University of New England

Graduate School of Agricultural and Resource Economics
&
School of Economics

Estimation of a Multi-Input Multi-Output Model of Lot-Fed Beef Cattle in Australia

by

Pauline Fleming, Euan Fleming, Garry Griffith and David Johnston

No. 2004-13

Working Paper Series in

Agricultural and Resource Economics

ISSN 1442 1909

http://www.une.edu.au/febl/EconStud/wps.htm

Estimation of a Multi-Input Multi-Output Model of Lot-Fed Beef Cattle in Australia

Pauline Fleming, Euan Fleming, Garry Griffith and David Johnston **

Abstract

Most analyses of technical efficiency and productivity focus on the activities of firms or institutions using inputs to produce outputs. In this paper, we report the results of an efficiency analysis that is couched in a different context. We analyse the efficiency with which physical characteristics of individual lot-fed Australian beef cattle are combined with conventional inputs to produce a final product with several attributes that consumers value.

Data on 214 animals across seven breeds were used to estimate a stochastic input distance function with multiple inputs and multiple outputs. Estimates were obtained after controlling for differences between breeds, seasons and sex. Because of variations in feeding regimes for different markets, the data set was confined to animals whose meat was destined for the Korean export market. Technical efficiency measures are reported for each animal, along with the estimated mean technical efficiency.

The conventional inputs included in the analysis are feed and number of days in a feedlot (reflecting capital, veterinary and supervisory inputs). Physical measures of cattle traits on their entry into the feedlot are age, liveweight, muscle score, eye muscle area, rump fat depth and rib fat depth. Outputs are carcass weight, meat quality (assessed by using sensory scores on tenderness, juiciness, flavour and overall acceptability), marbling and the proportion of meat weight retained after cooking.

A high mean technical efficiency was estimated for the cattle but it was found that breeds have significantly different output frontiers and inefficiency levels. These differences are most likely associated with variation in genetic merit between sires within a breed and the different farming and climatic backgrounds of cohorts of animals.

Results are reported on the input-output relationships as well as the relationships between the outputs. Important findings in respect of output relationships in this sample are that the proportion of meat weight retained after cooking is highly significantly and positively associated with the meat quality sensory score, and carcass weight is significantly and negatively associated with the meat quality sensory score. No significant relationship was discerned between carcass weight and the proportion of meat weight retained after cooking.

Key Words: beef, feedlot, input distance function, meat quality, scope economies, technical efficiency

---

** Pauline Fleming is a Lecturer in the School of Economics at the University of New England.

Euan Fleming is an Associate Professor in the School of Economics and in the Graduate School of Agricultural and Resource Economics at the University of New England.

Garry Griffith is Principal Research Scientist in the NSW Department of Primary Industries and Adjunct Professor in the School of Economics at the University of New England.

David Johnston is Senior Scientist in the Animal Genetics and Breeding Unit, University of New England.

Contact information: School of Economics, University of New England, Armidale, NSW 2351, Australia. Email: pfleming@une.edu.au.

1. Introduction

Reverter, Johnston, Ferguson et al. (2003) reported on analyses undertaken of the relations between the physical characteristics of beef cattle in the production process in Australia. The analyses provided correlations between animal, carcass and meat quality traits. The methods they used to carry out such analyses entailed the estimation of least-square means and variance components.

The aim of this study is to extend the analyses undertaken by Johnston, Reverter, Burrow et al. (2003), Reverter, Johnston, Perry et al. (2003), Johnston, Reverter, Ferguson et al. (2003) and Reverter, Johnston, Ferguson et al. (2003) in three directions. First, the relations between physical characteristics are studied in a flexible production function framework instead of estimating least-square means and variance components. The estimation of a flexible production function can be crucial in capturing the interaction between the physical characteristics of cattle that breeders may be able to influence through genetic selection and the provision of conventional inputs in feedlot production. It is the aim of this study to specify and estimate production relations from the time cattle enter a feedlot to the stage where meat is produced and eaten by consumers.

Second, a stochastic input distance function is estimated to allow production relations to be expressed in terms of best performance rather than average performance. The frontier in meat production performance is of particular interest. In addition, technical efficiency indices are calculated to assess each animal that passes through the feedlot, to indicate the extent to which its performance deviates from the frontier. A by-product of this analysis is that estimated technical efficiency indices in a multi-input multi-output framework can be compared with conventional estimates of feed-use efficiency.

Third, a major focus of our analysis is on the relations between the characteristics of meat output, reflecting their complementarities and trade-offs. To this end, we use results from the estimated stochastic input distance function to measure scope economies in feedlot beef production.

Most analyses of technical efficiency and productivity focus on the activities of firms or institutions using inputs to produce outputs. Our analysis differs from this conventional approach in that we focus on individual animals rather than firms as production units.

The analysis is set in the context of how efficiently individual lot-fed beef cattle can be turned into meat output with multiple attributes that consumers value.

2. Variables and Data

The data used in the analysis are a sub-set of the data used by Johnston, Reverter, Burrow et al. (2003), Reverter, Johnston, Perry et al. (2003), Johnston, Reverter, Ferguson et al. (2003) and Reverter, Johnston, Ferguson et al. (2003). They were collected as part of a straightbreeding project implemented by the Cooperative Research Centre for Cattle and Beef Quality (Beef CRC). The aim of the project was to estimate genetic and phenotypic relationships between measures of animal, carcass and meat quality characteristics.

