CENTRE of POLICY STUDIES and the IMPACT PROJECT

Eleventh Floor
Menzies Building
Monash University Wellington Road
CLAYTON Vic 3168 AUSTRALIA

Telephone: from overseas:
(03) 990 52398, (03) 990 55112 61 3 990 55112

Fax numbers: from overseas:
(03) 990 52426, (03)990 55486 61 3 990 52426 or
61 3 990 55486

e-mail impact@vaxc.cc.monash.edu.au

Internet home page http//www.monash.edu.au/policy/

SCALE EFFICIENCY IN THE NEW ZEALAND DAIRY INDUSTRY:

A Non-Parametric Approach

by

Mohammad JAFORULLAH
University of Otago

and

John L. WHITEMAN*
Monash University

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ABSTRACT

The objective of this paper is to measure the scale efficiency of the New Zealand dairy industry and to examine the relationship between farm size and efficiency. Data envelopment analysis (DEA) is applied to a sample of 264 dairy farms. The results suggest that 19 per cent of these farms are operating at optimal scale, 28 per cent at above optimal scale, and 53 per cent at below optimal scale. On average the optimal size for New Zealand dairy farms is estimated at 83 hectares with a herd of 260 animals. Average technical efficiency is estimated at 89 per cent.

Keywords: Data envelopment analysis (DEA), benchmarking partnerships, technical efficiency, optimal, supra-optimal and sub-optimal scale.

JEL Classification: D24.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

Scale Efficiency in the New Zealand Dairy Industry: A Non-Parametric Approach

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University of Otago

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John L. WHITEMAN*
Monash University

1. Introduction

In a recent paper, Jaforullah and Devlin (1996) point out that one of the more conspicuous outcomes in the New Zealand dairy farming sector in recent years has been an apparent acceleration in the long-term trend of increasing farm size. In 1980 the average size of dairy farms was 79 hectares, 89 hectares in 1990, and already 107 hectares by 1995.[1]

Jafforullah and Devlin observe that this acceleration in the rate of increase in the size of dairy farms has coincided with moderate growth in returns to dairy farming as a result of more stable international prices for dairy products. They also point out that the industry has experienced increased optimism with the recent favourable GATT outcome. As a result the industry is experiencing increasing investment and an increase in the number of farms. Large publicly listed companies (such as *Tasman Agriculture* and *Applefields*) are becoming involved in the industry. The farms operated by these groups tend to be substantially larger than the traditional New Zealand farm.[2] Ownership of dairy farms by private (non-farmer) investors is also becoming increasingly common. In addition as a result of the increasingly good outlook for the New Zealand dairy industry, sheep and beef farms, predominantly in the South Island, are being converted to dairy farms. Conversions were initiated in the Southland region in the late 1980s by the listed companies as a means of

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* The co-operation of the Livestock Improvement Corporation and the New Zealand Dairy Board in granting access to the data used in this study is gratefully acknowledged. The authors also wish to thank Mathew Peter of the Centre of Policy Studies for helpful comments.

1 Source: New Zealand Yearbooks, Statistics New Zealand.

2 In 1993 the 34 farms operated by Tasman Agriculture had an average herd size of over 350 milking cows, compared with the average New Zealand milking herd size of 170 cows (Tasman Agriculture Limited, 1993). These are still relatively large farms. According to Cloutier and Rowley (1993), the milking herd size per farm in Quebec, Canada ranged from 28 to 60 cows.

achieving substantial land holdings in the dairy industry. As well as the publicly listed companies, conversions by individual owner-operators have also been common. As a result of the relatively low land prices in the Southland region, these converted farm units have often been 50 per cent larger than the traditional New Zealand dairy farm. Jaforullah and Devlin suggest that the number of conversions has been substantial with an estimated 98 extra dairy farms in the Southland region in the 1992-93 and 1993-94 seasons. This has led to a doubling of land prices in the region since these conversions began.

The objective of this paper is to examine the question as to whether this noticeable trend towards increasing dairy farm size is improving the efficiency of New Zealand dairy production. Jaforullah and Devlin addressed the same question utilising a parametric stochastic production frontier approach. Their analysis showed that there was no significant relationship between farm size and efficiency. However their stochastic production frontier model failed to address the multi-product nature of dairy production.

