN, VFD, MAT* and *K* are dairy output, livestock capital, farm land area, fodder expenditures, materials and services expenditures and plant and structure capital. The value D_{V98} is a dummy variable used to measure the potential effects of the 1998 drought in Victoria. The technical inefficiency model or equation (2) is specified by

$$\begin{aligned}\mu_{it} = \delta_0 + \delta_1 SIZE + \delta_2 \ln COWP + \delta_3 SWING + \delta_4 HERRING + \\ \delta_5 ROTARY + \delta_6 FEED + \delta_7 IRRI\end{aligned} \tag{6}$$

where *SIZE, COWP, SWING, HERRING, ROTARY, FEED* and *IRRI* are the area utilised by the milking herd, the number of cows milked at peak time, swingover dairy shed, herringbone dairy shed, rotary dairy shed, the measure of feeding concentrates (average kg of grain per cow) and the proportion of irrigated area.

Additional likelihood ratio (*LR*) tests are summarized in table 3. The relevant test statistic is

$$LR = -2\{\ln[L(H_0)/L(H_1)]\} = -2\{\ln[L(H_0] - \ln[L(H_1]\} \tag{7}$$

where $L(H_0)$ and $L(H_1)$ are the values of the likelihood function under the null and alternative hypotheses respectively. The null hypothesis that technical inefficiency effects are absent ($\gamma = \delta_0 = \delta_1 = \ldots = \delta_7 = 0$) and that the technology variables do not influence technical inefficiencies ($\delta_1 = \ldots = \delta_7 = 0$) in equation (6) are both rejected, as is $\delta_0 = \delta_1 = \ldots = \delta_7 = 0$. Finally, the null hypothesis that $\gamma = \sigma_u^2/(\sigma_v^2 + \sigma_u^2) = 0$, or that inefficiency effects are not stochastic, is also rejected. All results indicate the stochastic effects and technical inefficiency matter so that usual OLS estimates are not appropriate.

Maximum likelihood estimates of the model were obtained through a coded three-step procedure, using (in large part) Frontier 4.1. OLS estimates are first obtained, followed by a grid search that evaluates a likelihood function for values of γ between zero and one. Finally, the best likelihood values selected in the grid search are used as starting values in a quasi-Newton iterative procedure to form maximum likelihood estimates at a point where the likelihood function obtains its global maximum (see Coelli, *et al.* 1998).

5.2 Estimated results

Results for the stochastic production frontier model (equation 5) are reported in table 4. Two different cases are reported, one with and without the dummy variable to account for the 1998 drought in Victoria. Estimated results for the technical inefficiency model, equation (6), are reported in table 5.[5] A negative sign on a

[5] It is important to note that the results for the estimates of the stochastic frontier were confirmed using a 'random coefficients approach', following Kalirajan and Obwona (1994), allowing for the possibility of non-neutral shifts in the production frontier. Estimated coefficients varied little from those reported in table 4 and all technical efficiency rankings for dairy farms remain unchanged. Recall that although it is impossible to know water use and rainfall on each dairy farm exactly, the cost of water delivery and irrigation capital is included in the values of materials and services and plant and structure capital.

coefficient indicates that an increase in the value of that variable results in a fall in inefficiency; a positive value an increase in inefficiency.

6. Production and efficiency of Australian dairy farms

Based on the estimated results there are a number of key issues to address are: (i) the share parameters for inputs in dairy production function; (ii) the effects of technology and farm specific variables on the economic efficiency; (iii) the comparison of economic efficiency among states and regions in New South Wales and Victoria; and (iv) farm profiles based on efficiency rankings.

6.1 Share parameters for inputs in the stochastic dairy production function

Although the dummy variable for the drought in Victoria tests as negative (as expected) and significant, there is little difference between the estimated coefficients in models 1 and 2 in table 4. Coefficient values constant returns to scale, implying no scale effects in the size of operation so that farm size and output are proportional (at least for the estimated or 'local' results presented here). In more general terms, productivity change will depend on improvements in technology and efficiency, and not necessarily on larger or smaller farm size.[6]

All input variables are measured in log form, so that estimated coefficient values represent 'share parameters' or elasticities. Thus, a 1 per cent increase in the number of livestock capital results in an estimated increase in dairy output of 0.50 per cent. Of all input variables livestock capital has the highest share coefficient (0.50), followed by labour (0.18), fodder (0.14), materials and services (0.10), plant and structure capital (0.07) and land (0.06). Estimated results for the effect of the drought in 1998 in Victoria indicate a substantial reduction in dairy output of 10 per cent.