The total data set comprises 7622 cattle across four temperate breeds (Hereford, Angus, Shorthorn and Murray Grey) and three tropically adapted breeds (Belmont Red, Brahman and Santa Gertrudis). The breeds are randomly allocated a relevant code for analysis as Temp1, Temp2, Temp3, Temp4, Trop1, Trop2, or Trop3. The meat from these cattle is supplied to the Korean, Japanese and Australian domestic markets. This large data set was drastically reduced by the absence of data on feed inputs and consumer-assessed meat quality for a majority of animals, and a desire to concentrate the analysis on animals whose meat was destined for one market. Animals produced for the Korean market (to around 280 kg carcass weight) were selected as they provided the largest data set (214 animals). We confined the analysis to this one market to avoid difficulties in accounting for the distinct production process followed and different output preferences that exist in each market.

Details on cattle included in the sample for estimating the model are presented in Table 1. Only the Trop2 and Trop3 breeds contain heifers; all other breeds consist solely of steers. Also shown are numbers of breed cohorts entering feedlots across years and seasons in the sample.

Johnston, Reverter, Burrow et al. (2003) described the data collected on 20 animal, carcass and meat quality traits and the measurement procedures they used. Many of these traits are included in this study. Six animal traits, measured on entry to the feedlot, are included as inputs in the production process: age (in days), liveweight (in kilograms), rib fat depth (in millimetres),[1] rump fat depth at the P8 site (in millimetres),[2] eye muscle area

[1] Rib fat depth is measured as the real-time ultrasound subcutaneous fat depth between the 12th and 13th ribs (Johnston, Reverter, Burrow et al. 2003, p. 109).

(in square centimetres) and muscle score.[3] We also included two conventional inputs, namely individual feed intake per day (measured using automatic feeders) and number of days in the feedlot. The latter variable is included to capture inputs common to all animals (veterinary supplies, supervision, provision of feeding facilities and other capital structures) as well as the number of days of feed intake. The fact that no data are available on the amounts of those inputs common to all animals is not considered a drawback. It is reasonable to assume that they are the same for each animal and can be measured by the amount of time that an animal spends in the feedlot.

Table 1

Information on the Sample

Breed	Temp1	Temp4	Temp2	Temp3	Trop1	Trop2	Trop3
Heifers	0	0	0	0	0	35	15
Steers	53	11	36	19	16	18	11
Total	53	11	36	19	16	53	26
Entry liveweight	398 kg	415 kg	398 kg	336 kg	397 kg	373 kg	415 kg
Cohorts	9	2	6	3	3	3	4
Years	1	1	1	1	2	2	2
Seasons	2	1	2	2	1	1	1

Other key slaughtering and post-slaughter inputs are omitted from this study, opening the possibility of biased results, although Johnston, Reverter, Ferguson et al. (2003, p. 136) reported that considerable effort was made to standardise these inputs. Similarly, animals were subject to similar backgrounding prior to entry to the feedlot, as the animals were received by the Beef CRC as weaners prior to backgrounding. Variations occur in physical characteristics among animals of the same breed entering the backgrounding

[2] Rump fat depth is measured as the real-time ultrasound subcutaneous fat depth at the intersection of a line parallel to the spine from the *tuber ischium* and a line perpendicular to it from the spinous process of the third sacral vertebra (Johnston, Reverter, Burrow et al. 2003, p. 109).

[3] The muscle score is a visual assessment of muscling based on thickness and convexity of shape relative to frame size (Johnston, Reverter, Burrow et al. 2003, p. 109).

stage due to herd-of-origin effects brought about by differences between cohorts in sires and dams, and seasonal conditions in the pre-weaning stage. Figure 1 gives the timetable for preparing cattle for the Korean market. The shaded area shows the period during which the cattle are under the control of the Beef CRC management.

