Economic Efficiency, Structure and Scale Economies in the U.S. Dairy Sector

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Abstract

This study uses a new dataset based on the 2000 Agricultural Resource Management Survey, the most recent national survey of dairy producers in the United States. A shadow cost function is employed to decompose and analyze economic efficiency and scale economies. The study details the development of the data employed in the analysis and focuses on the estimation of scale relationships across farms in different regions and of different sizes. Preliminary results point to important scale economies and suggest that surviving small farms are on average more economically efficient but can exploit scale economies to a much lesser degree than larger farms. The preferred specification of the cost function does not show a region of decreasing returns to scale.

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[*] The views expressed here are those of the authors, and not necessarily those of the Economic Research Service or the U.S. Department of Agriculture.

1. INTRODUCTION

The important structural changes taking place in the dairy industry are of important policy and academic concern. Dairy farms have larger herd sizes and cows produce more milk. At the same time, the demand for dairy products remained stagnant leading to an imbalance between supply and demand and a consequent reduction in the number of dairy farms. Despite the general trend of increases in farm size in the dairy sector, there is a very heterogeneous pattern of structural change across regions related to costs of production, technology, weather and geography among other factors [Wolf (2003)]. Moreover, Blayney and Normile (2004) contend that the main drivers of these changes are a mixture of technological, efficiency and scale changes and note a lack of empirical evidence on important technology indicators such as scale economies and their variation across geographical areas in the U.S.. This research seeks to help fill this gap.

This study uses a new dataset of 620 dairy farms based on the 2000 Agricultural Resource Management Survey, the most recent national survey of U.S. dairy producers, in order to estimate, decompose and explain economic efficiency, as well as to estimate scale economies. It builds on other research that examined specifically scale economies in the dairy sector [for example, Alvarez and Arias (2003), Kumbhakar (1993), Kumbhakar, Biswas and Von Bailey (1989), Moschini (1988)] and studies that have used the shadow price approach to estimate efficiency in the dairy sector [for example, Maietta (2000) and Stefanou and Saxena (1988)]. This research estimates scale economies across regions, technologies and farm sizes. Results point to important scale economies and suggest that surviving small farms are more economically efficient, on average, with no indication of decreasing returns to scale—results which contrast with those presented in other studies [for example in Kumbhakar (1993) and Alvarez and Arias (2003)].

A shadow cost model is employed. This estimation strategy has been successfully used to address the problem (known as the Greene problem) of estimating and decomposing allocative and technical inefficiency in a translog system-of-equations [Fried, Lovell and Schmidt (forthcoming)]. This approach is consistent with the conclusions of Kumbhakar and Wang (forthcoming) who argue against lumping together allocative and technical efficiency in the estimation of cost frontiers since it biases the cost function parameters, returns to scale, input price elasticities and cost inefficiency. The next section will provide background on the linkage between changes in structure and scale economies in the US dairy sector. Section three will discuss the model and section four the data sources and variable construction. The following section will present and discuss the results and section 6 will offer a summary and conclusions.

2. STRUCTURAL CHANGE AND SCALE ECONOMIES IN THE US DAIRY SECTOR

The transformation of dairy operations is usually defined as changes in herd size, total and milk per cow production, and organizational shifts. Here we focus on the changes in structure that have occurred during the last twenty years only. Figure 1 shows the inverse relationship between number of cows in the national herd and production of milk per cow. Given that demand growth for dairy products has not kept pace with the increase in milk production per cow, the national herd has declined. The herd size in the United States declined from 1985 to 2005 from close to 11 million to 9 million head, a 21 % decrease. During this same period milk production per cow increased from 13,024 to 19,576 pounds, a 33 % increase. The result of these production trends has been that total milk production has increased from 143,012 million pounds in 1985 to 176,989 million pounds in 2005, an increase of 19 % [US Department of Agriculture, National Agricultural Statistical Service (USDA-NASS)].

Simple correlation analysis provides some evidence that scale economies are important determinants of productivity. There is a wide variation in milk produced per cow across states. The correlation between milk produced per cow and milk cows per establishment across dairy farms in the United States is strong and positive indicating a role for scale economies in determining productivity. A simple correlation analysis using publicly available data at the state level from the National Agricultural Statistical Service (USDA-NASS) showed a correlation of 0.431 between milk produced per cow and cows per establishment in 1985 and of 0.521 for 2005 (USDA-NASS).

Further evidence of scale economies is shown in Figure 2. From 1998 to 2005 the number of dairy farms decreased from 117,145 to 78,295, a 50 % decrease. The decline was not symmetrical across farm sizes resulting in a decline in the number of small and an increase in the number of large dairy farms. The cow inventory of dairy farms with herd sizes between 1 and 49 and 50-199 milk cows declined from 14.1 of the total number of cows to 8.4 percent and from 43.6 to 31.7 percent, respectively. In contrast, dairy operations with between 200-1999 head and 2000 or more head experienced an increase from 35 percent to 40.2 percent of the total and 7.3 to 19.7 percent, respectively (USDA-NASS).

The change in size structure has not affected all regions of the country equally either. An idea of the regional shifts that have occurred lately can be grasped by looking at the ranking of milk producing states in 1985 and 2005. In 1985 the ten largest milk-producing states were, in order, Wisconsin, California, New York, Minnesota, Pennsylvania, Michigan, Ohio, Iowa, Texas and Washington; in 2005, they were California, Wisconsin, New York, Pennsylvania, Idaho, Minnesota, New Mexico, Michigan, Texas and Washington. In 1985 the top 10 states produced 67 % of the national milk supply, while in 2005 the top 10 produced 72 %.

These regional shifts also imply a shift in the use of different production systems.[1] Many operations in states like California, Idaho and New Mexico, for example, have seen so called dry-lot systems emerge with low capital requirements and large herd sizes that has enabled them to exploit scale economies and achieve lower cost per unit of output. For example, in 1985 in California the average number of milk cows per operation was 200, while in Idaho and New Mexico, it was 40 and 48 head, respectively. By contrast, in 2005 California had an average of 763 cows per operation, Idaho had 535, and New Mexico had 729 cows. More traditional states increased their average size of operation but by a much smaller percentage. In Wisconsin, New York, and Pennsylvania the average number of cows per operation in 1985 was 46, 55, and 35 cows, respectively; in 2005 it was 81, 97 and 63 cows. These states do not rely so much on purchased feed as on homegrown feed or pasture (USDA-NASS).

Given the heterogeneity of the changes in the size of dairy farms across technologies and regions, the question of the nature of scale economies in the dairy sector and agriculture in general becomes crucial. In general, according to Chavas (2001), the average cost curve for the agricultural sector in developed countries tends to be L shaped. Scale economies tend to exist for small farms, but there is no strong evidence that diseconomies of scale tend to exist for large farms, i.e. there is a wide range in which scale economies are constant. For dairy specifically, Jones (1997) presents a similar picture in which scale economies are exhausted quickly. Moreover, the variation in sizes can be explained by a myriad of variables internal and external to the dairy farm such as pecuniary economies, transaction costs, tax policy, regulation, and risk. Wolf (2003) argues that dairy farms in traditional areas such Wisconsin, New York, and Pennsylvania face higher adjustment costs (because of high sunk costs) than in emerging regions that will constrain their growth and their adoption of technology.

