

Variations in regional productivity in Australian wool production

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Abstract. We estimate total factor productivity in wool production spatially across benchmarked farms in four climatic areas in Eastern Australia. Estimates are decomposed into an environment-technology gap and technical efficiency relative to the production possibilities in each area. The environment-technology gap reflects the regional differences in the environment and variations in production technologies used in the wool enterprise. Significant gaps are found to exist between areas but they are relatively small in magnitude, emphasising the adaptability of the wool enterprise to environmental variability. Technical inefficiencies are also present in all areas but are larger among farmers who do not regularly receive consultancy advice in the benchmarking group. There is little variation in mean total factor productivity between the climatic areas.

Keywords: wool, efficiency, environmental-adaptability, consultancy.

Introduction

For most agricultural enterprises, a significant productivity gap would be expected to exist between producers operating in different agroclimatic areas of Australia. In this study we assess whether such a gap exists for wool production, which is arguably less sensitive to environmental conditions than many other forms of agricultural production. There has been a long history of successful adaptation to varied regional conditions that has taken place in the industry over the past two centuries.

The physical conditions have historically favoured wool production in wide areas of rural Australia given exogenous factors such as soil, climate, vegetation, location, pests and diseases (Williams 1973). In the early period of European settlement, the wool enterprise was well suited to managing the risks associated with agricultural production and marketing, saving scarce labour resources and avoiding the need for large amounts of capital expenditure. Limited labour supply and high land-labour ratios encouraged industries that did not rely on intensive labour use. Labour-saving production methods suited to a pastoral activity such as wool production were fostered rather than the more intensive activities found on small European-style farms that characterised farming systems in the early years of European settlement. The storability and high value-weight ratio of wool made it especially suitable as an export product in remote areas.

The production environment nevertheless varies considerably for wool producers in Australia as a function of spatial and temporal changes in natural resources, infrastructure, markets and institutions. Rainfall is often considered the major factor placing different limitations on production possibilities in agricultural production between regions. Other natural resource factors are also important, notably other climatic factors, soils, vegetation and topography. All of these factors may influence both the amount of wool produced and its quality.

The main factors influencing the volume of wool produced are the amount and quality of feed available, which vary spatially according to rainfall, temperature, humidity, frosts, soils, availability and palatability of pasture species, and pests among other factors (Bell 2006; Lewer 2006). Diseases such as blowflystrike, body lice, helminthiasis and bacterial diseases (Walkden-Brown and Besier 2006) also influence the condition of sheep and the amount of wool they produce, as well as its quality (and therefore prices that producers receive). Other major influences on wool quality are fibre diameter and staple length and strength (Yamin et al. 1999), and fleece rot and vegetable matter. All factors vary spatially. For example, vegetable matter tends to be a greater problem in mixed farming and pastoral areas (Fleet and Langford 2006), though chenopod shrublands found in large tracts of pastoral areas have a low grass seed burden (Lewer 2006). Fleece rot is more common in higher rainfall areas (Mortimer 2006). Disease risk factors include environmental variables such as temperature, rainfall, quantity and quality of pasture, toxicity and air quality (Walkden-Brown and Besier 2006). The natural environment for wool production also affects technology choice. Wool producers have long been adapting their production and marketing technologies to suit their operational environment as a result of experimentation, testing, and trial and error (DAFF 2001; Australian Government 2008). It means that the natural environment now exerts a less dominant influence on wool production because the various adaptations and innovations occurring in the industry have enabled wool producers to achieve greater control over their production process.

The question nevertheless remains whether wool producers are able to adjust their production technologies fully to the environment to bridge the productivity gap between a producer operating in a favourable agroclimatic system and one operating in a more difficult one. The often extreme difficulties imposed by adverse and diverse conditions for production may mean that no amount of adaptation has been sufficient to bridge this gap, and some processes may have actually widened the gap where environmental damage has occurred in a more challenging environment and easy productivity gains are made in a more favourable one. Furthermore, some factors work in opposite directions in influencing the value of a wool clip. For example, a reduction in fibre diameter can lead to a decrease in staple strength (Greef 2006).

