ANIMAL EFFICIENCY IN AN INTENSIVE BEEF PRODUCTION SYSTEM

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Abstract

A stochastic input distance function is estimated to analyse the efficiency with which physical characteristics of individual lot-fed beef cattle in Australia are combined with conventional inputs to produce a final product possessing defined quality attributes. High mean technical efficiency estimates are reported for all animals and by breed. All partial output elasticities with respect to inputs are of expected sign. Of four outputs included in the analysis, carcass weight and moisture retention in meat after cooking have highly significant coefficients of expected sign, but two meat quality variables have coefficients of unexpected sign indicating that they decline as inputs increase. Some evidence is detected of scope economies between moisture retention in meat and the inverse of meat compression.

Keywords: efficiency, intensive agriculture, scope economies

JEL classification: Q12, C51

Growing importance of multiple meat outputs

The intensive beef cattle industry in Australia has responded to more discriminating meat demand from both domestic and overseas consumers by attempting to improve all dimensions of beef output, particularly various aspects of beef quality (Egan et al., 2001; Johnston, Reverter, Ferguson et al., 2003). These efforts have been in response to the need to arrest a negative trend in beef consumption and, on a more positive note, evidence that consumers will buy more and pay more for beef of higher quality (Boleman et al., 1997).

The Cooperative Research Centre for Cattle and Beef Quality (Beef CRC) project was established to improve understanding of the relevance and magnitude of the genetic and non-genetic influences on beef quality traits in Australian production systems (Bindon, 2001). Its aim is to improve these traits by developing suitable selection criteria that are heritable, cost-effective to measure and correlated to traits in the breeding objectives (Johnston, Reverter, Burrow et al., 2003).

Three breeding objectives of the Beef CRC specified by Johnston, Reverter, Burrow et al. (2003) are to:

1. quantify the effects of different market weight endpoints and finishing regimes on the phenotypic expression of numerous animal, carcass and meat quality traits for temperate and tropically adapted breeds;
2. estimate genetic parameters, including heritabilities and genetic and phenotypic correlations for animal, carcass and meat quality traits in temperate and tropically adapted breeds; and
3. determine the existence of genotype by environment interactions for all traits by keeping records on animals in different markets and finishing regimes as separate traits.

Analytical approach

Most analyses of technical efficiency and productivity focus on the activities of firms or other organisations in using inputs to produce outputs. This analysis differs from past efficiency studies in that it focuses on individual animals. In intensive agriculture, the efficiency in production of individual animals is often of immediate interest to managers and analysts in addition to the overall efficiency of the firm.

We define the relations between physical characteristics in the framework of a flexible production function in order to capture 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. A stochastic input distance function is estimated that allows production relations to be expressed in terms of best performance rather than average performance.

Technical efficiency measures of each animal that passes through the feedlot are a useful output of this research. They indicate which animals are not reaching their full potential (by the extent to which their location is distant from the frontier), which should be useful information to managers of feedlots. The feedlotting production process is highly controlled and based on the use of progeny from superior sires. Therefore, technical inefficiency is expected to be kept to low levels although Fleming et al. (2004) did report some significant technical inefficiencies in their study. Estimated technical efficiency indices in a multi-input multi-output framework are compared with conventional estimates of feed-use efficiency. The frontier in meat production performance is of particular interest in this study. Results from the estimated stochastic input distance function are used to measure scope economies (diseconomies) in feedlot production, reflecting the complementarities (trade-offs) between the meat outputs.

Animals included in the data set

Cattle used in this study were from the straightbreeding project of the Beef CRC. The temperate progeny were finished in north-eastern New South Wales and animals from four temperate breeds subject to feedlot finishing were included in the data set for analysis. Three finishing regimes were put in place for tropically adapted progeny from three breeds. The first two regimes, which consisted of animals grown out and finished on pasture or feedlot in a sub-tropical environment of central Queensland, are not of interest in this analysis. Progeny undergoing the third treatment were sent to temperate environments in north-eastern NSW for grow-out and feedlot finishing. They represent about one-third of the tropically adapted animals and were included in the data set for analysis.

All sires were performance-recorded and genetic linkages across herds and years within a breed were generated through the use of common link sires. The total numbers of sires used were 232 and 163 for temperate and tropically adapted breeds, respectively. Progeny were born during the years 1993-1998 in 23 co-operator herds for temperate breeds and 13 co-operator herds for tropically adapted herds throughout eastern Australia. Parentage and date of birth were recorded on all animals in the co-operator herds and, at weaning, the animals were delivered to CRC-managed properties in central Queensland and north-eastern NSW (Bindon, 2001; Upton et al., 2001).

