Investigating technical and scale efficiency of dairy farms in south-western Victoria: a non-parametric approach

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The aim of this article is to investigate issues related to technical efficiency and scale of dairy farms in south-western Victoria, Australia. Data envelopment analysis (DEA) is the technique used and is applied to a sample of 59 farms in the 1999-2000 lactating season. The key result is that 51 per cent of the farms are operating at optimal scale, 34 per cent are below and 15 per cent are above optimal scale. On average, the optimal size for a south-western dairy farm is estimated at a land area of 215 hectares with a dairy herd of 305 animals, assuming the optimal input use for other inputs. Average overall technical efficiency is high for the sample; estimated at 94 per cent.

1. Introduction

In recent years there have been a number of changes to the Australian dairy industry. Historically, the industry has been highly regulated and has seen substantial restructuring over the past 20 years. July 1, 2000 brought significant reforms and with recent drought conditions, many farmers have been suffering from losses in average cash income. These pressures have resulted in the number of dairy farms almost halving in the past two decades, with an overall 78 percent increase in milk production per farm since 1991-92 (ABARE 2004). This is a common trend for dairy farms not only in Australia, but in other major dairying countries, such as New Zealand and Canada, where structural changes have resulted in a trend where dairy farms have both decreased in number and increased in size. For those farms that have survived the pressure, finding better farm management practises is arguably becoming more important than ever.

Comparative farm analysis, or benchmarking, is common practice to try to identify scope for improvements in farm management. Various benchmarking techniques are available and widely used, not only in the agricultural sector but also in other industries where benchmarking is of interest. However, there is much discussion about its value as a management tool, the choice of different estimation methods[1] and how relevant these techniques are for the agricultural sector.[2] This paper utilises data envelopment analysis (DEA), a common non-parametric approach to benchmark analysis to examine the relationship between farm size and efficiency. In 1970-71, the average Australian dairy herd size per farm was 71 head of dairy cattle. Since then, there has been a steady increase in which by 2001-02 the average number of dairy cattle per farm had risen to

[1] The three most common techniques used in benchmark analysis in agriculture are stochastic production frontier (SPF) methodology, Malmquist total factor productivity indices approach and data envelopment analysis (DEA).
[2] See Mbaga et al. (2003) for a discussion about the benefits and flaws of DEA and SPF methods.

263 (ABS 2004). This trend toward larger dairy farms may indicate that there are efficiency gains from larger farms. If this is the case, DEA is a tool that can explore these issues related to efficiency and farm size.

Malcolm (2004) discusses the importance of the role economics plays in farm-management analysis and how economic illiteracy is abundant in farm analysis. He discusses how failure to understand that economics is the core discipline of farm management analysis and failure to apply the whole farm approach leads to the wrong questions being asked and the wrong answers being given. DEA is useful as it captures the efficiency of a whole farming system rather than partial-productivity measures that are quite common in agriculture. For example, narrow-based partial measures such as 'output per hectare' or 'output per cow' say little about the efficiency of a dairy farm's productivity as it does not consider the total inputs that were used to create the output. Additionally, these simple ratios do not allow easy identification of the factors which influence these measures[3]. This paper will investigate the farming systems in the south-western region of Victoria and address issues of optimality in production. That is, an investigation of current farming systems used in the region and an attempt to answer questions, such as what is the optimal size of a farm and what mix of inputs are optimal. These issues are of interest to the dairy industry in the south-west region.[4]

Analysing real farming system with DEA can provide a powerful insight into agricultural systems relative to other farms in the region. Farrell (1957) argues that this is more appropriate as it compares a farm's performance with the best actually achieved rather than with some unattainable ideal. This paper mainly focuses on a dataset for a sample 59 farms in the south-west dairy region for 1999-2000 and additionally analysing additional samples, 1996-97, 1997-98, and 1998-99 to test the validity of the results in other years.

There are two primary objectives of this paper. First, to assess technical efficiency of dairy farms in the sample, this will allow identification of the most efficient farms and the underlying reasons for the increased efficiency. Second, I will investigate scale efficiency of the sample dairy farms which will allow estimation of an optimal size for a dairy farm in the south-west region.

2. Definitions of efficiency

This paper is concerned with two types of efficiency; technical efficiency and scale efficiency. Technical efficiency can be examined from an input-orientation or from an output-orientation. Input-orientated technical efficiency means a farm minimises the quantity of inputs, while holding output constant. An output-orientation implies a farm maximises output, given the current quantity of inputs which remain fixed. It is more or

[3] In relation to dairy farming Kerr et al. (1995) has drawn attention to some of the difficulties in using various partial-productivity measures.
[4] The idea for this article stems from WestVic Dairy. WestVic Dairy is one of the three major dairy farming cooperatives in Victoria, Australia. Its area of specific interest is the south-western region of Victoria. WestVic are interested in expanding their knowledge of the available techniques that can more accurately reflect the efficiency and productivity of dairy farms in its region.

less a different way of looking at the same issue. For this type of farm analysis it is seemingly more common to use an input-orientated approach.[5]

Scale efficiency refers to the optimal size of a diary farm. Scale efficiency assumes a farm is operating under a variable returns to scale production frontier which implies that an optimal scale for production exists. Farms that are operating in the increasing returns to scale portion of the production function can increase efficiency by increasing the size, or scale, of their farm. Farms operating in the decreasing returns to scale portion of the frontier will be able to increase scale efficiency by reducing the size of the farm.

Allocative efficiency is another key definition of efficiency that is common in economic literature. Allocative efficiency is the ability of a farm to optimise on the use of inputs given their respective prices. A simple example may be if two inputs, labour and capital, are used to produce an output, milk. If the price of labour increases, then achieve allocative efficiency it would be optimal to substitute a certain amount of labour for capital in order to minimise total cost. Given unit input prices are accessible allocative efficiency can also be estimated using DEA for farms in the region. However, allocative efficiency requires input unit price information which was not available for this study. Allocative efficiency has been omitted from the analysis as it is outside the scope of this paper.

3. Measuring efficiency with DEA

3.1. Data envelopment analysis

DEA is a benchmarking technique based on the non-parametric mathematical programming approach to frontier estimation. It posits that the efficiency of a decision-making unit, or in this case a farm, is measured relative to the efficiency of all other farms. This relative measure is subject to the restriction that all farms are on or below the frontier. The definitions of efficiency can be traced back to Farrell (1957) who introduced a simple method for measuring the efficiency of a farm[6] directly from observed data. He used a single output case taking into account multiple inputs. He proposed that the efficiency of a farm consisted of both technical efficiency and allocative efficiency. It is these two measures that are combined to provide a measure of total economic efficiency. Since the work of Farrell there has been much development of this benchmarking technique. The DEA methodology was formally developed and named by Charnes et al. (1978), where efficiency was defined as the weighted sum of outputs over a weighted sum of inputs, where the weight structure is calculated by the means of mathematical programming and constant returns to scale (CRS) were assumed. Banker et al. (1984) extended the model to include variable return to scale (VRS) which allowed for optimisation of farms based on size. Since then, the methodology has been extended to accommodate multiple outputs as well as multiple inputs and additionally, with the

[5] This claim is based on studies identified whilst undertaking the literature review. See Jaforullah and Whiteman (1999), Mbaga et al. (2003) and Weersink et al. (1990).