In light of the prominence accorded to rainfall in influencing agricultural production, we assess the presence of differences in productivity between wool producers between four climatic areas in New South Wales and Victoria based on broad differences in rainfall regimes. We achieve this aim by measuring productivity, which is decomposed into the environment-technology gaps caused by spatial differences in the environment in which the wool is grown and technical inefficiency within these areas.

Study regions

The sheep production environment chosen for analysis covers most of New South Wales and parts of Victoria. It is divided into four climatic areas based on rainfall patterns:

- Northern New South Wales (CA1)
- South-Western New South Wales (CA2)
- Central and South-Eastern New South Wales (including a small part of North-Eastern Victoria) (CA3)
- South-Western Victoria (CA4).

CA1 comprises one Australian Sheep Region and part of another defined by Hassall and Associates Pty Ltd (2006) that are both predominantly self-replacing Merino sheep production systems operating in a summer rainfall climate. The regions are the elevated Armidale High Rainfall Sheep Region, which comprises mostly productive temperate pastures, and the flat to undulating New South Wales portion of the Northern Wheat/Sheep Region, which has lower rainfall, hotter temperatures and a greater emphasis on cropping. Soils, topography and climatic conditions vary across space in the area as a whole, and productivity potential is therefore diverse as demonstrated by DAFF (2001) and Walcott and Zuo (2003).

CA2 is part of the Central Pastoral Sheep Region (Hassall and Associates Pty Ltd 2006) in Western New South Wales, experiencing low winter rainfall. DAFF (2001) and Walcott and Zuo (2003) classify this region as having low to very low productivity potential for agricultural pursuits. Arid zone soils, native pastures and self-replacing Merino sheep production systems predominate (although the region is home to the highest proportion of wether-based enterprises). Rainfall tends to be extremely variable over time and across space, and lamb survival rates are low (Hassall and Associates Pty Ltd 2006).

CA3 comprises parts of two Australian Sheep Regions in New South Wales: the Eastern Wheat/Sheep Region and the Eastern High Rainfall Sheep Region (Hassall and Associates Pty Ltd 2006). It has evenly spread winter rainfall. The Eastern Wheat/Sheep Region has a wide range of annual pastures and winter and summer crops produced on both irrigated and dryland farms (Hassall and Associates Pty Ltd 2006). In the Eastern High Rainfall Sheep Region, pastures are mainly productive temperate pasture species. Both regions have a greater preponderance of sheepmeat enterprises than the first two climatic areas. According to DAFF (2001) and Walcott and Zuo (2003), this region has consistently high productivity potential with pockets of very high potential.

CA4 corresponds to the region termed the Southern High Rainfall Region by Hassall and Associates Pty Ltd (2006), and has winter rainfall dominance. Pastures are typically improved, and grazing enterprises commonly comprise both wool and sheepmeat self-replacing production systems (Hassall and Associates Pty Ltd 2006). Environmental conditions tend to be favourable for wool production, indicated by the high to very high productivity potential accorded to it by DAFF (2001) and Walcott and Zuo (2003).

Conditions in CA1 make it difficult for average producers to bridge the productivity gap between themselves and the best-practice farmers on a regular basis. The physical features of CA2 are also likely to make it difficult for the best producers in this region regularly to bridge the productivity gap between themselves and the best producers in more favourable regions. Furthermore a substantial performance gap may exist between producers with and without access to irrigation facilities. On the other hand, the more favourable conditions for agricultural production in CA3 should make it easier for sheep producers to operate at consistently high levels of technical performance. Wool producers in CA4 should also find it relatively easy to operate at a high performance level. But because some producers do not pay for and receive regular consultancy advice technical efficiency is likely to be variable within regions.

Alternative classifications could have been chosen, such as an east-west orientation based on annual rainfall amounts. But we were constrained by the arrangement of the available data. In any event, our categories reflect to some extent variations in annual rainfall patterns.

