# RURAL ECONOMY

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Staff Paper 96-13

# STAFF PAPER

**Department of Rural Economy**
Faculty of Agriculture, Forestry,
and Home Economics
University of Alberta
Edmonton, Canada

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The authors are, respectively, Assistant Professor, School of Agribusiness and Resource Management, Arizona State University, Tempe, Arizona, and Associate Professor, Department of Rural Economy, University of Alberta, Edmonton, Alberta.

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**Abstract**

This study investigates the relationships between farm size, milk yield, cost of production, and technical efficiency in the Alberta dairy industry. Estimates of a stochastic production frontier are obtained with two alternative methods; an iterative "average frontier" (AF) procedure and a maximum-likelihood composed error (CE) term method. An index of technical efficiency is calculated for every herd in the sample, with the AF method resulting in an average efficiency ratio of 85 percent, and the CE method producing an average efficiency ratio of 83 percent. Regressions of production cost on milk output, herd size, and efficiency are used to test for the effects of size economies, yield economies, and technical efficiency on production cost. These results suggest that herd expansion, on average, would lower the average cost of production throughout the province. Romain and Lambert use a similar method in a study of Quebec and Ontario dairy farmers which shows a limited potential to exploit economies of herd size. While not a formal test of the similarity of the two industries, the results of this study indicate a significant difference between the optimal structure of dairy production in Alberta and Quebec. Such regional differences will have important implications for the possible reapportionment of the national milk market, whether by regulatory or free-market mechanisms.

## Introduction

With the possibility of free trade in dairy products within the North American market, the size and prosperity of the Canadian dairy industry will depend upon the ability of producers to remain competitive. Evaluations of competitiveness between countries are potentially useful in helping to predict the future geographic structure of dairy production. However, these comparisons have proven to be difficult due to both a lack of comparable data and considerable debate over the appropriate metric. For example, in a comparison of Canadian and U.S. costs of production, Barichello et al (1996) cite exchange rate fluctuations, capitalization of program benefits into input prices, and interest rate differences, among others, as problematic. In the same paper, productivity growth rates between Alberta and Wisconsin are compared and it is argued that differences in the definition of milk yield, labour market policies, and feed market distortions inevitably cloud the results.

Evaluations of competitiveness between provinces are also fraught with their own problems but are, nonetheless, equally as important. With the balkanization of the Canadian fluid milk market under provincial supply management programs, the future structure of domestic production is nearly as uncertain as the continental picture. Several attempts to clarify the industry's expectations of this uncertain future document differences in either production costs between provinces (e.g., Jeffrey 1992; Barichello et al 1996; National Dairy Policy Task Force 1991), or in the relationships between production efficiency and costs of production (e.g., Barichello et al 1996).[1] Because predictions concerning the industry structure are forward looking, analyses of the ways in which producers can improve efficiency and cost provide valuable new information for dairy policy research. This study applies such an approach to the Alberta fluid milk industry.

The objective of this study is to determine the relationship between production cost, herd size, milk yield, and technical efficiency in the Alberta dairy production sector. With this knowledge, producers may be provided with insights into key factors to maintaining or improving competitiveness. Policy makers will be in a better position to assess the relative importance of regional differences in production methods or individual managerial skill in the determination of inter-regional comparative advantage.

This objective is achieved through the estimation and analysis of a milk production "frontier"; that is, the statistical relationship between input use and milk yield given the assumption of efficient production. The study begins with a brief review of recent studies of Canadian dairy efficiency and costs of production. The second section provides a discussion of the conceptual basis for efficiency measurement. The third section introduces and describes two methods that are used to estimate stochastic production frontiers for Alberta dairy production. Simple linear regression models are then used to investigate relationships between both efficiency and production cost and a set of management-characteristic variables. The interpretation of the results focuses on the apparent differences between Alberta and Ontario/Quebec, using the results of a study by Romain and Lambert as the basis for comparison.[2] An assessment of the ability of Alberta dairy producers to improve their competitiveness through efficiency gains will help to predict the future structure of dairy production in Canada.

## Canadian Dairy Efficiency

Within the context of multi-lateral U.S. and Canadian production cost comparisons, Barichello et al (1996) show a sample of producers in Alberta to have a slight cost advantage similar groups in Ontario and Quebec. Jeffrey (1992) supports this conclusion and also shows that Alberta producers have an advantage over those in British Columbia and Saskatchewan. Both of these studies cite economies of yield and herd size as critical factors in the determination of Alberta's cost advantage, but do not account for other cost determinants that have been shown to be equally important. For example, Romain and Lambert demonstrate that individual producer efficiency is a critical factor in the explanation of differences in production cost among dairy producers in Quebec and Ontario. Their results suggest that a 10 percent improvement in technical efficiency can reduce cash costs by $4.10/hectolitre in Quebec and $3.64/hectolitre in Ontario.

Several studies have examined the relationship between technical efficiency and production cost for U.S. dairy farms (e.g., Bravo-Ureta 1986; Bravo-Ureta and Rieger 1990, 1991; Grisley and Mascarenhas 1985; Kumbhakar et al. 1989; Tauer 1993; Tauer and Belbase 1987). However, little evidence concerning this relationship exists for Canadian dairy farms in general (other than Romain and Lambert's study), and less for Alberta dairy in particular.[3] With definitions of efficiency and methods of measurement similar to those used in previous studies, the results of this study should be somewhat comparable to those from other regions.

