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Economic Performance in Alberta Dairy:
An Application of the Mimic Model

Timothy J. Richards and Scott R. Jeffrey

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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 in the School of Agribusiness and Resource Management at Arizona State University in Tempe, Arizona and associate professor in the Department of Rural Economy at the University of Alberta in Edmonton, Alberta.

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Abstract

Dairy production at the farm-level is undergoing a rapid transformation in preparation for more open competition in the future. However, the means by which dairy farms can best improve their economic performance is of some question. Using measures of allocative, technical, and overall efficiency as indicators of a latent "performance" variable, this study specifies and estimates a multiple-indicator, multiple-cause (MIMIC) model of Alberta dairy production. Variables thought to "cause" performance include herd size, milk yield, breeding and veterinary expense, capital-to-labour ratio, concentrate-to-forage ratio, and operator experience. The results show that gains in performance may be made through increased capital intensity, greater spending on breeding and herd health, and, albeit marginally, through increased milk yields. Despite current trends toward larger dairy herds, this may not be a fruitful avenue for future improvements in dairy efficiency.

Introduction

In 1996, representatives of Canada's dairy farmers successfully defended the existing tariff rates on imports of milk and milk products from a U.S. challenge before the World Trade Organization (WTO). These tariffs are deemed necessary to protect the domestic supply management system that is designed to stabilize revenues and maintain adequate returns to Canadian dairy producers. Despite this reprieve from U.S. competition, dairy farmers in many regions appear to be adapting their production practices in preparation for more competitive dairy markets. The most common response has been herd expansion. However, adjustments may also include new feeding strategies and profit-oriented breeding programs (Kennelly 1996). Each method of improving economic performance involves a significant, uncertain, and largely fixed investment. Consequently, it is critically important for both farmers and policy makers alike to have accurate information on the relative contribution from each of these factors.

Defining economic performance in terms of either production cost or productivity growth, many recent studies use regional, cross-sectional, aggregate data in an attempt to determine the factors that cause dairy farms located in different provinces or states to differ in performance (National Dairy Policy Task Force 1991; Jeffrey 1992; Barichello and Stennes 1994; Richards 1994). Such comparisons, however, are fraught with difficulties as they rely on data that are often collected for different purposes, using a variety of assumptions. Further, with the balkanization of both the domestic Canadian and U.S. markets, differences that arise through these comparisons may be simply a reflection of policies designed to maintain the existing market structure. Consequently, studies that focus on the factors that contribute to the performance of farms within a given region provide a more relevant analysis of how they are likely to fare in a

more open market. Defining economic performance in terms of technical efficiency, or the ability to produce a maximum amount of output from a given set of inputs, Romain and Lambert (1994a,b) and Weersink et al (1990) provide examples of empirical studies that investigate the determinants of eastern Canadian dairy performance. This paper provides the results for similar analysis regarding the Alberta fluid milk industry, using an alternative performance measure and analytical approach.

The objective of this study is to determine the relationship between economic performance and a set of socioeconomic and managerial variables in the Alberta dairy production sector. With this knowledge, producers will have a greater insight into possible methods to maintain or improve the economic performance of their herd, while policy makers will be in a better position to assess the relative importance of each factor in determining the ability of the industry as a whole to adapt to a new economic environment.

This objective is achieved through a two-stage empirical procedure. In the first stage, Kopp and Diewert's (1982) dual cost frontier decomposition method is used to obtain estimates of technical and allocative efficiency levels for individual producers. In the second stage, these efficiency estimates are used as imperfect indicators of each producer's latent economic performance in a Multiple Indicator, Multiple Cause (MIMIC) modelling framework (Joreskog and Goldberger 1975; Anderson 1989; Bollen 1989). Allocative and technical inefficiency constitute indicators in the MIMIC model while herd size, breeding expense per cow, farmer experience, and various other managerial variables comprise the set of "cause" variables for the latent performance variable. The use of a MIMIC approach to estimate a structural model for the

unobserved variable avoids measurement error problems that commonly arise from using more typical proxy variable methods (Gao and Shonkwiler 1993).

Canadian Dairy Performance

The definition of economic performance in the dairy sector, as with any other industry, is contentious and subject to interpretation. However, research on the determinants of performance often has a significant influence on the policy debate surrounding dairy issues (National Dairy Policy Task Force 1991). Much of the research in this area has relied on aggregate, cross sectional comparisons between regions to determine the factors that lead to production cost advantages. For example, Barichello and Stennes (1994) and Jeffrey (1992) compare dairy production costs between provinces and conclude that larger herd sizes and higher yields are responsible for relatively low production costs. Romain and Lambert (1994a,b) extend this analysis with farm-level data to demonstrate that individual producer technical efficiency is a critical factor in the explanation of differences in production costs among dairy producers in Quebec and Ontario. However, these analyses do not account for the fact that technical efficiency and production costs are determined simultaneously, so the results are of limited practical value.