Adaptations to the wool production environment

Evidence from studies of the Australian wool industry outlined below suggest that significant differences exist in production possibilities between wool-producing regions The historical development of wool production and innovations within the wool industry appear to have enabled it to adapt to various production environments. The forms of adaptation and innovation to modify the environment are many and varied.

Innovations in sheep breeding

Variation in performance between sheep occurs as a result of their genes and the environment in which they are located. The main initial innovation in the wool industry was the introduction of Merino sheep on which the industry is still largely based. Even in the harsher environments, wool production still flourishes because of the suitability of Merinos to Australian production conditions, especially in areas with a hot arid climate. Merino sheep have proved adaptable to Australian production conditions chiefly because they 'apply an impressive array of behavioural adaptations to their herbivorous mode of life' (Colditz and Dart 2009, p. 2). Taylor (2006) provided a chronology of Merino breeding and genetics research in Australia from 1930 to 2000, which demonstrates that genetic improvements and selection of Merino sheep breeds and sires have long been a feature of research activities and management strategies to suit particular environments. They are exemplified by genetic selection for resistance to roundworms, blowfly resistance, dermatophilosis and fleece rot (Mortimer 2006), fleece weight and diameter (Taylor 2006), staple strength and style (Greef 2006) and body weight (Hinch 2006). An example of how genetic advances can help modify environmental impact is breeding for larger-framed Merinos that are better adapted to semi-arid rangelands (Lewer 2006), typified by the challenging conditions prevalent in CA2.

Improving wool quality

Farmers produce wool of varying quality and opt to produce wools of different wool diameter (microns), and therefore it is not a homogeneous product. These variations in wool quality influence the prices received by the grower. Using their estimated model for wool micron, length and vegetable matter for auction sales in Australia and New Zealand for the 1986-87 selling season, Angel et al. (1990) demonstrated how prices vary when each pair of these attributes is considered. Vegetable matter content was found to affect finer micron wool more than broader micron wools, and the effect of micron on prices was far greater than the effect of vegetable matter on prices. These attributes vary spatially, but outcomes from the considerable research effort that has gone into improving wool quality, such as better measurement and description of objectionable fibres and improved processing to remove vegetable matter (Fleet and Langford 2006), are likely to have lessened the impact on productivity of these spatial variations.

Managing pastures and grazing intensity

Advances in the management of pastures and grazing pressure in the wool industry are epitomised by the introduction of improved pasture species, rotations, fertiliser application in hilly farming areas, aerial sowing, better use of native pastures, improved drought management, supplementary feeding and spatial diversification of properties owned to exploit regional differences in seasonal conditions. In particular, areas of sown pasture increased rapidly between 1950 and the mid-1970s (DAFF 2001). Irrigation has been used to improve pasture production, particularly in dry years (DAFF 2001) in areas of unreliable rainfall, but has been restricted to regions where the necessary infrastructure exists.

Hodgson (1990) provides a good summary of the science behind sheep grazing management and how grazing management systems vary according to the physical environment and pasture species. Scott et al. (2000), Chapman et al. (2003), Graham et al. (2003), Michalk et al. (2003), Sanford et al. (2003), Bell (2006) and Lewer (2006) analyse how different grazing methods improve the performance of animals, particularly sheep, in different parts of Australia that correspond to our four climatic areas.

Developing and managing on-farm water supply for livestock

The development and management of on-farm water supply for sheep has been a major factor enabling farmers to increase their productivity, especially in drier areas. Abel et al. (2006) observed that the 'spread of water points across previously unwatered country simultaneously gave sheep access to more grazing while reducing stocking density by orders of magnitude'. Pasture usage is improved with more watering opportunities for sheep (Squires 1981). Fencing to separate flocks has been crucial in this process (Abel and Langston n.d.). The development of on-farm water supply has been particularly important in the Pastoral Zone (and therefore CA2).