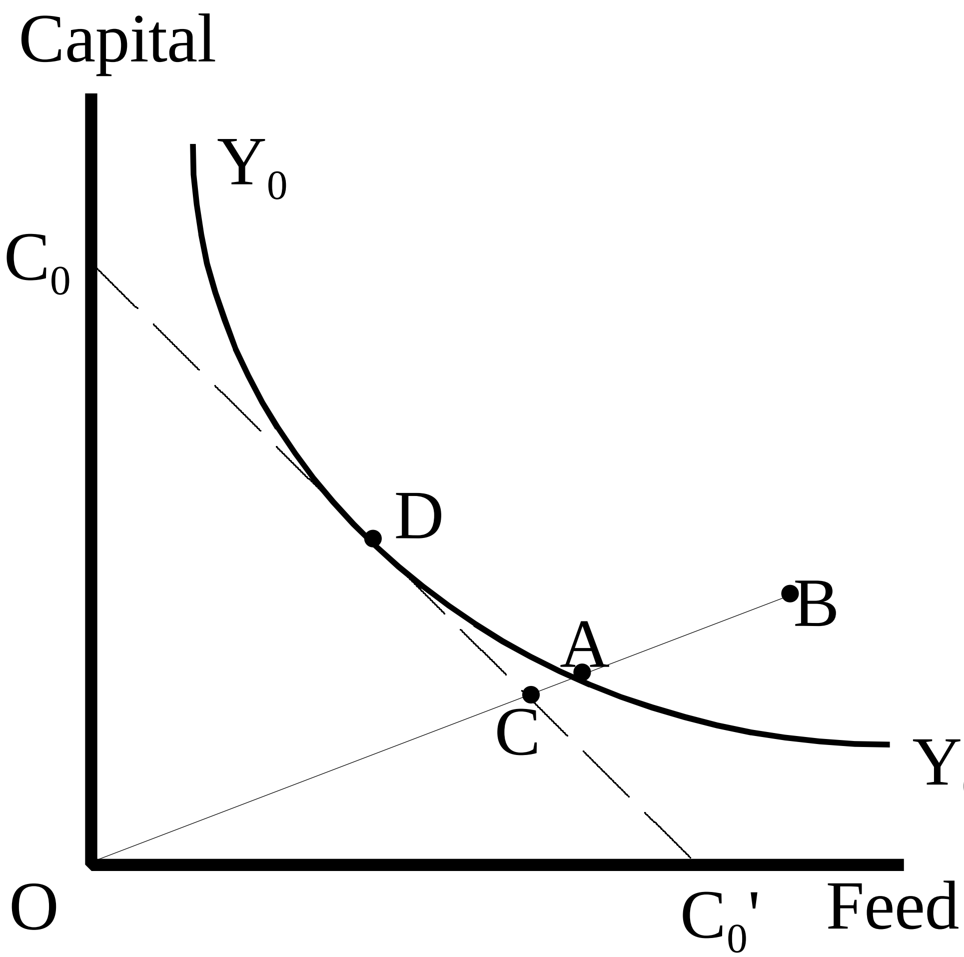
## Productive Efficiency - Definition and Discussion

Rigorous empirical investigations of firm efficiency find their roots in the pioneering work of Farrell (1957). Farrell decomposes overall economic efficiency into technical and allocative components. Technical efficiency is defined as the ability of a producer to achieve the maximum output possible from a given set of inputs. Allocative efficiency, in contrast, refers to the producer's ability to respond to economic signals and choose optimal input combinations (i.e., proportions) given relative input prices; that is, input price ratios equal to the ratios of marginal productivities. Economic efficiency is the product of technical and allocative efficiency.

The concepts of technical and allocative efficiency, and their measurement, may be depicted graphically. In Figure 1, the curve $Y_0Y_0'$ represents efficient combinations of two inputs, feed and capital, in producing output level $Y_0$ (i.e., the efficient isoquant). The line $C_0C_0'$ represents input combinations (i.e., combinations of feed and capital) having an aggregate cost of $C_0$ (i.e., an iso-cost line). The efficient isoquant represents the production "frontier"; all points on $Y_0Y_0'$ are technically efficient. Point D on the efficient isoquant is also allocatively efficient as it represents the least-cost feasible combination of capital and feed needed to produce $Y_0$. Being both allocatively and technically efficient, point D is also termed the point of economically efficient production.

Suppose that point B represents an observed combination of inputs used to product $Y_0$. At this point, production is neither technically or allocatively efficient. The degree of technical inefficiency for this producer is given by the ratio OB/OA; that is, the ratio of the distance between potential (i.e., efficient) and actual input use. The degree of allocative inefficiency for this producer is given by the ratio OA/OC; that is, the distance between the isoquant and iso-cost

**Figure 1** **Technical and Allocative Efficiency**



line, given the observed input ratio. Economic efficiency for the firm is given by the ratio OB/OC (i.e., the product of the technical efficiency and allocative efficiency ratios).

It is clear from Figure 1 that technical efficiency does not necessarily imply overall economic efficiency, nor does it imply cost minimization. A farm may achieve technical efficiency by employing inputs without regard to their price. Despite a relatively high level of production, a producer that follows this strategy will not likely minimize cost.

Empirical measurement of efficiency often involves the specification and estimation of a production "frontier". Several approaches have been used to estimate these frontiers. Farrell's original approach is deterministic and non-parametric, with any deviation from the frontier being attributed to inefficiency. This type of production frontier, estimated through the use of linear programming, is sensitive to outliers.

Developments in more recent efficiency studies relax the degree of determinism through the specification of a probabalistic production frontier. These frontiers may be estimated through the use of linear programming or econometric methods. Either method yields estimates of an efficient production frontier where the error terms are still constrained to be negative, however. Timmer (1971) and Bravo-Ureta (1986) provide examples of this approach using linear programming methods.[4] Again, however, all of the deviations from the production frontier using these methods are assumed to be due to inefficiency rather than to random events.

Aigner et al (1977) address this limitation through the development of a stochastic production frontier. This approach allows for deviations from the production frontier due to both inefficiency and random events. The stochastic frontier consists of a production relationship where observed production differs from potential output by an i.i.d. normal error term and a half-normal distributed error:

$$
\begin{aligned}
y_i &= f_i(x,\beta) + (v_i - u_i) \\
v_i &\sim N(0,\sigma^2_v) \qquad u_i \sim |N(0,\sigma^2_u)|
\end{aligned}
\tag{1}
$$

where x is a vector of inputs, f(·) a well behaved production function, β a vector of estimated parameters, and y is the level of output. The two error terms $v_i$ and $u_i$ represent deviations from the frontier due to random events and technical inefficiency, respectively. This approach is referred to as the composed-error (CE) method.