Cattle were assigned to one of three target market carcass weight groups—Australian domestic (220 kg), Korean (280 kg) and Japanese (340 kg)—and cross-classified with a finishing regime of pasture or feedlot. These target weights were selected because they are indicative of the Australian domestic and export (Korean and Japanese) markets, respectively (Johnston, Reverter, Burrow et al., 2003). This analysis was confined to lot-fed animals produced to specifications for the Korean market (to around 280 kg carcass weight) to avoid difficulties in accounting for the distinct production process followed and different output preferences that exist in each market.

A further narrowing of the dataset was undertaken to simplify the interpretation of results by excluding heifers, of which there were only 71 compared with 533 steers that comprised the final data set. This data set is much larger than that used by Fleming et al. (2004). It should enable a better analysis of scope economies and diseconomies, and a more valid comparison of technical inefficiencies across breeds.

A confidentiality requirement in access to the data means names of individual breeds cannot be revealed. Therefore, the four temperate breeds are notated as Temp1, Temp2, Temp3 and Temp4, and the three tropically adapted breeds are Trop1, Trop2 and Trop3. The timetable for preparing cattle for the Korean market is illustrated in Figure 1, adapted from Fleming et al. (2004). The shaded area shows the average period during which cattle are under the control of the Beef CRC Management.

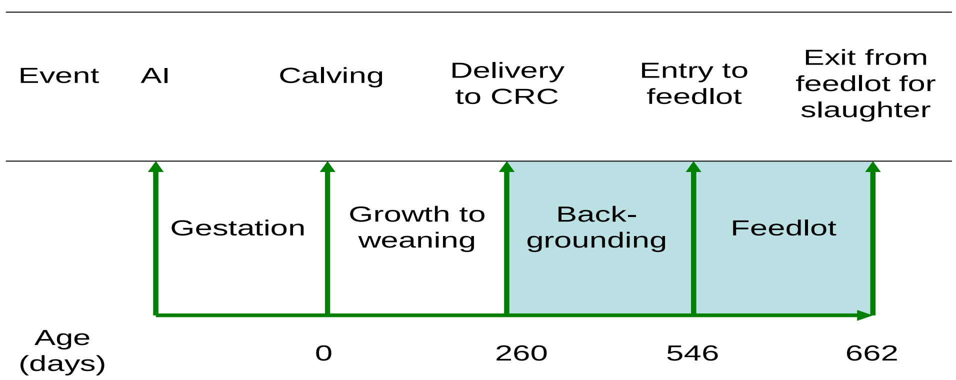

Figure 1. Timetable for preparing lot-fed cattle for the Korean market.

Measurements of animal traits included in this analysis were taken at three stages. The first stage is post-weaning and the second stage begins at the start of finishing, just after animals complete their grow-out period. Final records were taken at the end of finishing, just prior to slaughter, when the average weight of an intake was predicted to achieve target carcass weights for their assigned market. All end-of-finishing measurements were taken within 21 days of slaughter, with the average being eight days prior to slaughter.

Variables

Eight inputs and four outputs were considered for inclusion in the estimated model. The number of inputs was reduced from eight to six by eliminating rib and rump fat depths for ease of running the model when using a flexible functional form. These two input variables did not contribute significantly to an explanation of output in the model results that Fleming et al. (2004) reported. Four included variables are animal traits, measured on entry to the feedlot: age (in days), liveweight (in kilograms), eye muscle area (in square centimetres) and muscle score. 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). Two conventional inputs are also included: daily feed intake (measured using automatic feeders) and number of days in the feedlot (capturing inputs common to all animals such as veterinary supplies, supervision, provision of feeding facilities and other capital structures as well as the number of days of feed intake). No data are available on the use of the latter inputs but they should be the same for all animals, in which case the lack of specific data should not impede the analysis because these inputs can be measured by the amount of time that an animal spends in the feedlot (Fleming et al., 2004, p. 3).