6.2 The effects of technology and farm specific variables on the economic efficiency

A number of technology and farm-specific features are considered in the technical inefficiency model. They are farm size, type of dairy shed, the proportion of irrigated area, the use of feeding concentrates and the type of system that recycles waste. All other variables in the technology data set tested as highly insignificant. All results are summarized in table 5. For ease of reporting, numerical values are scaled by 10^2 or *E+02* units. Farm size in terms of the area of the farm utilized by the milking herd tested as insignificant (although a variable deletion test failed to exclude the variable from the overall regression).[7] The number of cows milked at peak season tested as

[6] Estimating a stochastic production frontier, without a technical inefficiency model, Jaforullah and Devlin (1996) show that despite an industry trend toward larger dairy farm size in New Zealand, that there is no evidence that larger farms are more efficient and that the dairy farm sector is characterized by constant returns to scale. Loyland and Ringstad (2001) find unexploited scale-economies in Norwegian dairy production, but attribute these to agricultural policy, with a comprehensive system of public economic support and regulation.

[7] In the panel data set, the proportion of farm size with a range of 200 to 300 cows is 62 per cent, from 300 to 500 cows 24 per cent, less than 100 cows 13 per cent and more than 500 cows 6 per cent. As mentioned, Jaforullah and Devlin (1996) also find no relationship between farm size and efficiency. Hallam and Machado (1996) find that larger farm size per cow increases efficiency, but do so using a two-step procedure (OLS estimates of farm characteristics on efficiency rankings) with potential bias in the results. Based on a survey questionnaire (of dairy firms, scientists and other experts), Caraveli and Traill (1998) find some support for the claim that new technologies imply that average costs of production fall more for larger farms.

significant (albeit at the 10 per cent level), but its coefficient value is very small, suggesting little change in efficiency from an increase in this variable.

The major determinants of efficiency differences in this study are the type of dairy shed and the proportion of land irrigated. Recall that dairy sheds are classified in the technology survey as walk-through (single unit), walk-through (double unit), swingover unit, herringbone (hi line and low line) and rotary. In general terms, there has been a substantial investment in dairy shed technology in the past decade. Replacing or modifying the dairy shed represents a significant capital outlay that tends to be accompanied by a substantial improvement or replacement of dairy shed equipment (Martin, *et al.* 2000). In Victoria and New South Wales about 51 per cent of dairy sheds are swingover, 22 per cent herringbone units, 18 per cent rotary and 9 per cent are walk-through. Estimated results indicate that swingover, herringbone and rotary sheds are all efficiency enhancing---and certainly so compared to walk-through---and of these swingover sheds test as the most efficiency enhancing (-16.61), with rotary (-13.01) and herringbone (-12.20) to follow. The result for rotary sheds may be surprising since in terms of cows milked per hour rotary sheds have more than double the capacity of swingover units (Martin, *et al.* 2000). But recall that the measure of plant and structure capital includes the capital value of the dairy shed. Rotary units are relatively costly which implies a higher value (everything else equal) for plant and structure capital for those farms using rotary units. Since efficiency is measured as output given the value of inputs and technology, rotary units may not generate the additional output relative to the cost of inputs compared to swingover units. Another possibility is that at least on some farms rotary units are used at levels well below their capacity.