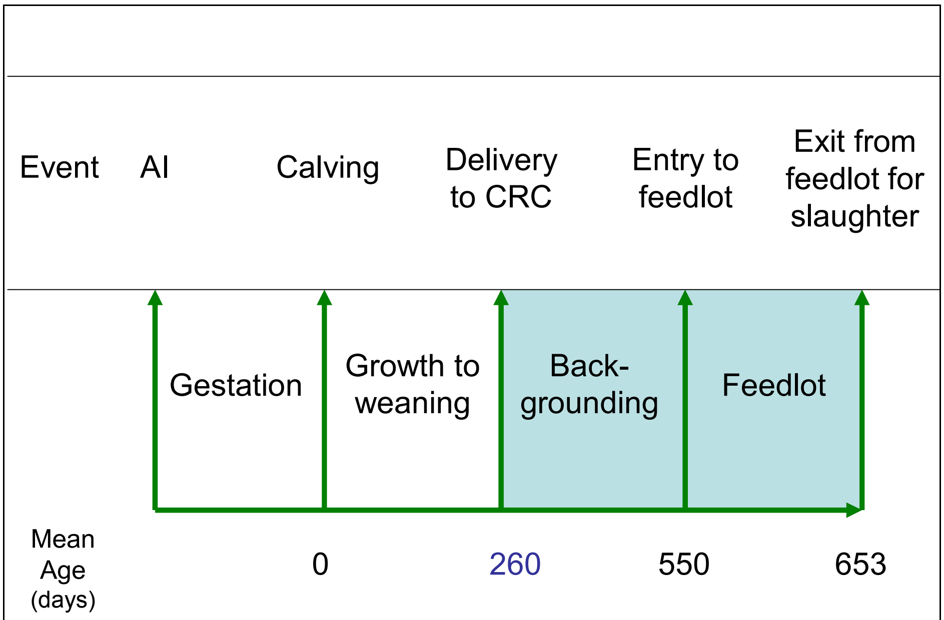

Figure 1 Timetable for preparing lot-fed cattle for the Korean market

Four output variables are included in the analysis: amount of carcass weight produced, proportion of carcass weight retained after cooking, meat quality and marbling. The amount of carcass weight produced is measured as hot carcass weight in kilograms. The proportion of carcass weight retained after cooking was derived from a variable reported by Reverter, Johnston, Ferguson et al. (2003, p. 151) as cooking loss percentage. Because it is desirable for output variables in a production function to have positive relations with inputs, retention weight after cooking was calculated by subtracting cooking loss percentage from 100.

A composite index of four sensory measures of quality was used to measure the quality of meat output. Johnston, Reverter, Ferguson et al. (2003, p. 137) termed this variable the sensory MQ4 score, including tenderness, juiciness, flavour and overall acceptability scores. Because of the very high correlations among all of these four individual scores (Johnston, Reverter, Ferguson et al. (2003, p. 143), we expect to lose little information by using the composite index rather than four individual meat quality variables.

Two alternatives were available to represent the marbling of meat: the proportion of intramuscular fat and a discrete marbling score specified by AUS-MEAT (1998). The former was preferred because it is a continuous variable and suffers less than the latter from data omissions that would have reduced the degrees of freedom in model estimation.

3. Model Specification

We use a multi-input multi-output stochastic input distance function to calculate technical efficiency indices for each sampled lot-fed animal, mean technical efficiency for each breed and mean technical efficiency across all animals. Prior to estimation, the means of the log variables were adjusted to zero so that the coefficients of the first-order terms may be interpreted as elasticities, evaluated at the sample means.

Following Coelli and Perelman (1996), the translog stochastic input distance function used in this analysis can be defined as:

$$\text{(1)} \quad \begin{aligned} \ln d_I &= \beta_0 + \sum_{m=1}^{8} \beta_m \ln X_m + \sum_{n=1}^{4} \alpha_n \ln Y_n + 0.5 \sum_{m=1}^{8} \sum_{m'=1}^{8} \beta_{mm'} \ln X_m \ln X_{m'} \\ &+ 0.5 \sum_{n=1}^{4} \sum_{n'=1}^{4} \alpha_{nn'} \ln Y_n \ln Y_{n'} + \sum_{m=1}^{8} \sum_{n=1}^{4} \omega_{mn} \ln X_m \ln Y_n \end{aligned}$$

where X_m is the m-th input, Y_n is the n-th output, and α, β and ω are parameters to be estimated. The eight inputs in the model are feed intake, number of days in the feedlot, age, liveweight, muscle score, rib fat depth, rump fat depth and eye muscle area. The four outputs are carcass weight, meat quality, retention of weight and marbling.

Zero-one dummy variables are included in the distance function for year, heifer and breed dummy variables. As observations spanned 1996 and 1997, a 1997 dummy variable is included to test for any difference in productivity between years. The heifer dummy variable is included to test whether heifers are less productive than steers. Heifers comprised 35 of the 53 Trop2 cattle and 15 of the 26 Trop3 cattle whereas other breeds comprised solely steers. Hence, the heifer dummy will capture the effect of tropically adapted females rather than a generic female effect. The breed dummy variables are included to test whether different levels of genetic advance have been made between the seven breeds in the data set.

Again following Coelli and Perelman (1996), we set $-ln\ d_I = v - u$ in equation (1) and impose the restriction required for homogeneity of degree +1 in inputs ($\Sigma\beta_m = 1$) to obtain the estimating form of the stochastic input distance function:

(2)
$$-\ln A = \beta_0 + \sum_{m=1}^{7} \beta_m \ln(X_m / A) + \sum_{n=1}^{4} \alpha_n \ln Y_n + 0.5 \sum_{m=1}^{7} \sum_{m'=1}^{7} \beta_{mm'} \ln(X_m / A)(\ln X_{m'} / A)$$
$$+ 0.5 \sum_{n=1}^{4} \sum_{n'=1}^{4} \alpha_{nn'} \ln Y_n \ln Y_{n'} + \sum_{m=1}^{7} \sum_{n=1}^{4} \omega_{mn} \ln(X_m / A) \ln Y_n + v - u$$

where A is the age of the animal; the vs are assumed to be independently and identically distributed with mean zero and variance, σ_v^2; and the us 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 unknown variance, σ_u^2, and unknown mean, μ, defined by:

(3) $$\mu = \delta_0 + \sum_{i=1}^{6} \delta_i z_i ,$$

where:

z_1 is the breed dummy variable for temperate breed 2 (Temp2);
z_2 is the breed dummy variable for temperate breed 3 (Temp3);
z_3 is the breed dummy variable for temperate breed 4 (Temp4);
z_4 is the breed dummy variable for tropically adapted breed 1 (Trop1);
z_5 is the breed dummy variable for tropically adapted breed 2 (Trop2); and
z_6 is the breed dummy variable for tropically adapted breed 3 (Trop3).