3. SHADOW COST FUNCTION MODEL

We use a shadow cost function to estimate and decompose economic efficiency. Since dairy farmers do not have the flexibility to adjust capital to their optimal proportions in the short run, we estimate the variable cost function $vc(y,w,K)$. This function shows the minimum expenditures on variable inputs required to produce the output vector y, given input price vector w and capital stock K. The function $vc(y,w,K)$ is nonnegative and homogeneous of degree +1. Given (y,K), $vc(y,w,K)$ is concave in w, nondecreasing in y and w, and nonincreasing in K [Kumbhakar and Lovell (2000)].

Dairy farms face a number of output and environmental regulations and input market restrictions such as labor shortages. Such constraints affect the prices that farmers actually employ in making decisions. These so-called shadow prices are known to management but differ from those that can be observed. The requirements for estimating a cost function are violated if costs are minimized over shadow prices, and actual, observed prices are used instead. The shadow price approach estimates parametrically the relevant shadow prices faced by farms. Therefore, the shadow cost approach is especially appropriate to analyze industries such as dairy.

The dairy enterprise is modeled using a multioutput technology. Since there is no reason to expect that the major types of output of a dairy operation move together in response to price changes, aggregation of these outputs is not justifiable. Crops and livestock and livestock products are modeled as separate outputs. Thus the dairy farm produces $y = (y_1, y_2)$ representing a livestock (of which 72 % is milk) and crop outputs, respectively. The output vector y is determined by a well-behaved transformation function $f(x,k,z,y)=0$. The firm uses input vector $x=(x_1,x_2,x_3;k)$ where inputs 1, 2 and 3 represent labor, energy and feed and where k is the fixed level of capital, respectively. The observed input price vector is $w=(w_1,w_2,w_3)$. The firm minimizes variable costs. The optimization problem is represented as:

$$\text{Min } vc = w^{'}x \text{ s.t.:}$$

$$f(x,k,z,y)=0 \tag{1}$$

$$r(x,k,z)=r^{s}, \qquad s=1,2,...,S$$

where vc represents observed variable costs, $w^{'}x$, and z represents a vector of external and internal variables affecting dairy farm costs. There are S unobserved restrictions, r. The first order conditions for the problem are:

$$\frac{f_i}{f_j}=\frac{w_i+\sum_{s=1}^{S} l_s \frac{\partial r_s}{\partial x_i}}{w_j+\sum_{s=1}^{S} l_s \frac{\partial r_s}{\partial x_j}}=\frac{w_i^*}{w_j^*} \tag{2}$$

where $\frac{f_i}{f_j}$ is the marginal rate of transformation, l_s are the Lagrangean multipliers of the s constraint, $w^* \in \Re_{++}^{n}$ is a vector of input shadow prices, and $w \in \Re_{++}^{n}$ is a vector of observed input prices.

We introduce vector q_n to establish the connection between the n observed w and n shadow w^* variables. In this formulation, an input price needs to be chosen as a numeraire because one of the variables in q_n cannot be identified as the cost function is linearly homogeneous in factor prices. The second input, energy, is chosen to serve this role. Thus, we will refer to q_{n2} as the distortion that affects input price *n* when input 2 is used as a base. Thus, the connection between shadow and observed prices is established through the vector $w^* = (q_{12} w_1, w_2, q_{32} w_3)$. If the input price vector *w* is used instead of w^* when estimating the shadow cost function and the variables q_{n2} are not equal to unity, the shadow cost function will be misspecified. The parameters q_{n2} represent the degree of departure from optimal proportions relative to the second input. If $q_{n2} > 1$ then x_n is under utilized; if $q_{n2} < 1$ then x_n is over utilized. Figure 3 shows the measurement of technical and allocative inefficiency in an input oriented shadow cost approach, where the parameter *f* represents the percentage cost differential due to input oriented technical inefficiency. Technical efficiency is defined as $\frac{OfX}{OX}$, allocative efficiency as $\frac{OX'}{OfX}$, and cost efficiency as $\frac{OX'}{OX}$.

The shadow conditional input demand equations $x^*(w^*, y, k, z)$ are obtained by solving for the optimal input levels from equation (2). The minimum shadow cost of producing output *y* is an unobserved function of shadow prices: $vc^* = w^{*'} x^*$. Applying Sheppard's Lemma we can derive the variable cost shares:

$$s_i^* = \frac{w_i^* x_i^*}{vc^*} = \frac{\partial \ln vc^*}{\partial \ln w_i^*} \qquad \forall \qquad i = 1,2,3 \tag{3}$$

Following Atkinson and Halvorsen (1986), the relation between the observed, non-minimizing cost function and the unobserved shadow cost function and associated share equations are:

$$vc = \frac{1}{f} vc^{*} \sum_{j=1}^{n} [s_j^{*} (q_{n2})^{-1}] \ , \qquad (4)$$

and

$$s_i = \frac{s_i^{*} (q_{n2})^{-1}}{\sum_{j=1}^{3} s_j^{*} (q_{k2})^{-1}} . \qquad (5)$$

We estimate (4) and (5) [2] using the following translog [3] specification:

$$\begin{aligned}
\ln vc = {} & b_o + d_1 z_1 + d_3 z_3 + d_9 z_9 + d_{10} z_{10} + d_{11} z_{11} + \sum_{n=1}^{2} b_{y_n} \ln y_n + \sum_{n=1}^{3} b_{w_n} \ln(q_{n2} w_n) \\
& + b_K \ln K + 1/2 \sum_{n=1}^{2} \sum_{k=1}^{2} b_{y_n y_k} \ln y_n \ln y_k + 1/2 \sum_{n=1}^{3} \sum_{k=1}^{3} b_{w_n w_k} \ln(q_{n2} w_n) \ln(q_{k2} w_k) \\
& + 1/2 \sum_{n=1}^{3} \sum_{k=1}^{2} b_{w_n y_k} \ln(q_{n2} w_n) \ln y_k + 1/2 b_{KK} (\ln K)^2 \\
& + \sum_{n=1}^{2} b_{y_n K} \ln y_n \ln K + \sum_{n=1}^{3} b_{w_n K} \ln(q_{n2} w_n) \ln K \\
& + \ln \left\{ \sum_{n=1}^{3} (q_{n2})^{-1} \left[b_{w_n} + \sum_{k=1}^{3} b_{w_n k} \ln(q_{k2} w_k) + \sum_{k=1}^{2} b_{w_n y_k} \ln y_k + b_{w_n K} \ln K \right] \right\}
\end{aligned} \qquad (6)$$

In equation (6) symmetry $b_{w_n w_k} = b_{w_k w_n}, k \neq n$ is imposed as required by Young's Theorem. In addition, linear homogeneity requires the following restrictions:

$$\begin{aligned}
& \sum_{n=1}^{3} b_{w_n} = 1 \\
& \sum_{k=1}^{3} b_{w_n w_k} = 0, n = 1,2,3 \\
& \sum_{k=1}^{3} b_{y_m w_k} = 0, m = 1,2 . \\
& \sum_{n=1}^{3} b_{w_n K} = 0
\end{aligned} \qquad (7)$$

The following determinants of input oriented technical efficiency were employed: z_1, whether or not the dairy farm is located in the traditional dairy region; z_3, is the proportion of purchased to total feed used by the dairy farm; z_9, whether the dairy enterprise is a small farm[4] or not; z_{10}, indicates the degree of specialization by the enterprise; and z_{11} is the cow mortality rate. Some of these determinants are dummy variables, and the interpretation of an estimated coefficient of .1, for example, would be that when that factor is present, costs would be 10 % higher than without it.