An alternative approach used in several studies is to examine the relationship between managerial characteristics or farm endowments and productive efficiency for dairy farms. The majority of these studies focus on dairy farms in the U.S. (e.g., Bravo-Ureta 1986; Bravo-Ureta and Rieger 1990, 1991; Grisley and Mascarenhas 1985; Kumbhakar et al. 1989, 1991; Tauer 1993; Tauer and Belbase 1987) or eastern Canada (e.g., Weersink et al. 1990, Fan et al. 1996).

However, little evidence exists concerning the relationship between managerial factors, farm characteristics and the performance of western Canadian dairy farms.

Productive Efficiency - Definition and Discussion

Rigorous empirical investigations of firm efficiency find their roots in the pioneering work of Farrell (1957). Farrell's decomposition of overall economic efficiency into technical and allocative components is well understood so is only briefly reviewed here. Technical efficiency is defined as the ability of a producer to achieve the maximum output possible from a given set of inputs. Allocative efficiency refers to the producer's ability to respond to economic signals and choose optimal input combinations (i.e., proportions) given relative input prices. Economic efficiency is the product of technical and allocative efficiency.

Estimates of technical efficiency typically begin with specification of a stochastic production frontier based on concepts developed by Aigner et al (1977) and Meeusen and van den Broeck (1977). However, analyzing efficiency from a dual cost frontier perspective (Schmidt and Lovell 1979) may be preferable for several reasons. First, estimating a cost frontier does not require an assumption that producers maximize expected profit (Zellner et al. 1966), typically made to justify input exogeneity in a single equation production frontier framework. Adopting a dual cost frontier approach requires a more reasonable assumption of input price exogeneity. Also, since milk production in Alberta is controlled by a system of supply-management quotas, assuming that farmers minimize cost subject to a fixed output constraint is a more plausible behavioural assumption (Moschini 1988).

Another limitation of production function estimates is that they are commonly subject to problems of multicollinearity (Kopp and Diewert 1982). Also, defining inputs in simple quantity terms does not account for variations in their quality. With prices as regressors in the cost function, quality and spatial variation are each sources of variability. A final advantage of the

cost function approach, while not relevant in this analysis, is the ability to estimate efficiency in the presence of multiple outputs (Coelli 1995).

Most importantly, however, the dual cost function approach provides a means by which efficiency can be separated into its technical and allocative components. Accounting for both sources of efficiency is critical. Kumbhakar (1987) argues that analyses that do not consider all types of inefficiency have little value because they capture only one part of the problem faced by producers. True economic efficiency must consider optimal responses to price signals rather than simply analyzing engineering proficiency (i.e., technical efficiency).

The approach taken in this study is to estimate a composed-error cost frontier. The resulting frontier is purged of random deviations in a manner similar to Bravo-Ureta and Rieger (1991) to arrive at a cost frontier where any remaining deviations are assumed to be due to overall productive inefficiency (i.e., technical and allocative). Schmidt and Lovell (1979) define such a frontier cost function as follows:

$$C_i = C_i(\boldsymbol{w}, y, \beta) + (v_i + u_i), \quad v_i \sim N(0,\sigma^2{}_v) \quad u_i \sim |N(0,\sigma^2{}_u)|, \qquad \textbf{(1)}$$

where the overall error term is decomposed into v_i and u_i. Deviation from the frontier due to random events is represented by v_i. Inefficiency is captured by the one-sided distribution of u_i with higher values of u_i representing greater deviations from minimum cost (i.e., greater inefficiency).

Implementation of this method requires an assumption 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.[1] Given the assumption of a half-

normal distribution made for this study, maximum likelihood estimates of the cost function and distribution parameters are determined using the following log-likelihood function:

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

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

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

where ϕ is the standard normal density function and all other parameters are defined as before.

Using the dual cost frontier, consistent estimates of technical and allocative efficiency are determined by numerically calculating the technically and allocatively efficient input vectors. Following the approach developed by Kopp and Diewert (1982) and simplified by Zieschang (1983), the estimated frontier cost function C() is used to derive a set of optimal input demand functions using Shephard's Lemma:

$$x^e = \nabla_w C(w^a, y^*) \quad \textbf{(4)}$$

where x^e denotes the technically and allocatively efficient input bundle, w^a is the vector of observed input prices, and y^* is actual output, assumed to be exogenous.

In order to assess overall economic efficiency for an individual firm, input bundle x^c is calculated. Bundle x^c has the same cost as x^e, given observed input prices, but represents input use in the same proportions (i.e., ratios) as the actual input bundle, x^a. Following the method used by Kopp and Diewert (1982), x^c is established by solving the following system for x_i^c:

$$\begin{gathered} x_i^c / x_n^c = x_i^a / x_n^a, \quad \forall\ i = 1, 2, \ldots n-1, \\ \sum w_i^a x_i^c = C^a \end{gathered} \tag{5}$$

where x_i^a is the observed input level for the ith input, and C^a is the predicted cost of producing with an efficient input bundle. Overall economic efficiency (EE) is calculated as the ratio of vector norms between efficient and actual input bundles:

$$EE = \|\boldsymbol{x}^c\| / \|\boldsymbol{x}^a\| \tag{6}$$

Since x^c lies below the y^* isoquant (i.e., is not a feasible input vector), it cannot represent a technically efficient input bundle. In order to assess technical efficiency, input bundle x^b is calculated. Bundle x^b is the vector of inputs on the efficient isoquant for observed output (y^*) that represents input use in the same proportions as the actual input bundle x^a. Kopp and Diewert (1982) demonstrate that x^b is the "optimal" input vector for some unknown input price vector (w^b) and is obtained using Shepard's lemma while ensuring consistency with observed input ratios. Consequently, vectors x^b and w^b are calculated by simultaneously solving:

$$x_i^b / x_n^b = x_i^a / x_n^a, \quad i = 1, 2, \ldots n-1,$$
$$x_i^b = \nabla_{w_i} C(w^b, y), \quad i = 1, 2, \ldots n. \tag{7}$$

for x_i^b and w_i^b, where x_i^a and $C()$ are defined as before. Technical efficiency (TE) is calculated as the ratio of vector norms:

$$TE = \|\boldsymbol{x}^b\| / \|\boldsymbol{x}^a\| \tag{8}$$

Finally, given that economic efficiency is the product of technical and allocative efficiency, allocative efficiency (AE) may be calculated as the ratio of vector norms for the economically efficient bundle and the technically efficient bundle:

$$AE = \|\boldsymbol{x}^c\| / \|\boldsymbol{x}^b\| \tag{9}$$

In many studies, these efficiency measures are used as dependent variables in "second-stage" regressions to explain the causes of inefficiency. Typically, the explanatory variables consist of socioeconomic factors such as a farmer's age or education, or other variables describing the farming operation, including farm size or variable and fixed input ratios (e.g., Kalirajan 1990; Fan et al. 1996). In justifying this approach the argument is made that farm-specific factors exert only an indirect effect on production through their association with inefficiency, so their effect is appropriately modelled in a two-stage procedure (e.g., Kalirajan 1991).

Coelli (1995), however, points out the inconsistency of assuming that the inefficiency effects are independently and identically distributed in the first stage, while treating them as dependent variables in the second stage. If inefficiency is correlated with the production inputs, then estimates of both the production frontier and the inefficiency effects will be inconsistent (Kumbhakar et al. 1991). These authors also make the point that the technical inefficiency index is inappropriate as a dependent variable in an OLS regression because it is one-sided, or after transformation by the Jondrow et al. (1982) method, bounded on the (0, 1) interval.

Kalaitzandonakes and Dunn (1995) discuss the problems inherent in measuring both the dependent and independent variables in the second stage. They show that the effect of education on technical efficiency depends on how efficiency is measured. Not only are these efficiency measures imperfect indicators of true efficiency, but education, farm acreage, and age are also only proxy variables for knowledge, farm size, and experience. Use of these proxies in a second-stage regression is likely to bias estimates of their effect toward zero.

Several alternative methods exist for alleviating these problems. These range from relatively simple solutions such as grouping farms by size and using non-parametric hypothesis tests to evaluate efficiency differences by group (Bravo-Ureta and Rieger 1991), to more involved procedures estimating a model where each input elasticity is allowed to vary by farm (Kalirajan and Obwona 1994) or allowing the inefficiency terms themselves to vary systematically with firm-specific factors (Kumbhakar et al. 1991; Reifschneider and Stevenson 1991). These developments tend to make single-stage estimation procedure considerably more complex and vulnerable to measurement errors in the regressors, however. Consequently, a structural latent variable method is desirable.

In this structural latent variable (also known as a covariance structure, or MIMIC) model, efficiency estimates constitute imperfect indicators of an unobservable, or latent, managerial performance variable. Various farm-specific factors are included as determinants or "causes" of the latent variable. This allows testing of hypotheses related to the effect of these farm specific factors on managerial performance. This approach has seen many recent applications to farm production analysis (e.g., Kalaitzandonakes et al. 1992; Kalaitzandonakes and Dunn 1995; Ivaldi et al. 1994, 1995)

MIMIC models consist of two sets of equations; structural equations and measurement equations. Structural equations specify relationships between the set of latent variables ( ), their causes (***z***), and a random error term ( ):

$$= \Phi \quad + \quad \boldsymbol{z} + \quad , \qquad \textbf{(10)}$$

where Φ and are parameter vectors showing the marginal effects of the latent variables on each other and the cause variables on the latent variables, respectively. Measurement equations relate each indicator variable (***y***) to the latent variables and a vector of random measurement-errors (Joreskog and Goldberger 1975; Bollen 1989; Anderson 1989):

$$\boldsymbol{y} = \quad _{y} \quad + \epsilon . \qquad \textbf{(11)}$$

In the measurement equations, the components of $_{y}$ are also known as factor loading coefficients. Further, the error terms of (10) and (11) are uncorrelated with each other, have zero means, and have covariance matrices given by and , respectively (Bollen 1989).