Health management and animal husbandry

Sheep are susceptible to a range of infectious, parasitic, nutritional and neoplastic diseases, but have proved excellent animals for experimentation in physiological studies (Colditz and Dart 2009). An impressive stock of research results have accumulated, which has no doubt aided the adaptation of sheep to different environments. Traditional control measures of grazing management and chemicals have been augmented in recent times by breeding for disease resistance and the strategic use of nutrition, biological control and vaccination to control disease (Walkden-Brown and Besier 2006). Sheep husbandry skills and expertise have also accumulated over time, to similar effect. Examples of the broad range of advances in animal husbandry are more effective drenching regimes, modified timing of mating to suit seasonal conditions and aerial mustering on farms with difficult topography.

Environmental degradation

Modification of the grazing environment has not always been positive and led to a narrowing of productivity differences across space. Wool producers are facing a number of environmental challenges. Degradation in grazing areas has reduced the landscape function through soil erosion, loss of soil structure, loss of native species, woody weed infestation, scrub encroachment, feral animals, salinity, chemical residues, and loss of wildlife habitat and biodiversity (Abel and Langston n.d.; Gardiner et al. 1998;

Department of the Environment, Water, Heritage and the Arts 2002). It may have accentuated differences in productive capacity between regions by having differential effects on the natural resource base.

Greater understanding of agroecosystems and better decision making by graziers

As Abel and Langston (n.d., p. 22) pointed out in respect of the Pastoral Zone, biodiversity is 'a source of adaptive capacity – "resilience-in-waiting"'. Ecological innovations and the accumulation of knowledge of the links between productivity and biodiversity, and the limits placed on sheep carrying capacity by environmental degradation, have therefore become more prominent features in graziers' management programs in recent years. Early efforts to conserve the production environment entailed control measures to deal with pests and weeds. Biological control agents have had a substantial effect on the rabbit population since 1950, providing an obvious example of pest control in sheep production. It was initially achieved through the myxamotosis virus and, and more recently, through 1080-based baits and the Calici virus. The construction of rabbit proof fencing and the fumigation and destruction of warrens have also played a role in controlling the population. More recently, conservation measures have been taken through programs such as sustainable grazing systems. Livestock have been excluded from degraded areas, weeds have been more effectively eradicated, and greater use has been made of perennial pastures and the maintenance of vegetation along drainage lines (Department of the Environment, Water, Heritage and the Arts 2002). Maintaining flexible and proactive farming operations has helped wool producers manage the environmental risks they face. Strategies include enterprise diversification and stocking rate changes in response to rainfall, spatial diversification and the strategic trading and movement in sheep, and weed and disease control (Abel and Langston n.d.; Lewer 2006; Stafford Smith and McKeon 1998; Howden et al. 2009). Use of decision support tools and remote sensing of feed on offer has helped sheep producers make better predictions about future production conditions, improving the sustainability of grazed pastures. The Department of the Environment, Water, Heritage and the Arts (2002) pointed out the value of measures such as the formal monitoring of vegetation and pasture condition, and monitoring water tables.

Exploiting scale in farming operations

Choosing the optimal scale of farming, and maintaining a flexible farming system to allow for variations around this scale according to climatic and market conditions, enables wool producers to maximise their productivity. It has long been a major factor influencing the productivity of grazing enterprises in Australia, with inexorable increases in the average size of broadacre properties (ABARE 2007). This has long been apparent in the Pastoral Zone where the disadvantage of low output per sheep per hectare has been offset by developing large properties (Davidson 1967). Abel and Langston (n.d.) also point out that property size is an important determinant of adaptive capacity.

Development of supporting rural institutions and infrastructure

Various forms of institutional support have assisted wool producers, particularly in terms of research and extension, as noted above, but also in facilitating the accumulation of human and social capital (Nelson et al. 2007). They include the role of the family farm and local support networks, structural adjustment programs, soil conservation programs and drought assistance. Abel et al. (2006) identified the importance for the pastoral system of 'networks of properties held by pastoral families or companies, supporting services, communication and transport networks, abattoirs, and markets for wool and meat'. They also referred to the beneficial links to 'a system comprising state and federal governments, lobby groups, voters, media, and the Australian and international economies', arguing that pastoralists gained considerable access to external resources through exertion of their economic power and political influence. There is, however, a negative side to institutional intervention. Walker and Janssen (2002, p. 719) concluded that 'command-and-control approaches to rangeland policy and management are bound to fail'.