Implementation of the CE method requires an assumption to be made concerning the distribution for the non-negative error term $u_i$. Several alternative error distributions appear in the literature, including the exponential, gamma and half-normal distributions.[5] Given the assumption of a half-normal distribution made for this study, maximum likelihood estimates of the production function and distribution parameters are determined using the following log-likelihood function:

$$
LLF(\beta,\sigma,\lambda) = -N\log\sigma - K + \sum_i \left[ \log\Phi\left( \frac{-\epsilon_i\lambda}{\sigma} \right) - \frac{1}{2}\left( \frac{\epsilon_i}{\sigma} \right)^2 \right] \tag{2}
$$

where: $\epsilon_i = v_i - u_i$, $\lambda = \sigma_u/\sigma_v$, $\sigma^2 = \sigma^2_v + \sigma^2_u$, and $\Phi$ is the cumulative distribution function for the standard normal distribution. Because the residual of this procedure is $\epsilon_i$, and not $u_i$, the component of the error due to inefficiency is not directly observable from the estimates of the model. Thus only inferences can be made about sample mean inefficiency levels. However, Jondrow et al (1982) provide a convenient means by which the firm specific inefficiency term may be recovered. In particular, the distribution of $u_i$, conditional on the value of $\epsilon_i$, is characterized by:

$$E[u_i|\epsilon_i] = \frac{\sigma\lambda}{(1 + \lambda^2)}\left[\frac{\phi(\epsilon_i\lambda/\sigma)}{\Phi(-\epsilon_i\lambda/\sigma)} - \frac{\epsilon_i\lambda}{\sigma}\right] \tag{3}$$

where $\phi$ is the standard normal density function and all other parameters are defined as before. Greene (1990) provides an analogous expression for the gamma distribution.

Both deterministic and stochastic methods have been widely used in analyzing individual firm efficiency. In recent years, however, the stochastic production frontier approach has become more popular due to its flexibility.[6] It should be noted that deterministic and stochastic methods do not necessarily produce similar results. For example, Bravo-Ureta and Rieger (1990) and Kalaitzandonakes et al (1992) demonstrate that conclusions about individual farm efficiency obtained using stochastic methods differ from those obtained using deterministic frontiers.

While many applied production efficiency studies limit their discussion to technical efficiency considerations, there is an increasing emphasis being placed on measuring economic efficiency (or allocative efficiency) as well. Such studies typically involve the estimation of a frontier production function. Duality is used to derive a frontier cost function, which is then used in the measurement and analysis of allocative and/or economic efficiency for individual firms. In order to obtain the cost function, the functional form for the production frontier must be self-dual in nature.[7] The most popular choice of functional form in these studies is Cobb-Douglas. An example of this approach is given by Bravo-Ureta and Rieger (1991).

For the purposes of this study, it is useful to discuss one other specific stochastic production frontier methodology; the “average frontier” (AF) method. Using this approach, an “average” production function is estimated, relating output levels to various input levels for all producers in a sample. The function is then reestimated, excluding those observations that fall below this average function. This provides a more efficient average production function. The process is repeated until further estimation is no longer possible, leading to a frontier production function that describes the average best technology of the most efficient producers. This frontier function is then used to assess technical efficiency for individual producers.[8] The AF approach is used by Romain and Lambert (in Barichello et al 1996) in their study of production efficiency for Ontario and Quebec dairy producers.

## Empirical Methods and Data

Technical efficiency for Alberta dairy producers is analyzed in this study through the estimation of two production frontiers. To be consistent with much of the current literature in productive efficiency analysis, a stochastic frontier is estimated using the CE approach. In order to maintain comparability with Romain and Lambert’s recent study of Ontario and Quebec dairy producers, the AF method is also used to estimate a production frontier for Alberta producers.

Besides the choice of methodological approach to be taken, a decision must also be made regarding functional form. Romain and Lambert estimate a transcendental production function for milk production in Ontario and Quebec. The inputs considered in their analysis are hay, concentrates, labour, and capital equipment. To maintain comparability with their study, a similar specification is chosen to represent Alberta dairy producers, as follows:

$$Y_i = \beta_0 G_i^{\beta_1} H_i^{\beta_2} L_i^{\beta_3} K_i^{\beta_4} F_i^{\beta_5} \exp[\alpha_1 G_i + \alpha_2 H_i + \alpha_3 L_i + \alpha_4 K_i + \alpha_5 F_i + \gamma_t D_t] \epsilon_i \qquad \textbf{(4)}$$

where: $Y_i$ ≡ quantity of milk output as hectolitres per year per cow, for the $i^{th}$ producer;
$G_i$ ≡ quantity of grains and concentrates, as tonnes per year per cow, for the $i^{th}$ producer;
$H_i$ ≡ quantity of hay and forage, as tonnes per year per cow, for the $i^{th}$ producer;
$L_i$ ≡ quantity of hired labour, as hours per year per cow, for the $i^{th}$ producer;
$K_i$ ≡ quantity of capital services, measured as an index per cow, for the $i^{th}$ producer;
$F_i$ ≡ quantity of family and operator labour, as hours per year per cow, for the $i^{th}$ producer;
$D_t$ ≡ a dummy variable for the years 1989 and 1990;
$\epsilon_i$ ≡ an error term representing random deviations from the frontier, for the $i^{th}$ producer.
$\beta_j$, $\alpha_j, \gamma_t$ are parameters to be estimated

This specification is used for both the AF and CE procedures.[9] Ordinary least squares is used to obtain parameter estimates for the AF model, whereas the maximum likelihood procedure in LIMDEP is used for the CE model. The resulting frontiers are used to assess technical efficiency.