[6] Farrell (1957) discussed efficiency of a firm in his original analysis. Farm is used throughout as it is the focus of the paper.

advancements in computer software DEA calculations have become less of a barrier to analysts.

Malcolm (2005) discusses an issue in agriculture where many farmers fail to acknowledge that maximum output is not the optimum. To address this issue a second objective of the paper is to investigate the scale efficiency of the dairy farms in the sample. This measure of scale efficiency examines the optimal size of a dairy farm for the south-west dairy region. If a farm is operating at optimal scale there will be no efficiency gains from changing the size of the farm. Farms that are operating at the optimal size are operating on the CRS portion of the VRS production function and will have a scale efficiency score equal to one. This indicates that they are neither experiencing increasing nor decreasing returns to scale in production and hence cannot increase efficiency by changing the size of the farm. Farms with scale values of less than one indicate non-constant returns to scale. A scale value less than one can indicate one of two outcomes. First, the farm may be operating in the increasing returns to scale portion of the VRS frontier, it can increase efficiency by increasing the size of the farm. Alternatively, the farm may be operating in the decreasing returns to scale portion of the production frontier, it can increase efficiency by decreasing the size of the farm.

3.2. A simple explanation of benchmarking performance with DEA

Figure 1 illustrates a DEA example for 59 sample farms in the south-west dairy region for the period 1999-2000. For illustrative purposes this is a simple one input, one output model. The input is 'cows,' which is the number milked on a farm and the output is 'net milk income' represented in dollar values. Figure 1 is a scatter-plot which graphs the two variables against each other for each individual farm. As one would expect, there is a positive trend between the variables in which as the number of cows increases, net milk income for the farm also increases.

First, the DEA methodology will make individual calculations for farm efficiency based on the assumption of a CRS production frontier. We can observe in figure 1 that the CRS frontier is estimated by achieving the maximum gradient, or envelope, of the frontier by passing through the farm of which what is deemed the benchmark farm for the sample. This frontier 'envelops' all of the data, meaning all farms must lie on or below the frontier. We can observe the benchmark farm under CRS as farm F*. This farm receives a technical efficiency score of unity or 1, hence this is the only farm on the CRS frontier meaning all other farms receive a technical efficiency score of less than one depending on their position relative to the frontier. Farms further away receive a lower score.

Second, the same exercise is calculated using a VRS frontier specification. Like CRS, a VRS frontier is estimated that 'envelops' all the data, but will be a tighter fit of the data as observed in figure 1. In this example, more farms are on the VRS frontier, however when the model becomes multi-dimensional (more than a single input and output) this is not always the case.

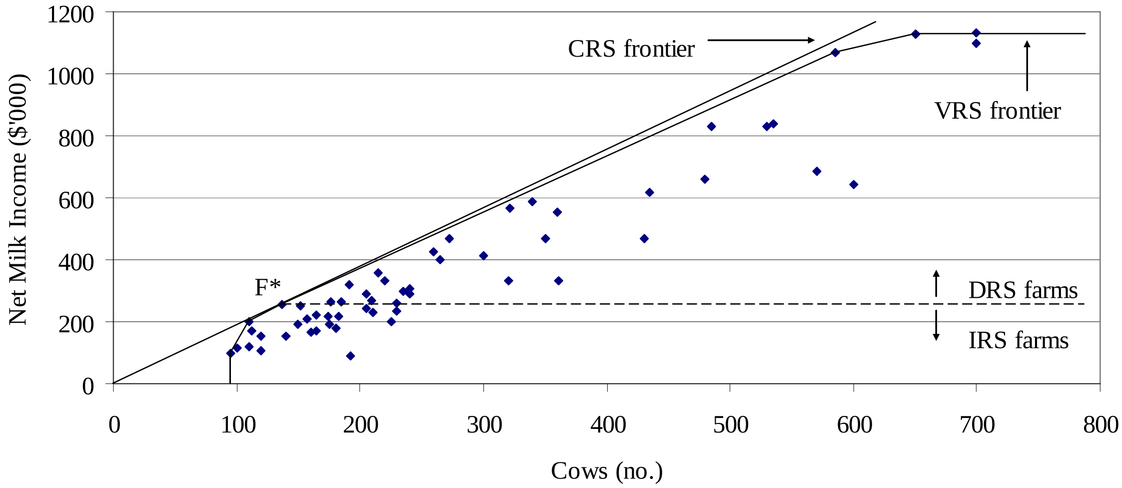

Figure 1 One input, one output, simple two-dimensional DEA model, 1999-2000

As for CRS, farms on the VRS frontier receive a technical efficiency score of 1. There are more technically efficient farms under the VRS assumption. Farm F* is the benchmark farm for the sample. This is the only farm which is both efficient under CRS and VRS and additionally the only farm which is scale efficient. For this sample, farm F* is in a unique situation as it cannot increase efficiency by changing the inputs/output mix or the size of the farm. The farms underneath the dashed line are operating in the increasing return to scale portion of the frontier. This means that a farm can become more efficient by increasing the size, or scale, of its operations. Above the dashed line are the farms operating in the decreasing returns to scale portion of their frontier and coincidently can increase efficiency be reducing the size of their farms.

All farms receive two technical efficiency scores that are less or equal to 1. The farms inside the VRS frontier obtain a score based on how far away they are relative to the CRS frontier and a score relative to the VRS frontier. The VRS score will always be higher or equal to the CRS score. The reason for this is that farms are estimated to be more efficient under VRS as they are closer to the frontier.

This one input, one output model is a very simple representation of dairy farming and hence does not reflect, or capture, what is happening in reality. The purpose of explaining this simple model is to illustrate conceptually the DEA methodology in a format that makes the underlying process easy to understand. This paper estimates a specification that much more accurately reflects true dairy production than in the above example. This is a six input, two output model. Due to the multi-dimensional nature of the model it is not possible to graphically represent it in a simple form as explained in figure 1. The general implication of having more inputs and/or outputs is that the DEA program will estimate more that one farm on the CRS frontier because is that it is likely that one farm will not be the sample minimiser in all inputs, but rather different farms will be in different inputs. That is, some farms are better at managing different inputs than others and so more farms will be on the frontier. The multi-dimensional nature of the model means that it is not as simple as to which farm is most efficient as we have seen in the one input one output model. Effectively the process recognises that different inputs/output mixes can be used to be efficient, meaning there is not necessarily only one way to be technically or scale efficient.

4. The mathematics of DEA

DEA utilises linear programming methods to construct a non-parametric production frontiers over the data. In this paper the methodology of Fare et al. (1985) is used to measure the technical efficiency and scale efficiency of south-western dairy farms. This section is an adaptation which also draws upon the methodology used in Jaforullah and Whiteman (1999).

To obtain estimates of technical efficiency and scale efficiency three models with different types of scale behaviour are to be calculated. First, we will assume that there are P number of inputs that make up the input mix to produce M number of outputs for N number of dairy farms. Therefore let Y be a matrix of outputs $(M \times N)$ to represent the data for all farms in the south-western region with element y_{ij} representing the ith output of the jth dairy farm. Let X be a matrix of inputs $(P \times N)$ with elements x_{kj} representing the kth input of the jth dairy farm, y^j be a $(M \times 1)$ vector of outputs, and x^j be the $(P \times 1)$ vector of inputs of the jth dairy farm.