Outputs considered for inclusion were carcass weight, meat quality, moisture retention in meat after cooking (hereafter retention), and marbling. The choice of meat quality as an output variable is of particular interest. Fleming et al. (2004) used a sensory quality variable obtained from consumer tasting (MQ4, which is a composite sensory measure comprising tenderness, juiciness, flavour and overall satisfaction). We replaced this measure by two objective measures of meat quality, namely the inverse of meat shear force and the inverse of meat compression. These two measures should be reasonably closely correlated to the sensory quality measure (Reverter, Johnston, Perry et al., 2003), but may more accurately reflect meat quality than the sensory measure given that the latter is subjective and is unlikely to be representative of consumers as a whole (Fleming et al., 2004). Consumer sensory measures are also much more expensive to collect than objective measures.

Four outputs were included in the final estimated model: carcass weight, retention, and two objective quality variables, namely the inverse of shear force and compression. The marbling output variable was omitted in this study because Fleming et al. (2004) found it was highly insignificant in their estimated model, in line with their expectation that marbling is less important in the Korean market than it is in some other export markets (notably Japan).

The amount of carcass weight produced refers to hot carcass weight (in kilograms) and retention was derived from a variable reported by Reverter, Johnston, Perry et al. (2003, p. 151) as cooking loss percentage. This figure was then subtracted from 100 because it is desirable for output variables in a production function to have positive relations with inputs. The measure of shear force, taken from Johnston, Reverter, Ferguson et al. (2003, p. 137), is described as the modified Warner-Bratzler shear force of two muscles, the *M. semitendinosus* and *M. longissimus*, using a triangulated 0.64-mm-thick blade pulled upward through the cooked sample at 100mm/min at right-angles to the fibre direction. Compression, also obtained from Johnston, Reverter, Ferguson et al. (2003, p. 137), was measured as the product of hardness and cohesiveness of the cooked *M. semitendinosus* and *M. longissimus* samples. A blunt cylindrical metal rod (6.3mm in diameter) was driven into the sample at 50mm/min, twice in exactly the same position. The mean (in kilograms) of six sub-samples was recorded for both these traits. The inverse of each was then calculated for use in model estimation because lower shear force and compression reflect higher-quality meat output.

Model specification

A multi-input multi-output stochastic input distance function was used to calculate technical efficiency indices for each sampled animal and to calculate the mean technical efficiency across all animals and by breed. Prior to estimation, the means of the natural logs of input and output variables were adjusted to zero so that the coefficients of the first-order terms may be interpreted as elasticities, evaluated at the sample means.

We chose to estimate a distance function rather than a cost function because cost data do not exist for most inputs in the feedlot production system under study. Two criteria were used to determine the choice between a stochastic input distance function and a stochastic output distance function: exogeneity and hypothesis testing. First, exogeneity is typically the main criterion guiding the decision between these two approaches, in that a stochastic input distance function is preferred when there is an exogenously determined set of outputs (and, vice versa, an output distance function is preferred when a producer seeks to maximise output from a given set of inputs). In this study, the carcass weight is fixed by export contract at approximately 280 kg to meet Korean market requirements (although weights of individual animals within a feedlot intake vary as a result of different growth rates). Also, exporters need to conform to quality specifications within fairly narrow bounds. It therefore makes sense for feedlot managers to adjust their inputs, including the heritable traits of animals, in order to produce specified meat output weight and characteristics. In particular, they would be expected to attempt to reach the desired output levels in the minimum number of days in the feedlot using the minimum amount of daily feed rations within that period. Second, one of the main aims of this study is to test whether significant economies or diseconomies of scope exist between outputs in the feedlot production process. In order to estimate the relevant coefficients needed to measure scope economies for all output variables, it is preferable to use an input variable on the left-hand side of the estimating equation so that significance tests can be carried out on all combinations of meat outputs.

A variable-returns-to-scale model using data envelopment analysis was also estimated with the same data set as a precautionary measure to assess whether scale efficiency exists among the animals in the data set. This model is estimated through the formation of a convex hull of intersecting planes that envelop data points more tightly than the conical hull of the standard constant returns-to-scale model (Coelli, Rao and Battese 1998, pp. 150-158). The aim of this additional model estimation was to determine whether variable returns to scale could lead to incorrect technical efficiency indices in the event that an output orientation should be preferred to an input orientation. Scale biases can arise from imposing an input-oriented framework on output-oriented results in that the technical efficiency estimates from this approach overestimate the true measures under increasing returns to scale and underestimate them under decreasing returns to scale. The mean scale efficiency estimate was 0.994, with scale-inefficient animals fairly evenly spread between decreasing and increasing returns to scale. This mean estimate is extremely close to unity, suggesting very little scale inefficiency. We conclude from this result that the risk of under-estimating or over-estimating technical efficiency indices through inappropriate orientation is negligible.