As noted earlier, technical efficiency does not guarantee cost or economic efficiency. A farm may achieve technical efficiency by employing inputs without regard to their price. Producers following this strategy will not likely minimize cost. An assessment of production costs in relation to such factors as variable input prices, fixed factor levels, amount of output level and degree of technical efficiency may be accomplished through the specification of a dual cost function. However, the production frontier approach violates one of the necessary conditions for duality; technical efficiency. As well, the transcendental form is not self-dual, so a cost function cannot be derived from the production frontier.

To explain inter-farm variations in production cost, therefore, the relationships between milk yield, herd size, producer age, a proxy for genetic quality (annual expenditures on breeding and veterinary care), and production cost are estimated using a purely empirical cost equation approach. To allow for the possibility that the effects of yield and herd size on production cost may be non-linear, these variables are specified as quadratics. The parameter estimates from this model may be used to provide an indication of the optimal yield and herd size. If the data show herd sizes and yields to be below these optimal levels, this suggests that there are unexploited economies in Alberta dairy production. The specific cost equation modelled in this study is structured as follows:

$$\begin{aligned} COP_i = a_i + b_1 Y_i + c_1 Y_i^2 + b_2 COWS_i + c_2 (COWS_i)^2 \\ + b_3 G_i + b_4 H_i + b_5 TE_i + b_6 AGE_i + b_7 BE_i + \epsilon_i \end{aligned} \tag{5}$$

| | | |
|---|---|---|
| where: $COP_i$ | ≡ | cost of production as $/hectolitre, for the $i^{th}$ producer; |
| $COWS_i$ | ≡ | herd size for the $i^{th}$ producer; |
| $TE_i$ | ≡ | technical efficiency ratio for the $i^{th}$ producer; |
| $AGE_i$ | ≡ | age of the $i^{th}$ producer; |
| $BE_i$ | ≡ | breeding and veterinary expense per cow, for the $i^{th}$ producer; |
| $\epsilon_i$ | ≡ | error term reflecting random deviations, for the $i^{th}$ producer. |

and $Y_i$, $G_i$ and $H_i$ are defined as before. Ordinary least squares is used to estimate this equation. The results from this estimation procedure are used to examine factors influencing costs of milk production in Alberta.

The data for this study are from the Alberta Agriculture-Alberta Milk Producers' Society annual cost of production surveys from 1989-1991. The sample consists of an unbalanced panel of 55 Alberta fluid milk producers chosen in such a way to be representative of each region and herd size group. Participation in the survey is voluntary and each producer typically participates for four consecutive years. The resulting sample size is 181 pooled observations. A dummy variable technique shifts the production function intercept from the base year, 1991.

Total cost is defined on a dairy enterprise basis. As a result, all costs incurred in raising calves to milking age are included. For the cost equation, the dependent variable is defined as total production costs; that is, the total cost per hectolitre including capital costs such as interest, depreciation, and a return to equity. A more detailed description of the cost definitions and survey method is provided by Susko (1992).

Output consists of the total amount of milk shipped from the farm, to both the fluid and industrial markets, in hectolitres per year. Although the producers in the Alberta Agriculture survey are largely fluid milk producers, all must hold some industrial (market sharing) quota in order to sell milk produced in excess of their utilized fluid allocation. Because milk shipments go to both markets, the price is a net, or blended price per hectolitre.

Variable production inputs include hours of hired labour, tonnes of grain and concentrates, and tonnes of forage. Forage is defined as the sum of hay, silage, and pasture consumption. Total feed expenditure divided by the tonnage fed gives the average price per tonne of feed. Expenditures for homegrown feed are calculated using regional average rates. Prices and quantities for grain and concentrates are calculated in a similar way. Because of the geographical diversity of producers in Alberta, and the marked differences in local feed markets, a significant amount of both cross sectional and time-series price variation exists in the sample. Wages for hired labour are the hourly rates actually paid by the producer. Due to a lack of worker training or experience data, the wage is unadjusted for quality.

Several inputs are classified as fixed in nature. This includes capital and family/operator labour. Within this classification, the survey reports annual herd size, value of capital stock, amount of family labour, and quota holdings. Family wage rates are calculated by dividing the total family wage bill by the number of hours worked. However, the wage is not adjusted for unskilled or child labour because of insufficient information. Capital consists of the value of buildings and equipment specific to the dairy enterprise. Ball's (1985) method is used to provide an annual capital rental price series. The rental price is then used to derive an annual capital quantity level from reported stock values.

For estimation purposes, a correction for embodied technological (genetic) improvement in cattle produces an annual series of equivalent-cattle livestock inputs. The pace of genetic progress in dairy cows has been so rapid that cattle from two different vintages may be considered as two qualitatively different inputs. The index used consists of the provincial average breed class average (BCA) for Holstein cattle. Although it is preferable to use an index independent of actual milking performance, this index is the best available for the sample period. Howard and Shumway's (1988) method is used to construct a rental price series for cattle. Their approach involves calculating the annual rental price that would result in a producer being indifferent between buying a heifer and milking her for three lactations and then selling her for slaughter, and renting her for three lactations. Table 1 provides summary statistics for each of the variables described above.

**Table 1: Summary Statistics from the Alberta Dairy Cost of Production Survey, 1989-1991**

| Variable | Units | Average | Standard Deviation | Minimum Value | Maximum Value |
|---|---|---|---|---|---|
| Milk Output | hl./cow | 67.13 | 11.79 | 33.72 | 118.45 |
| Grain and Concentrate | tonnes/farm | 246.26 | 191.18 | 51.39 | 819.26 |
| Hay and Forage | tonnes/farm | 428.74 | 256.86 | 57.00 | 1199.33 |
| Hired Labour | hours/farm | 1833.20 | 3591.80 | 0.00 | 30738.00 |
| Family and Operator Labour | hours/farm | 3581.30 | 1769.80 | 250.00 | 13626.00 |
| Capital | $/farm[a] | $264,420.00 | $241,160.00 | $8,770.50 | $1,587,300.00 |
| Quota | litres/day | 897.86 | 817.21 | 285.00 | 9445.00 |
| Herd Size | cows/farm[b] | 65.94 | 35.65 | 24.50 | 214.50 |

[a] This figure represents the “stock” of capital, rather than the “flow” (i.e., capital usage) calculated for use in the production function estimation procedure.