In order to obtain an estimate of the CRS input-orientated approach we must solve the following linear mathematical programming problem:

$$\begin{aligned} \lambda_c^j &= \min\nolimits_{\lambda,z} \lambda \\ \text{s.t.} \quad y^j &\le Yz \\ Xz &\le \lambda x^j \\ z &\in R_+^N \end{aligned} \qquad (1)$$

where:
c indicates a CRS specification.
λ = a scalar containing the efficiency score
$Y = (M \times N)$ – a matrix of outputs for the sample
$X = (P \times N)$ – a matrix of inputs for the sample
$y^j = (M \times 1)$ – a vector of outputs for the jth farm
$x^j = (P \times 1)$ – a vector of inputs for the jth farm
$z = (N \times 1)$ – vector of weights to be estimated
R_+ = a positive real number

Maximum technical efficiency occurs when λ_c^j is equal to unity. This means that under the CRS assumption, within this sample, this farm is technically efficient, indicating that it is operating at best practice and cannot increase efficiency by taking action to change its input/output mix. The linear programming problem must be solved *N* times, once for each farm in the sample, and hence a value for λ_c^j is obtained for each farm.

When λ_c^j is less than unity the DEA results suggest that the farm is operating at below best practice. This means that potential efficiency gains can be achieved by emulating the input/output mix of those farms that are benchmark partners (peer farms) within the sample.

The scalar value λ represents a proportional reduction in all inputs such that $0 \le \lambda \le 1$, and λ_c^j is the minimising value of λ that indicates the degree of reduction in inputs that are required to achieve technical efficiency. $(\lambda_c^j \times x^j)$ represents the vector of technical efficient inputs of the *j*th dairy farm. In other words, this will show the possible reduction in inputs if the farm were to become technically efficient.

Unique benchmarks are constructed for each farm in the sample when the linear programming problem is solved. A benchmark can reflect the contributions of a number of farms however, only best-practice farms, that is $\lambda = 1$, can contribute to the benchmark of individual farms. The reason is because the performance of a non-best practice farm can be improved upon, and hence will not be a benchmark for any farms.

The second exercise is to calculate the VRS input-orientated measure. CRS is only appropriate when all farms are operating at an optimal scale. Coelli et al. (1998) suggest reasons such as imperfect competition and constraints on finance may mean a farm is not operating at an optimal scale. Another reason may be that it simply takes time to adjust to optimal scale. The use of VRS specification permits the calculation of technical efficiency free from these scale efficiency effects. VRS is calculated using a similar approach to CRS with the same inputs matrix, *X*, and output matrix, *Y*. It is solved for each farm as the solution to the following.

$$\begin{aligned} \lambda_v^j &= \min_{\lambda,z} \lambda \\ \text{s.t.} \quad y^j &\le Yz \\ Xz &\le \lambda x^j \\ lz &= 1 \\ z &\in R_+^N \end{aligned} \tag{2}$$

Where:
v indicates a VRS specification
$l = (1 \times N)$ vector of ones

Here *lz* = 1 is a convexity constraint to account for VRS. The VRS specification envelops a VRS frontier around the data points as shown in figure 1. This approach forms a convex hull of intersecting planes which envelope the data points more tightly than under CRS. This will produce technical efficiency scores that are either equal to, or greater than, those obtained under the CRS specification. The convexity constraint also ensures that an inefficient farm is only benchmarked against farms of similar size. This convexity restriction is not imposed under CRS DEA and so a farm may be benchmarked against farms which are substantially larger or smaller than it.

Scale efficiency is calculated from the results of the two technical efficiency estimates for each farm. As seen in equation 3, the scale efficiency of the *j*th farm is CRS technical efficiency for the *j*th farm divided by the VRS technical efficiency of the *j*th farm.

$$S^j = \lambda_c^j / \lambda_v^j \tag{3}$$

If there is a difference in the CRS and VRS technical efficiency scores for a farm, then this implies the farm is exhibiting scale inefficiency. If this value is unity then the *j*th farm is scale efficient (i.e. $S^j = 1$). This indicates that the dairy farm is operating at an efficient size and therefore there are no efficiency gains to be made by increasing or decreasing the farm size. If this value is less than unity, then farm efficiency can be improved upon by changing the scale of the farm. One shortcoming of this scale efficiency measure is that it does not indicate whether the farm is operating in the increasing or decreasing returns to scale portion of the production frontier. To determine whether the farm should increase or decrease the size of the farm we need to estimate non-increasing returns to scale (NIRS), a third type of specification. The NIRS technical efficiency for the *j*th south-western dairy farm is calculated as the solution to the following mathematical programming problem.

$$\begin{aligned} \lambda_n^j &= \min_{\lambda,z} \lambda \\ \text{s.t.} \quad & y^j \le Yz \\ & Xz \le \lambda x^j \\ & lz \le 1 \\ & z \in R_+^N \end{aligned} \tag{4}$$

Where:
n indicates NIRS specification

NIRS identifies what portion of the production frontier the farm is operating in by comparing the results to those obtained under CRS and VRS. If $S^j < 1$ and $\lambda_c^j = \lambda_n^j$, then the DEA results imply that the scale inefficiency is due to increasing returns to scale. If $S^j < 1$ and $\lambda_c^j < \lambda_n^j$, then the DEA results imply that the scale inefficiency is due to decreasing returns to scale.

λ_v^j is also known as pure technical efficiency which is the technical efficiency of the *j*th farm net of inefficiencies due to scale. This is because $(1 - \lambda_v^j)$ indicates the amount of inefficiency that can be eliminated due optimal input use. This differs from λ_c^j (also known as overall technical efficiency) because $(1 - \lambda_c^j)$ is inefficiency that includes both technical inefficiency and scale inefficiency; and hence λ_c^j will be a lower score than λ_v^j if the *j*th farm exhibits scale inefficiency. Rearranging equation 3 further illustrates this point. As seen in equation 5, overall technical efficiency is the product of VRS technical efficiency and scale efficiency.

$$\lambda_c^j = \lambda_v^j \times S^j \tag{5}$$

Equation 5 shows that there are two sources of technical efficiency. The first is scale inefficiency ($1 - S^j$). The second is pure technical inefficiency ($1 - \lambda_v^j$).

The output DEA produces includes measures of each farms overall technical efficiency, pure technical efficiency and scale efficiency and identification of its best practice benchmark. Additionally, the software identifies specific benchmark peers, of similar scale, for farms that are technically inefficient.

