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# Technology choice and efficiency on Australian dairy farms*

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Deregulation of the Australian dairy industry, specifically the removal of price subsidies to 'market milk', as well as ongoing drought in many dairy regions, has placed considerable pressure on farm cash income and a search for ways in which dairy farms can be made to operate more efficiently. Using traditional farm survey data and a unique biannual data set on farm technology use, this paper estimates a stochastic production frontier and technical efficiency model for dairy farms in New South Wales and Victoria, determining the relative importance of each input in dairy production, the effects of key technology variables on farm efficiency, and overall farm profiles based on the efficiency rankings of dairy producers. Results show that production exhibits constant returns to scale and although feed concentration and the number of cows milked at peak season matter, the key determinants of differences in dairy farm efficiency are the type of dairy shed used and the proportion of irrigated farm area. Overall farm profiles indicate that those in the 'high efficiency group' largely employ either rotary or swing-over dairy shed technology and have almost three times the proportional amount of land under irrigation.

**Key words:** Australian dairy farms, dairy production and efficiency, dairy technology, stochastic production frontier.

## 1. Introduction

The Australian dairy industry has been under considerable pressure lately. Deregulation has resulted in the removal of state government price subsidies to 'market milk' and a consequent fall in cash receipts. More importantly, the ongoing drought in many dairy regions has resulted in massive falls in incomes. The drought of 2002–2003 alone generated a fall in average cash income of over 75 and 60 per cent in Victoria and New South Wales respectively – the largest decline in farm cash income in more than 25 years (ABARE 2004).

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For those farms that have survived, the pressure to find productivity and efficiency gains has become irresistible. With world prices for milk expected to ease from current highs and to remain soft to at least 2010 (Ashton 2005), the pressure to improve performance will only continue.

Unfortunately, results from earlier research on productivity in Australian dairy are not very encouraging. Using an index number approach, Kompas and Che (2004) showed a significant increase in total factor productivity in the 1990s relative to the 1980s, but also clear evidence of a ‘productivity slowdown’ in the 1990s. This slowdown has continued to 2002–2003 (ABARE 2004). A drawback of the index number approach, however, is its inability to decompose changes in productivity because of technological advances from those that result from changes in efficiency or simply the seasonal weather patterns that may affect outputs and inputs. More to the point, there is no way to determine what drives productivity and efficiency differences.

In this paper, based on estimates of a stochastic production frontier and an associated inefficiency model, productivity levels are partially decomposed to allow for random effects and differences in levels of efficiency across dairy farms. The study concentrates on the main dairy regions in Australia: Victoria and New South Wales. It combines an annual farm survey with a unique biennial farm survey on technology use 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 effects of technology choice and other key drivers of efficiency differences on dairy farms, and overall farm profiles based on the efficiency rankings of dairy producers.

Section 2 of the paper provides a brief background on the dairy industry and the regional identifiers used in the database. Section 3 outlines the model to be estimated and defines production and efficiency measures. Section 4 describes the dataset 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 dataset of 415 observations for 252 dairy farms in a biennial sequence for the years 1996, 1998 and 2000. Section 5 sets out the econometric specification and estimated results and section 6 provides a discussion of the results, including a comparison of efficiency levels and a profile of Australian farms based on efficiency differences. The results highlight the importance of dairy shed technology and the role of irrigation and water availability.

## 2. Background

Dairy is one of Australia’s most important agricultural industries with a farm gate production value of $A2.8 billion in 2004 (ABS 2005). Australia is also the third largest dairy product exporter in the world, with export sales of processed milk and manufactured dairy products of $A2.4 billion in 2004 (ADIS 2005). Throughout the 1990s, the gross value of the industry expanded significantly, almost doubling, with average annual growth rates of 5 per cent for output and 4 per cent for cow numbers (Kompas and Che

2004). With deregulation and the ongoing drought, the number of dairy farms has almost halved in the past two decades, with an overall 78 per cent increase in milk production per farm since 1991–1992 (ABARE 2004). Although dairy production is well developed in every state, Victoria and New South Wales are dominant; accounting for more than 75 per cent of milk output, 76 per cent of dairy farms and 76 per cent of cow numbers (ADC 2005).