These covariance matrices are central to the estimation method. Whereas ordinary least squares regression finds parameter estimates by minimizing the sum of squared deviations between the fitted and observed values of $\boldsymbol{y}$, the fact that some of the dependent variables in a MIMIC model are unobserved makes this impossible (Gao and Shonkwiler 1993; Bollen 1989). Therefore, estimates of the model parameters are found instead by minimizing the difference between the sample covariance matrix of observed variables (**S**) and a fitted covariance matrix (( )) for a parameter vector, . Bollen (1989) provides details on the decomposition of ( ) into its component moment matrices of $\boldsymbol{y}$ and $\boldsymbol{x}$. The difference between these two matrices is expressed in terms of a general class of loss functions (Browne 1994):

$$F(\ ,\ \boldsymbol{S}) = (\boldsymbol{s} - \boldsymbol{\sigma})' \ ^{-1}(\boldsymbol{s} - \boldsymbol{\sigma}), \qquad \textbf{(12)}$$

where $\boldsymbol{s}$ and $\boldsymbol{\sigma}$ are vectors of the non-redundant elements of their corresponding symmetric matrices, and is a positive-definite weighting matrix. Given an assumption of multivariate normality for the observed variables, Ivaldi et al.(1994) explain that minimizing the specific form of F:

$$F(\ ,\ \boldsymbol{S}) = \log|\ \ | - tr(\boldsymbol{S}\ \ ^{-1}) - \log|S| - n, \qquad \textbf{(13)}$$

is equivalent to maximum likelihood, where n is the number of observations. An explanation of the specific form of each structural and latent variable equation, as well as the frontier cost function specification itself, is provided in the following section.

Empirical Models

Specification of a dual cost function provides all the information required to estimate economic efficiency (Kopp and Diewert 1982). In principle, implementation of this approach is theoretically possible with a variety of non-homothetic, flexible functional forms. In order to obtain plausible solutions for the technically efficient input vector this study uses a Cobb-Douglas cost function.[2] Although this is a simplistic representation of Alberta dairy technology, the Cobb-Douglas functional form is parsimonious and has been widely used (Schmidt and Lovell 1979, Kumbhakar 1987). Following the general specification in (1), the cost frontier is written:

$$\log C(y, \boldsymbol{w}) = \log(\beta_o) + \sum_i \beta_i \log(w_i) + \sum_j \ {}_j \log(z_j) + \log(y) + (v + u) \qquad \textbf{(14)}$$

where w_i is the price of the ith variable input, z_j is the jth fixed input, y is the output, defined as milk per cow, and $(v + u)$ is the composed error term. Cost, or C(), is defined as total operating cost per cow, thus excluding any fixed capital costs.

As noted earlier, the cost frontier is purged of random variation by adding v to cost, so that any remaining variation is due to inefficiency alone. The cost frontier, in combination with observed input levels and prices, is used to calculate economically and technically efficient input vectors for each sample observation, as described earlier. Each efficiency index (AE, TE, EE), given actual input ratios, is then determined by calculating the ratio of vector norms. These indices constitute the set of indicator variables in the structural latent variable model of dairy performance.

Consistent with the general structure of equations (10) and (11), the empirical MIMIC model consists of equations that relate unobserved dairy performance to a set of cause variables,

and then identify the latent construct through a set of measurement equations. Because this model consists of only one latent variable (*PERF*), there is only one structural equation:

$$PERF = {}_1X_1 + {}_{11}X_1^2 + {}_2X_2 + {}_{22}X_2^2 + {}_3X_3 + {}_4X_4 + {}_5X_5 + {}_6X_6 + , \qquad \textbf{(15)}$$

where X_1 is herd size, X_2 is milk yield per cow, X_3 is breeding expense per cow, X_4 is the number of years of experience in dairy, X_5 is the capital-to-labour ratio, and X_6 is a ratio of grain and concentrates expense to hay and forage expense. These "cause" variables are selected to reflect each element of the continuing debate among Alberta dairy producers as to how best to improve dairy performance (Kennelly 1996).

This debate centers on the roles of genetic advancement, scientific ration formulation, improved dairy supplements, and larger herds as potential causes of improved dairy performance. Breeding expense serves as a measure of the increased sophistication in dairy breeding, while the ratio of concentrates to forage provides a measure of variation in feed quality. The capital-to-labour ratio is intended to reflect improvements in dairy milking and feeding technology.

While each of these variables is available from the survey data described below, data for the measurement equations are provided by the efficiency indices. Each efficiency index serves as an indicator of the latent performance variable, so that the set of measurement equations is given as:

$$\begin{aligned} AE &= {}_1PERF + \epsilon_1 \\ TE &= {}_2PERF + \epsilon_2, \\ EE &= {}_3PERF + \epsilon_3, \end{aligned} \qquad \textbf{(16)}$$

where *AE*, *TE*, and *EE* are indices of allocative, technical, and economic efficiency, respectively. In order to identify the unobserved *PERF* variable, $_3$ is normalized to 1.0. As suggested by Weersink et al. (1990), a logistic transformation is applied to each dependent variable in (14) prior to estimation.[3] To interpret the results of this estimation, however, each parameter is suitably transformed to be consistent with the specification in (14). Categorizing the explanatory variables as either "cause" or "indicator" variables depends upon the expected direction of causality (Gao and Shonkwiler 1993). While cause variables lead to changes in the latent variable, indicators reveal that these changes are likely to have occurred. Ultimately, the choice of cause and indicator variables is constrained by the available data.