[b] Cattle numbers have been “corrected” for embodied technological change by scaling them using average annual BCA values.

## Results and Discussion

Iterative applications of ordinary least squares provide estimates of the frontier production function for the AF method. Beyond four iterations the sample size became too small to obtain further estimates. Table 2 shows the results from both the initial and final estimation stages.

Of the individual parameters in the final iteration of the AF frontier, the constant term ($\beta_0$), grain and concentrates ($\alpha_1$), hay and forages ($\beta_2$ and $\alpha_2$ ), hired labour ($\alpha_3$) and family/operator labour ($\beta_5$) are statistically significant at the 5 percent level. Exclusion of technically inefficient producers causes the explanatory ability of the model to rise from 81.54 percent of total variation explained initially to over 99 percent in the final round. However, because the number of observations included in the final iteration is only 21 farms, the stability of these parameter estimates is subject to some question. Nonetheless, this frontier serves as the benchmark that describes the most technically efficient dairy farms in Alberta.

In this respect, technical efficiency ratios for all farms can be calculated with reference to this frontier. Because the frontier represents the "average" production function for the 21 most efficient firms, the range of efficiency ratio values extends beyond 1.00; that is, beyond 100 percent efficiency.[10] In fact, using the AF frontier, individual efficiency ratio values range from a low of 47 percent of the most efficient farms to a high of 111.44 percent. The average efficiency ratio is 84.90 percent with a standard deviation of 12.38 percent.

The production frontier estimates resulting from the use of the AF method may be examined in relation to those determined with the CE model. The parameter estimates from the two methods may thus be compared to determine if they are "consistent" in terms of their

**Table 2: Frontier Production Function for Alberta Milk Production (AF Method)**

| | Milk Production Function Estimates[a] | | | |
|---|---|---|---|---|
| | Initial Iteration | | Final Model | |
| Parameter[b] | Coefficient | t-ratio[c] | Coefficient | t-ratio[c] |
| $\beta_0$ | -6.6031 | -14.9000* | 3.6626 | 21.3000* |
| $\beta_1$ | 0.0037 | 0.0571 | -0.0109 | -1.1650 |
| $\beta_2$ | -0.0143 | -0.1400 | -0.1205 | -6.8850* |
| $\beta_3$ | 0.0087 | 3.3000* | 0.0013 | 1.2390 |
| $\beta_4$ | -0.0004 | -11.5900* | 0.00001 | 0.2518 |
| $\beta_5$ | -0.0009 | -0.2958 | 0.0025 | 3.2930* |
| $\alpha_1$ | 0.2404 | 0.6131 | 0.1441 | 2.4540* |
| $\alpha_2$ | 0.3348 | 1.0360 | 0.6156 | 9.4840* |
| $\alpha_3$ | -0.0580 | -1.5670 | 0.0405 | 4.2830* |
| $\alpha_4$ | 1.2443 | 17.3500* | -0.0068 | -0.3257 |
| $\alpha_5$ | 0.3412 | 2.3090* | -0.0071 | -0.2817 |
| D90 | -0.0918 | -1.2280 | -0.0008 | -0.0541 |
| D89 | -0.1877 | -2.4340* | -0.1730 | -1.2470 |
| $R^2$ | 0.8154 | | 0.9902 | |
| N | 181.0 | | 21.0 | |

[a] The initial iteration estimates are for the initial production function estimated using all data points in the sample. The final model represents the production frontier, estimated using the most "efficient" observations.

[b] The parameters listed here are as defined in Equation 2. D89 and D90 are the $\gamma_t$ coefficients for the dummy variables for 1989 and 1990, respectively.

[c] An asterisk represents statistical significance at a 5% level.

interpretation. Given the same variable definitions and data, Table 3 shows the results from the maximum likelihood estimation of the CE stochastic production frontier.

Similar to the AF estimates, a limited number of parameter estimates for the CE frontier are statistically significant; the constant term ($\beta_0$), grain and concentrates ($\beta_1$ and $\alpha_1$), hired labour ($\beta_3$ and $\alpha_3$), and family/operator labour ($\beta_5$). Using the CE frontier as the standard, technical efficiency ratios are again calculated for each observation in the sample. Individual ratio values range from 30.96 percent efficient up to 97.95 percent of the frontier. The average efficiency ratio is 83.35 percent with a standard deviation of 12.54 percent.

From a comparison of Tables 2 and 3, it is obvious that the AF and CE methods do not produce similar results in terms of the production frontier estimates. The technical efficiency ratios for individual farms vary depending on the method used as well. These discrepancies are not surprising, given the difference in the numbers of observations used and the differences between the two methods in the assumptions concerning the error terms. Thus, the two production frontiers cannot be compared directly.

While the AF and CE frontiers and efficiency measures cannot be compared directly, they can be compared in terms of their consistency. The degree of covariability between technical efficiency measures from the AF and CE frontiers is measured by calculating the correlation coefficient. The resulting coefficient is 0.91, and is statistically significant at a 5 percent level. The two frontiers may also be compared in terms of the consistency with which they rank the individual farms' technical efficiency from most efficient through least efficient. This is evaluated by calculating the Spearman's Coefficient of Rank Correlation. The resulting coefficient is 0.88, which indicates a very strong correspondence between the ranking for the two efficiency measures

**Table 3: Frontier Production Function for Alberta Milk Production (CE Method)**

| Parameter[a] | Coefficient | t-ratio[b] |
|---|---|---|
| $\beta_0$ | 4.2528 | 12.1490* |
| $\beta_1$ | -0.0627 | -1.8920* |
| $\beta_2$ | 0.0291 | 1.6050 |
| $\beta_3$ | 0.0015 | 2.0230* |
| $\beta_4$ | 0.0002 | 1.3250 |
| $\beta_5$ | 0.0031 | 2.3460* |
| $\alpha_1$ | 0.3964 | 3.3690* |
| $\alpha_2$ | -0.0666 | -0.6390 |
| $\alpha_3$ | 0.0076 | 1.9110* |
| $\alpha_4$ | -0.0251 | -0.5840 |
| $\alpha_5$ | -0.0801 | -1.3100 |
| D90 | -0.0448 | -1.8820* |
| D89 | -0.0249 | -1.1090 |
| $\lambda$ | 4.1846 | 2.9060* |
| $\sigma$ | 0.2197 | 14.9700* |
| Log-Likelihood | 114.3961 | |
| N | 181.0 | |

[a] The parameters listed here are as defined in Equations 2 and 4. D89 and D90 are the $\gamma_t$ coefficients for the dummy variables for 1989 and 1990, respectively.