5. Data and sources

The data are sourced from The Department of Primary Industry (DPI) who between 1995 and 2001 conducted dairy farm performance analysis for farmers who voluntarily completed the department's questionnaires. The DPI originally used the data for a different benchmarking exercise as part of a state-wide 'Target 10' program.[7] The purpose of the program was to assist dairy farmers to review and analyse their physical and economic farm performance to detect opportunities for improvement. The farms analysed were not selected from a random sample, but were farms whose owners or managers agreed to take part in the dairy farm performance review and supply the relevant data. The implication of voluntary participation is that a sample will not be an accurate representation of farms in the region. There is a tendency for the more efficient farms to take part as they have a stronger interest to increase productivity both on their farm and in their industry. In some instances these are probably the farms that have the least to gain from benchmarking studies such as these. For this reason, the results could suggest that the south-western dairy region is more efficient than it may otherwise be. This is only an issue depending on the rationale behind the study. If the intended purpose for the region is to identify how efficient their region is, there is a need to obtain a true random sample for the region if a future study is to take place. This may mean using more traditional data collection techniques based on a number of randomly selected farms so that the sample mean is near normal, rather than opening the survey to all farms. However, if the purpose is to increase the efficiency of the region through benchmark analysis a dataset where all farms are encouraged to participate is adequate, aiming to ensure the inclusion of some of the most efficient farms as these will be important when forming a benchmark for the sample.

The primary focus of this paper is on the most recent data available of which is a sample of 59 farms for the 1999-2000 lactating season. Investigating a single year is effectively

[7] This program is no longer undertaken and the department now only does this analysis for farmers on a fee-for-service basis.

like analysing a point estimate for the region as it doesn't tell you anything about technical or scale efficiency for the region relative to other years. There is a tendency in agriculture for farms to go through short-term random fluctuations in production that will impact on the estimation of technical efficiency and productivity change. The implication is that these short-term fluctuations will not be identified if only one year is analysed, and hence a farm may simply be deemed efficient or inefficient. Examples of adverse fluctuations may be a disease outbreak that lowers the quality of the milk (and hence the price received), or the renovation of paddocks can influence productivity for a single year.

A secondary focus of the paper estimates the same model for three additional samples, 1996-97, 1997-98 and 1998-99 to try to identify if there are any major inconsistencies with the 1999-2000 sample. The different samples do not contain the exact same farms and is a limitation of this analysis because we cannot identify whether a particular farm has had a bad year. For this reason the inter-year analysis in this paper is not the ideal approach however it will provide an insight as to whether there are any random effects that are influencing the efficiency of the whole sample. There are only a small number of farms that participated throughout the entire four year period, meaning individual year-to-year productivity changes could not be accomplished. Ideally, this would be a worthwhile exercise, as we would be able to observe the growth farms experience under different farm management practices. Comparisons are made to the total sample from previous years, which effectively is like comparing different sub-samples of the total population of dairy farms in the south-west region. Additionally, the optimal quantities of key inputs are examined between years to identify the degree of variation in results as an effect of the non-random samples.

Table 1 lists the variables used in the model. It shows the six input, two output model and the composition of each variable. A significant aspect of DEA often overlooked is the importance of standardising variables in order to make meaningful inferences. As observed in table 1, all the variables in the model have been quoted in dollar values, except for the number of dairy cows milked. Standardisation or adjustment of an input value needs to occur to reflect its true quality or productivity. If not, a false assumption is created that assumes the inputs are equally productive between farms. This is not the case. For example, if land for each farm was simply quoted in hectares, it assumes that all land is equally productive. If this were the case why would a farmer pay a premium for a particular piece of land? If a farmer was indifferent between land it would be irrational to pay more for one hectare of land relative to another. The reason premiums are paid is because some land is more productive, or will earn a higher return per hectare, relative to other land. Factors such as the fertility of the land and rainfall can explain different land values. It is for these reasons that we need to standardise land per farm as one hectare in one paddock is not necessarily equal to one hectare in another paddock. Dollar values per hectare effectively standardise land capturing its relative productivity.

The importance of standardisation of land is further highlighted due to total farm land including both ‘home’ farm land and ‘outpaddock’ farm land. Without standardisation we are assuming that are both equally productive and this would misrepresent those farms with large amounts of outpaddock land. This tends to be a major limitation of a few past studies and an issue to be conscious about in DEA. Cloutier and Rowley (1993) performed a relative technical efficiency study on Quebec's dairy farms and used total quantity of milk (litres) as the sole output. However, the quality of milk is not reflected in litres as a measure of milk. Revenue received from milk is a function of the protein and butterfat content in the product. By using litres of milk they are penalising the farms that do produce high quality milk because they are treated the same as lower quality milk producers. Using dollar values for milk avoids this problem.

Table 1 Inputs and outputs

Outputs	
Net Milk Income ($)	Net milk income = Gross milk income – Levies and cartage
Cow Sales ($)	Dollar value of sales
Inputs	
Cows (no.)	Maximum number of cows milked
Farm Land ($)	Farm Land = Value of hectares home + Value of hectares outpaddock
Feed Costs ($)	Fertiliser Weed and pest Fodder Agistment Concentrates Irrigation Fuel and oil Other
Overhead Costs ($)	Labour Proxy wage for unpaid labour Administration Rates Vehicles and registration and insurance Repairs and maintenance Shed power and heating Dairy supplies Other
Herd Costs ($)	Artificial breeding Herd testing Animal health Calf rearing
Assets ($)	Plant and machinery Other

The dataset from the DPI was not able to accurately value the productivity of dairy cows per farm. This is a limitation of this study meaning the all cows are assumed to be equally productive. Either using dollar values or standardising the quantity variables is important so fair comparisons can be made between farms. This is extremely important when it comes to interpretation of the results as it can lead to biased results. However, having cows as the only non-standardised measure should have only a minimal effect on the results considering the appropriate measures have been taken for all other variables.

Additionally, it is important to include outpaddock land. Outpaddock land it is not the most productive dairy land however it does play its own important role. This land is typically used for such activities as drying-off periods and for the rearing of young cows until they are mature for milking. In the sample there were some farms who did not own outpaddock land and it is important to recognise these farms. It may indicate that they will have higher agistment costs, so we aim to truly reflect the different farming systems by including both types of land. Effectively this will enable identification of the best farm management practices by aiming to capture all the different farming systems as accurately as possible.

Fraser and Cordina (1999) mention the measurement and inclusion of important variables is a key aspect of DEA which is often overlooked. The possibility of omitting important variables from the model is also an issue to consider. If this occurs an indirect assumption is made that the inputs or outputs are proportional to the size of the dairy farm, or that they are perfectly correlated with the other variables. If this is the case, then it is legitimate to leave out the variable as it will not change the benchmarking process if the input or output is proportionally the same for all dairy farms. If it is not the case, then the results will be less meaningful as the true farming system will not be captured in the model.

Table 2 Descriptive statistics for the sample of 59 south-western dairy farms, 1999-2000

Dairy farm outputs and inputs	Mean	Median	Standard deviation	Minimum	Maximum
Net Milk Income ($)	413831	289311	302041	88390	1131158
Stock Sold ($)	23701	17000	19555	894	81490
Cows Milked (no.)	293	225	175	95	700
Farm Land ($)	1178296	1068708	600014	355824	3430588
Feed Costs ($)	177577	122303	133512	27700	581579
Overhead Costs ($)	80527	52271	78189	16382	320088
Herd Costs ($)	24371	20371	15859	3600	73079
Asset Value ($)	114195	112000	65295	13500	280000

6. Results

6.1. Results for the 1999-2000 lactating season

Average overall technical efficiency for WestVic Dairy farms in 1999-2000 is high at 94 per cent as indicated in table 3. Overall technical efficiency is a product of pure technical efficiency and scale efficiency.