Method of analysis and data

The method of analysis used is the stochastic metafrontier framework developed by Battese and Rao (2002), Battese et al. (2004) and O'Donnell et al. (2008). The metafrontier is a production function that envelops all individual group frontiers, which are boundaries of restricted sets of production technology.

Battese and Rao (2002) use the term, metatechnology ratio, to describe the gap in performance between a firm in a group (in this study, a farm in a climatic area) and the best-practice firms forming the production frontier for all groups (the metafrontier). In view of the presence of environmental constraints in wool production, we call this ratio the environment-metatechnology ratio (EMTR) to reflect the fact that farmers are constrained in their production processes by the environment in which they operate, and use those processes based on technologies adapted to that environment. The EMTR measures the ratio of the output of the frontier production function for a particular region to the potential output that is defined by the metafrontier function, given the observed inputs (Battese and Rao 2002; Battese et al. 2004). Values lie between zero and one: the higher the values of the EMTR for the individual frontier of the climatic area, the closer it is to the metafrontier. The performance of farms relative to the frontier of their individual climatic area reflects their technical efficiency within that environment, and is termed the TE-A. These values also lie between zero and one, with higher values indicating a higher level of technical efficiency. TE-M measures the individual farm relative to the metafrontier, and is the product of TE-A and EMTR. It provides a means to compare total factor productivity indices between farms and to measure mean total factor productivity across climatic areas in a manner analogous to the temporal measurement of change in total factor productivity as outlined by Coelli et al. (2005, p. 301).

The following three propositions are examined by estimating EMTRs and TE-As for wool producers in the four climatic areas:

1. Variations in EMTRs between climatic areas are expected to exist, with higher mean EMTRs in the more favourably endowed CA3 and CA4.
2. EMTRs of individual farms are expected to be more widely distributed in the more diverse climatic areas of CA1 and CA2.
3. TE-A scores of farms in CA4 are expected to be lower with higher variance, with higher TE-A scores for farms receiving consultancy advice.

We use farm-level data obtained over ten years from two benchmarking groups:

1. A commercial organisation, which provides consulting advice to all farmers in regions CA1, CA2 and CA3 and some farmers in CA4.
2. A government-based organisation, which collects benchmarking data from farmers in CA4 but does not provide any consultancy advice.

The unbalanced panel data set contains 1157 observations from 372 farmers covering the ten-year period from 1994/95 to 2003/04. The data set contains farm-level input and output data for farm enterprises. The wool output variable was calculated as the sum of implicit wool output and net trading profit or loss on adult sheep. Implicit output was obtained by dividing wool revenue in each year by the wool price index and the net trading revenue by the sheep price index. Both indices are published by ABARE (2007). The wool output was calculated per dry sheep equivalent (DSE) (that is, constant returns to scale are assumed) because data on farm area were unavailable for farms in the government-based benchmarking group.

Seven input variables were included in the estimated models: agistment, health, pasture, selling, shearing, labour and overheads. Overheads that were included were restricted to those that have a direct influence on wool production. All input variables were calculated as costs per DSE that were deflated by the index of prices paid by farmers (ABARE 2007). Information about the data set and variables are provided in Table 1, where the figures in parenthesis are standard deviations.

Results

We follow Coelli et al. (2005) and assume that all firms have access to the same technology in every period and that the covariances between all error terms are zero. This enables us to treat the panel data as if they were from a single cross-section. We have confirmed this approach by including a time trend in the initial model which was found to be insignificant; thus, it was excluded in the final model.

A likelihood ratio test result justifies the estimation of a metafrontier production model, and a generalised-likelihood ratio test result suggests that the group frontiers are not identical (*p*-value = 0.0000).