In terms of the dataset, and based on production systems and natural conditions in New South Wales and Victoria, dairy producers are divided into dairy regions by ABARE. In Victoria, Region 21 (Goulburn–Murray) 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 dairy regions. Region 22 in southern Victoria includes the south-west areas where production is mainly pasture based. Region 23 in Victoria includes the Gippsland area where relatively few farms have irrigation.

Region 11 (north coast) and Region 12 (central and south coast) in New South Wales include the coastal areas, 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, much of which is based on irrigated grazing, includes the Murrumbidgee Irrigation Area and Murray Valley areas.

## 3. Summary of theoretical framework

Stochastic production frontiers were first developed by Aigner *et al.* (1977) and Meeusen and Van den Broeck (1977). Recently, there has been widespread application of stochastic production frontiers to assess firm inefficiencies in various agricultural and industrial settings (e.g., Battese and Coelli 1992; Coelli and Battese 1996; Kong *et al.* 1999). 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 $\beta$ 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 $\beta$ 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.

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),

$$u_{it} = \delta_0 + z_{it}\delta \tag{2}$$

defines an inefficiency distribution parameter for $z_{it}$ a vector of firm-specific effects that determine technical inefficiency and where $\delta$ 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.

The technical efficiency ($TE$) of the $i$th firm in the $t$th period can be defined as

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

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

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

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 $\phi(\cdot)$ the distribution 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 across farms.

## 4. Database and variable summary

The unbalanced panel dataset used in this study was extracted from ABARE annual farm 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 whereas 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

**Table 1** Description of variables

| | Variables | Description |
|---|---|---|
| Frontier production function | | |
| *Y* | \$A | Total output: gross value from milk and dairy cattle sold |
| *KLI* | No. cows | Capital livestock |
| *LAB* | week | Total labour, including hired labour |
| *LAN* | ha | Land operated as of June 30 |
| *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* | ha | Area of farm utilised by the milking herd |
| *COWP* | No. | Number of cows milked at peak time |
| *SWING* | | = 1 for swing-over herringbone dairy sheds<br>= 0 for other |
| *HERRING* | | = 1 for double unit hi-line and low-line herringbone dairy sheds<br>= 0 for other |
| *ROTARY* | | = 1 for rotary dairy sheds<br>= 0 for other |
| *FEED* | kg/cow | Feeding concentration average (grains) |
| *IRRI* | per cent | Proportion of the total area operated that is irrigated |

during the year) and cattle sold. ABARE surveys are carried out only for dairy farms where more than 80 per cent of income is derived from dairy products directly, so for the most part farms with large breeding programs are excluded and output is mainly milk. Total gross milk income is calculated at the manufacturing price, since price-subsidised ‘market milk’ is distorted and there is no fundamental difference between the two products (ABARE 2001).

Input variables consist of six major components: livestock capital, land area, labour, fodder expenditures, materials and services, and plant and structure capital. Livestock capital (*KLI*) measures the total number of dairy cattle on hand as of June 30 of each year. Land (*LAN*) is farm area operated as of June 30 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 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*), valued at the time of the survey, is defined as ‘plant and structure capital, which includes buildings, machinery, vehicles and other capital stock items, such as the value of plant and structure capital as well as the value of the dairy shed and irrigation system’, depreciation adjusted (Kompas *et al.* 2001, p. 86). All values are in constant prices indexed by base year 1996. The price deflators used for inputs (including indexes for seed, fodder, livestock,