In this paper we employ a non-parametric technique, data envelopment analysis (DEA), to examine the relationship between farm size and efficiency in a multi-product framework utilising the same database as Jaforullah and Devlin (1997). DEA identifies a unique and achievable best practice benchmark for each dairy farm in the sample. As well as measuring efficiency, DEA indicates how individual farmers can eliminate inefficiency through the formation of benchmarking partnerships.

The following section describes the measurement of efficiency using DEA. The data is described in Section 3. Section 4 provides a discussion of the results. The principal conclusions are outlined in Section 5.

2. The measurement of efficiency of New Zealand dairy farms

The measurement of efficiency derives from Debreu (1951) and Farrell (1957). Farrell's concepts of *technical efficiency*, *price efficiency* and *overall efficiency* and Debreu's notion of the *coefficient of resource allocation* are now embraced by the concepts of technical, allocative and productive efficiency. Technical efficiency measures an enterprise’s success in producing as large as possible output from a given set of inputs.[3] Allocative efficiency represents a measure of the extent to which an enterprise uses its inputs in the least cost proportions, given their prices.[4] Kopp (1981, p.478) referred to allocative efficiency as ex ante efficiency because it focuses on the appropriateness of the choice of technology. He referred to technical efficiency as ex post efficiency because it focuses on how well an enterprise uses its chosen technology. Leibenstein and Maital (1992) referred to this as X-efficiency. Productive efficiency is simply the product of the technical and allocative efficiencies of enterprises.

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3 Farrell (1957, p254).

4 Farrell (1957, p.254).

New Zealand dairy farms produce a wide range of outputs. These include milkfat, milksolid and milkprotein products. Inputs include land, labour, capital (including buildings), the dairy herd, expenditures on animal health and herd testing, feeding supplements and grazing, and fertilizer.

While dairy farms are able to improve their technical efficiency by using existing inputs more effectively, the improvement of allocative efficiency requires fundamental changes in input structures. In the present paper we focus on the technical efficiency of New Zealand dairy farms.

The use of linear programming to measure technical efficiency is usually attributed to Charnes, Cooper and Rhodes (1978) although others had applied linear programming techniques to input-based efficiency measurement in the late 1960s and early 1970s.[5] A more recent development has been the decomposition of technical efficiency into its scale and other components by Fare, Grosskopf and Lovell (1985). In this paper the technical efficiency of New Zealand dairy farms is decomposed into measures of scale and pure technical efficiency.[6]

Following Fare, Grosskopf and Lovell (1985) input oriented technical efficiency measures satisfying three different types of scale behavior are specified. These are constant returns to scale (CRS), non-increasing returns to scale (NRS), and variable returns to scale (VRS).

Let ***Y*** be an (MxN) matrix of outputs for New Zealand dairy farms with elements y_{ij} representing the ith output of the jth dairy farm. Let ***X*** be a (PxN) matrix of inputs with elements x_{kj} representing the kth input of the jth dairy farm. z is an (Nx1) vector of weights to be defined. The vector y^j is the (Mx1) vector of outputs and x^j is the (Px1) vector of inputs of the jth dairy farm.

The CRS input measure of technical efficiency for a New Zealand dairy farm is calculated as the solution to the following mathematical programming problem:

(2.1)
$$\lambda_c^j = \min_{\lambda,z}\lambda$$
$$\text{s.t.} \quad y^j \le \mathbf{Y}z$$
$$\mathbf{X}z \le \lambda x^j$$

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5 Boles (1966).

