Productivity Change in the Australian Sheep Industry
Revisited

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Abstract

Recent low estimates of total factor productivity change for wool producers in the Australian sheep industry indicate that they are struggling to improve their performance. This evidence is at odds with the views of many technical observers of industry performance, prompting us to re-estimate total factor productivity change for farmers in a benchmarking group in south-west Victoria who had been the subject of such a negative finding. An important transformation in sheep production in Australia in recent decades has been a change in enterprise mix, notably a greater presence of prime lamb production. This change complicates the process of computing efficiency and productivity change. We demonstrate that a multi-input multi-output approach, based on the use of a stochastic output distance function and assuming non-neutral technical change, helps to avoid errors of estimation of productivity change. Following this approach, we find substantial technical progress and productivity gains on farms over the period, 1995/1996 to 2003/2004, for merino wool specialists. Growth in total factor productivity on properties operating wool and prime lamb enterprises is less impressive, indicating an initial decline in total factor productivity in 1996/1997 as farmers adopted a more diversified enterprise mix. Following this decline, however, farms achieved a modest increase in total factor productivity.

Keywords: sheep; stochastic output distance function; technical change; total factor productivity
Introduction

The genesis of this study lay in a project that was part of the research activities of the Australian Sheep Industry Cooperative Research Centre. The project entailed collaborative research with sheep industry benchmarking groups, analysing technical efficiency and productivity change in wool production in a number of locations in Australia. One of the collaborating benchmarkers was the Victorian Department of Primary Industries through its Farm Monitor Project (FMP), which has a long history of benchmarking production on farms located in south-west Victoria.

The data collected under the FMP had already been used by Fraser and Hone (2001) to analyse total factor productivity (TFP). They had reported a decline in TFP in wool production over the period, 1990/1991 to 1997/1998, that is at odds with the expectations of the benchmarkers who felt considerable progress has been made over the past two decades in introducing improved technologies in Australian wool production arising from considerable research and development activity. Examples include improved pasture varieties, better feeding strategies, genetic advances (Kingwell, Bathgate and O’Connell 1999) and better timing of the key operations of lambing and shearing. Our initial efforts to test Fraser and Hone’s (2001) results, reported below, led us to a similar finding, and so began our search to find out why the expectations of benchmarkers differed from what the results of our data analysis and that by Fraser and Hone (2001) had shown.

In this study, we contrast the single output analysis with the multiple output analysis in the context of the different types of sheep enterprises in Australia to resolve this apparent difference between expectations and existing empirical evidence.

Existing Empirical Evidence

There have been many previous studies of the productivity changes in Australian agriculture and in the Australian sheep industry in particular. Table 1 contains some of the productivity growth figures relating to the Australian sheep industry reported by several researchers over the past few decades. Most authors (Lawrence and McKay 1980, Coelli and Kingwell 1991, Mullen and Cox 1996, Stoneham et al. 1999, ABARE 2004a) used data published by the Australian Bureau of Agricultural and
Resource Economics (ABARE). The estimated productivity changes they calculated relate to either the national, state or zone level for slightly different data periods.

Using a data set from the early 1950s to the early 1990s, the annual productivity growth estimates for sheep-related enterprises on a national or state level were between 2 per cent to 3 per cent. Once the time period was reduced by only considering productivity changes from 1977, the annual productivity growth estimates dropped to under 1 per cent on an Australia-wide basis. The national figure masks large interstate differences in annual productivity growth estimates, ranging from 1.9 per cent in Queensland to 0 per cent in Victoria (Stoneham et al. 1999). More recently, ABARE (2004a) published annual productivity growth estimates using a time period starting in 1988. Here, the national annual productivity growth estimate is 1.2 per cent.