Table 3 Technical and scale efficiency scores of south-western dairy farms, 1999-2000

	Overall technical efficiency[8]	Pure technical efficiency[9]	Scale efficiency
Average	0.940	0.957	0.982
Standard deviation	0.094	0.083	0.030
Minimum	0.588	0.608	0.868
No. of efficient farms	30	40	30

As shown in table 3 overall technical efficiency is 94 percent. Technical inefficiency scores from CRS DEA is made up of two components, one due to technical inefficiency and one due to scale inefficiency. Pure technical inefficiency accounts for four percentage points and scale inefficiency accounts for only two percentage points. This implies that technical inefficiency can only be reduced on average by six per cent for the sample. Figure 2 show the inefficiency for the sample graphically.

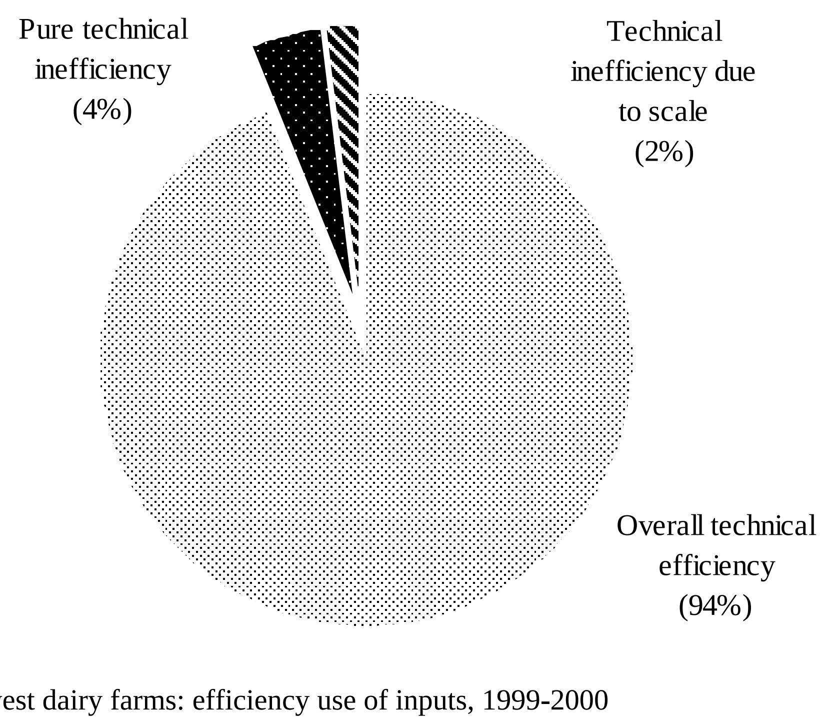

Figure 2 South-west dairy farms: efficiency use of inputs, 1999-2000

[8] Overall technical efficiency is also known as CRS technical efficiency.
[9] Pure technical efficiency is also known as VRS technical efficiency.

The scale efficiency results, summarised in figure 3, indicate that of the 59 dairy farms examined, 51 per cent (30 farms) are operating at optimal scale, 34 per cent (20 farms) are operating at below optimal scale, and 15 per cent (9 farms) are operating at above the optimal scale. A purpose for the findings in this study would be to use the results to provide information to dairy farmers to enable more farms to work towards an optimal scale. This would effectively minimise the farms in the increasing and decreasing returns to scale portions of figure 3.

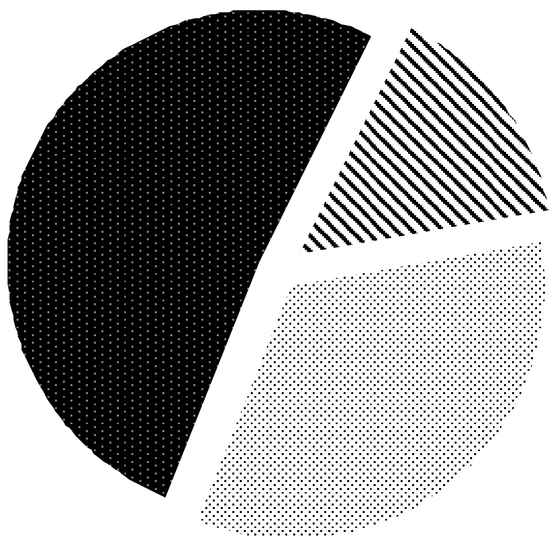

Figure 3 The scale efficiency of south-west dairy farms, 1999-2000

Table 4 provides summary statistics for each of the farms in sub-optimal, optimal and supra-optimal categories. If we look down the optimal column, we observe the average optimal quantities of inputs and outputs for dairy farms in the region as estimated by DEA. On average, the optimal size for a south-western dairy farm is estimated as a dairy herd of 305 cows that produces $469,868 in milk, provided an optimal mix of inputs.

The estimation for land value in table 4 is a dollar value. To gain a more tangible understanding of the optimal dairy farm size it is useful to covert these figures back into hectares. This can be achieved both in terms of home farm land and outpaddock land. Table 5 displays this conversion and shows that the average optimal farm has 162 hectares of home farmland, with 53 hectares of outpaddock, the sum of the two making the optimal average farm size of 215 hectares. It should be noted that this is an average figure for optimal farms indicating that there are optimal sized farms with values above and below these figures. The minimum and maximum figures are as reported in table 5.

Table 4 Technical efficiency and scale of south-west dairy farms, 1999-2000

	Sub-optimal	Optimal	Supra-optimal
Dairy farms	20	30	9
	34%	51%	15%
Net milk income ($)			
Average	285414	469868	514591
Minimum	88390	108000	260663
Maximum	658527	1131158	831309
Stock sold ($)			
Average	16745	28030	24730
Minimum	894	2100	1227
Maximum	55495	81490	51000
Dairy herd (no.)			
Average	223	305	404
Minimum	95	100	230
Maximum	480	700	600
Land value ($)			
Average	909730	1204412	1688057
Minimum	356812	355824	1079086
Maximum	1284616	3430588	2794763
Feed costs ($)			
Average	135448	193655	217603
Minimum	30474	27700	87988
Maximum	327620	581579	356985
Overhead costs ($)			
Average	54740	92450	98092
Minimum	16382	17628	37390
Maximum	136248	320088	187525
Herd costs ($)			
Average	22086	24631	28584
Minimum	8003	3600	10411
Maximum	42716	73079	58328
Asset value ($)			
Average	101380	104099	176328
Minimum	17100	13500	70000
Maximum	280000	225000	280000
Average measure of technical efficiency (%)	96.02	100	96.79

Table 5 Conversion of land value to hectares of land, 1999-2000

	Sub-optimal	Optimal	Supra-optimal
Home ($)			
Average	739168	976350	1422280
Minimum	326172	355824	988400
Maximum	1185080	2505594	2273320
Outpaddock ($)			
Average	170562	228061	265777
Minimum	0	0	0
Maximum	512733	924994	555975
Home (ha.)			
Average	132	162	235
Minimum	60	64	160
Maximum	220	338	368
Outpaddock (ha.)			
Average	44	53	54
Minimum	0	0	0
Maximum	141	205	115
Average total land (ha.)	176	215	289

6.2. Comparisons to previous years' samples

DEA for only one year acts a like a point estimate in the sense that it is not known how the sample has performed in comparison to previous years. For example, in the 1999-2000 lactating season there may have been severe drought conditions that adversely affected output. Without the previous years' results for the same sample, identification of such divergences cannot happen. Factors, other than weather conditions, may include changes in regulation or the current economic climate that can either positively or negatively influence the results.