6 Fare, Grosskopf and Lovell decompose the measure of technical efficiency into three components: a measure of scale efficiency, a measure of efficiency relating to input congestion, and a measure of pure technical or managerial efficiency. In the present study we assume that dairy farms are subject to strong input disposability (i.e. have no difficulty in disposing of excess inputs) and hence that there is no inefficiency due to input congestion.

$$z \in R_+^N$$

where λ is a scalar value representing a proportional reduction in all inputs such that $0 \leq \lambda \leq 1$, and λ_c^j is the minimising value of λ so that $\lambda_c^j \bullet x^j$ represents the vector of technically efficient inputs for the ith dairy farm.[7] Maximum technical efficiency is achieved when λ_c^j is equal to unity. In other words, according to the DEA results, when λ_c^j is equal to unity, a farm is operating at best-practice and cannot, given the existing set of observations, improve on this performance.[8]

Likewise, the NRS input measure of technical efficiency for a New Zealand dairy farm is calculated as the solution to the following mathematical programming problem:

$$\lambda_n^j = \min_{\lambda,z} \lambda \tag{2.2}$$

$$\text{s.t.} \quad y^j \leq \mathbf{Y}z$$

$$\mathbf{X}z \leq \lambda x^j$$

$$z \in R_+^N$$

$$\text{and} \quad lz \leq 1$$

where *1* is a (1xN) vector with elements the scalar 1.

Finally, the VRS input measure of technical efficiency for a New Zealand dairy farm is calculated:

$$\lambda_v^j = \min_{\lambda,z} \lambda \tag{2.3}$$

$$\text{s.t.} \quad y^j \leq \mathbf{Y}z$$

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7 Note that λ_c^j represents the proportional reduction achievable for all inputs. It is still possible that a greater proportional reduction may still be achieved for one or more of the inputs of the jth farm in which case measured technical efficiency may still involve some input slack.

8 Note that technological progress or the addition of new data (dairy farms) may change the best-practice frontier. So even though a farm is identified as best-practice in one sample or in one time period, it may not necessarily be best-practice in another sample or time period. However, a farm that is identified as inefficient in the present sample will remain inefficient so long as the present sample remains a subset of all other samples that include the farm. The farm can, however, become efficient in subsequent time-periods by improving its performance and by adapting relatively faster to technological change.

$$\mathbf{X}z \leq \lambda x^j$$
$$lz = 1$$
$$z \in R_+^N$$

The input scale efficiency measure is defined as the function:

(2.4) $$S^j = \lambda_c^j \,/\, \lambda_v^j$$

If $S^j = 1$ then the dairy farm is scale efficient. If $S^j < 1$, the farm is scale inefficient.

If $S^j < 1$ and $\lambda_c^j = \lambda_n^j$ then scale inefficiency is due to increasing returns to scale.

If $S^j < 1$ and $\lambda_c^j < \lambda_n^j$ then input scale inefficiency is due to decreasing returns to scale.

The above decomposition of the CRS input measure of technical efficiency implies that:

(2.5) $$\lambda_c^j = \lambda_v^j * S^j$$

λ_v^j is called the measure of pure technical efficiency, ie the technical efficiency of the jth dairy farm net of inefficiencies due to scale. The remaining technical inefficiency [i.e.: 1- λ_v^j] is called controllable or x-inefficiency.[9]

3. Data and source

The data is based on a survey of factory-supplying dairy farmers conducted by the Livestock Improvement Corporation Limited in 1993 for the New Zealand Dairy Board. The sample was randomly selected from Board records. It initially comprised 452 dairy farms. However 76 of these farmers failed to meet survey criteria (e.g. having at least 30 cows, separate accounts for, and deriving at least half of their gross income from dairy operations), 82 farmers declined to participate in the survey, and a further 30 provided data that could not be used.[10] The remaining 264 farmers were considered to be reasonably representative of New Zealand dairy farmers although there was the possibility that non-respondents operated farms that were less technically efficient than the farms operated by respondents to the survey.

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[9] We are assuming that there are no differences in the operating environments of dairy farms. If differences in operating environments do exist, their effects should be added to the sum of the uncontrollable or exogenous sources of technical inefficiency.

[10] Livestock Improvement Corporation (1993).

The information collected in the survey was farmer specific, relating to all farms owned by each farmer. However, the farmer had to be an owner-operator (or 50/50 sharemilker)[11] to be surveyed. A farmer that owned two or more farms, and had a 50/50 sharemilker on one or more of these farms, would not have been surveyed since he did not own all the cows.