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

| Variables | | | Mean | SD | Minimum | Maximum |
|---|---|---|---|---|---|---|
| Frontier production function | | | | | | |
| Total output | *Y* | $A | 379 000 | 385 000 | 46 000 | 4 754 000 |
| Capital livestock | *KLI* | no cows | 243 | 186 | 32 | 1967 |
| Labour | *LAB* | weeks | 227 | 119 | 53 | 1456 |
| Land operated | *LAN* | hectare | 290 | 391 | 36 | 5079 |
| 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 | *K* | $A | 121 000 | 107 000 | 4000 | 949 000 |
| Technical inefficiency model | | | | | | |
| Area of farm utilised by 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 | 1339 | 2005 | 20 | 21 778 |
| Proportion of irrigated farm area | *IRRI* | % | 15.4 | 28.4 | 0.0 | 99.0 |
| Type of dairy shed (percentage of farms) | | | | | | |
| • Swing-over herringbone sheds | *SWING* | | 50.6 | | | |
| • Double unit (hi-line and low-line) herringbone sheds | *HERRING* | | 22.1 | | | |
| • Rotary dairy sheds | *ROTARY* | | 17.8 | | | |

chemicals, plant equipment and labour) are constructed from the indexes of prices paid by farmers in Australia from 1996 to 2000 (ABARE 2003).

### 4.2 Variables in the technical inefficiency model

The technology survey conducted by ABARE consists of over 25 measured applications of farm technology, from the use of a computer to the type of dairy shed (Rodriguez and Riley 2001). In a number of cases, specific technology variables tested as insignificant determinants of efficiency (e.g., whether a farm effluent system recycles waste, the management practice of inducing and scoring calves, the practice of synchronised oestrus, the year a farm first used a computer, the use of the Internet, and the use of embryo transplants), and were excluded. Of those remaining (see Table 1), the key potential drivers of farm efficiency estimated in Equation (2) include farm size (*SIZE*), or area utilised by the milking herd, the number of cows milked at peak season (*COWP*), the type of dairy shed technology, classified as walk-through, swing-over (*SWING*), herringbone (*HERRING*), and rotary (*ROTARY*), feeding concentration (*FEED*) measured as total grain per cow, and the proportion of total area that is irrigated (*IRRI*). Summary statistics for all relevant variables are indicated in Table 2.

## 5. Econometric specification and estimated results

Based on the theoretical framework (section 4), generalised likelihood ratio tests are used to help confirm the functional form (e.g., general translog, linear homogeneous, constant elasticity of substitution) and specification. The correct critical values for the test statistic from a mixed $\chi^2$ distribution (at the 5 per cent level 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, labour (weeks worked), 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. A specification with regional dummy variables was also attempted, but proved inferior (on likelihood ratio tests) to the specification given by Equation (5). The technical inefficiency model or Equation (2) is specified by

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

**Table 3** Generalised likelihood ratio hypotheses tests for the stochastic production frontier and technical inefficiency models

| Null hypothesis | $\chi^2$-statistic | $\chi^2_{0.99}$-value* | Decision |
|---|---|---|---|
| Production function is Cobb–Douglas (non-translog form)** | 12.82 | 31.35 | cannot reject $H_0$ |
| Cobb–Douglas production function with constant returns to scale<br>$\beta_1 + \beta_2 + \ldots + \beta_6 = 1$ | 2.92 | 8.27 | cannot reject $H_0$ |
| Parameter restrictions for the stochastic production 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 $H_0$ |

**Notes:** (*) The critical values are obtained from Table 1 of Kodde and Palm (1986). (**) The null hypothesis ($H_0$) is that all translog coefficients, or the 15 pairs of translog relationships among livestock capital, labour, land area, fodder expenditures, material and services expenditures, and plant and structure capital are zero.

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, swing-over, herringbone, and rotary dairy sheds, the measure of feeding concentrates (average kilogram of grain per cow) and the proportion of irrigated area. Although not selected by likelihood ratio tests, a specification with regional dummies included in the inefficiency model generated results similar to the specification that includes the proportion of irrigated area in Equation (6).

Additional likelihood ratio (*LR*) tests are summarised 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 FRONTIER 4.1 (see Coelli *et al.* 1998). Results for the stochastic production frontier model (Equation 5) are reported in Table 4. Two different cases are reported, one with (model 1) and one without (model 2) a dummy variable to account for the 1998 drought in Victoria. Both models are reported since it is not necessarily clear to what extent drought conditions in Victoria in 1998 affected farms in the survey database, since rainfall levels for individual farms are not available.