Due to data constraints individual farm analysis to identify inter-year changes in efficiency could not be undertaken for the farms over the four year period. The reason for this is that most farms participated in one or two sample years with only a small number that participated in the program over the entire four years period studied. It is possible that an individual farm may have been technically efficient (that is a benchmark for others) for three out of the four years. An explanation of having one bad year may be that the farmer could have lost efficiency if they had a major disease outbreak through the herd, or some other similar occurrence. This illustrates another key reason why it is good to have data on the same farms for different years. Given the data constraints, the next best option is to run the same model for the previous years' samples. However, it must be clarified that the samples are comprised of different farms. There are farms that participated between one to four years due to the voluntary nature of the program. Farms enter the sample as others leave and so absolute productivity comparisons are made difficult between samples. This means that caution is required when interpreting the average technical efficiency and scale results from other years because they are not the same farms in each sample. The farms in different years' are simply different sub-samples of the total population of dairy farms in the south-west region. Figure 4 displays the inter-year efficiency score results.

This analysis is not ideal however there is still some useful information obtained from the results. First, in a general sense the results look quite consistent for all years giving confidence for the 1999-2000 results. For example, there is not one year that seems to have results that are significantly different from the other years. This possibly rules out the occurrence of a 'bad year' for the sample. We must allow for some variation between the years as different samples will create different estimates.

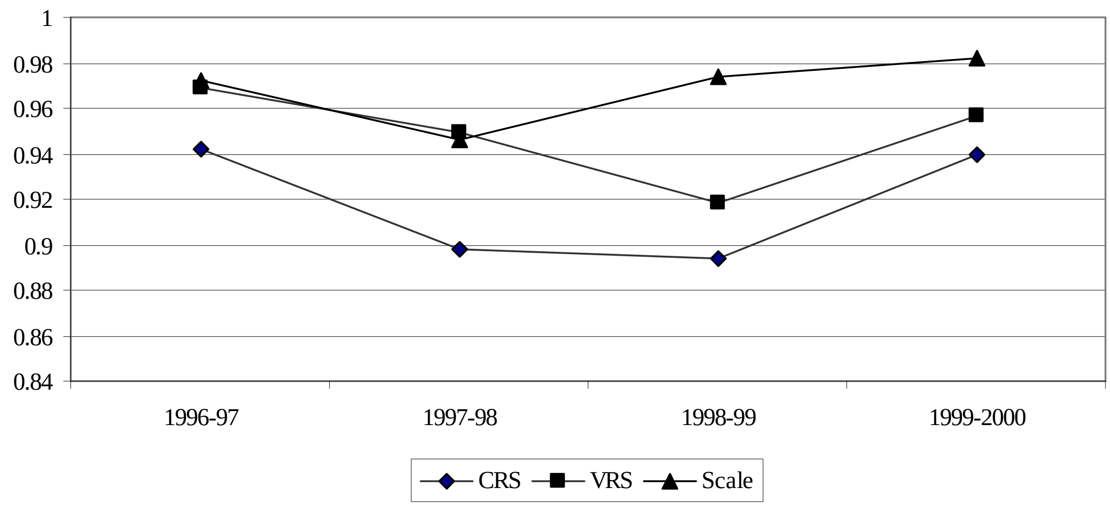

Figure 4 Comparison of efficiency scores across samples

Figure 4 suggests that efficiency for the region is consistent and high for all years. This provides increased confidence that the results for 1999-2000 are a reasonably precise representation for the sample relative to other years. However, accurate conclusions cannot be made as to whether one year is better than another in absolute terms.

Table 6 shows the different average optimal farms sizes in other years. The non-random sample issue is further highlighted as different samples will obtain different estimates and shows that care is needed when interpreting these results. If random samples were obtained, or a true representation of the south-west dairy farming region, this would allow much tighter and more accurate estimates regarding these efficiency and optimality issues. Additionally, the differences between years illustrate DEA being a relative, not absolute, measure as the results will depend on the farms included in the sample.

Table 6 Key results from previous years' samples

	1996-97	1997-98	1998-99	1999-2000
Sample size	59	113	78	59
Overall technical efficiency	0.942	0.898	0.894	0.940
Average optimal dairy herd	302	269	281	305
Average optimal total land	250	237	229	215

6.3 Discussion on individual farm results

The individual farm DEA results reveal insights as to where the specific areas of input inefficiency lie. This is very useful for the less efficient farms. By looking at the farms direct comparisons can be made between them and their efficient peers. This information would be very useful, particularly for a dairy extension worker, as it is quite easy to detect the problems that are preventing these farms from achieving full efficiency. The DEA output identifies best-practice peer farms for benchmark comparisons for farms operating on similar scales. For example, a farm may be inefficient due to its use of inappropriate technology. If this is the case, the extension worker can provide technical advice to the farmer in question. If the inefficiency is simply due to farmer inexperience, then information or training facilities can be provided or the facilitation of links to the efficient peers through a discussion group.

The information on scale efficiency is also of interest, but arguably not as important as the individual results on technical efficiency. Observing the results in table 4 we can see a positive relationship over most of the variables as the scale increases from sub-optimal through to supra-optimal. It is important to note that not all efficient farms are characterised by these efficient average values. For this reason, it is not recommended that a farm should simply try to replicate these optimal average values to become efficient. These are more or less a guide, which adequately illustrates the average relationship between sub-optimal, optimal and supra-optimal dairy farms. For example, we can see that there is an efficient farm with at dairy herd of 700, as reported as the maximum value of cows. One may question how can this be when the average is 305 and 700 is even greater than the maximum value in the supra-optimal category. Simply put, this is an example of how DEA can be more useful than many partial-productivity measures. DEA investigates farming efficiency where efficiency was defined as the weighted sum of outputs over a weighted sum of inputs. This explains why there can be some relatively large, or small, farms that are still efficient. DEA yields a relative measure and while the dairy herd input is large for this farm, the farm is using the CRS ratio of inputs that makes the farming system efficient like the other relatively smaller farms operating in the CRS portion of the frontier. It is observed that the size of a farm is measured as a ratio of the sum of all inputs over the sum of all outputs.

As discussed, this study reports an average optimal size for a dairy farm, however it does not suggest or recommend that all farms should strive to achieve that size. Rather, in order to improve overall technical efficiency in the industry each farm should be investigated individually. This will enable the extension worker to observe what it is doing with its input/output mix, and suggest ways in which technical inefficiencies can be eliminated. If the farm is already at optimal scale no action is to be undertaken. This discussion illustrates the potential uses for the DEA results primarily for dairy extension providers. They can investigate the farms on the efficient frontiers and document the observed 'best practice' farm management. Due to the detailed nature of results the software produces there is too much information to provide details on all individual farms. Instead, I will discuss three particular farms that are of differing cases from the sample to demonstrate the type of information gained from DEA analysis and how it can be used. These results will illustrate the implication of using input-orientated DEA as the model specification. That is, we will observe the potential reduction in inputs that will produce the same level of output.