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

$$d(x,y) = \{\mathrm{D}:(x/D) \in L(y)\}, \quad (1)$$

where $L(y)$ represents the set of all fixed variable input vectors, x, that can produce the output vector, y. The expression, $d(x,y)$, is non-decreasing in the input vector, x, increasing in the output vector, y, and linearly homogeneous and concave in x (Coelli, Rao and Battese, 1998, p. 65).

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). The indices are changed from the input distance function form to conform to Farrell's approach, inverting them so they lie between 0 and 1 (Coelli and Fleming, 2004).

The model structure of Coelli and Perelman (1996) is followed to define the translog stochastic input distance function used in this analysis as:

$$\ln d_I = \beta_0 + \sum_{m=1}^{6} \beta_m \ln X_m + \sum_{n=1}^{4} \alpha_n \ln Y_n + 0.5\sum_{m=1}^{6} \sum_{m'=1}^{6} \beta_{mm'} \ln X_m \ln X_{m'}$$
$$+ 0.5\sum_{n=1}^{4} \sum_{n'=1}^{4} \alpha_{nn'} \ln Y_n \ln Y_{n'} + \sum_{m=1}^{6} \sum_{n=1}^{4} \omega_{mn} \ln X_m \ln Y_n \qquad (2)$$

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 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 known variance, σ_u^2, and unknown mean, μ, defined by:

$$\mu = \delta_0 + \sum_{i=1}^{10} \delta_i z_i \qquad (3)$$

where:

z_1 is the breed dummy variable for Temp2

z_2 is the breed dummy variable for Temp3

z_3 is the breed dummy variable for Temp4

z_4 is the breed dummy variable for Trop1

z_5 is the breed dummy variable for Trop2

z_6 is the breed dummy variable for Trop3

z_7 is the year dummy variable for 1995

z_8 is the year dummy variable for 1996

z_9 is the year dummy variable for 1997

z_{10} is the year dummy variable for 1998.

Ten zero-one dummy variables are included in the distance function for breed and year effects. Because seven breeds were used in the project, six breed dummy variables were included, with Temp1 breed as the base, to test for different levels of genetic advance or backgrounding between the seven breeds. Sample observations were collected from 1994 to 1998, so four year dummy variables were used to test for any productivity differences between years, with 1994 as the base.

The variance parameters, σ_v^2 and σ_u^2, are replaced by $\gamma = \sigma_u^2/(\sigma_v^2+\sigma_u^2)$ and $\sigma_s^2=(\sigma_v^2+\sigma_u^2)$ and input distances are predicted as $d_i = E[\exp(u)|e]$, where $e = v - u$ (Coelli and Perelman, 1996, p. 14). Again following Coelli and Perelman (1996), the natural log of the distance function is set such that $-\ln d_I = v - u$ in equation (2), and the restriction required for homogeneity of degree +1 in inputs is imposed such that $\beta_1 + \beta_2 + \beta_3 + \beta_4 + \beta_5 + \beta_6 = 1$. The choice is arbitrary as to which input variable (-ln age_i in this study) to put on the left-hand side to enable model estimation. Consider the distance function as a function of all inputs and outputs. If we were to shift -ln age_i to the right-hand side while putting the input distance on the left-hand side, and if u were equal to zero for animal i (no inefficiency), the left-hand side would equal zero. It would mean that this animal is on the frontier ($d_i = 1$) as exp(0) is 1.

The coefficients of the first-order terms in the estimated model can be interpreted as partial elasticities. In the cases of the input variables, the coefficients reflect the percentage change in the set of outputs for a one per cent change in this input. In the cases of the output variables, the coefficients reflect the percentage change in each of these outputs brought about by a one per cent change in the set of inputs.

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

Results and discussion

Estimates of production relations

Estimates of the maximum-likelihood estimation of the stochastic input distance function model are presented in Table 1. The estimated ordinary least squares model has high explanatory power, explaining 98 per cent of the variation in the dependent variable. The sum of the coefficients of inputs using ordinary least squares estimates is 0.907, which means that the implied elasticity for the age of the animal when entering the feedlot (the variable on the left-hand side of the estimated model) is +0.093 assuming homogeneity of degree +1 in inputs.

Table 1. Final maximum-likelihood estimates of the input and output elasticities.