The proportion of land (farm area used by the herd) irrigated also tests as significant and substantial (-13.37). In the data set this proportion ranges greatly from 0 to 99 per cent. The irrigated areas in Victoria and New South Wales are mainly located in Region 13 in New South Wales and Region 21 in Victoria. In the measurement of the input variables the cost of irrigation is included in plant and structure capital and the cost of water (and drainage rates) is partly accounted for in the value of materials and services. In cases with larger than average rainfall periods farms without irrigation will experience a ‘gift of nature’ that should normally appear as higher efficiency levels in the estimations. In the panel data set in this study (over the period of 1996-2000) however farms that are irrigated test as much more efficient, delivering more dairy output for a given amount of inputs.[8] This may be doubly important given the (out of sample) recent and severe drought in Australia. Drought conditions in key dairy farming regions resulted a dramatic 8.4 per cent fall in Australian milk production in 2002-03 relative to the previous year (ADC, 2003). In NSW however with a larger proportion of irrigated farming, the fall was only 3.1 per cent, compared to 11.1 per cent in Victoria. Water delivery is thus highly important, as suggested by the coefficient on irrigation in the inefficiency model.

Finally, the use of feeding concentrates also has an effect on efficiency but its effect is small (-0.01). This too is a surprise given the large increase in the use of

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[8] Nothing precise is said in this regard on the efficiency of irrigation systems and it is unclear whether the ‘true’ cost of water---delivery charge vs. market value---is reflected in the value of materials and services. The proper use of data on rainfall levels by farm, if available, would be a useful extension to this study especially for areas that are not irrigated. The relatively low value of γ in the estimates indicates that random stochastic effects, such as weather and rainfall patterns, still explain a fairly large proportion of the differences in efficiency across farms.

concentrates on dairy farms in Australia, although this often depends simply on weather and rainfall conditions particularly on farms that have less irrigation.[9]

6.3 Estimated results for dairy farm efficiency

The maximum likelihood estimates provide measures of technical efficiency for each farm in the data set, using equations (3) and (4). The distribution of farm efficiency is graphed (figure 2) indicating a normal distribution with small variance. Economic efficiency is high, with a mean value of roughly 87 per cent. Although (drought adjusted or model 1) mean values for efficiency do not vary greatly from NSW to Victoria there is a good deal of variation within a state and region. For NSW and Victoria combined the mean value of efficiency is very high at 87.39 per cent, with a range from 69.42 to 100 per cent. In NSW alone, the mean is 88.34 per cent, with a range of 71.18 to 100 per cent. In Victoria the mean is 86.75 per cent with a range of 69.42 to 96.61 per cent. For NSW and Victoria combined average efficiency in 1996, 1998 and 2000 is 87.6, 86.8 and 87.8 per cent respectively.[10]

Specific regional results for average technical efficiency are presented in tables 6 and 7, allowing for a comparison among regions in each state. In New South Wales there is little difference among regions. However, Region 13 (the irrigation districts of New South Wales in Riverina) tests as the most efficient. Region 11 (north coast New South Wales) reads as the lowest in efficiency, a value which contrary to all other regions falls through time. In Victoria, Region 21 (Goulburn-Murray) achieves the highest efficiency levels, and is a measure above Region 22 (southern Victoria) and 23 (Gippsland) in particular.

6.4 Farm profiles by efficiency rankings

Although average farm technical efficiency does not vary much by state and region---perhaps not surprising since these dairy farms are purportedly among the best in Australia---efficiency, as mentioned, does vary considerably within a state or region, with a range roughly from 60 to 100 percent of maximum potential output. Using the farm level efficiency measures from the frontier estimates combined with the broader set of farm characteristics in the survey data set provides a useful (overall) profile of dairy farms by efficiency ranking.[11]

For convenience efficiency rankings are arbitrarily divided into ‘low’ (69 to 82 per cent), ‘medium’ (83 to 92 per cent) and ‘high’ (greater than 92 per cent). Summary characteristics for each efficiency group (by average values in that group) are arranged by the main categories of output and inputs (table 8).

[9] A suggestion provided at the DRDC ‘Workshop in Dairy Productivity’ in Melbourne to exclude an apparent ‘outlier’ in the data set (a large farm in NSW with swingover dairy shed technology) resulted in no change in farm efficiency rankings, rankings in the inefficiency model or input coefficients in the production frontier. However, the difference in efficiency between rotary and swingover sheds did decrease slightly.