[b] An asterisk represents statistical significance at a 5% level.

(Steel and Torrie 1980). It may be concluded, then, that the two frontiers are relatively consistent.

While interprovincial comparisons of these inefficiency ratios cannot be used to suggest that one group is more or less efficient than any other, the AF results for Alberta indicate that 10.3 percent of the sample farms are 100 percent efficient. By comparison, Romain and Lambert's estimates indicate that 2.3 percent of the producer sample in Quebec and 9.4 percent of the Ontario sample are 100 percent efficient. In Alberta, 95 percent of the producers are between 62 percent and 110 percent efficient with the AF method. Given the nature of the error term for the CE method, none of the producers are entirely efficient using the CE production frontier. However, 95 percent of the sample in the CE method lie above 56% efficient.

Perhaps more interesting are comparisons between the effects of efficiency, and other variables, on the cost of milk production. As noted earlier, regression models are used to estimate the relationship between herd size, milk yield, feed usage, technical efficiency, operator age, and veterinary and breeding expense and the cost of production. A comparison of these results to those of Romain and Lambert reveals aspects of the structure of dairy production that are similar between the two regions, and those that are different. In order to maintain comparability between the two studies, the discussion initially focuses on the cost equation estimated with the AF efficiency measure as an explanatory variable. A similar analysis with the CE measure follows.

The estimation results for the cost equation, using the AF frontier as the basis for the technical efficiency measure, are provided in Table 4. Of the explanatory variables included in the analysis, herd size (quadratic term only), hay fed per cow, level of technical efficiency, producer age and breeding/veterinary expenses are statistically significant. Milk yield is not statistically

**Table 4: Empirical Cost Equation for Dairy Production in Alberta (AF Model)**

| Variable[a] | Estimated Coefficient | t-ratio[b] |
| --- | --- | --- |
| Constant | 57.6240 | 9.0140* |
| Milk Yield | 0.0049 | 0.0288 |
| $(\text{Milk Yield})^2$ | 0.0005 | 0.3775 |
| Herd Size | -0.0999 | -2.6910* |
| $(\text{Herd Size})^2$ | 0.0002 | 1.3810 |
| Grain/Cow | 0.5929 | 1.3250 |
| Hay/Cow | 0.9313 | 5.0230* |
| Technical Efficiency | -33.6770 | -6.8080* |
| Producer Age | 0.0806 | 2.4370* |
| Breeding/Vet. Expense | 0.0005 | 4.5670* |
| $R^2$ | 0.5416 | |
| N | 181.0 | |

[a] Milk Yield refers to milk production per cow. Technical efficiency refers to the technical efficiency ratio calculated using the estimated production frontier. Breeding/Vet Expense refers to the expenditures for breeding and veterinary services.

[b] An asterisk represents statistical significance at a 5% level.

significant using this specification. The overall regression explains slightly more than 50 percent of the variability in production costs, which is not surprising given that the cost variable includes fixed costs such as debt servicing, depreciation and a return to equity.

The results presented in Table 4 suggest that there are significant herd size economies to be exploited by Alberta producers; that is, given the average herd size in the sample, production costs decrease with increased herd size. This result is somewhat in agreement with Romain and Lambert's estimates. They show that cash costs fall with increased herd size in Ontario, but that production costs in Quebec do not vary significantly with herd size. Given the average sample herd size from Table 1, the Alberta results in Table 4 may be used to show that production costs fall by $0.073/hl./cow for increases in herd size. This is potentially significant, although less than the $0.127 shown for Ontario producers by Romain and Lambert.

A priori, both yield and herd size should have a non-linear effect on costs - total cost per litre should fall over some very low range of production, reach some minimum and then rise when capacity and other constraints are met. As a formal test of such U-shaped costs, these results show that a quadratic specification for herd size provides a better description of Alberta production costs than does the linear version. Romain and Lambert suggest that costs increase rapidly beyond a 40 cow threshold in Quebec. The current analysis, using the results from Table 4, shows the optimal herd size in Alberta to be 250 head. Since the average herd size in this sample is 66 cows, there would appear to be an opportunity to lower average costs of production through the exploitation of size economies.

The existence of herd size economies found in this study is consistent with the conclusions drawn from previous research in other geographic regions. Weersink et al (1990) report that every 1 percent increase in herd size yields a 5 percent increase in efficiency for Ontario dairy farmers. This is presumably only valid over a small range of possible herd sizes. Tauer (1993), in a sample of New York dairy farms, shows that each cow adds 1 percent to the short-run technical efficiency of milk production. Bravo-Ureta and Rieger (1991) add to the weight of evidence in support of a positive effect on efficiency from increased herd size using a sample of New England dairy farms.

In contrast to the herd size effect, milk yield per cow does not appear to have a significant effect on costs of production for Alberta producers, given the results in Table 4. This differs from the positive relationship between yield and cost found by Romain and Lambert for both Ontario and Quebec. This result also contradicts the findings of Barichello et al (1996) who conclude that Canadian dairy competitiveness can be improved through higher milk yields. From Table 4, given herds of similar size, efficiency, and feed use, yield information does not significantly contribute to the determination of production costs.