Estimates of the metafrontier production function are presented in Table 2. The standard deviations of the metafrontier estimates were calculated using parametric bootstrapping as suggested by Battese et al. (2004). Apart from labour and pasture/feed, estimated coefficients of the stochastic metafrontier production function were found to be significant and of expected sign.

Estimated mean EMTRs, TE-As and TE-Ms are presented in Table 3 and their distributions are presented in Figure 1. The value of EMTR ranges from 0.20 to 1. The maximum value of 1 was observed in all climatic areas, which indicates that all four frontiers were tangential to the metafrontier at least at some point.

The mean EMTRs were found to be significantly different for all climatic areas. The results support the first proposition of higher mean EMTRs in the more favourably endowed CA3 and CA4 than those in CA3 and CA4. But, although the differences are significant, the variations in EMTRs are minor in magnitude, with a relatively small range in mean values from 0.72 in CA2 to 0.80 in CA3. CA1 and CA2 recorded relatively low mean EMTRs of 0.73 and 0.72, respectively. It implies, for instance, that wool producers in CA2 produce on average only 72% of the potential wool output than could have been obtained from the best production technology available and most suitable environmental conditions for wool production in Eastern Australia.

EMTRs within climatic areas have low standard deviations relative to their means, indicating low dispersions for all areas (Table 3). They are more widely dispersed among farms in CA2, in line with the second proposition that EMTRs are more widely distributed in the physically more diverse climatic areas. Figure 1 shows that there are quite a few high individual EMTRs in CA2, indicating that at least some properties in the Pastoral Zone have been able to adapt fully to the most favourable production conditions. The most plausible explanations are that these properties are among the best fine wool producers in Australia and have regular access to adequate water supplies. In contrast, CA1 has very few observations on or near the metafrontier and, contrary to the second proposition, has the lowest standard deviation of EMTRs (Table 3). Higher mean EMTRs were found to exist in CA3 (0.80) and CA4 (0.77). The highest estimated mean EMTR in CA3 is consistent with the high productivity potential across the area. Variations in EMTRs within areas are attributable to the fact that not all producers take advantage of available production technologies. For example, Hinch (2006) reported uneven progress in adopting genetic advances in the sheep industry.

Turning now to the technical efficiency estimates, the TE-As represent what is feasible for farmers to achieve in each climatic area. Farms in CA1 and CA2 on average achieved higher technical efficiencies relative to their respective frontiers whereas their lower EMTRs indicate that they tended to be furthest from the metafrontier. The result of a statistical test indicates that the mean TE-As for CA1 and CA2 are not statistically different. Observations in CA1 are relatively closely grouped such that the mean TE-A score is high at 0.86. Both CA3 and CA4 have a substantial proportion of TE-A observations on or close to their respective frontiers and CA3 has a relatively high mean TE-A score of 0.80. Observations are relatively widely spread in CA4, with a mean TE-A score of only 0.74 despite having a substantial proportion of observations on or close to the metafrontier. This result is consistent with the third proposition that farms not receiving regular consultancy advice will have lower efficiency. A statistical test indicates that there is a significant difference in TE-A scores between those farms with consultancy advice and those that do not receive any advice, with the former having a higher mean technical efficiency. Variation in technical efficiency in CA4 therefore seems to depend on whether paid consultancy advice is regularly received by farmers in the benchmarking groups. It is probable that the consultancy advice improves performance and/or higher-performance farmers are more likely to pay for consultancy advice.

Conclusion

Results reported in this paper show that productivity levels achievable by producers in challenging environments appear to be similar to those achievable by producers in more favourable environments, with only small, albeit significant, environment-technology gaps present between four selected climatic areas in Eastern Australia. Even within the climatic areas, farm-level EMTRs are tightly distributed around the mean. Thus, constraints on production imposed by the rainfall regime do not greatly restrict wool production. This result can be attributed to the various processes of successful adaptation to climatic conditions and the suitability of the Merino to a wide range of production conditions from the beginnings of the wool industry in Australia. The success of these farm-level adaptation processes, aided by the adoption of improved technologies, is due in large part to the research and development work carried out by the research and extension staff and consultants in the sheep industry. These processes have suited the varied environmental conditions in which wool is being produced, and have endowed producers with greater control over their environment. Environmental constraints appear to be as limiting within the delineated climatic areas as between them, due to a complex set of physical constraints in addition to rainfall and differences in adoption rates of available production technologies.