The survey contained comprehensive and disaggregated information on the characteristics of each farm, including details of land use, dairy herd, outputs, costs, revenue and assets. For the purposes of the present study, it was assumed that dairy farms produced three outputs: milkfat, milksolid and milkprotein products, all measured in kilograms. It was also assumed that there were seven inputs: land (hectares), labour (hours), dairy cattle (number), expenditures ($) on animal health, feed supplements, fertilisers and capital (i.e. buildings and equipment). Data relating to these inputs and outputs are summarised in Table 1.

Table 1

Descriptive Statistics for the Sample of 264 New Zealand Dairy Farms

Dairy farm outputs and inputs	*Mean*	*Median*	*Standard deviation*	*Minimum*	*Maximum*
Milkfat (kg)	29,159	25,521	15,122	4,409	80,001
Milksolids (kg)	50,677	444,74	26,016	7,509	184,998
Milkprotein (kg)	21,518	18,822	10,952	3,100	80,001
Total area (hectares)	91	75	66	16	485
Total labour (hrs per wk)	80	80	36	40	410
Total dairy herd	258	225	134	65	1,066
Animal health ($)	9,263	7,978	5,595	462	33,537
Feed supplements and grazing ($)	9,347	7,112	7,982	0	50,443
Fertilisers ($)	12,037	9,629	11,763	0	84,931
Assets ($)	359,517	313,232	301,752	4,456	2,023,623

[11] The 50/50-sharemilking agreement is the most common form of sharefarming contract in New Zealand dairy farming, under which the farmer and the sharemilker each receive 50 percent of the revenue from milk sales. Under this arrangement, the sharemilker typically provides the dairy herd and some assets (such as tractors and farm bikes) and is responsible for all day-to-day farm operations. The farmer provides the farmland, buildings and plant and participates in seasonal activity, such as hay and silage making.

4. Results

The DEA results are summarised by the frequency distributions in Table 2. Under the CRS measure of technical efficiency 20 percent of the sample of New Zealand dairy farms are identified as technically efficient, i.e. operating at best-practice. The average CRS measure of technical efficiency for all farms in the sample is 0.83 or 83 percent. This compares with an average CRS measure of technical efficiency of 0.88 and 0.91 reported by Cloutier and Rowley (1993) for a sample of 187 Quebec dairy farms in 1988 and 1989 respectively.

Table 2

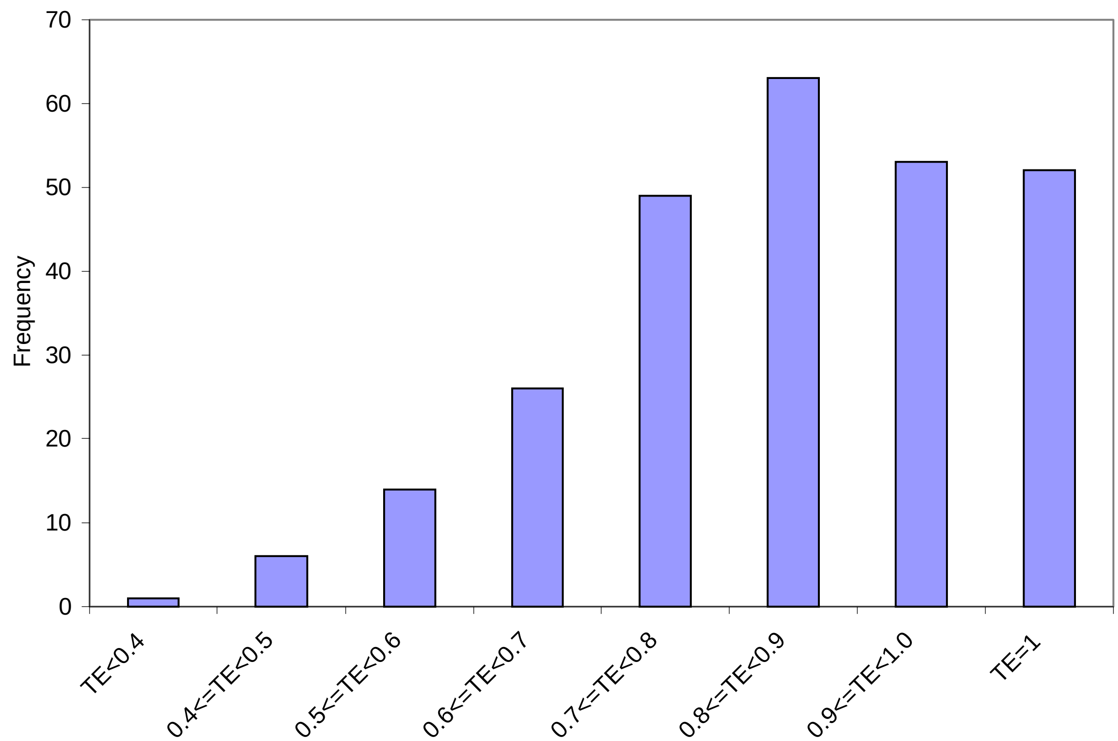
Frequency Distributions of Technical and Scale Efficiency Scores