Data

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 Alberta fluid milk producers chosen by Alberta Agriculture officials in such a way to be representative of each region and herd size group. The resulting sample consists of 181 pooled observations.[4]

Variable input prices used in estimating the dual cost frontier include prices for grains and concentrates, forage (i.e., hay, silage and pasture) and hired labour. Feed prices are determined by dividing total feed expenditures by the amount fed to provide the average price per tonne for the particular producer. Expenditures for homegrown feed are calculated using regional average prices, whereas purchased feeds are valued using local market prices. Given the geographical diversity of producers, differences in local feed markets, and differing proportions of homegrown and purchased feeds used by producers, a significant amount of both cross sectional and time-series price variation exists in the sample. The price of labour is calculated as the total cost of hired labour plus family labour, divided by total hours. Due to a lack of worker training or experience data, the wage is unadjusted for quality.

Total cost is defined as the weighted sum of expenditures on these variable inputs for the dairy enterprise. As such, it includes expenditures for activities not directly related to producing milk, such as raising calves to milking age. Total enterprise costs are divided by the herd size to obtain a cost per cow.

The cost frontier is defined as a short-run, or variable cost frontier. Observed cost levels are, therefore, conditional on existing capital stocks. Several inputs may be classified as being

fixed, such as capital, herd size, and quota holdings. However, the estimated cost frontier includes only capital as a fixed factor. Capital consists of the value of buildings and equipment specific to the dairy enterprise. Ball's (1985) method provides an annual capital rental price series.[5] The rental price is then used to derive an annual capital quantity level from reported stock values. Herd size is excluded as costs are defined in terms of variable inputs only, and are measured on a per cow basis. Quota is excluded as a fixed variable because its inclusion would lead to near, but not perfect, multicollinearity with milk output.

The dual cost function is also conditional on the level of quota-regulated output (Moschini 1988). Output consists of the total amount of milk shipped from the farm, to both the fluid and industrial markets, in hectolitres per cow 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.

While not included as a fixed factor in the cost function analysis, herd size is included as a cause variable in the structural equation for the MIMIC model. However, the pace of genetic progress in dairy cows has been sufficiently rapid that cattle from two different vintages are two qualitatively different inputs. Therefore, herd size for each observation is “deflated” by an index of genetic progress to incorporate the influence of technological (genetic) improvement in dairy cattle. Thus, the herd size included as the cause variable represents the number of genetic equivalent-cattle livestock inputs. The index used to deflate the observed herd size is the provincial breed class average (BCA) for Holstein cattle.[6] Annual changes in the provincial BCA represent improvements in milk productivity which are at least partly attributable to genetic

progress. While the BCA index is also affected by feeding and other management practices, it represents the best available proxy to a true measure of exogenous genetic improvement.

The other cause variables (i.e., breeding expense, number of years of experience, capital-to-labour ratio, ratio of grain and concentrate expense to forage expense) are taken or calculated directly from the survey data. Susko (1992) provides a more detailed description of the survey instrument and input classifications. Table 1 provides summary statistics for some of the relevant survey variables.

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 presented here have not been "corrected" using the scaling method outlined in the discussion concerning the survey data.

Results and Discussion

Although the focus of this section is on investigating the determinants of economic performance in Alberta dairy production, the cost structure is of some interest. Table 2 provides both OLS estimates of a Cobb-Douglas cost function, and maximum likelihood estimates of a Cobb-Douglas cost frontier. Because the parameter estimates differ very little quantitatively, nothing is lost by interpreting the structure of Alberta dairy production in terms of the cost frontier. The cost frontier is first evaluated for consistency with concavity and monotonicity. Upon examination of the Hessian for the estimated cost function, it is determined to be concave.

Table 2: Frontier Cost Function for Alberta Milk Production (OLS and ML Methods)

	Milk Cost Frontier Estimates			
	OLS		ML	
Variable	**Coefficient**	**t-ratio[a]**	**Coefficient**	**t-ratio**
Constant	2.3479	3.0754*	1.8893	2.2176*
Wage	0.2272	1.9318*	0.1853	1.2633
Grain Price	0.0934	1.9223*	0.1190	2.7591*
Forage Price	0.4495	3.4897*	0.4391	3.0471*
Capital	0.0508	2.5485*	0.0490	2.6022*
Milk Output	0.8838	12.7476*	0.8976	13.2891*
σ_u / σ_v	----		1.7468	4.4637*
$\sqrt{\sigma_v^2 + \sigma_u^2}$	----		0.2045	8.3546*
R^2	0.6316		LLF	91.8004
$F_{5, 175}$	60.2600		N	181.0

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

Monotonicity is evaluated at the mean of each variable using the input demands derived from the cost frontier using Shephard's lemma. This condition is satisfied for all inputs.

The specific parameter estimates for the cost function provide insights into the cost structure of the Alberta dairy sector. The results suggest slightly increasing returns to scale, with the scale elasticity being equal to 1.114.[7] In addition, the own-price elasticities for labour, concentrates and forage are -0.815, -0.881 and -0.561, respectively.