The decomposition of farms according to whether or not they are specialist sheep farms and according to the percentage of total farm receipts received from prime lamb production yield interesting divergences in annual productivity growth rates. Farms with sheep as one of their enterprises exhibit higher annual productivity growth than the specialist wool producers (prime lamb receipts less than 5 per cent) and specialist prime lamb producers (prime lamb receipts greater than 20 per cent). This higher rate presumably reflects the mixed-enterprise farmers’ ability to increase their farm productivity by increasing the allocation of resources to other more profitable enterprises on the farm (for example, crops or beef) at the expense of the sheep enterprises and also possibly to exploit scope economies. The annual productivity growth rates for the specialist wool producers (0.3 per cent) and prime lamb producers (0.8 per cent) since 1988 are disturbingly low. The annual productivity growth for both specialist sheep farms and all sheep farms when prime lamb receipts lie between 5 per cent and 20 per cent is especially interesting. Farms that obtained from 5 per cent to 20 per cent of their receipts from prime lamb had a TFP growth of 2.8 per cent if they were sheep specialist farms and 2.1 per cent TFP growth for all sheep farms. These results suggest that there are productivity gains obtainable by changing the emphasis in the production of the possible outputs in the sheep enterprise.
<table>
<thead>
<tr>
<th>Author</th>
<th>Data period</th>
<th>Area</th>
<th>Data</th>
<th>Enterprise</th>
<th>Method</th>
<th>TFP % p.a.</th>
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<tbody>
<tr>
<td>Lawrence and McKay</td>
<td>1952/53 – 1976/77</td>
<td>Australia</td>
<td>ABARE</td>
<td>Sheep</td>
<td>Tornqvist</td>
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<td>Coelli and Kingwell</td>
<td>1952/53 – 1987/88</td>
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<td>ABARE</td>
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<td>Tornqvist</td>
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<td>1953 – 1994</td>
<td>Australia</td>
<td>ABARE</td>
<td>Broadacre agriculture</td>
<td>Various</td>
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<td>Stoneham et al.</td>
<td>1977/78 – 1996/97</td>
<td>Victoria, Queensland, Australia</td>
<td>ABARE</td>
<td>Sheep</td>
<td>Fisher</td>
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<tr>
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<td></td>
<td>1977/78 – 1989/90</td>
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<td>1988/89 – 2001/02</td>
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<tr>
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<td>prime lamb&lt;5%</td>
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<td></td>
<td>Specialist sheep farms:</td>
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<td>2.8</td>
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<tr>
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<td>prime lamb&lt;5%</td>
<td></td>
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<td></td>
<td></td>
<td>0.3</td>
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<tr>
<td>Fraser and Hone</td>
<td>1990/91 – 1997/98</td>
<td>South-west Victoria</td>
<td>SWFMP Farm level</td>
<td>Wool</td>
<td>DEA and Malmquist</td>
<td>-2.5</td>
</tr>
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</table>

Fraser and Hone (2001) undertook their analysis using farm-level data published by FMP. They used a balanced panel of 26 wool producers covering 8 years from 1990/1991 to 1997/1998. Output-orientated DEA and Malmquist methods were applied to obtain yearly technical efficiency measures and TFP indices for each farm. They found that farm-level TFPs were volatile between years and between farms. The average decrease in TFP of 2.5 per cent per annum over eight years masked individual annual changes of 38 per cent TFP growth and 29 per cent TFP decline. Similarly, variation could be observed between the 26 farms within each year. Fraser and Hone (2001, p. 230) noted that the farm-level variation of TFP within and between years was ‘driven more by technical change (or technical progress) rather than
improvements in technical efficiency’. In some years, the overall contracting frontier was attributed to ‘a constraint on production possibilities due to seasonal conditions rather than technological regress’. In other years, suggested reasons for the decline in TFP were reduction in the level of management, a deterioration of the natural resource base of the farms or a decline in capital stock. Fraser and Hone (2001 p. 229) conclude that the TFP values they obtained present a ‘worrying picture for this industry’.

Given this apparent desperate state of affairs in the Victorian sheep/wool industry and the disparity of TFP movement in relation to the proportion of prime lamb receipts, we decided to revisit the issue of productivity in sheep-related enterprises. By updating the FMP data set and increasing the diversity of sheep farms considered, we aim to examine if TFP and levels have changed. In particular, we examine whether the increasing emphasis on prime lamb production on sheep farms affects the annual productivity levels. Unlike Fraser and Hone (2001), we use a parametric approach with an underlying translog production function. This methodology enables us to incorporate environmental variables such as seasonal conditions in the estimation process.