The variance parameters, σ_v^2 and σ_u^2, are replaced by $\gamma=\sigma_u^2/(\sigma_v^2+\sigma_u^2)$ and $\sigma_s^2=(\sigma_v^2+\sigma_u^2)$ (Coelli and Perelman 1996).

The input distances are predicted as:

$$d_i = E[\exp(u) \mid e]$$

where $e = v - u$ (Coelli and Perelman 1996, p. 14).

Estimates of the parameters of the model were obtained using maximum-likelihood procedures in running the FRONTIER 4.1 program (Coelli 1996). Various hypothesis tests were undertaken using likelihood-ratio tests, based on a 5 per cent significance level.

4. Estimates of Production Relations

4.1 Input-output relations

Estimates of input and output elasticities from the maximum-likelihood estimation of the stochastic input distance function model are presented in Table 2. The sum of the estimated coefficients of the input variables is 0.78. Given the restriction required for homogeneity of degree +1 in inputs, the implied elasticity for the age of the animal when entering the feedlot is 0.22. Individual likelihood ratio tests on each input and output showed that all but one input and one output contribute significantly in model estimation.

Table 2

Estimates of the Input and Output Elasticities

Variable	Estimated elasticity	Standard error	*t*-value
Inputs:			
Feed per day	0.101	0.010	9.987
Days in feedlot	0.532	0.009	57.62
Liveweight	0.103	0.021	4.903
Rib fat depth	0.008	0.003	2.262
Rump fat depth	-0.002	0.004	-0.613
Eye muscle area	0.015	0.011	1.357
Muscle score	0.022	0.010	2.284
Outputs:			
Carcass weight	-0.237	0.014	-16.56
Weight retention	-0.252	0.040	-6.259
Meat quality	0.014	0.006	2.201

The number of days in the feedlot is highly significant and has the highest elasticity at 0.53. Other elasticities estimated to be significantly greater than zero are daily feed intake and weight on entering the feedlot (each 0.10), muscle score (0.02), eye muscle area (0.015) and rib fat depth (0.01). Only the estimated coefficient for the rump fat depth variable is insignificantly different from zero. The elasticities of animal characteristics are low. But these characteristics are virtually costless to maintain once they are established, in contrast to conventional inputs that need to be applied each year.

Coefficients on the two output variables, carcass weight (-0.237) and proportion of meat weight retained after cooking (-0.252), are negative, as expected, and highly significant at less than one per cent significance level. They reflect a positive impact of the set of input variables on these two outputs: a 10 per cent increase in all inputs would increase carcass weight by 2.4 per cent and the proportion of meat weight retained after cooking by 2.5 per cent. The significant and positive coefficient on the meat quality output variable was not expected. It indicates that the set of inputs as a whole have a negative impact on meat quality, although the small size of the coefficient (0.014) suggests this impact is not very great. A possible explanation of this unexpected result is that the high correlation between meat weight retention and meat quality, and the highly significant impact of inputs on the former, is masking the true impact of inputs on meat quality. The marbling output variable (intramuscular fat percentage) was found not to be significantly influenced by the set of inputs. A likelihood ratio test revealed that its omission from the estimated model had no significant effect and it is not reported in the results in Table 2.

4.2 Breed, heifer and year effects on productivity

Individual likelihood ratio tests were conducted on the breed, year and heifer dummy variables in the distance function. First, Figure 2 shows the production frontiers of each breed of cattle in the sample. The frontiers of Temp1, Temp2 and Temp4 cattle are also furthest from the origin. They are insignificantly different from each other, although it proved difficult to place the frontier for Temp4 cattle given their small number of observations.

The frontier of Temp3 cattle is slightly but significantly below that for these three breeds (its scale parameter is 2.1 per cent less than that of the frontier breeds). The frontiers of the three tropically adapted breeds are much lower than the frontiers of the temperate breeds (scale parameters are lower than frontier breeds by 15.2 per cent for Trop3, 17.6 per cent for Trop2 and 18.1 per cent for Trop1).

A significant and positive coefficient for the 1997 year dummy variable indicates that feedlot productivity was higher in that year than in 1996. A significant and negative coefficient for the heifer dummy variable indicates that tropical heifer productivity is lower than steer productivity. The effect of this dummy variable is to reduce the scale parameter for heifers to around 2 per cent less than the parameter for steers.