These results may be compared with the elasticities reported by Moschini (1988) for Ontario dairy farms.[8] Similar to the Alberta results, Moschini reports increasing returns to scale for most farm sizes. He also determines the demand elasticity for feed (concentrates and forage combined) to be -0.656, which is comparable to the individual elasticities for Alberta producers. However, the elasticity of labour demand from Moschini's study (-0.219) is far lower (i.e., more inelastic) than the value reported in the current study.

Also of interest is the distribution of efficiency by herd size. Summary statistics for the allocative, technical, and overall or economic efficiency indices are presented in Table 3.[9] The average level of economic efficiency calculated over all farms in the sample is 90.6%. The average level of allocative efficiency is 96.3%, while the average index of technical efficiency is 94.2%. While no normative conclusions can be drawn from this result on its own, this level of technical efficiency is higher than that reported by previous studies. Among dairy efficiency studies reviewed by Ahmad and Bravo-Ureta (1996), average indices of technical efficiency vary from a high of 90% for Argentinean dairy farms (Schilder and Bravo-Ureta 1994) to a low of 65% among a sample of Utah dairy farms (Kumbhakar et al. 1989).

Table 3: Frequency Distribution of Efficiency Indices by Herd Size: Alberta Dairy Production

		TE		EE		AE	
Herd Size	**N**	**Mean**	**σ**	**Mean**	**σ**	**Mean**	**σ**
20 - 40	27.0	0.9412	0.0094	0.9048	0.0203	0.9615	0.0238
41 - 60	80.0	0.9403	0.0100	0.9068	0.0205	0.9645	0.0234
61 - 80	41.0	0.9388	0.0073	0.9063	0.0226	0.9654	0.0226
81 - 100	12.0	0.9476	0.0185	0.9088	0.0272	0.9593	0.0333
101 - 120	4.0	0.9605	0.0268	0.8922	0.0407	0.9295	0.0501
121 - 140	7.0	0.9524	0.0217	0.9089	0.0097	0.9547	0.0244
141 - 160	4.0	0.9441	0.0008	0.8964	0.0072	0.9495	0.0071
161 - 180	1.0	0.9555	----	0.8505	----	0.8901	----
181- 200	2.0	0.9466	0.0009	0.9304	0.0053	0.9829	0.0046
201 +	3.0	0.9440	0.0007	0.9303	0.0035	0.9854	0.0032
N	181.0	0.9418	0.0117	0.9064	0.0218	0.9626	0.0253

Table 3 also provides an indication of the distribution for each measure across farm size. Measures of technical, allocative and economic efficiency appear to be very similar between herd size groups. This result, combined with the relatively high average level of efficiency, may be an indication of a high degree of homogeneity within the Alberta dairy sector. Although it is possible to conduct formal hypothesis tests to determine a statistical relationship between herd size and efficiency, such tests are likely to be of very low power in this case as there are few herds in many size groups, group sizes are arbitrary and the efficiency measures themselves are only imperfect indicators of overall economic performance for the dairy farm.

Since performance is inherently unobservable, estimates of the factors contributing to performance are determined through the use of the structural latent variable (MIMIC) model. Table 4 presents the results obtained by estimating both the latent variable (i.e., structural) and indicator (i.e., measurement) equations. Measurement equations provide estimates of the latent variable's effect on each indicator variable. Each efficiency index is, in turn, used as an indicator of economic performance. In order to identify the system, the coefficient relating performance to economic efficiency is normalized to 1.0. The parameter estimates for the other two equations, however, indicate how each type of efficiency changes with the level of performance.

The statistical significance of performance in each of the measurement equations is an important result in itself, suggesting that both technical and allocative efficiency are valid indicators of the unobservable performance variable. Given the cross-sectional nature of this data set, these measurement equations provide a relatively good fit, with performance explaining more than half of the variation in efficiency in each case. Interestingly, the level of technical efficiency is inversely related to performance while performance and allocative efficiency are positively related. Taken together, these results imply that there is a tradeoff between technical and allocative efficiency; that is, "better" producers who are more allocatively efficient tend to be less technically efficient. If allocative proficiency implies a higher level of "management" skill, while technical efficiency derives from better "shop floor" performance, this result suggests that better managers can compensate for being somewhat less efficient in a technical sense.

The structural equation estimates provide a means by which the central hypotheses of this paper are tested; specifically, how each farm-specific factor affects dairy performance. Before interpreting the structural parameters, it should be noted that the variance of the disturbance term

in this equation ( ) is significantly different from zero. This suggests that the set of indicators are better determinants of performance than the set of cause variables would be, had they been

Table 4: MIMIC Model: Structural and Indicator Equations for Latent Dairy Performance: Alberta Dairy Production