Data

Following Fraser and Hone (2001), this study also uses the published data from the FMP. The data series used in our analysis covers the 10 years from 1994/1995 to 2003/2004. The FMP covers participating farms in south-west Victoria and the data set contains farm-level input and output data for farm enterprises including wool, beef, prime lamb and some crops. We confine our analysis to the sheep enterprises of wool and prime lamb production, in contrast to Fraser and Hone (2001) whose focus was mainly on the wool enterprise. The farms with sheep enterprises have been subdivided into sub-groups of wool-only farms, and farms operating both prime lamb and wool production activities.

Fraser and Hone (2001) observed that environmental conditions are reasonably homogeneous throughout the region. Some spatial variation does exist, which means that a few sheep farmers may be restricted to concentrating on wool production. But most sheep farmers in the study area have a degree of choice between wool and prime lamb production. This choice does not entail just the extremes of a wool enterprise
versus a lamb enterprise. There are many gradations in emphasis that can be chosen between wool and prime lamb. Throughout our study period, and especially in the last five years, there was a noticeable movement from an emphasis on wool production towards prime lamb production.

**Analytical Method**

**Inputs and outputs**

The wool output variable was calculated as the sum of deflated wool revenue, to measure 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 published by ABARE (2004b). Lamb output is the value of lamb sales deflated by lamb price index, also published by ABARE (2004b). Both outputs were calculated per dry sheep equivalent (DSE).

Seven input variables were included in the estimated models: agistment, health, pasture, selling, shearing, labour and overheads. All input variables were calculated per DSE and deflated with the index of prices paid by farmers (ABARE 2004b). Data were obtained from the annual publications of statistical tables by farm number (Department of Primary Industries 2004).

Seasonal dummy variables were included to reflect changing environmental factors between the years. Not only do these variables reflect the seasonal climatic conditions, but they also reflect any other factors that would impede farmers achieving maximum productivity (for example, post-drought financial levels, shortage of animals for restocking).

**Models**

Malmquist indices were calculated to measure changes in TFP in the sheep industry over the study period, following the same methodological path for calculating TFP change outlined by Coelli, Rao, O’Donnell and Battese (2005). One of the major advantages of estimating a Malmquist index is that it assumes an underlying translog production function that allows flexibility in the relations between outputs and inputs in production technology. For this reason, we estimate models based on a translog functional form.
Four separate analyses were undertaken over the ten-year period from 1994/1995 to 2003/2004. Results are reported below and compared with those obtained by Fraser and Hone (2001) and ABARE (2004a). The first model (M1) entails an analysis of the production relations for a single output, wool, for all farmers. It is based on a data set similar to that used by Fraser and Hone (2001), albeit for a different study period. In the second model (M2), we estimated the production relations for the sub-group of specialist wool producers; that is, producers who engage in wool production but do not engage in prime lamb production. Obviously, wool is again the sole output considered. In the third model (M3), we estimated the production relations for farmers who produce both wool and prime lamb (that is, omitting the specialist wool producers) again with a single output, wool. In the final model (M4), we estimated the production relations for all farmers who produce both outputs but this time including two output variables, wool and prime lamb, in the model.

Stochastic production frontier analysis (SPFA) is used to estimate the first three models. As with the method of data envelopment analysis (DEA), applied by Fraser and Hone (2001), it allows the calculation of technical change, technical efficiency and TFP indices. SPFA is preferred to DEA for four main reasons. First, it accounts for noise, thereby avoiding the restrictive deterministic assumption of DEA. Second, it allows us to capture annual variations in environmental conditions and purge them from estimates of technical change. Third, it can be used to conduct hypothesis tests. Fourth, unlike DEA it allows the use of an unbalanced data set, which is an important consideration given the limited number of observations on producers operating both wool and prime lamb enterprises.

For the estimation of M4, we estimate a two-output model for wool and prime lamb production. Because SPFA allows specification of only one output, it was replaced by stochastic distance function analysis (SDFA). As for SPFA, SDFA provides estimates of technical change, technical efficiency and TFP indices.