The shadow cost shares derived from equation (5) are:

$$s_n = \frac{(q_{n2})^{-1}\left[b_{w_n} + \sum_{k=1}^{3} b_{w_n w_k} \ln(q_{k2} w_k) + \sum_{k=1}^{2} b_{y_k w_n} \ln y_k + b_{w_n K} \ln K \right]}{\sum_{j=1}^{3} (q_{j2})^{-1}\left[b_{w_j} + \sum_{k=1}^{3} b_{w_j w_k} \ln(q_{k2} w_k) + \sum_{k=1}^{2} b_{y_k w_j} \ln y_k + b_{w_j K} \ln K \right]} \tag{8}$$

The distortion factors q_{n2} are defined as a positive exponential function of z_1 and z_3, defined above, and operator experience, z_6, and use of cooperatives, z_7:

$$\begin{aligned} q_{12} &= \exp(q_{120} + q_{121} z_1 + q_{123} z_3 + q_{126} z_6 + q_{127} z_7) \\ q_{32} &= \exp(q_{320} + q_{321} z_1 + q_{323} z_3 + q_{326} z_6 + q_{327} z_7) \\ q_{22} &= 1 \end{aligned} \tag{9}$$

If q_{12} and q_{32} are equal to one, all the coefficients inside the exponential function are equal to zero and therefore all inputs are utilized in their optimal proportions.

The shadow variable cost function must satisfy the properties both of monotonicity with respect to shadow factor prices and output and of concavity in shadow factor prices. These properties are checked for each observation using the parameter estimates. That is, the elasticity of variable cost with respect to the output vector must be nonnegative and the shadow shares must also be nonnegative, while the Hessian matrix of second order derivatives of shadow variable costs with respect to shadow prices must be negative semidefinite:

$$h_y \geq 0$$

$$\hat{S}_i^* \geq 0 \quad \forall i \tag{10}$$

$$\frac{\nabla^2 V\hat{C}^*}{\nabla \hat{w}^{*2}} \text{ is negative semidefinite.}$$

As mentioned above, cost minimization requires that the elasticity of variable cost with respect to capital, h_K, be less than zero. This parameter represents the marginal value of capital that is defined as the marginal reduction in variables costs from additions to capital. A positive marginal product of capital implies that $h_K < 0$. On the other hand, a positive value for h_K would indicate overcapitalization.

The dairy industry, according to Wolf (2003), is characterized by fixity of farm assets and a slow response of farmers to changes in technology and prices. This is due to a combination of information asymmetries, transportation costs, and investment specificity that points to considerable adjustment costs that are region specific. Given asset fixity, it is appropriate to use the input quantity rather than its price in the cost function. Scale elasticity, of course, depends on which inputs are fixed and which are variable. If capital is characterized by fixity, following Caves et al. (1981) and Caves et al. (1984) short run and long run scale elasticities would be defined as:

$$SCE_{SR} = \frac{1}{\sum_{i=1}^{2} (\partial \ln V\hat{C}^* / \partial \ln y_i)} \tag{11}$$

$$SCE_{LR} = \frac{1 - \partial \ln V\hat{C}^* / \partial \ln K}{\sum_{i=1}^{2} (\partial \ln V\hat{C}^* / \partial \ln y_i)}$$

In the short run, capital is fixed. In the longer run the dairy farm might adjust production capacity. If SCE > 1 it implies total variable cost decreases with output given the level of capital. In contrast, if SCE < 1 it implies that total variable cost increases with output and that the scale elasticity is decreasing given the stock of capital.

The present study uses Kumbhakar (1997), and Kumbhakar and Lovell (2000) to decompose actual expenditures into the variable cost function, the percentage cost differential due to input oriented technical inefficiency and the percentage cost of allocative inefficiency:

$$\ln vc = \ln vc(y, w; k) + d_1 z_1 + d_3 z_3 + d_9 z_9 + d_{10} z_{10} + d_{11} z_{11} + \left\{ \begin{array}{l} \ln\left\{ \sum_{n=1}^{3} (q_{n2})^{-1} \left[b_n + \sum_{k=1}^{3} b_{nk} \ln(q_{k2} w_k) + \sum_{k=1}^{2} b_{ny_k} \ln y_k + b_{nK} \ln K \right] \right\} + \\ \sum_{n=1}^{3} b_n \ln q_{n2} + \sum_{n=1}^{3} \sum_{k=1}^{3} b_{nk} \ln w_n \ln q_{k2} + \frac{1}{2} \sum_{n=1}^{3} \sum_{k=1}^{3} b_{nk} \ln q_{n2} \ln q_{k2} \\ + \sum_{k=1}^{2} \sum_{n=1}^{3} b_{y_k n} \ln y_k \ln q_{n2} + \sum_{n=1}^{3} b_{Kn} \ln K \ln q_{n2} \end{array} \right\} \tag{12}$$

4. DATA SOURCES AND VARIABLE CONSTRUCTION

Most of the raw data used to construct the variables necessary to estimate the shadow cost function model represented by equations (6), (7), (8) and (9) came from the 2000 Agricultural Resource Management Survey Phase III Version 4 for dairy

(ARMS2000). ARMS2000 gathered information on 848 individual farms that identified themselves as dairies and contains most of the necessary farm-level detailed information on production, expenses, and farm management and technology characteristics to construct these. In the year 2000 approximately 91,240 dairy farms operated in the United States. ARMS2000 is a probability based stratified multiple frame survey. The list frame is a list of farms and associated characteristics such as farm output. The list is stratified within states according to size and commodities produced. Farms in different strata are sampled at different rates and larger farms are sampled at higher rates than smaller farms [Banker, Green and Korb (2001)].

A set of rules was applied to clean up the data, resulting in a dataset composed of 620 dairy farms. Inconsistencies in production and marketing, farmer refusal to provide information, missing variables, negative operating profits, or suspiciously large or small entries were used as criteria for elimination. The structure of the sample before and after cleaning is roughly comparable. In the original raw data, 32.19 % of the observations covered herd sizes 1-49; 49.65 % for herd sizes 50-199; 15.33 % for herd sizes 200-999, and 2.83 % for herd sizes of more than a 1000. After cleaning the structure of the sample was for herd sizes 1-49: 30.65 %; for 50-199: 51.13 %; for 200-999: 15.32 % and for more than 1000, 2.91 %.