Dependent Variable[a]	Explanatory[b] Variable	Estimated Coefficient	t-ratio[c]
Performance:			
	Herd Size	0.7184	2.4012*
	(Herd Size)^2	-0.7401	-2.4663*
	Milk Yield	0.4129	1.0782
	(Milk Yield)^2	-0.6321	-1.6394*
	Capital / Labour	0.7021	7.3162*
	Grain / Forage	-0.0633	-0.9413
	Breeding Expense	0.1263	1.6267
	Experience	0.0230	0.3124
	Var( )	0.0015	4.8109*
	R^2	0.3903	
Technical Efficiency	Performance	-0.5258	-1.9675*
	Var(ϵ_1)	0.0023	3.8450*
	R_1^2	0.6102	
Allocative Efficiency	Performance	1.4176	7.7561*
	Var(ϵ_2)	0.0020	8.6170*
	R_2^2	0.5863	
Economic Efficiency	Performance	1.0000[d]	----
	Var(ϵ_3)	0.0012	5.3473*
	R_3^2	0.6856	

[a] Technical (allocative) efficiency refers to the technical (allocative) efficiency ratio calculated using Kopp and Diewert's method.

[b] Milk Yield refers to milk production per cow. Breeding Expense refers to the expenditures for breeding and veterinary services.

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

[d] Parameter is normalized to 1.0 for identification purposes.

used simply as proxy variables. Four factors enter the structural equation in linear forms (experience, breeding expense, ratio of grain to forage, and ratio of capital to labour), while two enter as quadratics (yield and herd size). Yield and herd size are specified in quadratic form as it is likely that there are optimal levels of both at which performance is a relative maximum. Beyond a certain point, further increases in either are likely to lead to wasted inputs and declining efficiency.

The results in Table 4 suggest that the maximum efficiency herd size in Alberta is 48.5 cows. This is below the average herd size for the study sample (66 cows). Given the industry trend towards larger herds, this does not bode well for maximizing efficiency.

The evidence from other studies concerning the relationship between efficiency and herd size is mixed. The maximum efficiency herd size calculated in this study is consistent with the findings of Romain and Lambert (1994a) for Quebec dairy farms. However, it is far below the maximum efficiency herd size of 102 cows calculated for Ontario dairy farms by Weersink et al (1990). While the results from non-Canadian studies suggest, in general, a positive relationship between herd size and efficiency (e.g., Tauer and Belbase 1987; Tauer 1993; Bravo-Ureta and Rieger 1990, 1991; Kumbhakar et al 1989; Bailey et al 1989), the evidence is not entirely consistent (e.g., Ahmad and Bravo-Ureta 1996; Bravo-Ureta 1986).

It should be noted that the results concerning maximum efficiency herd size do not imply diseconomies associated with larger herd sizes. The term “economies of size” refers to the ability to lower average costs by increasing total output. The analysis in this study relates herd size to efficiency, rather than average costs. While the two concepts are related, optimizing cost is not the same as optimizing efficiency.

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. However, this result may also be partly a function of the data set used in the analysis. As indicated in Table 3, a large number of herds in the study sample are between 41 and 80 cows (i.e., approximately two-thirds). It may be the case that, given the management practices and dairy technology present on the majority of these farms, the maximum efficiency herd size is approximately 50 cows. Maximizing efficiency at larger herd sizes would require changes in management and technology by producers (e.g., shifting from pipeline to milking parlour technology).

Along with average herd size, milk yields are also increasing over time. Weersink et al (1990) interpret yield as a measure of both genetic production potential and feeding program effectiveness. In their sample of Ontario dairy farms, these authors find a linear relationship between yield and efficiency with an elasticity of 0.973. For Alberta dairy farms, estimates of a quadratic yield term imply that maximum efficiency occurs at a yield of 72.0 hl/cow per year. As this is more than the sample average milk yield of 67.2 hl/cow, these estimates suggest that dairy performance may be improved through further increases in milk yields. Given recent trends, however, it is clear that dairy farms are rapidly approaching the level of maximum-efficiency yield.

The results in Table 4 indicate that farmers may also improve their performance through a variety of other methods; specifically, performance increases with the amount spent on breeding

and veterinary expense per cow. Although this variable may increase if a herd has health problems, it is more likely a measure of the quality of bulls purchased through artificial insemination programs or the level of attention paid to herd health. Table 4 shows a marginal increase in the performance index of 0.126 for the next dollar spent on breeding, a result that is broadly consistent with Romain and Lambert (1994b) for both their Ontario and Quebec data.

Capital intensity, defined as the ratio of capital to labour, is also shown to contribute significantly to performance for Alberta dairy farms. A 10 percent increase in capital intensity causes performance to increase by 0.07. This result is contrary to the findings of Romain and Lambert (1994b), who determine that technical efficiency is directly related to the ratio of labour to capital for Ontario and Quebec dairy farms. Although they do not use a measure of relative input intensity, Weersink et al (1990) find that more highly capitalized farms are less technically efficient as efficiency falls in the total value of buildings per cow.

Many studies include education/experience as an explanatory variable for efficiency. The results in Table 4 suggest that experience does not exert a significant influence on efficiency. This result is consistent with other previous studies (e.g., Tauer and Belbase 1987; Weersink et al 1990), but differs from Romain and Lambert's (1994b) results which indicate that higher levels of education cause greater efficiency levels among Quebec dairy farmers.