**Table 4** Estimated results for the stochastic production frontier model

| | Maximum likelihood estimates | | | |
|---|---|---|---|---|
| | Model 1 | | Model 2 | |
| Variables (log form) | Coefficient | T-ratio | Coefficient | T-ratio |
| Constant | 5.12***<br>*(0.20)* | 25.35 | 5.01***<br>*(0.20)* | 24.10 |
| Livestock capital | 0.50***<br>*(0.03)* | 13.65 | 0.50***<br>*(0.03)* | 12.88 |
| Labour | 0.18***<br>*(0.03)* | 4.83 | 0.19***<br>*(0.03)* | 5.20 |
| Land | 0.06***<br>*(0.02)* | 3.14 | 0.07***<br>*(0.02)* | 3.36 |
| Fodder | 0.14***<br>*(0.01)* | 12.88 | 0.14***<br>*(0.01)* | 12.79 |
| Materials and services | 0.10***<br>*(0.01)* | 7.45 | 0.10***<br>*(0.01)* | 7.30 |
| Plant and structure capital | 0.07***<br>*(0.01)* | 4.04 | 0.06***<br>*(0.01)* | 3.81 |
| Dummy variable for the 1998 drought | –0.10***<br>*(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.

For reporting purposes, model 1 is generally taken as the preferred model. Estimated results for the technical inefficiency model, Equation (6), are reported in Table 5. A negative sign on a coefficient indicates that an increase in the value of that variable results in a fall in inefficiency; a positive value an increase in inefficiency. 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. This is broadly consistent with the ‘neutral shift’ of the production frontier found for New England dairy farms in Bravo-Ureta and Rieger (1990).

## 6. Production and efficiency of Australian dairy farms

Based on the estimated results there are a number of key issues to address: (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 confirm likelihood ratio tests for constant returns to scale, implying no scale effects in the size of operation or that farm size and output are proportional (at least for the estimated or 'local' results presented here), with no evidence for economies of size or cost savings due to farm size. In more general terms, productivity change will thus depend on improvements in technology and efficiency, and not necessarily on larger or smaller farm size.[1]

All input variables are measured in log form, so that estimated coefficient values represent 'share parameters' or elasticities. Thus, for model 1 (Table 4), 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). Examining cost shares over the survey period as well as in more recent ABARE survey data shows only slight changes in share coefficients and generally confirms that constant returns to scale holds. For New South Wales in 2002–2003, for example, the cost shares for livestock capital, labour, land, fodder, materials and services, and plant and structure are 0.42, 0.12, 0.08, 0.18, 0.13, and 0.07, respectively. In Victoria, over the same period, the comparable values are 0.43, 0.13, 0.08, 0.16, 0.12, and 0.08, respectively. 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, and the use of feeding concentrates. Results are summarised in Table 5. For ease of reporting, numerical values are scaled by a factor of 100. Farm size in terms of the area of the farm utilised by the milking herd tested as insignificant.[2] The number of cows milked at peak season tested as significant, albeit at the 10 per cent level, suggesting that farm size in this sense does matter. The use of feeding concentrates also has an

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[1] This is consistent with a study by Jaforullah and Devlin (1996), estimating a stochastic production frontier without a technical inefficiency model, showing that despite an industry trend towards larger dairy farm size in New Zealand, the dairy farm sector is characterised by constant returns to scale. For New England dairy farms, Bravo-Ureta and Rieger (1990) also find that constant returns to scale cannot be rejected for year 1982, but can be for the 1983 sample. Alternatively, 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.

[2] Jaforullah and Devlin (1996) also find no relationship between farm size and efficiency for New Zealand dairy, for 1991–1992 data. Alternatively, Kumbhaker *et al.* (1989) and Kumbhaker *et al.* (1991), using 1985 data for dairy farms in the USA, find that larger farms are more technically efficient.