Variable	Estimated elasticity	Standard error	*t*-ratio
Inputs:			
Age	0.093		
Feed per day	0.180	0.009	20.39
Liveweight	0.271	0.019	14.57
Muscle score	0.027	0.010	2.68
Eye muscle area	0.050	0.011	4.42
Days in feedlot	0.379	0.013	28.66
Outputs:			
Carcass weight	-0.446	0.017	-26.56
Retention	-0.142	0.064	-2.23
Shear force	0.017	0.009	1.84
Compression	0.016	0.003	5.49

Strong consistency was found for all results in a comparison of the ordinary least squares estimates with frontier estimates. The major difference is a slightly higher elasticity for days in feedlot on the frontier, suggesting that the best performing animals increase outputs more than average animals for every additional day spent in the feedlot. The consistency among other results reflects a situation where, although technically inefficient, the average animal is not too far from the frontier.

All elasticities in Table 1 are estimated to be significantly different from zero on the basis of likelihood ratio tests. As expected, the number of days in the feedlot, feed per day and liveweight on entry to the feedlot have the largest effects on the set of outputs at the margin. The estimated elasticities for the animal characteristics of muscle score (0.027) and eye muscle area (0.05) are low, but these traits, once established, are virtually costless to maintain. Despite their much higher elasticities, conventional inputs must be applied in each feedlotting process.

The coefficients for output variables, carcass weight and proportion of weight retained after cooking, are -0.446 and -0.142, respectively. Their negative signs are expected, reflecting the positive effects of all inputs on these two outputs (that is, output increases if all inputs are increased). A ten per cent increase in all inputs would increase carcass weight by 4.5 per cent and proportion of meat retained after cooking by 1.4 per cent.

Interestingly, the two quality variables, the inverse values of shear force and compression, return very small positive elasticities of 0.017 and 0.016 (the ordinary least squares estimates for these parameters are also positive and significant). These values were not expected to be positive because they imply that the set of inputs as a whole have a negative impact on meat quality, although this impact is minor given their small magnitudes. These results are consistent with the coefficient on the sensory meat quality variable estimated by Fleming et al. (2004) (0.014 and also of an unexpected sign). Fleming et al. (2004) proposed a possible explanation of this unexpected result, speculating that multicollinearity is occurring because of the high correlation between retention and meat quality. But omission of the retention variable in this study had little impact on the coefficients of the subjective meat quality variables or their signs. We therefore cannot support this explanation.

Breed and year effects on productivity

Individual likelihood ratio tests were conducted on the breed and year dummy variables in the distance function. First, Figure 2 shows the production frontiers of each breed of cattle in the sample. The frontiers of Temp2, Temp3 and Temp4 cattle are indistinguishable from that of the Temp1 base and significantly further from the origin than Trop2 and Trop3 cattle. This result suggests that no individual temperate breed has outperformed the others in terms of genetic advance. Interestingly, the Trop1 dummy coefficient is positive for the frontier estimates, while the Trop2 and Trop3 dummy coefficients are negative. The latter result is consistent with the result reported by Fleming et al. (2004) but the former result is not.

The result that Trop1 cattle have a frontier significantly higher than temperate breeds is in stark contrast to the result obtained by Fleming et al. (2004) where the frontier of this breed was significantly lower than that of the base breed (Temp1). A more detailed analysis of the data on animals found the average carcass weight across all cattle to be 285 kg and only 265 kg for Trop1 cattle, yet the weight of the heaviest Trop1 animal was much higher, at 348.5 kg. It is quite possible that one Trop1 animal was vastly more productive than the others (at least in terms of weight gain per kilogram of feed and time spent in the feedlot), causing the frontier to be distorted. An alternative explanation is a recording error. Outliers such as this do present a problem in setting the frontier, especially since it is not possible to trace back to the original data record.