Variable cost, *vc*, as defined in the previous section, is calculated as total expenditure in labor, feed and energy. We constructed all of the price indexes for the outputs and variable inputs using the multilateral Tornqvist price index proposed by Caves, Christensen and Diewert (1982, p. 78). This procedure compares the price faced by firm *k* to the geometric mean of prices:

$$\ln P_k^{CCD} = \frac{1}{2}\sum_{i=1}^{N}(w_{ik} + \overline{w}_i)(\ln p_{ik} - \overline{\ln p_i}) \qquad (13)$$

where k = 1,2,…N, are the number of firms

i = 1,2,…M, are the number of commodities

$w_{ik} = \frac{p_{ik}q_{ik}}{\sum_{i=1}^{M} p_{ik}q_{ik}}$ is the value of the i-th commodity for the k-th firm

$\overline{w}_i = \frac{1}{N}\sum_{k=1}^{N} w_{ik}$ and $\overline{\ln p}_i = \frac{1}{N}\sum_{k=1}^{N}\ln p_{ik}$

Thus, we constructed an implicit livestock quantity index, y_1, by dividing total livestock revenues by a price index, p_1, using prices (available from ERS) for the 15 livestock and livestock commodities identified in ARMS2000. In a similar fashion, we constructed a crop quantity index, y_2, for the 31 crop commodities identified in the ARMS2000 by using prices available from NASS and ERS by deflating total crop revenue by a Tornqvist multilateral price index.

We constructed a feed price index, w_3, for the 26 types of purchased, 16 types of homegrown and the 5 types of pasture feed identified in ARMS2000. The derivation of the labor, energy and capital prices and quantities was a great deal more challenging because the necessary information was not directly available from the 2000 ARMS survey Phase III version 4. We generated a labor price index, w_1, by using the cost of unpaid and paid labor for the farm operator, spouse, full and part time workers. Since the 2000 ARMS2000 Version 4 does not distinguish between earned and unearned income, the compensation of the operator, spouse and other family members was calculated as the marginal increase in total income from an extra hour of work controlling for variables like location, assets and education. The different types of labor costs were aggregated using a Tornqvist multilateral index.

In order to generate a price index for energy, w_2, prices and quantities by type of fuel must be available. Energy is not broken down by type of fuel in ARMS2000 Version 4. To address this problem, we used ARMS2000 Version 1 data to estimate fuel demand by energy type for the dairy enterprise using a seemingly unrelated regression model. We then used the parameters of this model to predict energy consumption by type in ARMS2000 Version 4. The different types of energy were aggregated using a Tornqvist multilateral index.

Capital stock is only available for the dairy portion of the farm in ARMS2000 Version 4, but the unit of observation is the farm. We approximated the farm level price of capital stock by a weighted average cost of capital. In this formulation the cost of capital is a weighted sum of the cost of debt and cost of equity. Cost of debt is the interest rate that farmers actually paid, and we determined the cost of equity using the capital asset pricing model.

Following Coelli, et al (2003):

$$WACC = [(1-g)\times r_e] + [g \times r_d] \tag{14}$$

where the leverage, g, is equal to debt/ (debt + equity), r_e is the cost of equity capital and r_d the cost of debt capital. Data on debt and equity capital comes from ARMS2000. Cost of debt capital is the BAA bond rate. The cost of equity capital is calculated using the capital asset pricing model (CAPM):

$$CAPM = r_e = r_f + b_e \times (r_m - r_f) \tag{15}$$

where r_f is the return of US treasury bills minus the rate of inflation for 2000; b_e is the revenue weighted average of livestock and crop industry betas, and r_m is the compounded annual returns for a 10 year holding period minus the rate of inflation for 1991-2000 [see Kaplan and Peterson (1998) for industry betas and Ibbotson Associates (2005) for inflation and returns].

Total capital, *K*, is calculated as operating profit divided by a rate of depreciation plus a weighted average cost of capital (WACC).[5] Operating profit is equal to crops and livestock sold minus explicit variable costs. We calculated the rate of depreciation as $d = \frac{S}{A} d_S + \frac{E}{A} d_E + \frac{L}{A} d_L$. Where *A*, total assets, is equal to *S*, the value farm structures and buildings, *E*, the value of machinery and equipment and *L*, the value of land. The rates of depreciation for structures, equipment and land are, respectively: 0.0237, 0.1179 and 0.0000 [See Jorgenson and Yun (1991), p. 82]. This method of estimating capital stock is explained and used in Bhattacharya, Parker and Raffie (1994); Morrison-Paul (1999) and Coelli, Estache, Perelman and Trujillo (2003). We described the variables hypothesized to influence dairy farm performance at the end of section 3. Descriptive statistics for these variables are presented in Table 1.

5. ESTIMATION AND RESULTS

The estimated econometric model consists of the observed variable cost function and the cost share equations. We dropped one share equation (for energy) because the shares must sum to unity. A symmetric error term is appended to equations (6) and (8). Linear homogeneity and symmetry are imposed. Since the errors of these equations are correlated, the model is estimated by nonlinear iterative seemingly unrelated techniques that approximate maximum likelihood when they converge. To increase the chance of finding a maximum and to aid convergence, we first estimated a linear model assuming allocative efficiency. Thereafter, we estimated the full model taking account of economic efficiency step by step by freeing the nonlinear allocative inefficiency parameters one by one. The first-order parameters can be interpreted as elasticities since the data were rescaled by dividing each observed variable by its sample means. The parameter estimates are presented in Table 2.

We checked nonnegativity, monotonicity and curvature properties for each observation and at the mean of the data. Table 3 summarizes the properties of the estimated shadow cost function. The concavity condition requires that the matrix of second order derivatives of the shadow cost function with respect to shadow prices be negative semidefinite. The condition is met at the mean of the data. Table 3 summarizes the properties of the estimated shadow cost function. Most estimated shadow shares and output elasticities are positive. Cost minimization also requires that the elasticity of shadow variable cost with respect to capital be negative. Most of the violations of this condition occur at herd sizes of less than 30 head, indicating that capital is generally being used optimally. In summary, the regularity conditions for the cost function are met at the mean of the data and observation by observation indicate that violations occur mostly when herd sizes are really small or large.

We tested a number of hypotheses, as presented in Table 4. Some of these results will be discussed in conjunction with the results in Table 2. Specification tests, hypotheses A(1) and A(2), on the underlying technology exclude a Cobb-Douglas as well as a homothetic translog cost function as the preferred functional form. Overall technical inefficiency and allocative inefficiency, hypotheses B(1) and C(1), matter when analyzing dairy farm costs. Moreover, the rejection of C(1) implies that the shadow and observed cost functions are not the same. The coefficients on the technical efficiency terms, hypotheses B(2), B(3), B(4), B(5), B(6), are all significant. Given this, the coefficient f_1 in Table 2 is interpreted as saying that traditional areas have variable costs that are 5 % lower than non-traditional ones. This finding could make sense from the standpoint that non-traditional dairy areas used more purchased feed and use more energy intensive production methods. Estimated parameter f_3 in Table 2 suggests that a higher proportion of purchased feed implies a lower variable cost. This result raised concern since the expectation was that variable costs would increase with the use of a higher proportion of purchased feed even if prices were imputed to estimate the cost of homegrown and pasture feed. We will, then, investigate this issue further.

Coefficient f_9 in Table 2 indicates that small farms have lower variable costs than other farms. This makes sense considering that the herd size of small farms is 6 times smaller than other farms. The coefficient f_{10} says that increased specialization increases variable costs. This too makes sense since milk production is more capital and input intensive the more specialized a diary farm is. The coefficient f_{11} indicates that the higher the cow mortality rate the higher the variable costs which again makes sense given that proportion of purchased feed and cow mortality rate are positively correlated (pair-wise correlations are presented in table 6).