Farmers in Northern and South-Western New South Wales achieved higher technical efficiencies relative to their respective frontiers than farmers in Central and South-Eastern New South Wales and South-Western Victoria; but average producers in these regions tended to be furthest from the potential output achievable across all climatic areas. Another result of interest is the wider distribution of technical efficiency scores within the South-Western Victoria region than in the other three climatic areas. This finding is probably attributable to the absence of consulting advice to some sampled farmers in this region because farms receiving consultancy advice had significantly higher technical efficiency scores than those that did not.

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Appendix

Table 1 Descriptive Statistics

Items	CA1	CA2	CA3	CA4	All
Number of observations	221	307	123	506	1157
Number of cross-sections	98	109	42	123	372
Wool income ($/DSE)	21.33 (7.069)	17.97 (4.91)	19.97 (5.97)	22.55 (11.53)	21.15 (9.05)
Agistment ($/DSE)	1.99 (3.23)	2.53 (4.69)	2.27 (3.61)	2.33 (2.35)	2.27 (3.20)
Health ($/DSE)	1.51 (0.74)	1.30 (0.74)	1.34 (0.92)	1.056 (0.62)	1.25 (0.77)
Pasture/Feed ($/DSE)	2.19 (1.29)	1.08 (1.72)	2.81 (1.67)	2.55 (1.23)	2.37 (1.50)
Overhead ($/DSE)	4.91 (1.76)	5.78 (2.78)	4.80 (1.90)	8.74 (5.90)	6.65 (4.59)
Shearing ($/DSE)	3.88 (1.23)	3.83 (1.24)	3.47 (1.16)	3.066 (1.093)	3.41 (1.20)
Selling ($/DSE)	1.97 (0.94)	1.84 (0.79)	1.89 (1.16)	1.90 (0.82)	1.90 (0.94)
Labour ($/DSE)	4.83 (2.29)	5.84 (3.58)	4.94 (2.00)	4.96 (3.53)	5.02 (2.99)

Table 2 Estimates of Parameters of the Metafrontier Production Function

Variable	**Coefficient**	**Standard error**	***t*-statistic**
Constant	0.539	0.042	12.79 [a]
Agistment	-0.034	0.008	-4.44 [a]
Health	0.053	0.035	1.54[c]
Pasture/Feed	0.016	0.014	1.16
Overhead	0.250	0.043	5.87 [a]
Shearing	0.076	0.039	1.96 [b]
Selling	0.215	0.032	6.78 [a]
Labour	0.035	0.037	0.96

Note: This is an abridged version of the translog model.

[a,b,c] indicate significant at 1, 5 and 10% levels, respectively.

Table 3 Estimated EMTRs, TE-As and TE-Ms

Statistic	**Region**	**Mean**	**Standard deviation**	**Minimum**	**Maximum**
Environment-metatechnology ratio (EMTR)	CA1	0.73	0.10	0.31	1.00
	CA2	0.72	0.17	0.20	1.00
	CA3	0.80	0.12	0.35	1.00
	CA4	0.77	0.13	0.27	1.00
Technical efficiency with respect to the regional frontier (TE-A)	CA1	0.86	0.08	0.33	0.96
	CA2	0.86	0.09	0.54	0.97
	CA3	0.80	0.13	0.30	0.97
	CA4	0.74	0.15	0.09	0.94
Technical efficiency with respect to the metafrontier (TE-M)	CA1	0.63	0.11	0.23	0.95
	CA2	0.62	0.16	0.17	0.93
	CA3	0.64	0.14	0.16	0.94
	CA4	0.57	0.15	0.08	0.91

Figure 1 Distributions of EMTRs, TE-As and TE-Ms by region