Finally this study investigates the hypothesis that efficiency rises in some measure of feed quality. While Weersink et al (1990) find that efficiency falls in the ratio of feed purchased off-farm, indicating home-grown feed is of higher quality, Romain and Lambert (1994b) conclude that Quebec dairy efficiency increases with the caloric content of feed, and is inversely related to the ratio of forage to concentrate. This study disagrees with this latter finding in that Alberta

dairy performance decreases in the opposite ratio -- of concentrates to forage. However, this result is statistically insignificant at conventional levels.

Conclusions

Empirical definitions of economic performance abound in the literature, including production costs, productivity growth, or various measures of technical, allocative, and overall efficiency. One common feature of all of these measures, however, is that they are each imperfect indicators of a variable that is inherently unobservable -- economic performance. This study uses a structural latent variable approach to investigate the determinants of economic performance in Alberta dairy. With this Multiple Indicator, Multiple Cause (MIMIC) model, measures of technical, allocative, and economic efficiency comprise a set of performance indicators, while causes of the latent variable consist of herd size, milk yield, capital/labour ratio, concentrate/forage ratio, operator experience, and breeding expense per cow. By minimizing the distance between sample and predicted covariance matrices, this method provides unbiased estimates of the effect of each cause variable on performance. Kopp and Diewert's (1982) method of decomposing economic efficiency into allocative and technical components provides the means by which the indicators are calculated from estimates of a dual stochastic cost frontier.

Estimates of efficiency using a farm-level panel data set of Alberta dairy farms suggest that the average dairy farmer is highly efficient relative to the best farmers in the industry. While this result cannot be used to compare efficiency levels with producers in other dairy industries, it does suggest that Alberta dairy farmers are relatively homogeneous compared to groups of dairy producers studied elsewhere. Estimates of the MIMIC model provide an indication of the factors that are important to Alberta dairy farm performance, and those that are not. Unlike previous

results for Quebec dairy found by Romain and Lambert (1994a,b), neither an operator's investment in human capital, nor the quality of feed appear to explain Alberta dairy performance. On the other hand, modeling the effect of herd size on performance as a quadratic results in an maximum efficiency herd size of approximately 50 cows, which is similar to Romain and Lambert's (1994a) optimal Quebec herd size, but below the optimal herd size in Ontario estimated by Weersink et al (1990). Given that this herd size for Alberta is far below the current provincial average, it may be that Alberta dairy producers are improving performance through other means. Further gains in performance through higher yields are possible, but the sample average of 67.2 hl/day is close to the optimal yield of 72 hl/day.

Alternatively, Alberta dairy performance may rise with further investment in breeding and veterinary services, and/or greater capital intensity. Careful attention to herd health, improved heat detection, and reduced incidence of mastitis and other common afflictions all require a greater investment in veterinary services, while adopting an artificial insemination program, transferring embryos, or simply using more expensive bulls all increase breeding expenses. These methods are associated with greater cow longevity and genetic production potential -- both critical factors in determining economic performance. Labour productivity is also important in dairy as labour costs constitute approximately 22% of total production cost (Susko 1992). Given more efficient milking technology, feed management techniques, and manure handling methods, capital investment is likely to lead to higher labour productivity and, consequently, to improvements in overall economic performance. A fruitful avenue for future research may consider the role of dairy policy, specifically supply management, on the incentive for farmers to invest in such productivity-improving technology.

Notes

1. Bravo-Ureta and Pinheiro (1993) provide a discussion concerning alternative distributions for the one-sided error term.

2. Despite the appeal of the translog form used by Kopp and Diewert (1982), the translog frontier estimated in this study violated concavity and thus could not be solved for the optimal input levels.

3. As Weersink et al. (1990) explain, this transformation is necessary as each dependent variable is bound on the [0, 1] interval. Estimating these equations without taking censoring into account leads to parameter bias.

4. Preliminary estimates fail to reject the null hypothesis that the cost function parameters are the same for each year. Therefore, the data are pooled for further estimation.

5. Specifically, a user cost for dairy capital is calculated by summing the opportunity cost of capital (average interest rate on debt financing multiplied by the reported book value of employed capital), the annual amount of depreciation calculated at straight line rates consistent with current tax code, annual expenditures for maintenance of dairy capital, and expenditures for rental services.

6. BCA is an index measure of milk productivity for dairy cattle. Higher BCA values represent greater milk production relative to the average for the breed. These values may be compared between individual animals or groups of animals at some point in time to identify the "better" milk producers. Alternatively, BCA values may be compared over time to provide an indication of technical "progress" in milk productivity.

7. Given the Cobb-Douglas functional form, the scale elasticity is equal to the inverse of the milk output coefficient (Beattie and Taylor 1985) and is consistent with economies of size in milk production per cow.

8. Moschini's (1988) results are not directly comparable to those reported here, as he estimates a cost function rather than a frontier. However, his study remains the seminal discussion of the structure of dairy costs under Canadian supply management.

9. The method of calculating efficiency used in this study is an extension of Kopp and Diewert's (1982) approach, and does not mathematically impose the [0,1] bound on technical efficiency. However, because this bound is conceptually correct, the efficiency measures in Table 3 have been scaled accordingly.

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