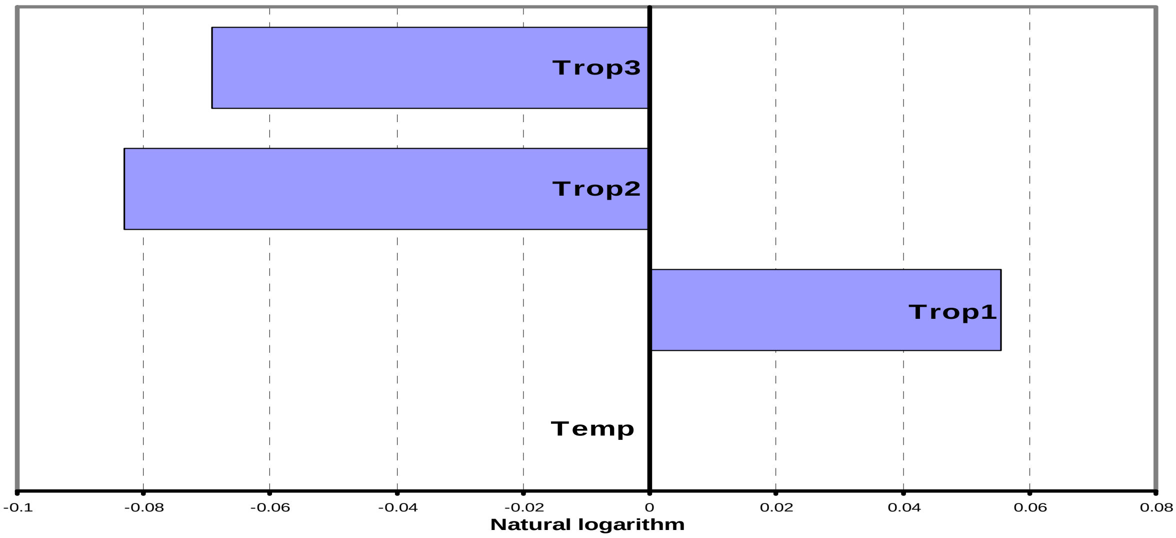

Figure 2. Effects of breed on the frontier.

The first of two notable results from including year dummy variables is a general outward shift of the production possibilities frontier over time, indicated by positive and significant coefficients for all year dummies (from 1995 to 1998, with 1994 as the base). Second, there was a particularly large shift of the frontier in 1998. The scale parameter in 1998 is 0.084, meaning that an animal on the frontier increased its productivity in 1998 over 1994 by 8.4 per cent, given input levels. Producers might have become better at exporting or better progeny might have been included in the cohorts of animals entering the feedlot over time.

Evidence of scope economies

A text-book definition states that economies of scope are present when the joint output of a single firm is greater than the output that could be achieved by two different firms each producing a single product (with equivalent production units allocated between the two firms). If a firm's joint output is less than that achievable by separate firms, then its production process involves diseconomies of scope – this possibility could occur if the production of one product somehow conflicted with the production of the second (Pindyck and Rubinfield, 2000, p. 231). Because animal outputs are jointly produced, all outputs must be produced to some extent and there is no opportunity not to produce any of the outputs. We therefore focus our attention on output relations in the vicinity of the sample means. Output combinations may be altered by varying the amounts and type of inputs used, such as number of days spent in feedlot and daily feed, adjusting the mix of breeds or by genetic selection. If scope economies exist for two meat outputs, one animal can produce both outputs at a lower cost than two animals specialising to a greater degree in the production of one of the two outputs at the same levels. Fleming et al. (2004) gave the example of a feedlot manager preferring to use animals capable of combining both high carcass weights and high quality meat than those that yield very high carcass weights but poor quality meat (or vice versa).

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

$$\partial^2 C / \partial y_n \partial y_{n'} < 0, \qquad n \neq n', \quad n, n' = 1, \ldots, N \tag{4}$$

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 output n reduces the marginal cost of producing an extra unit of output n'.

The first partial derivative of the input distance with respect to the n-th output is negative. The 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 (Coelli and Fleming, 2004). A positive second cross partial derivative is evidence of economies of scope:

$$\partial^2 D / \partial y_n \partial y_{n'} > 0, \qquad n \neq n', \quad n, n' = 1, \ldots, N \tag{5}$$

Conversely, a negative second cross partial derivative signifies diseconomies of scope (Coelli and Fleming, 2004).

The coefficient estimates of scope economies for each pair of outputs in the production system, as defined by equation (5), are listed in Table 2. Standard errors were obtained in order to test the hypothesis that there are no scope economies. These standard errors were calculated as Taylor series expansions.

Table 2. Estimated parameters of economies of scope.

Output combination	Scope economy parameter	Standard error	*t*-value
Carcass weight & Retention	-0.123	0.767	-0.160
Carcass weight & Shear force inverse	-0.039	0.123	-0.318
Carcass weight & Compression inverse	-0.025	0.027	-0.721
Retention & Shear force inverse	-0.374	0.340	-0.936
Retention & Compression inverse	0.165	0.126	1.311
Shear force inverse & Compression inverse	-0.012	0.021	-0.561

Using a five per cent significance level with a two-tail test, none of the scope economy parameters is significantly different from zero. The estimated t-values for the parameters involving carcass weight are all very low, indicating there are neither scope economies nor scope diseconomies (that is, the production possibility frontiers are linear). Relatively high standard errors for carcass weight and other outputs means that no scope economies (or diseconomies) are detected involving this output for any normal level of significance. Fleming et al. (2004) also found that this result holds in their study. The same conclusion is reached for the scope economy parameter between the two subjective meat quality variables.