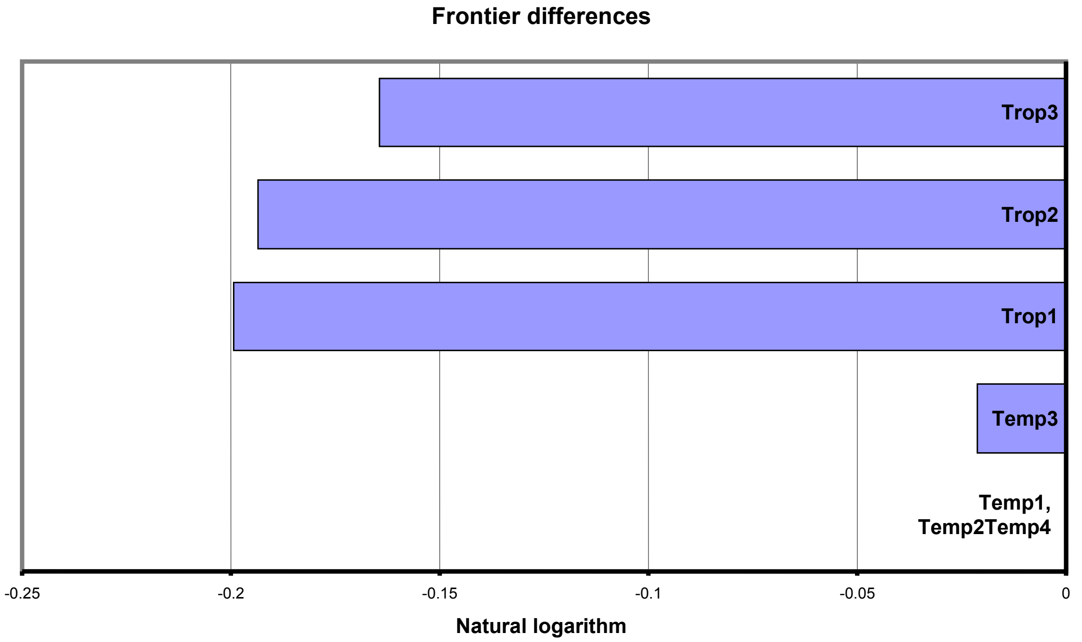

Figure 2 Comparison of production frontiers by breed

5. Technical Inefficiency Estimates

5.1 Evidence of technical inefficiency

The value of the test statistic for the null hypothesis of no technical inefficiencies of production (96.65) was found to be greater than the critical value obtained from Table 1 of Kodde and Palm (1986) for eight restrictions (14.85). We thus conclude that the technical inefficiency term (u_i) is a significant addition to the model. A likelihood-ratio test that the coefficients on the breed efficiency variables are zero is strongly rejected, indicating that these variables as a group contribute significantly to an explanation of technical inefficiency in lot-fed beef production.

The gamma value, reflecting the percentage of error due to inefficiency, is not significantly different from unity, indicating that all residual variation is attributable to inefficiency and the random error is negligible. The lack of random effects reflects the strong control that managers have over the production environment in feedlot operations.

5.2 Influence of breed on technical inefficiency

The distance that cattle are located away from the frontier is likely to be influenced by variations in production potential among progeny from different sires and recent advances in breeding technology. It is proposed that performance is more tightly grouped (the mean technical efficiency index is higher) among breeds where the progeny come from a small pool of sires and the breed has not experienced substantial genetic advances in recent years.

These propositions are tested by including six breed dummy variables in the inefficiency effects model. The seventh breed, which is Temp1, is treated as the base. Given that Temp1 progeny come from the widest pool of sires that have experienced considerable recent genetic advances, it is expected that the signs on the coefficients of the six breed dummy variables will be negative, indicating lower technical inefficiency than Temp1.

All *z*-variables included in Table 3 except two contribute significantly (jointly and individually) to the explanation of technical inefficiencies in feedlot beef production. The Temp4 and Trop3 dummy variables are the exceptions (with both failing at the 5 per cent significance level).

Table 3

Estimates of the Efficiency Model

Variable	Estimated coefficient	Standard error	*t*-value
Constant	0.0405	0.0046	8.811
Temp2 dummy variable	-0.0169	0.0087	-1.932
Temp3 dummy variable	-0.0478	0.0140	-3.409
Temp4 dummy variable	0.0084	0.0047	1.796
Trop1 dummy variable	-0.2054	0.0217	-9.467
Trop2 dummy variable	-0.0633	0.0161	-3.944
Trop3 dummy variable	-0.0100	0.0080	-1.259
Sigma squared	0.0004	0.00002	24.989

Plots of the distribution of the technical efficiency indices by breed are presented in Figure 3, with indices varying from 0.92 to 1.00. This is a narrow range but one to be expected given the controlled environment and identical management the animals receive from weaning through to slaughter. The high mean technical efficiency index indicates that a significant but small opportunity exists to increase beef output without using more physical and genetic inputs.

Controlling the quality of sires of progeny entering the feedlot is a way to raise technical efficiency. This point is illustrated in Figures 4 and 5. In analysing mean technical efficiencies of breeds, recall that the technical efficiency of each breed is to be interpreted relative to its own frontier. Figure 4 shows the percentage by which the mean technical efficiency of each breed is less than perfect technical efficiency (100 per cent) (that is, below its frontier). Trop1 cattle have the highest mean technical efficiency relative their own frontier, with Temp4 cattle having the lowest mean technical efficiency.