First, farm 3 in the sample is the least efficient both in terms of CRS and VRS technical efficiency. Farm 3 has seven peer farms which are all optimal (both technically efficient and scale efficient) and are of a similar scale, making them direct benchmark examples of the practices farm 3 should be aiming to learn from. This individual farm's DEA results suggest that the dairy herd could be reduced by 141 animals; the value of land can be reduced by $485,891; feed cost can be reduced by $96,368; total overhead costs could be reduced by $41,517; herd costs could be reduced by $10,067; and total asset value could be reduced by $46,982. These show the input inefficiency for farm 3 relative to its peer farms. These results indicate there are major problems in the management practices at this farm, especially if these results persist. The results suggest that farm 3's cows are underperforming relative to other farms. This means that the same output is possible with fewer cows, given relative performance. It may be that the milk quality is low or that the cows on average are simply not producing as much milk relative to other farms. The present number of cows should not be required to produce the current value of milk. The dairy farmer may or may not know this, so suggestions from an extension worker could be beneficial.

Farm 29 has the largest VRS technical efficiency score that is less than one. This value is 0.988 and the farm is operating in the DRS portion of the frontier. This farm is only slightly off the frontier meaning it is extremely close to being technically efficient. Farm 29 has 5 peer farms which it should be aiming to benchmark itself against. The DEA software suggests that the dairy herd could be reduced by 3 animals; a land reduction of $16,989; a $1,055 reduction in the feed costs; a $449 reduction in total overhead costs; a $173 reduction in herd costs; and a $1,206 reduction in the total asset value. Since the farm is very close to being technically efficient it is not surprising that farm 29 would not have to reduce its input use to the extent of farm 3, for example.

Farm 36 is the least scale efficient farm. It is operating in the decreasing returns portion of the frontier and has a scale value of 0.868. The farm is technically efficient under the VRS assumption, but not under CRS. For the reason the farm is technically efficient under VRS, it is on the VRS frontier and cannot increase efficiency by altering its inputs use. Therefore, farm efficiency can only be increased by reducing the scale of the farm.

When observing these input reductions the importance of having standardised inputs is emphasised. For example, for the case of dairy cows we are assuming that all dairy cows are equally productive, meaning they produce the same quantity and quality of milk, on average, per farm. We observe the DEA results suggesting that farm 3 should reduce its dairy herd by 141, or 39 per cent. At first glance, this may seem an irrational thing to do as you would not expect to be able to gain the same value of milk from fewer cows. The DEA results are not incorrect and there is a need to think further economically as there are potentially several reasons why the software is suggesting this result. We can only speculate what these reasons are without observing the actual farm. There are many explanations that could be possible given this result. General reasons why a dairy farm may be underperforming, not only in terms of a reduction in the dairy herd but all other inputs, could be that the farmer is just starting out and is going through a 'learning by doing' process. This means they are experimenting to discover the optimal output quantities of inputs through a process of trial and error. A farmer may not be getting a high value for their milk due to lower protein or butterfat quantities. This could be related to the type or the quantity of feed provided to the dairy herd. Alternatively, a farmer may have a relaxed attitude towards farming, and so may not realise the opportunity costs of an underperforming farm and may need advice. Mbaga et al. (2002) suggest that some farmers acknowledge that efficiency can be gained by increasing the scale of their operation, but may choose not to do so because they are close to retirement age, and/or due to limited borrowing capacity may not want embark on such ambitious expansion projects. Another possibility is that the farm has simply provided inaccurate data to the department and therefore have made their farm seem less (or more) efficient than it otherwise is.

There are endless possibilities as to why a dairy farm could be underperforming and only a few have been touched upon here. We can only speculate without further inspection of what the farm is actually doing relative to its benchmark peers. Nevertheless, these are examples of the types of inefficiency issues DEA can bring to the attention of analysts. Ultimately by eliminating these inefficiencies the south-west dairy region will become more efficient and competitive.

7. Comparison with other studies

Recent developments in more user friendly DEA computer software have lead to its increased popularity as a tool for analysis in agriculture. Additionally, the type of information DEA produces is very detailed, particularly in relation to input use, the optimal factor mix, the identification of efficient farms within a sample, and identification of the most efficient farms which are responsible for creating the benchmark. Coelli et al. (1998) mentions that care must be taken when comparing mean efficiency scores from two studies as they only reflect the dispersion of efficiency scores within each sample. There are a few aspects that need to be taking into consideration when attempting to make comparisons with other DEA studies. First, DEA is a benchmarking technique that compares farming systems within a sample. It does not compare the efficiency of one sample relative to another. The inclusion or exclusion of an efficient or non-efficient farm or the adoption of new technology by the farms may significantly change the results in a given sample. Second, most studies will use different model specifications which will alter the results in which a farming system is analysed relative to another. For these reasons DEA cannot conclude whether one region is more efficient as a whole relative to another.

Jaforullah and Whiteman (1999) used a three input, seven output model to estimate technical and scale efficiency of a sample of 264 New Zealand dairy farms using data from 1993. They used a three output seven input model. The results suggest that average technical efficiency was estimated at 89 per cent and that the optimal size for a dairy farm was 83 hectares with a herd of 260 animals. The major difference between New Zealand and Australian dairy farms is that that a much larger number of animals can be sustained on smaller amounts of land in New Zealand. This can be explained due to the increased rainfall New Zealand experiences, relative to farms in the south-western dairy region.

Fraser and Cordina (1999) performed DEA with a one input six output model on the efficiency of 50 northern Victorian, irrigated dairy farms for 1994-95 and 1995-96. Average technical efficiency was estimated at 90.5 per cent and 90.8 percent for the years respectively. The major difference between northern Victoria dairy farming and the south-west region is the reliance on irrigation in northern Victoria. Water is a major constraining input for this region and Fraser and Cordina found that there exists a potential 16 per cent reduction in water if all farms operated efficiently.

Cloutier and Rowley (1993) used DEA to explore the efficiency of Quebec dairy farms in 1988 and 1989. They chose a three output five input model and found average technical efficiency was 88.3 per cent and 91.3 per cent respectively for the two years. Their DEA results are based on constant returns to scale and so their results are only comparable to the overall technical efficiency estimated in this paper.

Mbaga et al. (2002) investigate efficiency for Quebec dairy farms and discussed some of the issues that analysts confront, such as choosing between parametric and non-parametric approaches. They investigate these issues by estimating SPF methodology and use three dominate functional forms of popular alternatives. To enrich the comparisons they also compute DEA efficiency scores, which circumvent the need to make decisions on the distributional assumptions. They discover the correlation between coefficients between DEA and parametric specifications were found to be very low, implying that the two approaches cannot be used interchangeably. Mbaga et al. (2002) mention that these findings have been reported in other studies and is certainly a cause for concern as researchers are left wondering which set of results, if any, are reliable. Under the DEA estimation the mean technical efficiency scores were quite high, estimated at 92.2 per cent. This indicates that increases in technical efficiency could not increase output by much. They suggest this finding is not surprising because Quebec dairy farmers have managed small farms for quite some time and have become very proficient. For the south-western region it is possible that the efficiency scores are high similar reasons due to dairy being a mature industry.