**Table 5** Estimated results for the technical inefficiency model

| | Maximum likelihood estimates | | | |
|---|---|---|---|---|
| | Model 1 | | Model 2 | |
| Variables | Coefficient (*scaled by E + 02 units*) | T-ratio | Coefficient (*scaled by E + 02 units*) | T-ratio |
| Constant | 33.03**<br>*(7.59)* | 4.35 | 38.5***<br>*(8.88)* | 4.33 |
| Area of farm utilised by the milking herd | 0.01<br>*(0.02)* | 0.02 | 0.01<br>*(0.03)* | 0.25 |
| Number of cows milked at peak season | –0.04*<br>*(0.27)* | 1.48 | –0.05*<br>*(0.03)* | 1.59 |
| Swing-over dairy shed | –16.61***<br>*(5.80)* | 2.84 | –22.02***<br>*(7.52)* | 2.92 |
| Herringbone dairy sheds | –12.20**<br>*(6.03)* | 2.02 | –13.48**<br>*(7.30)* | 1.84 |
| Rotary dairy shed | –13.01*<br>*(8.99)* | 1.45 | –14.73*<br>*(11.43)* | 1.28 |
| Feeding (grain) concentration per cow | –0.01***<br>*(0.00)* | 4.53 | –0.01***<br>(0.00) | 6.45 |
| Proportion irrigated area | –13.37**<br>*(9.7)* | 1.37 | –30.09***<br>*(9.01)* | 3.33 |
| | Coefficient | T-ratio | Coefficient | T-ratio |
| Sigma-squared | 0.05***<br>*(0.00)* | 13.03 | 0.05***<br>*(0.00)* | 13.94 |
| Gamma | 0.32***<br>*(0.09)* | 3.32 | 0.38***<br>*(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 level, and 0.01 level, respectively. Numbers in parentheses are asymptotic standard errors.

effect on efficiency, although this often depends simply on weather and rainfall conditions, particularly on farms that have less irrigation.

The major determinants of efficiency differences are the type of dairy shed and the proportion of land irrigated. Dairy sheds are classified in the technology survey as walk-through (single unit), walk-through (double unit), swing-over 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 swing-over, 22 per cent herringbone units, 18 per cent rotary, and 9 per cent are walk-through. Estimated results indicate that swing-over, herringbone and rotary sheds are all efficiency enhancing – and certainly so compared to walk-through sheds – and of these, swing-over sheds have the largest coefficient (–16.61), followed by rotary (–13.01) and herringbone (–12.20). 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 swing-over units (Martin *et al.* 2000). There may be a simple explanation. 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. Because efficiency is measured as the difference between actual and maximum output, given the value of inputs and technology, rotary units may not be generating sufficient additional output, relative to their input requirements, compared to swing-over 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) under irrigation also tests as significant and substantial (–13.37). In the dataset, this proportion ranges greatly from 0 to 99 per cent. Recall that 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 estimates (although including relatively coarse regional rainfall levels in the estimates proved insignificant).

However, in the panel dataset, given weather conditions at the time, farms with a larger proportion of land under irrigation test as much more efficient, delivering more dairy output for a given amount of inputs. This may be doubly important given the (out of sample) recent and severe drought in Australia, with clear policy implications. Ongoing drought conditions in key dairy farming regions, for example, resulted in a dramatic 8.4 per cent fall in Australia-wide milk production in 2002–2003 relative to the previous year. However, in New South Wales, with a larger proportion of irrigated farming, the fall was only 3.1 per cent, compared to 11.1 per cent in Victoria with a more heavy dependence on rainfall (ADC 2003).

It is important to note in this regard that nothing precise is said on the efficiency of irrigation systems and it is unclear whether the ‘true’ cost of water – delivery charge versus market value – is reflected in the value of materials and services in the estimates. If available, the proper use of data on rainfall levels by farm would also be a useful extension to this study, especially for areas that are not irrigated. The relatively low value of $\gamma$ 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.