As to the allocative inefficiency terms, location, proportion of purchased feed and use of cooperatives matter when analyzing allocative efficiency. A negative coefficient implies the factor contributes to over utilization of the input and a positive one to under utilization relative to energy. Optimal proportions, as mentioned in section 3, occur when the terms in equation (9) are not significantly different from zero. If they are different from zero, a departure exists between observed and actual costs. Analysis of these costs will be presented later in this section using equation (12).

Table 5 shows results for scale elasticities under different assumptions about the underlying technology. Model 1 is an estimation of the variable cost function without the technical and allocative inefficiency terms or the explanatory variables. Model 2 is a model with the distortions q but no f or variables **z**. Model 3 integrates q and f , the latter as a function of the **z** variables. Model 4 specifies both allocative and technical inefficiency as functions of the exogenous variables, **z**. Examining the long run elasticities we can appreciate a significant difference in results as we integrate allocative and technical efficiency into the cost function. A scale elasticity greater, equal, or smaller than 1 indicates that scale economies are increasing, constant or decreasing, respectively.

Results given in Table 5 show that the shape of the cost function is different for the different specifications implied by models 1, 2, 3 and 4. Most striking of all is that while model 1 implies that diseconomies of scale are present for farms with herd size more than 2000 head, in model 4 scale economies are constant. Given the hypotheses presented in table 4, it is preferred to model 1. Yet it contradicts other research that has found diseconomies of scale in dairy. This result is similar to the one given by Atkinson and Halvorsen (1984) in their seminal paper that found the number of electric utilities exhibiting decreasing returns to scale declined from 12 to 2 as allocative inefficiency was taken into account. We have not conducted formal tests on the difference between the models results. Therefore, these results are preliminary.

From equation (12) cost inefficiency is defined as the sum of percentage cost differentials due to input oriented technical and allocative inefficiency differentials. The cost of technical inefficiency is much smaller than the cost of allocative inefficiency. This result further indicates that allocative inefficiency is an important component when analyzing cost inefficiency of dairy farms. Table 6 shows significant pairwise correlations of variables hypothesized to influence the efficiency of dairy farms. Tables 7 and 8 present some preliminary results dealing with the cost of allocative and technical inefficiency and long run scale elasticities. In tables 7 and 8 and according to equation 12, cost inefficiency is defined as allocative plus technical inefficiency.

Starting with herd size at the top of table 7, our results show that as the dairy farm gets larger, cost inefficiency and its components increase as well. The reason might be that, for example, experience in managing a dairy farm and herd size are inversely correlated, and experience and cost inefficiency are inversely related as the top part of table 8 shows. Another possibility might be that cost inefficiency might be higher for larger farms since they tend to use more purchased feed as the middle and bottom portion of table 7 shows. Since the intense use of purchased feed and cow mortality are significantly directly correlated, it raises cost inefficiency. Long run scale elasticity and purchased feed proportion and specialization are directly related. Technical inefficiency goes up and allocative inefficiency goes down as purchased feed proportion rises. Since purchased feed proportion and specialization and herd size are directly correlated, the reason could be that smaller farms can target their feed formulas better than other dairy farms. More specialized larger farms could purchase a fewer number of inputs and could muster pecuniary economies that could make them less allocatively inefficient.

Experience has a uniform impact in reducing cost inefficiency and its components as table 8 shows. The effect of experience on scale economies is less uniform other than that managers at the beginning of their careers tend to manage larger enterprises than at the end. The scale elasticity for small farms is about half of other types of farms. This is not surprising since the herd size of small farms in the sample is an average of 49 cows and those of the other farms, 291. Small farms tend to be located in the traditional dairy areas, and they tend to be less inefficient than other types of farms. The conclusion we draw is that small farms maintain a higher-level efficiency relative to larger farms and this helps them countervail their scale economy disadvantage.

6. SUMMARY AND CONCLUSIONS

This paper used a multioutput shadow cost function system to analyze scale economies and decompose economic efficiency of the dairy sector in the United States using the 2000 ARMS survey. Regularity conditions of monotonicity in output quantities and shadow input prices, as well as concavity in shadow inputs are satisfied at the mean of the data. Also, the elasticity of capital stock with respect to variable costs is negative. We selected a cost function incorporating technical and allocative inefficiency coefficients through parametric tests. No evidence of decreasing returns to scale was found when using the preferred model.

Scale economies in the sector get exhausted rapidly. We found five characteristics affecting technical and four affecting allocative inefficiency of dairy farms. We decomposed cost inefficiency and found that variables like herd size, technology (proportion of purchased feed and degree of specialization in fluid milk production), experience, and location matter when analyzing their variation. Moreover, preliminary results point to important scale economies and suggest that surviving small farms are on average more economically efficient than larger farms, the latter having a countervailing scale economy advantage.

7. REFERENCES

Atkinson, S.E. and R. Halvorsen (1980), "A Test of relative and Absolute Price Efficiency in Regulated Utilities," *Review of Economics and Statistics* 62 (1): 81-88.

Atkinson, S.E. and R. Halvorsen (1984), "Parametric Efficiency Tests, Economies of Scale, and Input Demand in U.S. Electric Power Generation," *International Economics Review* 25 (3): 623-38.

Atkinson, S.E. and R. Halvorsen (1986), "The Relative Efficiency of Public and Private in a Regulated Environment: The Case of U.S. Electric Utilities," *Journal of Public Economics* 29 (3): 281-94.

Alvarez, A. and C. Arias (2003), "Diseconomies of Size and Fixed Managerial Ability," *American Journal of Agricultural Economics* 85 (1): 134-142.

Alvarez, A. and C. Arias (2004), "Technical Efficiency and Farm Size: A Conditional Analysis," *Agricultural Economics* 30: 241-250.

Banker, D., R. Green and P. Korb (2001), ARMS 2000 Phase III: Documentation and Data Files Specifications Farms Business and Farm Operator Household Data, mimeo, Washington, DC: ERS-USDA.

Bhattarcharyya, A, E. Parker and K. Raffie (1994), "An Examination of the Effect of Ownership on the Relative Efficiency of Public and Private Water Utilities," *Land Economics*, 70(2): 197-209.

Blayney and Normile (2004), *Economic Effects of U.S. Dairy Policy and Alternative Approaches to Milk Pricing*, Washington, DC: ERS-USDA, Report to Congress.

Caves, D., L. Christensen and J. Swanson (1981), "Productivity Growth, Scale Economies, and Capacity Utilization in U.S. Railroads, 1955-74," *American Economic Review*, 71(5): 994-1002.

Caves, D., L. Christensen and Diewert (1982), "Multilateral Comparisons of Output, Input, and Productivity Using Superlative Index Numbers," Economic Journal, 92(365): 73-86.

Caves, D., L. Christensen and M. Tretheway (1984), "Economies of Density versus Economies of Scale: Why Truck and Local Services Airline Cost Differ," *RAND Journal of Economics* 15(4), 471-489.