A choice needs to be made between an output and an input orientation when conducting SDFA. Most of the inputs used in sheep production are fixed in the short run, offering limited opportunity to producers to alter their resource mix. The best examples of these types of inputs are operator and family labour, land and livestock. For this reason, we chose an output orientation to estimate the multi-input multi-output stochastic output distance function. Results were used to calculate a technical
efficiency index for each sampled farm and mean technical efficiency across all farms for each year of the study period, using the time-varying option in FRONTIER 4.1 (Coelli 1996).

All models were based on a translog functional form that was fully flexible between inputs and outputs. The means of the logged variables were adjusted to zero prior to estimation so that the coefficients of the first-order terms of inputs could be interpreted as partial output elasticities, evaluated at the sample means.

Following Coelli et al. (2005), the stochastic frontier production function is defined as:

\[
\ln Y_i = \beta_0 + \sum_{j=1}^{7} \beta_j \ln X_{ji} + \sum_{k=1}^{7} \beta_{jk} \ln X_{ki} + \sum_{n=1}^{2} \alpha_m \ln Y_n \ln Y_n' + \sum_{m=1}^{7} \sum_{n=1}^{2} \omega_{mn} + v_i - u_i
\]

where:

- \(Y_i\) is the output of the \(i\)-th wool producer,
- \(X_{ji}\) is the \(j\)-th input of the \(i\)-th wool producer;
- the \(v_s\) are assumed to be independently and identically distributed with mean zero and variance, \(\sigma_v^2\); and the \(u_s\) are technical efficiency effects that are assumed to be half-normal and independently distributed such that \(u\) is defined by the truncation at zero of the normal distribution with known variance, \(\sigma_u^2\).

The translog output distance function is defined as:

\[
\ln d_o = \beta_0 + \sum_{m=1}^{7} \beta_m \ln X_m + \sum_{n=1}^{2} \alpha_n \ln Y_n + 0.5 \sum_{m=1}^{7} \sum_{m'=1}^{7} \beta_{mm'} \ln X_m \ln X_{m'} + 0.5 \sum_{n=1}^{2} \sum_{n'=1}^{2} \alpha_{nn'} \ln Y_n \ln Y_{n'} + \sum_{m=1}^{7} \sum_{n=1}^{2} \omega_{mn} \ln X_m \ln Y_n
\]

where:

- \(Y_n\) is the \(n\)-th output,
- \(X_m\) is the \(m\)-th input, and \(\alpha, \beta\) and \(\omega\) are parameters to be estimated.

The estimating form of the stochastic output distance function was obtained by setting \(-\ln d_i = v_i - u_i\) and imposing the restriction required for homogeneity of degree +1 in outputs. The negative of natural logarithm of prime lamb output was set as the dependent variable.

The output distances are predicted as:
\( (3) \quad D_i = E[\exp(u_i)| e_i] \)

where \( e_i = v_i - u_i \) (Coelli and Perelman (1996, p. 14).

The change in enterprise mix in M4 over time casts doubt on the validity of the assumption of neutral technical change. A likelihood ratio test was conducted that rejected this assumption, leading us to specify a model assuming non-neutral technical change by including the trend variable within the translog structure.

Following Battese and Coelli (1992), a time-varying inefficiency model is estimated as an exponential function, \( f(t) = \exp[\eta(t - T)], \quad t = 1, 2, ..., T. \) Eta is specified as the single unknown parameter to be estimated, which has a positive value when technical efficiency is improving and a negative value when it is decreasing over time (Coelli et al. 2005, pp. 278-280).

**Results**

Summary results are reported in this section while full details of model estimates are presented in Appendices 1 to 4 for M1, M2, M3 and M4, respectively. The trends in TFP estimated for the four models are illustrated in Figure 1 and Table 2. A test of neutral technical change was not rejected for models M1, M2 and M3, but was rejected for model M4.

All models were successfully estimated with good explanatory power and output elasticity estimates that conformed reasonably well to prior expectations. Note that the expected signs for coefficients in M4 differ from those in the first three models because of the different construction of the stochastic output distance function. Thus, the sign on the coefficient for the wool output/lamb output variable is expected to be positive and the signs on the coefficients for all the input variables are expected to be negative. Because of a limitation on degrees of freedom for the translog model, one explanatory variable (selling) was dropped from this estimated model. Variants on this model dropping one of the other input variables yielded robust results for the coefficients on the key trend variable and eta.
Figure 1: TFP trends among farms in the Farm Monitor Project, 1994/1995 to 2003/2004.