## 6.3 Estimated results for dairy farm efficiency

The maximum likelihood estimates provide measures of technical efficiency for each farm in the dataset, using Equations (3) and (4). The distribution of farm efficiency is normal (using a ‘best fit algorithm’) with a range of 69 to 99 per cent and a standard deviation of 5.40 per cent. Economic efficiency is relatively 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 New South Wales to Victoria there is a good deal of variation within a state and region. For New South Wales and Victoria combined, the mean value of efficiency is 87 per cent, with a range from 69 to 99 per cent. In New South Wales alone, the mean is 88 per cent, with a range of 71 to 99 per cent. In Victoria, the mean is 87 per cent with a range of 69 to 97 per cent. For New South Wales and Victoria combined, average efficiency in 1996, 1998 and 2000 is 88, 87 and 88 per cent, respectively. The larger standard deviation in New South Wales may be explained by the presence of less efficient farms due to previous quota (regulated) arrangements.

In an earlier study, by comparison, without the benefit of the technology use survey database and a smaller sample of 112 farms over three financial years 1978–1980, Battese and Coelli (1988) obtain an efficiency ranking of 77 per cent for New South Wales and 63 per cent for Victoria, with considerable variance among farms, especially in Victoria. The difference in efficiency levels over the years is undoubtedly largely explained by the adoption of new dairy shed technology. In the 1996–2000 dataset, for example, less than 10 per cent of dairy farms use (less efficient) walk-through sheds (see Table 2). In 1978–1980 this proportion was much higher.

Specific regional results for average technical efficiency are presented in Tables 6 and 7, allowing for a comparison among regions in each state. In Victoria, Region 21 (Goulburn-Murray), with a large proportion of land under irrigation, achieves the highest efficiency levels, and is a measure above Region 22 (southern Victoria) and 23 (Gippsland) in particular. In New South Wales there is little difference among regions. However, Region 13 (the irrigation districts of New South Wales in the Riverina) tests as the most efficient. The results generally confirm the important role of irrigation (and water availability in general) to this industry. Region 11 (north coast New South

**Table 6** Number of observations (Obs) and average technical efficiency in New South Wales

| | New South Wales | | Region 11 | | Region 12 | | Region 13 | |
|---|---|---|---|---|---|---|---|---|
| | Obs | Efficiency | Obs | Efficiency | Obs | Efficiency | 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 |
| Total/Mean | 166 | 88.4 | 42 | 85.2 | 90 | 89.0 | 34 | 90.4 |

**Table 7** Number of observations (Obs) and average technical efficiency in Victoria

| | Victoria | | Region 21 | | Region 22 | | Region 23 | |
|---|---|---|---|---|---|---|---|---|
| | Obs | Efficiency | Obs | Efficiency | Obs | Efficiency | 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 |
| Total/Mean | 249 | 86.8 | 86 | 87.2 | 89 | 85.9 | 74 | 84.7 |

Wales) reads as the lowest in efficiency, a value that unlike all other regions falls through time.

### 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 does vary considerably within a state or region, with a range roughly from 69 to 99 per cent 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 dataset provides a useful (overall) profile of dairy farms by efficiency ranking.

For convenience, efficiency rankings are divided into 'low' (69 to 82 per cent), 'medium' (83 to 92 per cent) and 'high' (greater than 92 per cent). The number of farms in each category is 70, 274 and 71, respectively (25, 98 and 43 for New South Wales and 45, 176 and 28 for Victoria). Summary characteristics for each efficiency group (by average values in that group) are arranged by the main categories of output and inputs in Table 8.

There are a number of points that arise from these farm profiles. First, as expected, dairy farms in the high-efficiency group use a high proportion of swing-over (43.7 per cent) and rotary (32.4 per cent) dairy shed technology. Those in the low-efficiency 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 dataset, or 16 years (32 bails) for high and 30 years (18 bails) for the low group. Second, also as expected, given the results of Table 5, farms in