8. Limitations in efficiency measurement

There has been much discussion in efficiency measurement to try to determine which approach will yield the most credible results. All techniques have advantages and shortcomings. The popular alternative to DEA is the stochastic production frontier approach (SPF). This requires the specification of a production technology by selecting a functional form. Different studies seemingly arbitrarily choose different specifications which will alter the results. Most common are the Cobb-Douglas or a flexible form, such as translogarithmic. Another requirement of the SPF approach is the choice and distribution of inefficiency scores. Finally, the SPF approach is only suited to single-output technologies. Multi-output cases can be examined if the outputs are aggregated into a single output. However, with this approach it is hard to conceptually separate the effects of inputs in how they influence the outputs.

The non-parametric DEA approach is not without its flaws and while it may not suffer from the above shortcomings, is has its own issues. DEA is very sensitive to extreme values which are essential in the estimation of the frontier. This means we must be cautious when deciding whether to or not to include outliers. If included and is a consequence of error in the data collection, the results may be significantly altered and subsequently will be much less meaningful. DEA does not allow an error term to capture random variation in output due to factors beyond the control of farms, such as normal variations in the weather. This issue can be overcome be using the SPF approach. A concept of this analysis that is important to clarify is that the efficiency measures are relative, not absolute. The implications are that efficiency scores from two samples reflect only the dispersion of farm efficiency within each sample. This means that care must be taken when comparing different studies or different samples. When comparing two average efficiency scores between samples they convey no meaning about the efficiency of farms in one sample relative to another. If comparisons are required it is essential to obtain random samples of farms, or in other words, a sample of farms that accurately reflects all types of farms for the region. For example, the implication of not including the most efficient farm in the region will lower the benchmark to conclude that a less efficient farm (however the best in the sample that will be deemed technically efficient) is the benchmark that the other farms are striving to learn from. The inclusion or exclusion of an important farm can have significant effects on the efficiency scores for the sample.

Coelli et al. (1998) note that if the sample of farms is too small many farms can spuriously appear on the DEA frontier when the sample is small and there are many outputs. Chambers at al. (1998) discuss the need to avoid the ‘curse of dimensionality’ that can affect DEA. This occurs when there are too many variables in the model specification resulting in a large proportion of the farms being efficient. Chambers et al. (1998) suggest as a rule of thumb that there should always be at least three times the observations (i.e. farms) as variables to be included in the model specification. The choice of variables is inhibited by what data are available which tends to be the major constraint in many studies. This is an issue to be conscious about but was not a problem in this paper.

Table 3 shows average overall technical efficiency at 94 per cent this indicates that south-western dairy farms are very efficient. One important reason that explains this occurrence is that the sample of farms used was not random, meaning the sample results may be positively skewed. It is likely that the more efficient farms participate in these types of programs as they have an increased interest in better ways to manage their operations, and thus are more willing to take the time to participate in such studies. This possibly indicates that the results suggest the region is more efficient than it may otherwise be. The implication is that the sample may not accurately reflect the efficiency of south-western farms. However in saying this, Mbaga et al. (2002) also reported high average overall efficiency scores of 92.2 per cent. This paper argued that the results are not surprising because Quebec dairy farmers have managed small farms for quite some time and have become very proficient. From the findings of this paper it cannot be established if this is situation for the south-west region as well. However, dairy farming is a mature industry in Victoria and it is possible that the region is very efficient.

This discussion is not an exhaustive list of the limitations, but rather a summary of the major ones. All approaches have distinct advantages and limitations that need to be taken into consideration before estimation. The choice of methodology should depend on the relevant issues such as the purpose of the study, the available data and the expertise of the analyst.

9. Conclusion

The primary objective of this paper was to examine the relationship between farm size and efficiency using non-parametric DEA. This paper has investigated the technical and scale efficiency of dairy farms in south-western Victoria. The results suggest that the region is highly efficient with an average overall technical efficiency score of 94 per cent in the 1999-2000 lactating season. Using the data an optimal size of a dairy farm was also estimated for the sample. This is a farm with a dairy herd of 305 animals and 215 hectares of land which comprises 162 hectares of home land and 53 hectares of outpaddock. The sample suggested that 51 per cent of the dairy farms are operating at an optimal scale, 34 per cent are operating at below optimal scale leaving the remaining 15 per cent operating at above optimal scale. However, care is needed in interpreting these results because the sample of farms was not random therefore dairy farms should not necessarily be striving to obtain a farm of this size. Rather, a dairy farm should be trying to optimise its production, given its current scale, by emulating its technically efficient peer farms that as identified by DEA.

It is likely that the results of this paper indicate that the region as a whole is more efficient than it may otherwise be. The reason for this is because the data were collected on a voluntary basis only including those farms which agreed to take part in the dairy farm performance program that ran between 1995 and 2001. This can be overcome in future studies, if desired, by obtaining a true random sample that equally reflect dairy farms of all efficiency levels for the region. Additionally, if benefits of such a program is made clear to those farmers who are likely to be less efficient, they may be more willing to participate in the program.

The south-western dairy region can benefit from this study for a few reasons. First, this paper illustrates that DEA can be a powerful tool to analyse the efficiency for dairying regions and is particularly useful for a farm extension worker. This study typically could be replicated or further customised for the region provided a system was in put in place to collect the relevant data. Second, the type of information DEA produces is very detailed and of great practical use. The program produces target values so inputs that can be minimised which identifies scope for reducing pure technical inefficiency. By looking at the individual farm results it is quite easy to observe where the areas for individual farm improvement lie. This would be particularly useful for the less efficient farms in the sample. By emulating the best practice technology of benchmark peers, the less efficient dairy farms can eliminate pure technical inefficiency. Further, if data were available every year for various farms, year-to-year total factor productivity comparisons for individual farms could be made. This is a productivity indices approach which is estimated using Malmquist DEA to investigate whether, and if so why, a farm has increased it productivity from one year to the next. This would be very interesting as it would be possible to observe the differences in year-to-year productivity from different farm management practices. Ultimately, once applied this will bring the sample of farms closer to the production frontiers, that is, the south-west dairy region as a whole will experience greater efficiency, lowering input costs and increasing the region's profit margins and competitiveness.

A worthwhile exercise for a future study may be to run a cost-DEA model which investigates allocative efficiency for the farms. This was not possible given the dataset and was outside the scope of the present study. Cost-DEA can provide an insight into the optimal mix of inputs utilising price information. The procedure will examine the optimal factor mix, or allocative efficiency, given input unit prices. This exercise would minimise the cost on the input factor mix for the efficient quantity of output from a price perspective. Economic efficiency is defined when a farm is both technically efficient and allocatively efficient.

The main strength of DEA over parametric approaches is the focus on individual farm performance. This is an advantage as it is more informative for extension workers to discover the best practices in farm management for the region. By identifying benchmark peers for farms of different scale extension workers can provide individual farm advice regarding how technical inefficiencies can be eliminated. The benefits of DEA are becoming more apparent than ever. DEA is increasingly being used as a benchmarking tool in Australia and throughout the world and to comparison to parametric approaches, DEA is attractive as it provides farm specific insights in regard to the optimal use of inputs.

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