Chavas, J. –P. (2001), "Structural Change in Agricultural Production," in Bruce L. Gardner and Gordon C. Rausser, eds., Handbook of Agricultural Economics, V1A, Agricultural Production, Amsterdam: Elsevier, pp. 263-285.

Christensen, L, D. Jorgenson and L. Lau (1973), "Transcendental Logarithmic Production Frontiers," *Review of Economics and Statistics*, 55(1): 28-45.

Coelli, T., A. Estache, S. Perelman and L. Trujillo (2003), *A Primer on Efficiency Measurement for Utilities and Transport Regulators*, WBI Development Studies: Washington, DC.

Fried, Lovell and Schmidt (forthcoming)

Ibbotson Associates (2005), *Stocks, Bonds, Bills, and Inflation 2005 Yearbook: Market Results for 1926-2004*, Chicago: R.G. Ibbotson Associates.

Jorgenson, D.W. and Yun, K. (1991), *Tax reform and the cost of capital*, Oxford: Oxford University Press.

Jones, B. (1999), "Growth in Dairy Farms: The Consequences of Taking Big Steps or Small Ones When Expanding", Madison: University of Wisconsin, Center for Dairy Profitability.

Kaplan, P. and J. Peterson (1998), "Full-Information Industry Betas," *Financial Management* 27(2): 85-93.

Kumbhakar, S., B. Biswas and D. Von Bailey (1989), "A Study of Economic Efficiency of Utah Dairy Farmers: A System Approach," *The Review of Economics and Statistics* 71: 595-604.

Kumbhakar, S. (1993), "Short-Run Returns to Scale, Farm-Size, and Economic Efficiency," The Review of Economics and Statistics 75(2): 336-341.

Kumbhakar, S. (1997), "Modeling allocative inefficiency in a translog cost function and cost share equations: An exact relationship," *Journal of Econometrics* 76: 351-356.

Kumbhakar, S. and H. Wang (forthcoming), "Pitfalls in the estimation of a cost function that ignores allocative inefficiency: A Monte Carlo analysis," *Journal of Econometrics.*

Kumbhakar, S. and K. Lovell (2000), *Stochastic Frontier Analysis*, Cambridge University Press: Cambridge, UK.

Lau, L. and P. Yotopoulos (1971), "A Test for Relative Efficiency and Application to Indian Agriculture," *American Economic Review* 61: 94-109.

Maietta, O. W. (2000), "The Decomposition of Cost Inefficiency into Technical and Allocative Components with Panel Data of Italian Dairy Farms," *European Review of Agricultural Economics* 27(4): 473-495.

Morrison Paul, C. J. (1999), Cost *Structure and Measurement of Economic Performance: Productivity, Utilization, Cost Economics and Related Performance Indicators,* Boston: Kluwer Academic.

Moschini, G. (1988), "The Cost Structure of Ontario Dairy Farms: A Microeconomic Analysis," *Canadian Journal of Agricultural Economics*, 36(2): 187-206.

Stefanou S. and S. Saxena (1988), "Education, Experience, and Allocative Efficiency: A Dual Approach," *American Journal of Agricultural Economics*, 70(2): 338-45.

US Department of Agriculture, National Agricultural Statistical Service (USDA-NASS). U.S. & All States Data–Dairy. Available at: http://www.nass.usda.gov:8080/QuickStats/Create_Federal_All.jsp Accessed: March 7, 2006.

US Department of Agriculture, National Commission on Small Farms (USDA-NCSF) (1998), A Time to Act: A Report of the USDA National Commission on Small Farms, MP-1545, Washington, DC: USDA-NCSF.

Wolf, C.A. (2003), "The Economics of Dairy Production", in Stephen P. Koontz, ed., *Economics of the Red Meat and Dairy Industries*, Philadelphia: W.B. Saunders Company, pp. 271-293.

Yotopoulos, P. and L. Lau (1973), "A Test for Relative Efficiency: Some Further Results," *American Economic Review* 63:1, 214-23.

[1] Blayney and Normile (2004) distinguish three production systems: confinement, pasture-based and dry-lot operations. The first two rely mainly in homegrown feed and the latter on purchased feed.

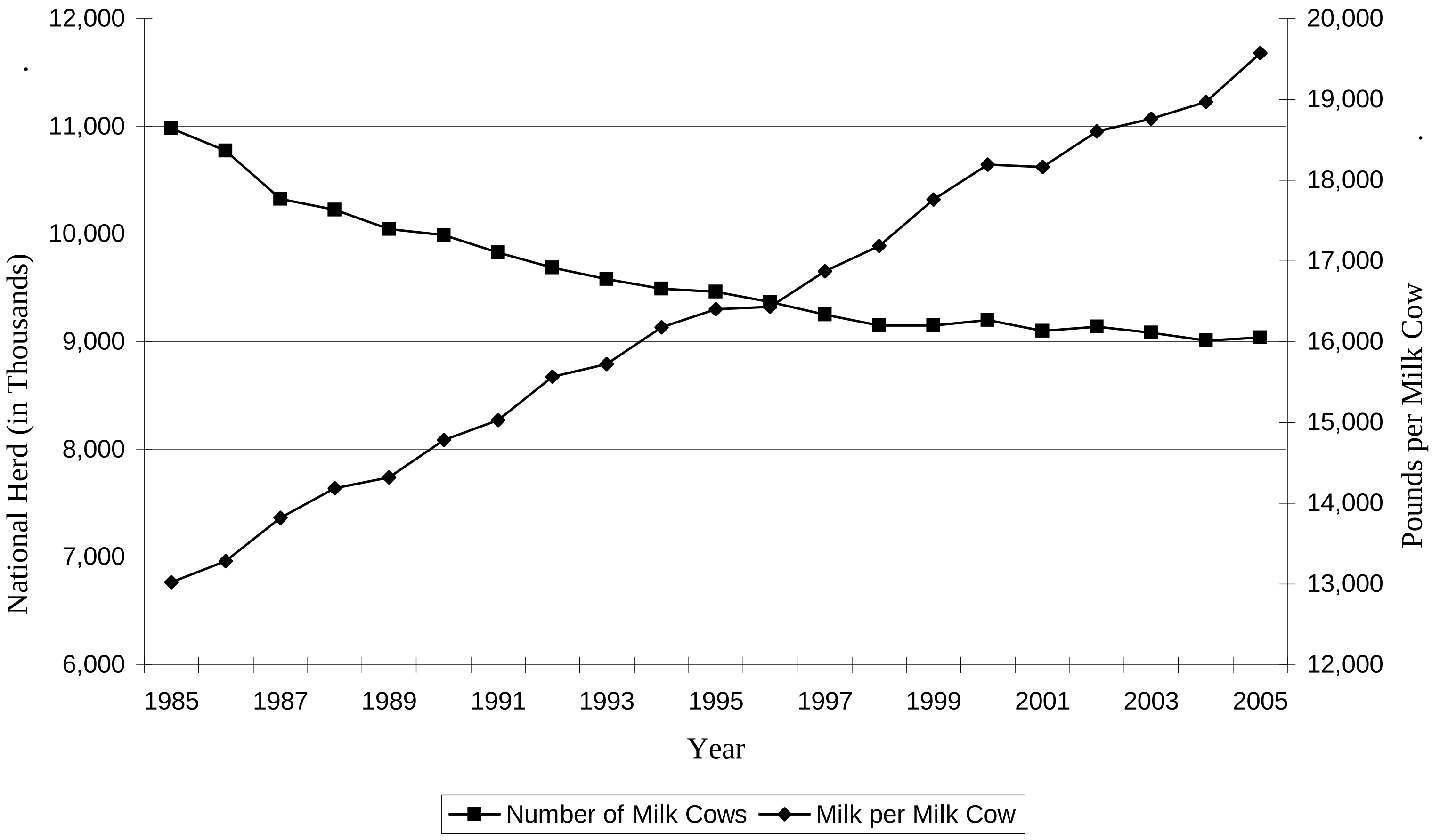
[2] This is based on the models presented in Kumbhakar and Lovell (2000) that introduce the shadow cost function approach to efficiency measurement as developed by Lau and Yotopoulos (1971), Yotopolous and Lau (1973), and Atkinson and Halvorsen (1980, 1984).