[10] The larger standard deviation in NSW may be explained by presence of less efficient farms due to previous quota (regulated) arrangements. In an earlier study (without the benefit of the technology data base and a much smaller sample of 112 farms over three years), Battese and Coelli (1988) obtain an efficiency of 77 per cent for NSW and 63 per cent for Victoria, with considerable variance among farms, especially in Victoria.

[11] Some care has to be taken with the interpretation here, since several of the characteristics that correspond to the farms with the estimated highest efficiency levels may be coincidental and not causal; e.g., farm size. The results from the inefficiency model in table 5 are more precise and should condition the overall conclusions gained from these farm profiles.

There are number of points that arise from this farm profile. First, as expected, dairy farms in the high efficiency group use a high proportion of swingover (43.7 per cent) and rotary (32.4 per cent) dairy shed technology. Those in the low group use walk-through predominately (50.8 per cent). This is also consistent with the age of the dairy shed (and number of bails) in the data set, or 16 years (32 bails) for high and 30 years (18 bails) for the low group. Second, as also expected given the results of table 5, farms in the high group (37.5 per cent) have the largest proportion of farm area irrigated, while those in the low group have the smallest (1.3 per cent). Although these effects were relatively small in the econometric estimates, feed concentration (total grain and concentrates used per cow) and the number of cows milked at peak season are also largest for the high group. Third, although these results did not test as significant in the econometric procedure, farms in the high efficiency group have the largest proportion of income from milk and dairy cattle sales and were generally larger farms in terms of land area, capital livestock, land value per hectare, labour used, the value of capital livestock and total fodder expenditures. However, in many cases these characteristics will simply imply more dairy output and not necessarily more efficient production.[12] Finally, yield per cow is seen to be a good predictor of farm efficiency. Yields for the high efficiency group are 5,000 liters per cow, for the medium 3,000 and the low group 2, 400 liters per cow.

The distribution of high, medium and low efficiency farms by state and region is summarized in Table 8. NSW has the highest proportion of farms in the high efficiency group, compared to Victoria, or 60.6 compared to 39.4 per cent. In Victoria, most of these high efficiency farms are in Region 21 (Goulburn-Murray) as expected. In NSW, most of the high efficiency farms are in Region 12 (central and south coast) although the distribution of farms in Region 13 (Riverina) is more highly skewed (by farm numbers) toward the high efficiency group (see table 10). Tables 10 and 11 show the distribution of efficiency by state and region for NSW and Victoria.

7. Concluding remarks

This paper estimates a stochastic production frontier and an associated technical efficiency model to determine the importance of inputs in dairy production and the farm-specific characteristics that explain differences in efficiency across dairy farms in Australia. Estimated production frontier results show that dairy production exhibits constant returns to scale and of all input variables livestock capital has the highest share coefficient, followed by labour, fodder, materials and services, plant and structure capital and land. Estimated results for the effect of the drought in 1998 in Victoria indicate a substantial reduction in dairy output of 10 per cent. This confirms the important role of irrigation (and water availability in general) to this industry.

Although mean efficiency levels vary little between NSW and Victoria there are considerable efficiency differences among dairy farms within states or regions. Dairy shed technology, the proportion of land irrigated, feed concentration and the number of dairy cows milked at peak season are the principal determinates of efficiency differences. Overall farm profiles also indicate that those in the high efficiency farm group have the largest proportion of income from milk and dairy cattle sales and were coincidentally larger farms in terms of land area, capital

[12] More efficient farms will typically have lower per unit costs and larger profits implying that a larger farm size may be acquired, but larger farm size does not necessarily imply higher efficiency given the results from table 5.

livestock, land value per hectare, labour used, the value of capital livestock and total fodder expenditures

In terms of overall regional comparisons, NSW has a higher proportion of dairy farms in the high efficiency group compared to Victoria. This can be largely explained by the larger proportion of irrigated areas in New South. This fact may also explain the strong development of dairy areas and numbers of farms in the irrigated areas of NSW recently. Water and its availability is a large part of the story in Australian dairy production. Although average farm efficiency is high in Victoria and NSW there has been little change in mean efficiency over time. In 1996, 1998 and 2000 the mean values are 87.6, 86.8 and 87.8 per cent for NSW and Victoria combined. Some regions of course perform better than others.