**Table 8** Summary characteristics by efficiency groups

| Average value of farm characteristics | Unit | Efficiency of farm group<br>Low<br>> 69% to 82% | <br>Medium<br>83% to 92% | <br>High<br>> 92% |
|---|---|---|---|---|
| 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 |
| 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 | litres/cow | 2400 | 3000 | 5000 |
| 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 |
| Labour | weeks | 186 | 216 | 306 |
| Land | | | | |
| Land area | ha | 76 | 279 | 350 |
| Value of land | $A | 1 047 000 | 1 381 000 | 1 842 000 |
| Land value per hectare (excluding houses) | $A/ha | 5200 | 5100 | 6000 |
| 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 |
| Feeding practice | | | | |
| Fodder expenditures | $A | 33 000 | 61 000 | 215 000 |
| Total grain and concentrates used per cow | kg/cow | 600 | 1000 | 3000 |
| Hay and silage production per cow (silage equivalent) | kg/cow | 3200 | 3300 | 3700 |
| Material and services expenditures | $A | 17 000 | 30 000 | 47 000 |
| Capital | $A | | | |
| Capital and structure capital | $A | 72 000 | 116 000 | 184 000 |

**Table 8** *Continued*

| Average value of farm characteristics | Unit | Efficiency of farm group<br>Low<br>> 69% to 82% | Medium<br>83% to 92% | High<br>> 92% |
|---|---|---|---|---|
| Type of dairy shed | | | | |
| • Walkthrough | % | 50.8 | 2.1 | 1.4 |
| • Swing-over | % | 16.9 | 59.3 | 43.7 |
| • Herringbone | % | 20.3 | 22.8 | 21.1 |
| • Rotary | % | 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 | % | 15.3 | 22.1 | 19.7 |
| Effluent system uses a ponding system | % | 33.9 | 56.8 | 64.8 |

the high-efficiency group have the largest proportion of farm area irrigated (37.5 per cent), whereas those in the low-efficiency group have the smallest level of irrigation (1.3 per cent). Feed concentration (total grain and concentrates used per cow) and the number of cows milked at peak season are also largest for the high-efficiency group. Third, yield per cow is seen to be a good predictor of farm efficiency. Yields for the high, medium and low-efficiency groups are 5000, 3000 and 2400 litres per cow respectively. Finally, 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, note that in many cases these characteristics will simply imply more dairy output and not necessarily more efficient production. In fact, the stochastic frontier results (with estimated constant returns to scale and cost shares that correspond) and the technical inefficiency model provide no evidence that larger farm size (in terms of area) lowers per unit costs or increases technical efficiency, although ‘size’ in the sense of cows milked at peak season does matter for efficiency. A useful extension of this work would be to examine measures of allocative efficiency, since getting the right mix of different inputs (e.g., stocking rates, feed concentrates) may be especially difficult in this industry, and may greatly affect the cost of production. Unfortunately, ABARE survey data are not readily amenable to estimates of stochastic cost frontiers.

## 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 largest 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.

Although mean efficiency levels vary little between New South Wales and Victoria, there are considerable efficiency differences among dairy farms within states or regions. For those farms looking for efficiency gains, the principal determinants of efficiency differences are dairy shed technology, the proportion of land irrigated, feed concentration, and the number of dairy cows milked at peak season. Overall farm profiles indicate that those in the high-efficiency group employ either rotary or swing-over dairy shed technology and have almost three times the proportional amount of land under irrigation. In terms of efficiency, the only measure of ‘size’ that matters is the number of cows milked at peak season. In other words, although it is true that the high-efficiency group contains large farms, these farms are efficient not because they are large in area but because they use better dairy sheds, rely more on irrigation and feeds, and milk more cows at peak season.

Finally, in terms of overall regional comparisons, New South Wales has a higher proportion of dairy farms in the high-efficiency group compared to Victoria. This can be mostly explained by the larger proportion of irrigated areas in New South Wales, and it may also partly explain why although the number of farms has fallen more dramatically in New South Wales between the years 2000 and 2004 (1725 to 1270 farms), compared to Victoria (7806 to 6242 farms), annual milk production has increased in New South Wales (4827 to 4983 litres per cow) and fallen in Victoria (4989 to 4871 litres per cow) (ABS 2005). In any case, for both production and efficiency, water and its availability is clearly a large part of the story in the Australian dairy industry, and a major challenge for domestic policy.

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