[3] See Christensen, Jorgenson and Lau (1973).

[4] Defined as farms having less than $250,000 in total revenues. A definition used by USDA's National Commission on Small Farms (USDA-NCSF) [see, for example, USDA-NCSF (1998)].

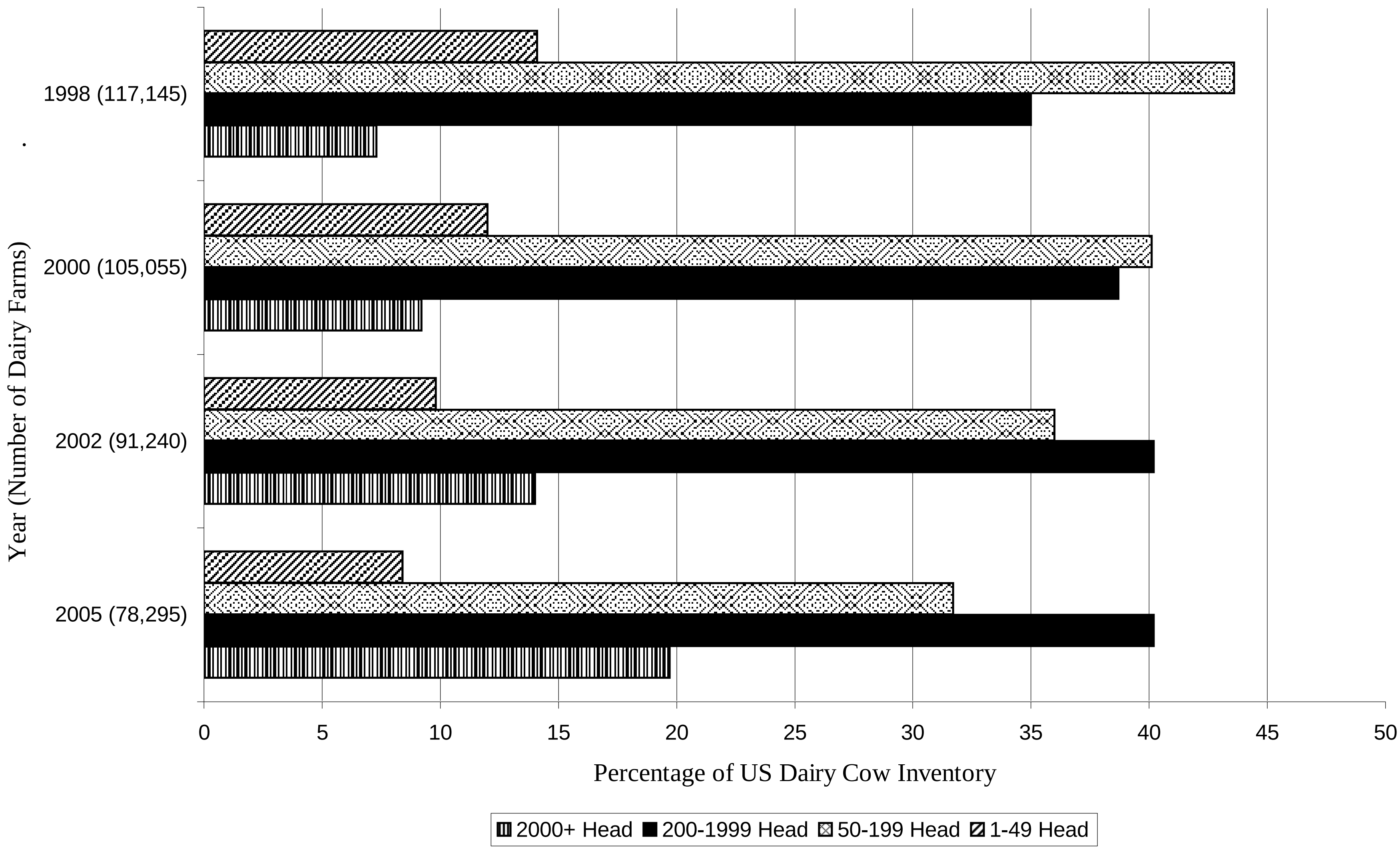
[5] Capital is calculated to be the residual of revenue less variable cost divided by the opportunity cost of capital as in Bhattacharyya, Parker and Raffie (1994).

Figure 1: National Herd and Milk per Cow in the United States



Source: USDA, NASS

Figure 2: Dairy Farm Size Distribution in the United States
(*Number of Dairy Farms in Parenthesis*)