Efficiency (E) score	*Constant returns to scale model* (No of farms)	*Variable returns to scale model* (No of farms)	*Scale efficiency* (No of farms)
$E<0.4$	1	0	0
$0.4 \le E < 0.5$	6	1	2
$0.5 \le E < 0.6$	14	5	4
$0.6 \le E < 0.7$	26	23	4
$0.7 \le E < 0.8$	49	25	15
$0.8 \le E < 0.9$	63	56	24
$0.9 \le E < 1.0$	55	50	165
$E=1$	50	104	50
Total no of farms	264	264	264
Mean efficiency	0.83	0.89	0.94
Standard deviation of efficiency scores	0.14	0.13	0.10
Minimum efficiency	0.39	0.42	0.45
Maximum efficiency	1.00	1.00	1.00

As can be seen in Figure 1, the frequency distribution is skewed towards the right, i.e. higher levels of technical efficiency, with nearly two-thirds of the sample achieving CRS technical efficiency scores of 80 per cent or more. Cloutier and Rowley (1993) also commented on the clear monotonic pattern and the asymmetric tails exhibited by the frequency distribution of technical efficiency scores.

Figure 1

Frequency distribution of the constant returns to scale measure of technical efficiency for a sample of New Zealand dairy farms



According to the above results, the average level of technical inefficiency is 0.17 or 17 per cent. This implies that, by adopting best practices, New Zealand dairy farms can, on average, reduce their inputs of land, labour, dairy cattle, expenditures on animal health, feed supplements, fertilisers, buildings and equipment by at least 17 per cent. The potential reduction in inputs from adopting best practices varies from farm to farm. The 52 best practice or frontier farms cannot reduce their inputs. However other farms can reduce their inputs by more than half according to the DEA results. They can do this by forming benchmarking partnerships with relevant best-practice farms and emulating the best practices of the latter.[12]

Since we have assumed constant returns to scale, the sources of inefficiency alluded to above may include inefficiencies due to scale as well as other sources of inefficiency such as inefficient farm management. Accordingly, we have relaxed the assumption of constant returns to scale and obtained a