Table 2: Estimated Percentage Changes in Efficiency, Technical Change and TFP over the Period, 1994/1995 to 2003/2004

<table>
<thead>
<tr>
<th>Model</th>
<th>Efficiency change</th>
<th>Technical change</th>
<th>TFP change</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Absolute (%)</td>
<td>Absolute (%)</td>
<td>Absolute (%)</td>
</tr>
<tr>
<td>M1</td>
<td>28.5</td>
<td>-46.1</td>
<td>-30.7</td>
</tr>
<tr>
<td>M2</td>
<td>16.3</td>
<td>35.9</td>
<td>58.5</td>
</tr>
<tr>
<td>M3</td>
<td>-13.2</td>
<td>-10.9</td>
<td>-22.7</td>
</tr>
<tr>
<td>M4a</td>
<td>-7.0</td>
<td>12.9</td>
<td>5.0</td>
</tr>
</tbody>
</table>


There are three important points to note on M1 results. First, they confirm the finding by Fraser and Hone (2001) of an overall decline in TFP. For the overlapping period of the two studies (1994/1995 to 1997/1998), the decline in TFP estimated in this study is similar to that reported by Fraser and Hone (2001) and so the benchmarkers’
expectations of technical progress are not validated. The second point to note is that, remarkably, the decline in TFP brought about by technical regress actually accelerated beyond the overlapping period. This accelerated decline in TFP meant that, by the end of the period, the TFP index had declined to less than 70 per cent of its value at the beginning of the period (Figure 1). That is, the production frontier receded but, as we show below, we do not believe this is a true picture of the industry. If true, it would indeed reinforce the observation by Fraser and Hone (2001), reported above, of a ‘worrying picture for this industry’. Third, the mean technical efficiency increased from 0.61 to 0.79, resulting in a situation where inefficient producers were closer to the frontier by the end of the period than they were at the start of the period even though the average producer also suffered technical regress.

For specialist wool producers the M2 results reported in Table 2 contrast sharply with M1 results, despite the fact that the only change made to the estimation procedure was to drop from the sample those farms that operated a prime lamb enterprise in addition to their wool enterprise. The production frontier for specialist wool producers shifted outwards substantially, with 36 per cent technical progress over the whole period. A moderate increase of 16 per cent occurred in efficiency (Table 2). As a result of these advances, TFP increased by an impressive 58.5 per cent (Figure 1). This result accords closely to what the benchmarkers thought had happened in wool production. It is also consistent with the result reported for technical progress and TFP growth on farms in a specialist wool-growing area of south-west Western Australia.

In M3, the TFP trend in wool for those producers omitted from M2 (that is, those who also operated prime lamb enterprises) is similar to that for the whole population, with a 23 per cent decline over the period. In contrast to M1 results, however, this decline is a combination of (more moderate) technical regress and an efficiency decline.

The trend in TFP for M4 is of particular interest because it shows what happens when both output variables are included in the estimates of productivity change. The trend shown in Figure 1 differs from those recorded for M1 and M3, with a slight overall TFP increase of 12.3 per cent. This increase is attributable to technical progress despite an initial decline in the first year of the study period (1995/1996, as no data are available on farms that ran both enterprises in 1994/1995). After this first year, the productivity decline in wool production experienced by sheep producers diversifying into prime lamb production was countered by the gains in productivity they reaped.
from the latter. Best-practice farms achieved most of this gain with an annual rate of technical progress of 1.5 per cent. Technical efficiency declined by 7 per cent over the whole period (Table 2). All decline in technical efficiency occurred between 1996/1997 and 2001/2002. Entrants into prime lamb production were probably not as experienced in prime lamb production as those farms involved in the enterprise from the beginning of the period. Table 2 shows that only a slight gain in TFP was achieved over the whole period, but the rate picked up from 1996/1997 to 2003/2004. This estimate is reasonably in line with the estimates of modest to substantial productivity gains reported by ABARE (2004a) and more impressive than the estimated static productivity on Victorian sheep farms reported by Stoneham et al. (1999).