The interpretation of Figure 5 is as follows. Examining the first row, the mean technical efficiency of Temp1 cattle (95.8 per cent) is not significantly different from the mean technical efficiencies of Temp4 (mean technical efficiency of 95.1 per cent) and Trop3 (mean technical efficiency of 96.7 per cent), but is significantly less than the mean technical efficiencies of the other breeds. As for Temp1, Temp4 and Trop3 cattle are significantly less efficient than other breeds. Trop1 cattle (mean technical efficiency of 99.9 per cent) and Trop2 cattle (mean technical efficiency of 99.2 per cent) have significantly higher mean technical efficiencies than all but Temp3 cattle (mean technical efficiency of 98.8 per cent).

Temp1 cattle come from most cohorts (and most sires), which would be expected to contribute to the relatively wide dispersion of technical efficiency indices for this breed. Temp4 cattle come from only two cohorts in one year but they have different pre-weaning backgrounds, resulting in a relatively wide dispersion of technical efficiency indices. The nature of their distribution, with few cattle near the frontier (Figure 3), suggests that our inability to specify a significant dummy variable for the breed in the estimated model has led to some frontier difference being picked up the breed dummy variable in the inefficiency effects model.

Figure 3 Distribution of technical efficiencies by breed

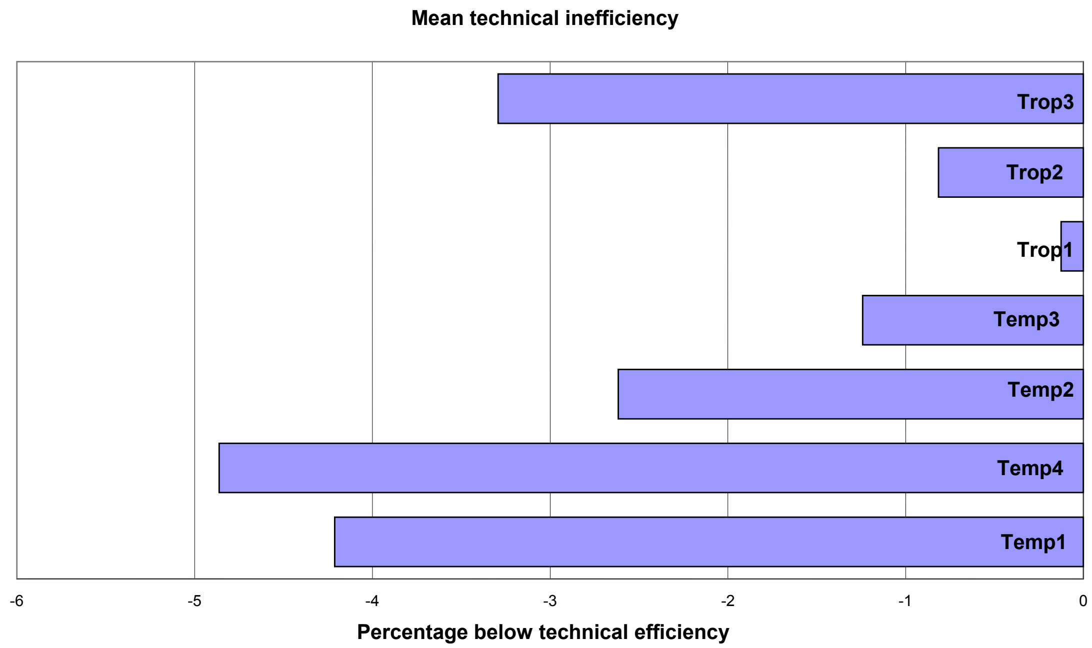

Figure 4 Comparison of mean technical efficiency indices across breeds

Temp2 cattle have the second highest number of cohorts, across two seasons, but a reasonably compact distribution of technical efficiency indices. The narrow distribution of technical efficiency indices for Temp3 can be attributed to similarities in background between cohorts.

The tropically adapted breeds have fairly similar variations in cohorts, years and seasons in their samples but quite marked differences in spread of technical efficiency indices. Trop3 cattle have a much lower mean technical efficiency and wider distribution than Trop1 and Trop2 cattle, which is unlikely to be due solely to having one more cohort. Their mean technical efficiency is not significantly different from Temp1, Temp4 and Temp2 cattle.

In summary, the results of inefficiency estimates accord with the proposition put forward earlier in this section about the effects of the width of the pool of sires and genetic advances on variations in technical efficiency indices. But further research is needed across a wider sample set to confirm these results.

Breed	Mean TE	Temp1	Temp4	Temp2	Temp3	Trop1	Trop2	Trop3
Temp1	95.79		=	×	×	×	×	=
Temp4	95.14	=		×	×	×	×	=
Temp2	97.38	✓	✓		×	×	×	=
Temp3	98.76	✓	✓	✓		=	=	✓
Trop1	99.88	✓	✓	✓	=		=	✓
Trop2	99.19	✓	✓	✓	=	=		✓
Trop3	96.71	=	=	=	×	×	×	

Notes:

Reading across rows, ✓: significantly more efficient; =: no significant difference in efficiency; ×: significantly less efficient.

Mean technical efficiency of a breed is measured relative to its own frontier.