Some of the other explanatory variables in the cost equation also affect costs of production. Increases in concentrate use per cow are marginally insignificant in terms of their effect on costs of production, while hay and forage use significantly raises costs. This result may capture the effect of attempts to produce “cheap milk” through grazing cattle and feeding inferior quality hay instead of grain and concentrates. When the lower yield is factored in, this does not appear to be a low-cost strategy.

Older producers in Alberta also tend to have higher production costs than do younger producers. This may suggest that new entrants to the industry are more likely to adopt cost reducing technologies than are incumbent producers. Production costs also increase directly with the amount of expenditure on breeding and veterinary services. This variable was intended to capture producers' investment in genetic advancement. However, it is clear that herds with health or reproduction problems dominate the expected effect.

Finally, improvements in technical efficiency tend to reduce costs for Alberta producers. In fact, every 10 percent increase in the efficiency ratio causes production costs to fall by $3.37/hl. This is consistent with Romain and Lambert's results, where a 10 percent improvement in efficiency results in production costs being reduced by $5.25/hl. in Quebec, and $4.84/hl. in Ontario.

A regression of production costs on a similar set of variables using the CE frontier efficiency measure provides another perspective on the comparison. The results of this estimation procedure are presented in Table 5. Milk yield (linear and quadratic terms), herd size (linear term only), technical efficiency and breeding/veterinary expense are all statistically significant. Again, slightly more than 50 percent of total variation in production costs is explained by this equation.

Some of the implications that may be drawn from the results in Table 5 are consistent with the earlier AF results. The presence of unexploited herd size economies is again indicated, with production costs decreasing by $0.066/hl. for every increase of one cow in herd size, given the average sample herd size of 66 cows. Given the regression results, the optimal herd size is approximately 287 cows, again significantly greater than the sample average.

Also consistent with the earlier analysis are the effects of grain and hay fed per cow. Neither term is statistically significant, although hay fed per cow is marginally insignificant. Increased grain and concentrates use per cow marginally decreases production costs, while the opposite is true for hay fed per cow.[11]

**Table 5: Empirical Cost Equation for Dairy Production in Alberta (CE Model)**

| Variable[a] | Estimated Coefficient | t-ratio[b] |
|---|---|---|
| Constant | 57.1340 | 8.2750* |
| Milk Yield | 0.9130 | 3.6820* |
| (Milk Yield)$^2$ | -0.0045 | -2.9480* |
| Herd Size | -0.0860 | -1.9960* |
| (Herd Size)$^2$ | 0.00015 | 0.7370 |
| Grain/Cow | -0.3461 | -0.6390 |
| Hay/Cow | 0.3411 | 1.4930 |
| Technical Efficiency | -59.5320 | -8.4460* |
| Producer Age | -0.0548 | -1.4120 |
| Breeding/Vet. Expense | 0.0005 | 4.3190* |
| $R^2$ | 0.5451 | |
| N | 181.0 | |

[a] Milk Yield refers to milk production per cow. Technical efficiency refers to the technical efficiency ratio calculated using the estimated production frontier. Breeding/Vet Expense refers to the expenditures for breeding and veterinary services.

[b] An asterisk represents statistical significance at a 5% level.

The cost equation results with the CE efficiency measure in Table 5 also support the strong relationship between technical efficiency and production cost.  A 10 percent improvement in technical efficiency results in a $5.99/hl. decrease in production costs.  Also, the direct relationship between production cost and breeding/veterinary expense is maintained in the equation.

The most significant difference between the results in Table 5 and the earlier (AF frontier-based) cost equation estimates is with respect to milk yield economies.  In Table 5, both milk yield terms are statistically significant, and the signs on these terms would suggest that there are significant diseconomies of milk yield for Alberta producers.  Given the sample average production level of approximately 67 hl/cow, every hectolitre increase in average milk yield per cow results in a $0.31/hl. increase in production cost.  Furthermore, the yield coefficients suggest that cost per hectolitre is maximized at a milk yield of 101.4 hl/cow/year (approximately 23,000 pounds).  Beyond this production level, costs per hectolitre decrease with further increases in milk yield, indicating possible milk yield economies.

There is an alternative explanation for the direct relationship between milk yield and production cost.  Rather than being an indication of diseconomies of milk yield, it may reflect the differences in the quality of rations (i.e., forages and concentrates) fed to lower versus higher producing cows.  Differences in the quality of feed between observations is not accounted for in the data set because of insufficient information.  Thus, variation in the costs of rations due to differences in feed quality cannot be captured by the feed variables.  To the degree that nutrition contributes to milk yield this variability may be captured by the corresponding differences in milk yields between producers.

Romain and Lambert also report the results of a regression analysis for technical efficiency using a similar set of explanatory variables. Table 6 presents the OLS results of an equivalent analysis using the CE model-based technical efficiency ratios as the dependent variable. Statistically significant explanatory variables include the constant term, milk yield, producer age and the capital/labour ratio.

From Table 6, it is obvious that one important contributing factor to technical efficiency is milk yield. Every additional hectolitre/cow improves technical efficiency by 0.79 percent. Increased capital use also contributes positively to technical efficiency in Alberta dairy production, as evidenced by the significant positive coefficient for the capital/labour ratio; a 10 percent increase in relative use of capital improves technical efficiency by 0.6 percent. Age also appears to be a more significant influence, as each additional year reduces technical efficiency by 0.26 percent. While not encouraging, given the rising average age of dairy producers, this may be indicative of the rapid pace of technological improvement in the industry and the necessity to stay current in order to match the "best practice" efficiency levels.