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Figure 1: Survey regions of New South Wales and Victoria

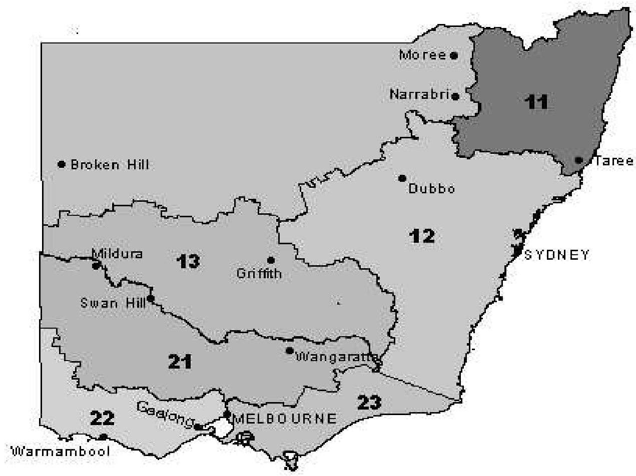

Figure 2: Distribution of efficiency measures for NSW and Victoria combined

(Normal distribution with range 69.42 to 100.00 per cent; mean 87.39 per cent and standard deviation 5.40 per cent)

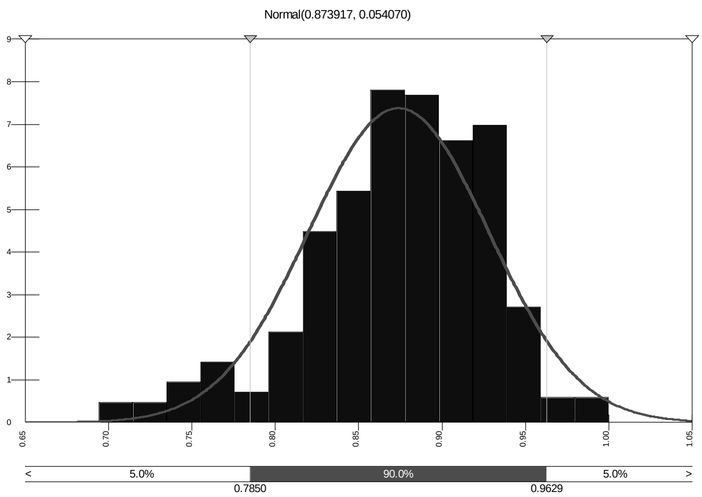

Table 1: Description of variables

Variables		Description
Frontier production model		
Y	*$A*	Total output: gross value from milk and dairy cattle sold
KLI	*no cows*	Capital livestock
LAB	*week*	Total labour work, including hired labour
LAN	*hectare*	Land operated as of June 30th
VFD	*$A*	Fodder expenditure
MAT	*$A*	Fertiliser, fuel, chemicals, material, drainage and water, services, etc
K	*$A*	Plant and structure capital
Technical inefficiency model		
SIZE	*hectare*	Area of farm utilised by the milking herd
COWP	*no*	Number of cows milked at peak time
SWING		= 1 for Swingover herringbone dairy sheds = 0 for other
HERRING		= 1 for double unit hi-line and low-line herringbone dairy sheds = 0 for other
ROTARY		= 1 for rotary dairy sheds = 0 for other
FEED	*kg/cow*	Feeding concentration average (grain)
IRRI	*percentag*	Proportion of the total area operated that is irrigated

Table 2: Summary statistics for variables *(415 observations for 252 farms)*

Variables			Mean	StDev	Minimum	Maximum
Frontier production model						
Total output	Y	*$A*	379,000	385,000	46,000	4,754,000
Capital livestock	KLI	*no cows*	243	186	32	1,967
Labour	LAB	*weeks*	227	119	53	1,456
Land operated	LAN	*hectare*	290	391	36	5,079
Fodder expenditures	VFD	*$A*	83,000	161,000	200	2,494,000
Materials and services	MAT	$A	31,000	32,000	300	245,000
Plant and structure capital value	K	$A	121,000	107,000	4,000	949,000
Technical inefficiency model						
Area of farm utilized by the milking herd	SIZE	*hectare*	128	90	1	600
Number of cows milked at peak season	COWP	*no*	211	137	35	980
Feeding concentration	FEED	kg/cow	1,339	2,005	20	21,778
Proportion of irrigated to farm area	IRRI	%	15.4%	28.4%	0.0%	99.0%
Type of dairy shed						
• Swingover herringbone sheds			50.6%			
• Double unit (hi-line & low-line) herringbone sheds			22.1%			
• Rotary dairy sheds			17.8%			