Figure 5 Comparison of technical efficiency indices across breeds

6. Economies of Scope

6.1 Measuring scope economies

The traditional text-book definition states that scope economies exist if a particular firm can produce two outputs at a lower cost than two separate firms specialising in the production of one of the two individual outputs. Outputs are produced as joint products in this analysis. Therefore, all outputs must be produced to some extent and no choice exists for some outputs not to be produced at all. The combinations of outputs produced can be altered by genetic selection, by varying the mix of breeds or by varying the amounts of inputs used, such as feed per day and the number of days an animal spends in the feedlot. Scope economies for two attributes of meat output are interpreted to mean that both attributes can be produced from one animal at a lower cost than it would take to produce the same levels of attributes from two animals that specialise to a greater degree in the production of one of the two attributes. For example, managers of a feedlot would rather use animals that combine both high carcass weights and high-quality meat than have animals that yield a high carcase weight but produce meat of poor quality (or vice versa).

Consistent with the above definition, scope economies (implying cost complementarities) exist between outputs *i* and *j* if:

(4) $$\frac{\partial^2 C}{\partial y_n \partial y_{n'}} < 0, \qquad n \neq n',\ n, n' = 1, \ldots, N,$$

where C is the cost of N outputs and y_n is the n-th output variable (Deller, Chicoine and Walzer 1988). The addition of an extra unit of output n reduces the marginal cost of producing an extra unit of output n'.

In this study, we diverge from this standard approach by estimating an input distance function instead of a cost function because cost data do not exist for most inputs in the production system under study. We also allow for the possibility of inefficiency in production in the model.

Following Coelli, Rao and Battese (1998, p. 64), we define the input distance function as:

(5) $$d(x,y) = \{\mathrm{D}: (x/D) \in L(y)\},$$

where $L(y)$ represents the set of all fixed and variable input vectors, x, that can produce the output vector, y. The expression, $d(x,y)$, is non-decreasing in the input vector, x, and increasing in the output vector, y, and linearly homogeneous and concave in x. The value of the distance function is equal to or greater than 1 if x is an element of the feasible input set, $L(y)$. That is, $d(x,y)\geq 1$ if $x \in L(y)$. It equals 1 if x is located on the inner boundary of the input set, where the firm is technically efficient, and exceeds 1 if the firm is technically inefficient. The input distance function value is therefore the inverse of the traditional input-oriented measure of technical efficiency, defined by Farrell (1957). We change the indices from the input distance function to conform to Farrell's approach, inverting them so that they lie between 0 and 1.

The first partial derivative of the input distance with respect to the n-th output is negative. This sign indicates that the addition of an extra unit of output, holding all other variables constant, reduces the amount needed to put the observation onto the efficient frontier by deflating the input vector. A positive second cross partial derivative is evidence of economies of scope:

$$(6) \qquad \frac{\partial^2 D}{\partial Y_n \partial Y_{n'}} > 0, \qquad n \neq n', \; n, n' = 1, \ldots, N.$$

Conversely, a negative second cross partial derivative signifies diseconomies of scope.

6.2 Evidence of scope economies

The coefficient estimates of scope economies in the production system are reported in Table 4, defined in equation (6), for each pair of outputs at the means of the sample data. In order to test the hypothesis that there are no scope economies, we calculated standard errors for these measures of scope economies using a Taylor series expansion. The relatively high estimated standard error for carcass weight and retention proportion indicates that we would be unable to reject the null hypothesis of no scope economies (or diseconomies) between these two outputs at any normal level of significance. Findings are similar for relations between intramuscular fat content and all other outputs.

The estimated value for retention proportion and meat quality is highly significant and quite large, at 1.10, indicating considerable potential for scope economies by producing animals for these two outputs. This result accords with expectations as the greater retention of juices after cooking is expected to result in meat that is more flavoursome, juicier and more tender.

Table 4

Estimates of Economies of Scope

Output pair	Estimated coefficient	Standard error	*t*-value
Carcass weight-Retention	-0.668	0.717	-0.931
Carcass weight-Meat quality	-0.147	0.054	-2.735
Retention-Meat quality	1.096	0.260	4.210

A significantly negative coefficient for carcass weight and quality indicates that a trade-off exists between producing animals for weight and for quality. This finding needs to be treated with some caution because the most plausible explanation, that meat of lower carcass weight temperate beef breeds tends to be preferred to that of larger tropically adapted breeds, does not stand up to scrutiny. The average carcass weight of tropically adapted cattle in the sample is 274 kg compared with 278 kg for temperate cattle. A more detailed examination by breed, however, reveals that Trop3 cattle in the sample have easily the highest mean carcass weight (302 kg) among breeds and easily the lowest mean MQ4 score of 46.7 compared with a mean score of 58.9 for all other animals. Thus, scope diseconomies between the carcass weight and quality outputs probably reflect the leverage on results of this breed.

7. Comparison of Technical Efficiency and Feed Use Efficiency Indices

Estimated technical efficiency indices were compared with the feed use efficiency indices calculated for each animal by the Cooperative Research Centre for Cattle and Beef Quality. The latter indices were converted to indices between zero and unity by setting equal to unity the index of the most efficient animal in converting feed into weight gain. The feed use efficiency indices of other animals were set in proportion to this animal. The modified index provides a direct comparison with the technical efficiency index, with both indices lying between zero and unity. The purpose of the comparison is to assess how closely the partial measure of feed use efficiency compares with the more comprehensive technical efficiency index, which takes account of all inputs and outputs.