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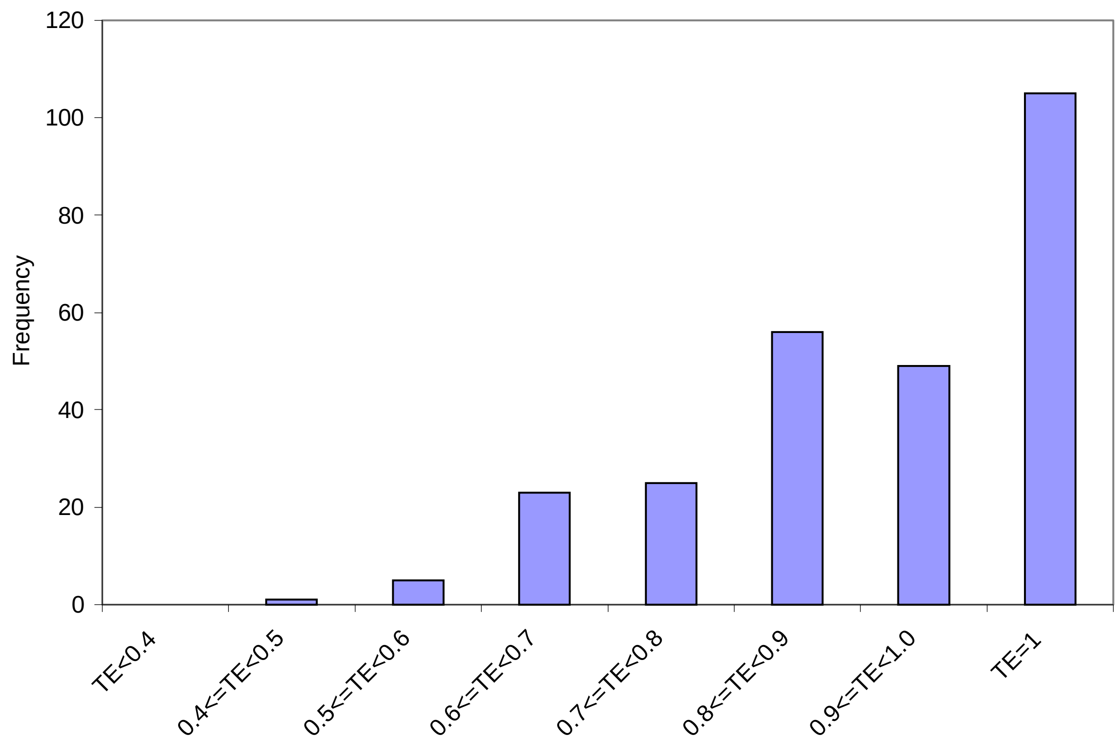
12 Note that the DEA can be used to identify potential benchmark partners as well as for measuring the technical efficiency of dairy farms. This is a major advantage over other techniques for measuring efficiency. DEA, not only measures efficiency, but also provides a guide to farmers for eliminating inefficiency.

variable returns to scale input measure of technical efficiency for each dairy farm. These results are also summarised in Table 2.

Under the VRS measure of technical efficiency about 40 percent of the sample of New Zealand dairy farms are identified as technically efficient and operating at best practice. The average VRS measure of technical efficiency for all farms in the sample is 0.89 or 89 percent. This means that 6 percentage points of the 17 per cent average inefficiency identified above are due to farmers operating at non-optimal scale. The skew to the right of the frequency distribution, Figure 2, is now more pronounced with nearly four-fifths of the sample of New Zealand dairy farms achieving technical efficiency of 80 per cent or more.

Figure 2

Frequency distribution of the variable returns to scale measure of technical efficiency for a sample of New Zealand dairy farms



As indicated earlier, the scale efficiency of the dairy farms can be measured by the ratio of the constant returns to scale and the variable returns to scale input measures of technical efficiency. A ratio of unity implies that the dairy farm is operating at optimal scale. A ratio of below unity implies that the dairy farm is experiencing technical inefficiency because it is not operating at its optimal scale.

The results for scale efficiency are also summarised in Table 2. These results suggest that 19 per cent of the dairy farms in the sample are operating at their optimal scale. On average, scale efficiency is about 94 per cent. As indicated above, inefficiency due to scale accounts for only 6 percentage points of the average technical inefficiency of 17 per cent. According to our results therefore, over 80 per cent of the farms in our sample are experiencing some technical inefficiency due to their size.

As indicated above, the existence of sub-optimal or supra-optimal scale is identified by the equality or the inequality of the variable returns to scale and the non-increasing returns to scale input measures of technical efficiency respectively. According to the results of this calculation, summarised in Figure 3, more than half the dairy farms in the sample are operating at below their optimal scale. This implies that these farms could increase their technical efficiency by continuing to increase their size. However this is not a universal phenomena as the results also indicate that just over a quarter of the farms in the sample are above their optimal scale and hence could increase their technical efficiency by downsizing. The remaining 19 per cent of farms are operating at their optimal scale.

DEA constructs a unique best practice benchmark for each dairy farm. Optimal scale, therefore, may differ for each farm based on its particular output and input configuration. The characteristics of dairy farms operating at optimal, supra-optimal and sub-optimal scales are summarised in Table 3. On average, the optimal size of New Zealand dairy farms is estimated at 83 hectares with a dairy herd of 260 animals.