Also from Table 6, it appears that technical efficiency is independent of herd size. This is inconsistent with the conclusions of many other similar studies. Romain and Lambert's results suggest that larger farms in Ontario and Quebec are more technically efficient, although the relationship for Ontario is not statistically significant. Studies by Tauer and Belbase (1987) and Bailey et al (1989) also suggest positive relationships between herd size and technical efficiency. Given the results of Kalaitzandonakes et al (1992), the conclusions reported by these studies may be somewhat dependent upon the model specification. Bravo-Ureta and Rieger (1990) do, however, report a consistently positive relationship between farm size and technical efficiency

**Table 6: Regression Results for Factors Influencing Technical Efficiency of Dairy Production in Alberta (CE Model)**

| Variable[a] | Estimated Coefficient | t-ratio[b] |
|---|---|---|
| Constant | 0.3602 | 7.4310* |
| Milk Yield | 0.0079 | 12.9770* |
| Herd Size | -0.0016 | -0.5860 |
| Concentrate/Forage Ratio | -0.0331 | -1.2910 |
| Producer Age | -0.00224 | -3.2380* |
| Breeding/Vet. Expense | -0.0000028 | -1.3480 |
| Debt/Equity Ratio | -0.00069 | -1.8010 |
| Capital/Labour Ratio | 0.00060 | 2.0340* |
| D89 | 0.0259 | 1.6770 |
| D90 | 0.0116 | 0.7830 |
| $R^2$ | 0.5883 | |
| N | 181.0 | |

[a] Milk Yield refers to milk production per cow. Concentrate/Forage Ratio represents the amount of grain and concentrate fed relative to the amount of hay and forage fed to the cattle. Breeding/Vet Expense refers to the expenditures for breeding and veterinary services. Debt/Equity Ratio measures the solvency (i.e., leverage) for the individual firm. Capital/Labour Ratio is the "flow" of capital used by the firm relative to the hours of labour. D89 and D90 are the coefficients for the dummy variables for 1989 and 1990, respectively.

[b] An asterisk represents statistical significance at a 5% level.

over four different methods of analysis applied to New England dairy farms.  This differs from an earlier study of New England dairy farms (Bravo-Ureta 1986) which shows technical efficiency to be independent of herd size.

Based upon the preponderance of evidence that shows large farms to be more efficient than smaller ones, particularly in dairy, it is tempting to suggest that peculiarities in Canadian dairy reverse this relationship.  Within a supply management system, producers faced with the cost of quota purchases upon entering the industry may be less likely to be able to acquire sufficient capital to begin production at an efficient scale.  This hypothesis should form the basis for future research.

## Conclusions

Predictions concerning the reallocation of dairy production that would accompany any changes to the current market sharing system in Canada require a detailed comparison of production costs between regions.  While several studies have shown that Alberta producers currently enjoy a cost advantage, little knowledge exists as to how the regional structure of costs would change if producers' decisions were more focused on the attainment of a regional comparative advantage.  Many now believe that unexploited economies exist in both milk yield and herd size in all provinces.  Without significant interprovincial competition, however, it is likely that these opportunities differ widely between provinces.

This paper compares the determinants of production cost between dairy producers in Alberta to a similar analysis of Quebec and Ontario dairy production by Romain and Lambert. Results from each region differ sharply with respect to the ability of producers to reduce costs through increased yields. Whereas in Alberta the minimum-cost yield may be above current production levels, Romain and Lambert show that costs rise in milk yield in Ontario and Quebec. Greater reductions in cost can also be achieved through efficiency improvements.

Similar generalizations for herd size are not clear. In Quebec, production costs do not fall in herd size, while in Ontario significant opportunities to lower costs appear to exist through expansion. In this respect, Alberta dairy producers are more like those in Ontario in that the optimal herd size (250 head or 281 head, depending on the choice of production frontier method) is over three times the current average herd size. Herd sizes are increasing rapidly throughout Canada, but a forced rationalization of the industry may accelerate this process.

This research contains several implications for the future of Canadian dairy. First, improvements in managerial ability (i.e., efficiency) appear to be one clear way to improve competitiveness. On a interregional basis, however, it appears as though dairy producers in Ontario and Alberta have a greater opportunity to become competitive than their Quebec counterparts. Given the disproportionate size of the Quebec dairy industry, these results suggest that freer trade within Canada may result in a significant reorganization of the dairy industry.

## Notes

1. Romain and Lambert, in Barichello et al (1996) provide an indirect comparison of competitiveness by showing how producers can lower their costs of production through changes in scale, production methods, technical efficiency, or other methods. Because their analysis identifies opportunities to improve, it represents an ex-ante analysis of competitiveness, whereas the comparison of current production costs provides an ex-post analysis.

2. Throughout the discussion in this paper, reference is made to a study by Romain and Lambert. Their study of efficiency in the Ontario and Quebec dairy sectors makes up one part of the the book chapter by Barichello et al (1996).

3. Weersink et al (1990) examine technical efficiency levels for Ontario dairy producers. Their study focuses on factors contributing to technical efficiency and does not consider costs of production in the analysis.

4. Battese (1992) provides a review of deterministic applications using both linear programming and econometric methods.

5. Bravo-Ureta and Pinheiro (1993) provide a discussion of this methodological issue.

6. Besides the parametric methods discussed here, non-parametric methods may also be used to analyze firm-level efficiency. Weersink et al (1990) provide an application of non-parametric methods to assess efficiency for Ontario dairy farms.

7. An alternative to this approach is to estimate the frontier cost function directly without the requirement of estimating a production frontier (e.g., Parikh and Shah 1994).

8. It should be noted that with the AF method, unlike other deterministic or stochastic methods, some producers will have technical efficiency levels that are greater than 100 percent.

9. Of course, the interpretation of the error term $\epsilon$ differs between the two models.

10. Whereas the earlier discussion of technical efficiency identifies an "inefficiency" ratio, the ratio actually calculated for the study sample represents (actual output)/(potential output), given actual input use. Thus higher values represent greater levels of technical efficiency.

11. Although the results are not presented in tabular form, an alternative regression uses the concentrate-to-forage ratio as an explanatory variable in place of the two separate feed variables. The parameter estimates from this regression indicate that a 10 percent increase in the ratio results in a $0.38/hl. decrease in production cost. Of course, this value is only applicable "at the margin".

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