Fleming et al. (2004) found strongly significant scope economies at output means for the combination of retention and the sensory meat quality variable. This result is not reproduced for the objective meat quality variables used in this study, at least in the case of retention and the inverse of shear force where the parameter indicates scope diseconomies (although very weakly significant). However, the result for retention and the inverse of compression is closer to expectation, with a positive sign and a t-value of 1.31. This parameter is significant at the 10 per cent level using a one-tail test, which is appropriate given our prior expectation of scope economies between these two outputs. Furthermore, there is a positive sign and the coefficient is significant at the 5 per cent significance level for this combination in the ordinary least squares results.

Technical inefficiencies

The value of the test statistic for the null hypothesis of no technical inefficiency (57.64) was found to be greater than the critical value for a mixed chi-squared distribution with nine restrictions (16.92) obtained from Table 1 of Kodde and Palm (1986). Therefore, there is inefficiency in the feedlot production system and it is concluded that the technical inefficiency term (u_i) is a significant addition to the model. Since the mean efficiency is 0.978, there is only a small level of inefficiency among cattle in the system. This figure is very close to the estimate by Fleming et al. (2004) of a mean technical efficiency of 0.975 and also to the estimate of 0.973 derived from the variable-returns-to-scale data envelopment analysis.

The gamma value is 0.582, indicating that 58.2 per cent of disturbance in the system is due to inefficiency, with one-sided error, and therefore 41.8 per cent is due to stochastic disturbance, with two-sided error, supported by a high *t*-value of 7.63. This result accords with the expectation that most disturbance is explained by inefficiency because of the reasonably strong control managers have over the production environment in feedlot operations, if not over the backgrounding of animals prior to their entry into the feedlot.

A likelihood-ratio test that the coefficients on the tropical breed and year efficiency variables are zero was strongly rejected, indicating that these variables as a group contribute significantly to an explanation of technical inefficiency in lot-fed beef production.

There is greater inefficiency in 1998 than in 1994. The most plausible reason is that the large shift of the frontier in 1998, mentioned above, has resulted in a situation where the average animal has not increased its productivity in 1998 over 1994 by as much as that of the most efficient animals. Average animals in 1998 were therefore slightly further from their frontier than average animals in 1994 were from their frontier.

A likelihood ratio test was run collectively for the three temperate breed regressor dummy variables and the three temperate breed efficiency dummy variables. The calculated chi-squared value is 4.06 compared with a critical chi-squared value for six restrictions of 12.59. Therefore, the null hypothesis that the coefficients on all these six variables are equal to zero cannot be rejected. It is concluded from this result that no significant differences are evident in the frontiers or the efficiencies across the four temperate breeds. This result contrasts with the finding by Fleming et al. (2004) that Temp4 had a significantly lower frontier than the other temperate breeds. The effects may not be so pronounced in this instance because there is more variation in backgrounding conditions (a much larger sample covering five years of production compared with two years in the previous study) such that differences in these conditions across cohorts may cancel each other out.

Figure 3 shows the results for breed effects on technical inefficiency. As for the productivity differences between breeds, no significant difference was detected between temperate breeds and a mixed result arose for the tropically adapted breeds. Ordinary least squares estimates show that the average animal for Trop1 is significantly less productive than the average animal for the base breed (the coefficient of the efficiency dummy variable for Trop1 is positive and highly significant). That is, the frontier for this breed is higher than that for the base breed but average Trop1 animals are significantly further below their frontier than average animals for the base breed are below their frontier. Their mean technical efficiency was only 90 per cent compared with an overall mean efficiency above 97 per cent. This result supports the contention made earlier that one Trop1 animal was vastly more productive than the others, or that a recording error was made, causing the frontier to be distorted. The other tropical breed dummies (Trop2 and Trop3) returned small negative values for the breed efficiency variables, reflecting means closer to their respective frontiers than average animals of the base breed are to their frontier.