Figure 3

The scale efficiency of New Zealand dairy farms

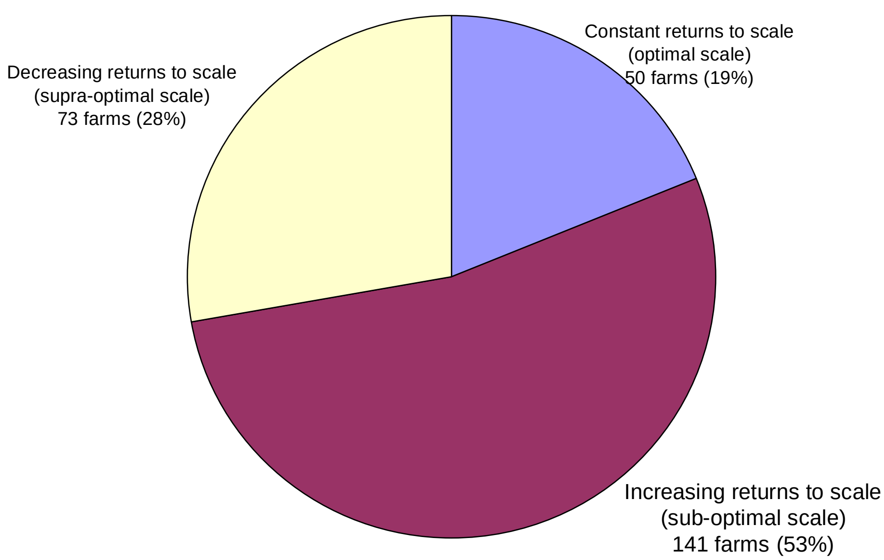


Table 3

Technical efficiency and scale of New Zealand dairy farms

Dairy Farms	*Optimal scale*	*Supra-optimal scale*	*Sub-optimal scale*
Number	50	73	141
Area (ha)			
Average	83	135	70
Minimum	32	40	16
Maximum	253	485	252
Dairy herd			
Average	260	369	201
Minimum	115	132	65
Maximum	506	1066	542
Average measure of technical efficiency (%)			
CRS	100	84	77
VRS	100	87	86

Our results suggest that 53 per cent of the sample of dairy farms are below optimal scale by an average of 13 hectares and 59 animals. By increasing their size to optimal scale, these farms would increase their average technical efficiency from 77 to 86 per cent, i.e. an improvement of 9 percentage points on average for each of these farms.

Our results also suggest that 28 per cent of farms in the sample are above their optimal scale by an average of 52 hectares and 109 animals. Downsizing to optimal scale would increase the technical efficiency of these farms from 84 to 87 per cent, i.e. an improvement in technical efficiency of 3 percentage points on average for each of these dairy farms.

5. Concluding remarks

In this paper, data envelopment analysis has been applied to measure the technical efficiency of a sample of 264 New Zealand dairy farms. The results suggest that the average technical efficiency of these farms is 83 per cent. This implies that, on average, by adopting best farm practices, these farms could have reduced their inputs of land, labour, dairy cattle, expenditure on animal health, feed supplements, fertilisers, buildings and equipment by at least 17 per cent.

Jaforullah and Devlin (1996) report the absence of a statistically significant relationship between farm size and technical efficiency based on estimation of stochastic production frontier models. While not contradicting their results, the DEA results reported in the present study suggest that New Zealand dairy farms may be able to increase their technical efficiency by an average of 6 percentage points by operating at optimal scale. More specifically, the DEA results suggest that more than half the dairy farms are operating at below their optimal scale. These farms could increase technical efficiency by increasing farm size. However the DEA results also suggest that there are a smaller number of farms that could increase their technical efficiency by reducing their size.

The strength of the non-parametric DEA methodology is that it focuses on individual farms. Cloutier and Rowley (1993) note that the DEA methodology provides a convenient procedure for monitoring the performance of individual dairy farms.

The DEA results for each dairy farm are available to determine whether an individual farm can increase its technical efficiency by increasing or decreasing its size or whether it is already operating at optimal scale. Although the parametric stochastic production frontier estimation methodology is increasingly being applied to estimate farm efficiency, the results outlined in the present study show that it is currently unable to provide and cope with the same level of detail as the DEA methodology.

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