The correlation coefficient between technical efficiency indices estimated for each animal in the sample in this study with their corresponding feed use efficiency indices was estimated at +0.29. While there is a positive correlation between the indices, the quite low coefficient suggests that they are not close in measuring the efficiency of an animal in the production process. The feed use efficiency index measures how well an animal turns feed into weight gain. It therefore takes into account only one input and one output in the production process whereas the technical efficiency index measures all inputs and outputs. As important as the input and output in the feed use efficiency index are, their relationship is not sufficient to get an accurate picture of feedlot production efficiency.

8. Conclusion and Future Research

8.1 Summary of results

This study has provided information about input-output relations, technical inefficiencies and scope economies in an intensive beef cattle-raising system in Australia. Distinct production frontiers were identified, with tropically adapted breeds having frontiers significantly lower than those of temperate breeds. The shape of the frontiers provides interesting results. Scope economies were found to exist between the proportion of meat retention after cooking and meat quality. While scope diseconomies were found between carcass weight and meat quality, we suspect the relationship between the two outputs could vary between breeds. Further analysis is needed to study this relationship within each breed before a definitive statement could be made about the presence of scope economies or diseconomies between carcass weight and meat quality.

Information provided technical inefficiency among breeds indicates that only a small but significant amount of technical inefficiency exists in feedlot production. This means that there is a limited opportunity to expand beef output by controlling the quality of sires of progeny entering the feedlot.

8.2 Future research

Future research is planned in three main directions. First, a more homogeneous data set of around 1800 cattle of two breeds will soon be available, with more information on sires of cattle in each cohort. It should enable a better analysis of scope economies and diseconomies, and a more valid comparison of productivity and technical inefficiency.

Second, it is planned to replace the sensory quality variable with two objective measures of meat quality, namely compression and shear force. These two measures are reasonably closely correlated to the MQ4 score obtained from consumer tasting (Reverter, Johnston, Ferguson et al. 2003), and indeed may more accurately reflect meat quality than the MQ4 score given the subjectivity of measures derived from consumer tasting panels. Also, consumer sensory measures are much more expensive to collect than objective measures.

Third, it is planned to obtain shadow prices of outputs by applying the dual Shephard's lemma under the assumption that producers are allocatively efficient in outputs (Grosskopf, Margaritis and Valdmanis 1995). These prices should prove of particular interest to the meat industry in Australia in identifying how much value consumers place on meat volume as opposed to quality.

References

AUS-MEAT 1998, *Handbook of Australian Meat*, Brisbane.

Coelli, T.J. 1996. *A Guide to FRONTIER Version 4.1: A Computer Program for Stochastic Frontier Production and Cost Function Estimation*, CEPA Working Papers No. 7/96, Department of Econometrics, University of New England, Armidale.

Coelli, T.J. and Perelman, S. 1996, *Efficiency Measurement, Multi-Output Technologies and Distance Functions: With Application to European Railways*, CREPP WP 96/05, Centre de Recherche en Economie Publique et Economie de la Population, Université de Liège.

Coelli, T.J., Rao, D.S.P. and Battese, G.E. 1998, *An Introduction to Efficiency and Productivity Analysis*, Kluwer, Boston.

Deller, S.C., Chicoine, D.L. and Walzer, N. 1988, 'Economies of size and scope in rural low-volume roads', *Review of Economics and Statistics* 70, 459-465.

Farrell, M.J. 1957, 'The measurement of productive efficiency', *Journal of the Royal Statistical Society, Series A, Part 3* 120, 253-290.

Grosskopf, S., Margaritis, D. and Valdmanis, V. 1995, 'Estimating output substitutability of hospital services: a distance function approach', *European Journal of Operational Research* 80, 575-587.

Johnston, D.J., Reverter, A., Burrow, H.M., Oddy, V.H. and Robinson, D.L. 2003, 'Genetic and phenotypic characterisation of animal, carcass and meat quality traits from temperate and tropically adapted beef herds: 1. Animal measures', *Australian Journal of Agricultural Research* 54, 107-118.

Johnston, D.J., Reverter, A., Ferguson, D.M., Thompson, J.M. and Burrow, H.M., 2003, 'Genetic and phenotypic characterisation of animal, carcass and meat quality traits from temperate and tropically adapted beef herds: 3. Meat quality traits', *Australian Journal of Agricultural Research* 54, 135-147.

Kodde, D.A. and Palm, F.C. 1986. 'Wald criteria for jointly testing equality and inequality restrictions', *Econometrica* 54, 1243-1248.

Reverter, A., Johnston, D.J., Perry, D., Goddard, M.E. and Burrow, H.M. 2003, 'Genetic and phenotypic characterisation of animal, carcass and meat quality traits from temperate and tropically adapted beef herds: 2. Abattoir carcass traits', *Australian Journal of Agricultural Research* 54, 119-134.

Reverter, A., Johnston, D.J., Ferguson, D.M., Perry, D., Goddard, M.E., Burrow, H.M., Oddy, V.H., Thompson, J.M. and Bindon, B.M. 2003, 'Genetic and phenotypic characterisation of animal, carcass and meat quality traits from temperate and tropically adapted beef herds: 4. Correlations among animal, carcass, and meat quality traits', *Australian Journal of Agricultural Research* 54, 149-158.