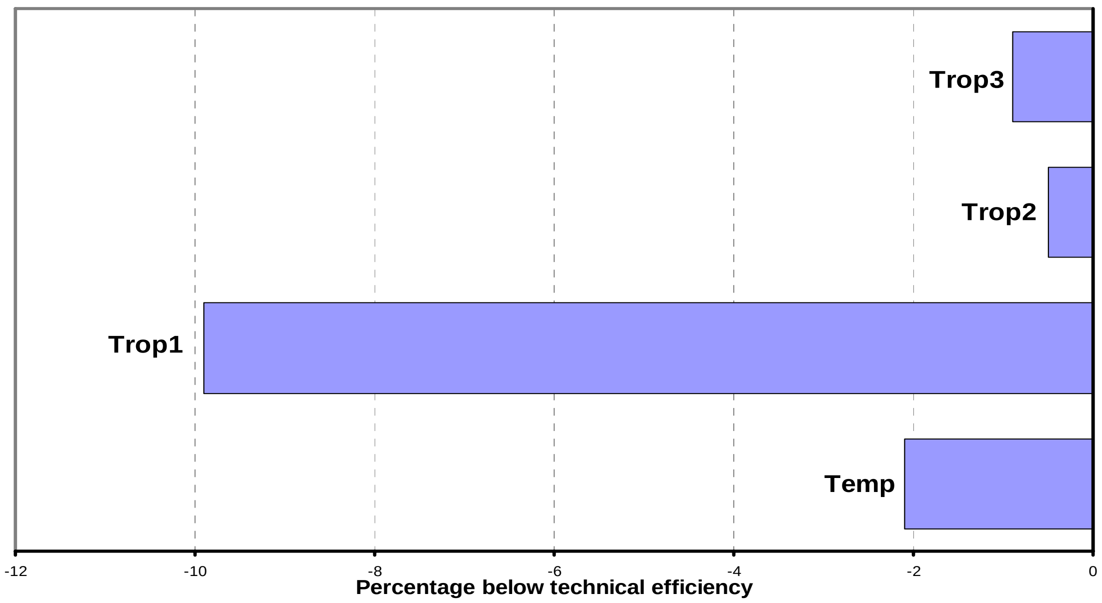

Figure 3. Effects of breed on technical inefficiency.

It was thought that there would be a reasonably high positive correlation between the efficiency with which cattle turn feed into weight gain and overall technical efficiency, but evidence suggests otherwise. While the correlation coefficient between the two efficiency measures is positive, it is very low at 0.03. Similarly, the Spearman rank correlation coefficient is only a little higher at 0.09. It is concluded that the commonly used feed efficiency indexes do not give a good guide as to the overall technical efficiency of an animal.

Conclusion

Data on 533 animals across seven breeds of beef cattle (four temperate and three tropically adapted) were used to estimate a stochastic input distance function with multiple inputs and multiple outputs for a cattle feedlot production system in Australia. The data set was restricted to steers whose meat was produced to Korean market specifications, to avoid the complicating effects on results of variations in feeding regimes for different markets.

The estimated model provides information about input-output relations, economies of scope and technical inefficiencies. Results suggest that no individual temperate breed has outperformed the others in terms of genetic advance or mean technical efficiency level. Temperate breeds were found to be more productive than two of the three tropically adapted breeds while the result for the other tropically adapted breed is problematic. It would simplify the interpretation of results in future studies if tropically adapted breeds were analysed separately from temperate breeds.

With one exception, neither economies of scope nor diseconomies of scope were established among four outputs: carcass weight, the proportion of moisture retention in meat after cooking, and two objective quality measures, the inverse of compression and the inverse of shear force. This finding contrasts with that of Fleming et al. (2004) who found strong scope economies between retention and subjectively determined meat quality. The scope economy parameter between retention and one of the meat quality variables, the inverse of compression, was positive and significant at the 10 per cent significance level, providing some evidence of scope economies consistent with the finding of Fleming et al. (2004). However, the parameter between retention and the other meat quality variable, the inverse of shear force, had an unexpected negative sign, indicating scope diseconomies (but it was not significant at any reasonable level of significance). Further analysis is needed to study both of these relationships before definitive statements may be made on the presence of scope economies or diseconomies.

Only a small (albeit significant) amount of technical inefficiency was found to exist in the lot-fed production system. This result indicates that the frontiers identified were generally indicative of the average performance, meaning limited opportunity exists to improve beef output by controlling the quality of sires of progeny entering the feedlot. Lower technical inefficiency for two of the three tropically adapted breeds compared with temperate breeds slightly offset their lower production frontier. Low comparability was detected between technical efficiency indices and commonly used feed efficiency indices.

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