Table 3: Generalised likelihood ratio tests of hypotheses for parameters of the stochastic cost frontier and technical inefficiency models

Null hypothesis	χ^2-statistic	$\chi^2_{0.99}$-value*	Decision
*Production function is Cobb Douglas (non-translog form)***	12.82	31.35	can not reject H_0
Cobb-Douglas production function with constant returns to scale			
$\beta_1 + \beta_2 + \ldots + \beta_6 = 1$	2.92	8.27	can not reject H_0
Restricted parameters of the stochastic cost frontier and technical inefficiency models			
$\gamma = \delta_0 = \delta_1 = \ldots = \delta_7 = 0$	39.04	22.53	reject H_0
$\delta_0 = \delta_1 = \ldots. = \delta_7 = 0$	65.54	20.97	reject H_0
$\delta_1 = \delta_2 = \ldots = \delta_7 = 0$	39.08	19.38	reject H_0
$\gamma = 0$	19.32	8.27	reject H_0

Note: *(*) The critical values are obtained from Table 1 of Kodde and Palm (1986). (**) The null hypothesis (H_0) hypothesis is that all translog coefficients, or the fifteen pairs of translog relationships livestock capital, labour, land area, fodder expenditures, material and services expenditures and plant and structure capital are zero.*

Table 4: Estimated results of the stochastic production function frontier model

Variables are in Log Form

Variables	Maximum Likelihood Estimate			
	Model 1		Model 2	
	Coefficient	T-ratio	Coefficient	T-ratio
Constant	5.12*** *(0.20)*	25.35	5.01*** *(0.20)*	24.10
Livestock capital	0.50*** *(0.03)*	13.65	0.50*** *(0.03)*	12.88
Labour	0.18*** *(0.03)*	4.83	0.19*** *(0.03)*	5.20
Land	0.06*** *(0.02)*	3.14	0.07*** *(0.02)*	3.36
Fodder	0.14*** *(0.01)*	12.88	0.14*** *(0.01)*	12.79
Materials and services	0.10*** *(0.01)*	7.45	0.10*** *(0.01)*	7.30
Plant and structure capital	0.07*** *(0.01)*	4.04	0.06*** *(0.01)*	3.81
Dummy variable of the 1998 drought	-0.10*** *(0.03)*	3.53		

Notes: **, ** and *** denote statistical significance at the 0.10 level, 0.05 and 0.01 level respectively. Numbers in parentheses are asymptotic standard errors.*

Table 5: Estimated results of the technical inefficiency model

Variables	Maximum Likelihood Estimate			
	Model 1		Model 2	
	Coefficient *(scaled by E+02 units)*	T-ratio	Coefficient *(scaled by E+02 units)*	T-ratio
Constant	33.03** *(7.59)*	4.35	38.5*** *(8.88)*	4.33
Area of farm utilized by the milking herd	0.01 *(0.02)*	0.02	0.01 *(0.03)*	0.25
Number of cows milked at peak season	-0.04* *(0.27)*	1.48	-0.05* *(0.03)*	1.59
Swingover dairy shed	-16.61*** *(5.80)*	2.84	-22.02*** *(7.52)*	2.92
Herringbone (hi-line and lo-line) dairy shed	-12.20** *(6.03)*	2.02	-13.48** *(7.30)*	1.84
Rotary dairy shed	-13.01* *(8.99)*	1.45	-14.73* *(11.43)*	1.28
Feeding (grain) concentration per cow	-0.01*** *(0.00)*	4.53	-0.01*** (0.00)	6.45
Proportion of the irrigated area	-13.37** *(9.7)*	1.37	-30.09*** *(9.01)*	3.33
	Estimated results of			
	Coefficient	T-ratio	Coefficient	T-ratio
Sigma-squared	0.05*** *(0.00)*	13.03	0.05*** *(0.00)*	13.94
Gamma	0.32*** (*0.09)*	3.32	0.38*** *(0.10)*	3.67
Ln (likelihood)	41.33		35.56	
Mean Technical Efficiency (per cent)	87.39		84.95	