Discussion

The analytical steps we took demonstrate the hazards of measuring efficiency and productivity change on a single-output basis when a production unit has more than one output. In this study, the encouraging picture revealed by M2 estimates assuages the concern about the M1 and M3 results showing strongly declining productivity in wool production. M4 results show that this decline is offset by productivity gains in joint production but not to the extent that significant gains are made in overall productivity. Nevertheless, results are not as bad as when only wool is considered as an output in joint-production systems and technical change is treated as neutral. As economic conditions change, the relative importance placed on producing one particular output will change. In measuring change in efficiency and productivity, we need to consider the changes to all the outputs of the production unit, not just those to one output, and changes in input-output relations. Concentrating on the changes in efficiency and productivity in regard to one output and assuming neutral technical change may lead to inappropriate overall conclusions.

Reasons are not hard to find for declining wool productivity in a production unit in which greater emphasis is being progressively placed on prime lamb production. Foremost among them is a higher proportion of broader wool included in the wool enterprise. The measure used for wool output in model estimation would take into account lower prices received for broader wool from first-cross and cross-bred sheep. Second, productivity and efficiency in wool production are likely to deteriorate when management effort is spread over two enterprises. Prime lambs require more
management input particularly during preparation and assessment for market. Third, there are increased feeding costs with prime lamb production that might not have been adequately delineated between the two enterprises in the costs records. Finally, finishing prime lambs may take precedence over wool production at certain times of the year, to the detriment of the wool enterprise.

Growth in the importance of prime lamb production on sheep properties cannot be explained by opportunities for TFP growth, given the contrasting estimates for specialist wool producers and joint wool-prime lamb production units. The explanation lies in the increases in the relative prices of lamb and wool over the study period. It would be interesting to assess the extent of technical progress and changes in technical efficiency and TFP in prime lamb production by estimating a model comprising producers who engage only in prime lamb production. Unfortunately, insufficient observations are available at present to perform such an analysis.

Results reported in this study suggest an absence of scope economies from combining wool and prime lamb production through input complementarities and greater operational flexibility in an uncertain production environment. Further, it is conceivable that the scope for productivity gains would be severely curtailed as greater specialisation occurs in prime lamb production. This is implied by recent empirical evidence published by ABARE (2004a) and reported in Table 1. Sheep producers with between 5 per cent and 20 per cent of their receipts from prime lambs achieved impressive productivity growth rates between 2.1 per cent and 2.8 per cent in the period from 1988/1989 to 2001/2002, whereas those with more than 20 per cent of their receipts from prime lambs achieved much lower productivity growth rates in the range 0.8 per cent and 1.6 per cent over the same period. Clearly, more research is needed on production relations on mixed wool-prime lamb sheep properties.

The high rates of TFP growth estimated in M2 should be kept in perspective in that members of benchmarking groups tend to perform better than the average wool producer. Unlike other benchmarking groups, FMP members do not receive farming advice under the project but they do volunteer their data and receive reports on their performance. Therefore, this estimated rate might be higher than those for the whole population of wool producers. Nevertheless, they are indicative of what can be achieved by farmers in the wool industry, and lead us to conclude that the situation is not as dire as Fraser and Hone (2001) feared.
Conclusion

Understanding the nature of technical change in the Australian sheep industry is essential for estimating efficiency and productivity change accurately. Recent changes in economic conditions within the industry have brought about changes in enterprise mix, notably a greater presence of prime lamb production, that complicate the process of computing efficiency and productivity change. We demonstrate that it is desirable to analyse production by specialist producers of wool or prime lamb separately from that by joint-enterprise producers. A multi-input multi-output approach is essential for farms with joint wool-lamb production systems, based on the use of a stochastic output distance function, and it is necessary to check for non-neutrality in technical change in these systems.

Following this approach, we report substantial technical progress and productivity gains on specialist wool properties over the period, 1994/1995 to 2003/2004. Modest technical progress is estimated for farms operating both wool and prime lamb enterprises over the period, 1995/1996 to 2003/2004. But productivity gain over the same period is negligible, although it is more impressive from 1996/1997 onwards.

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