Notes: **, ** and *** denote statistical significance at the 0.10 level, 0.05 and 0.01 level respectively. Numbers in parentheses are asymptotic standard errors.*

Table 6: Average technical efficiency New South Wales

	New South Wales		Region 11		Region 12		Region 13	
	No obs	Efficiency	No obs	Efficiency	No obs	Efficiency	No obs	Efficiency
1996	40	88.4%	9	87.8%	23	88.0%	8	89.9%
1998	63	87.9%	17	84.6%	33	89.3%	13	88.5%
2000	63	88.8%	16	84.4%	34	89.5%	13	92.4%
Obs/Mean	166	88.4%	42	85.2%	90	89.0%	34	90.4%

Table 7: Average technical efficiency Victoria

	Victoria		Region 21		Region 22		Region 23	
	No obs	Efficiency	No obrs	Efficiency	No obs	Efficiency	No obs	Efficiency
1996	88	87.2%	29	90.9%	33	86.0%	26	84.6%
1998	79	85.9%	28	86.6%	30	86.2%	21	84.6%
2000	82	87.1%	29	91.2%	26	84.7%	27	85.0%
Obs/Mean	249	86.8%	86	87.2%	89	85.9%	74	84.7%

Table 8: Summary characteristics of efficiency groups

No	Average value of farm features	Unit	Efficiency of farm group		
			low	medium	high
			>69% to 82%	83% to 92%	>92%
I	**Total output**				
	Total output	*$A*	168,000	332,000	744,000
	Milk output	*litres*	537,000	1,065,000	2,239,000
	Proportion income from milk in total output	*%*	91.5	93.5	95.9
II	**Cow and cow management practice**				
	Capital livestock	*no*	155	230	373
	Value of capital livestock	*$A*	144,000	221,000	366,000
	Number of cows milked at peak season	*no*	148	222	312
	Yield per cow milked for 3 months or more.	*ltrs/cow*	2,400	3,000	5,000
	Operation uses the management practice:				
	• synchronised oestrus (0 or 1)	*%*	13.6	38.2	49.3
	• inducing calves (0 or 1)	*%*	23.7	43.2	28.2
	• score (0 or 1)	*%*	28.8	40.0	53.5
III	**Labour**	*weeks*	186	216	306
IV	**Land**				
	Land area	*ha*	276	279	350
	Value of land	*$A*	1,047,000	1,381,000	1,842,000
	Land value per hectare (excluding houses)	*$A/ha*	5,200	5,100	6,000
	Proportion of the irrigated area operated		1.3	12.9	37.5
	Area of the farm utilised by the milking herd.	*ha*	101	129	164
V	**Feeding**				
	Fodder expenditures	*$A*	33,000	61,000	215,000
	Total grain and concentrates used per cow	*kg/cow*	600	1,000	3,000
	Hay and silage production per cow (silage equivalent)	*kg/cow*	3,200	3,300	3,700
VI	**Material and services expenditures**	*$A*	17,000	30,000	47,000
VII	**Capital**	*$A*			
	Capital and structure capital	*$A*	72,000	116,000	184,000
	Type of dairy shed				
	• Walkthrough (0 or 1)	*%*	50.8	2.1	1.4
	• Swingover (0 or 1)	*%*	16.9	59.3	43.7
	• Herringbone (0 or 1)	*%*	20.3	22.8	21.1
	• Rotary (0 or 1)	*%*	10.2	15.4	32.4
	Age of dairy shed	*year*	30	17	16
	Number of operators	*no*	1.7	1.8	2.1
	Number of bails	*no*	18	26	32
	Effluent system recycles waste (0 or 1)	*%*	15.3	22.1	19.7
	Effluent system uses a ponding system (0 or 1)	*%*	33.9	56.8	64.8