Source: USDA, NASS

Figure 3: Shadow Price Approach to Estimating Cost Efficiency

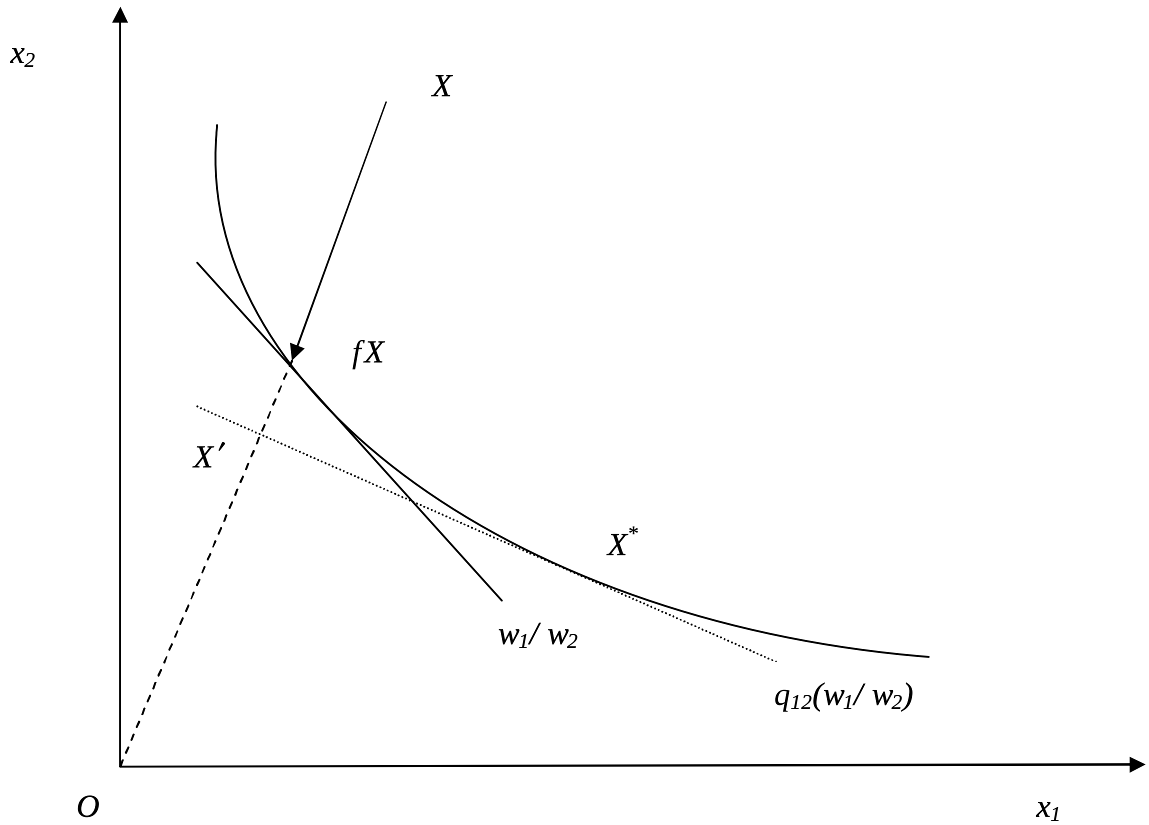


Table 1: Summary Statistics for Variables Used in the Shadow Cost Function					
Variable and Units	Parm	Mean	Std Dev	Min	Max
Expenditure (*E*) (in $)		391,645	590,172	34,179	6,557,535
Livestock (y_1) quantity index	b_{y1}	511,390	1,054,165	6,562	12,498,124
Crops (y_2) quantity index	b_{y2}	67,346	106,642	0	1,319,820
Labor (w_1) price index	b_{w1}	1.283	1.138	0.297	10.161
Energy (w_2) price index	b_{w2}	1.017	0.173	0.722	1.487
Feed (w_3) price index	b_{w3}	1.019	0.174	0.542	1.705
Capital (*K*) in $	b_K	1,678,355	3,437,666	16,648	36,590,516
Variables Hypothesized to Influence Dairy Farm Performance (Technical f, Allocative q Efficiency)					
Traditional Dairy (z_1)	f_1, q_1	0.203	0.403	0	1
Purchased Feed Proportion (z_3)	f_3, q_3	0.545	0.284	0	1
Experience (z_6)	q_6	24.990	12.845	0	73
Cooperate (z_7)	q_7	0.653	0.476	0	1
Small Farm (z_9)	f_9	0.473	0.500	0	1
Specialization (z_{10})	f_{10}	0.727	0.172	0.111	1
Cow Mortality Rate (z_{11})	f_{11}	0.06	0.047	0	0.333

Table 2: Parameter Estimates of the Shadow Cost Function
(t-statistics in Parentheses)

b_o	-0.64*** (-6.06)	$b_{w_2w_3}$	0.03* (1.88)	b_{KK}	0.02 (0.39)	q_{120}	-2.51*** (-7.61)
b_{y_1}	0.79*** (15.03)	$b_{w_3w_3}$	0.05*** (3.55)	b_{y_1K}	-0.11** (-2.04)	q_{121}	0.29* (1.73)
b_{y_2}	0.14*** (9.14)	$b_{w_1y_1}$	-0.15*** (-11.23)	b_{y_2K}	-0.002 (-1.18)	q_{123}	0.86*** (3.11)
b_{w_1}	0.57*** (12.51)	$b_{w_2y_1}$	0.02 (1.08)	$b_{y_1y_1}$	0.36*** (6.11)	q_{126}	-0.002 (-0.25)
b_{w_2}	0.19*** (4.46)	$b_{w_3y_1}$	0.13*** (6.32)	$b_{y_2y_2}$	0.006*** (9.12)	q_{127}	0.30** (1.99)
b_{w_3}	2.41*** (5.23)	$b_{w_1y_2}$	-0.0003 (-0.71)	$b_{y_1y_2}$	-0.0002 (-0.10)	q_{320}	-2.84*** (-9.36)
b_K	-0.35*** (-9.02)	$b_{w_2y_2}$	0.0008* (1.61)	f_1	-0.05* (-1.79)	q_{321}	0.30*** (4.83)
$b_{w_1w_1}$	0.22*** (29.71)	$b_{w_3y_2}$	-0.0005* (-1.69)	f_3	-0.11** (-2.11)	q_{323}	-0.002 (-0.02)
$b_{w_1w_2}$	-0.14*** (-8.50)	b_{w_1K}	0.03* (1.88)	f_9	-0.11*** (-3.45)	q_{326}	0.004** (2.22)
$b_{w_1w_3}$	-0.08*** (-5.39)	b_{w_2K}	0.05*** (3.55)	f_{10}	0.47*** (4.95)	q_{327}	-0.002 (-0.04)
$b_{w_2w_2}$	0.11*** (4.05)	b_{w_3K}	-0.15*** (-11.23)	f_{11}	0.63*** (2.99)	*LLF*	1805

****Significant at 1%*
***Significant at 5%*
**Significant at 10%*

Table 3: Shadow Cost Function Calculated Indices
[Violations of Monotonicity, Nonnegativity and Concavity Properties (Obs by Obs Tests)]

Herd Size (# of Obs) *(Y index mean │ std dev)*	$\hat{h}_{y_1} \geq 0$	$\hat{h}_{y_2} \geq 0$	$\hat{s}_1^* \geq 0$	$\hat{s}_2^* \geq 0$	$\hat{s}_3^* \geq 0$	$\frac{\nabla^2 V\hat{C}^*}{\nabla \hat{w}^{*2}} (NSD)$	$\hat{h}_K < 0$
Herd < 30 (52) (112,904 │ 72,982)	10 %	4 %	0 %	2 %	2 %	38 %	27 %
50 < Herd ≥ 30 (138) (152,694 │ 67,200)	3 %	1 %	0 %	1 %	1 %	34 %	6 %
100 < Herd ≥ 50 (195) (250,871 │ 100,743)	0 %	4 %	0 %	1 %	0 %	39 %	1 %
200 < Herd ≥ 100 (122) (454,943 │ 189,282)	0 %	14 %	0 %	0 %	0 %	54 %	1 %
500 < Herd ≥ 200 (62) (962,418 │ 306,876)	0 %	20 %	0 %	0 %	0 %	65 %	0 %
1000 < Herd ≥ 500 (33) (2,169,788 │ 709,007)	0 %	15 %	0 %	0 %	0 %	82 %	0 %
2000 < Herd ≥ 1000 (13) (4,511,886 │ 1,381,150)	0 %	62 %	8 %	0 %	0 %	92 %	0 %
Herd ≥ 2000 (5) (8,931,476 │ 3,301,395)	0 %	40 %	40 %	0 %	0 %	100 %	0 %
Mean of Data (590,243 │ 1,134,854)	*0 %*	*0 %*	*0 %*	*0 %*	*0 %*	*0 %*	*0 %*

Table 4: Hypotheses Tests on the Parameters of the Estimated Shadow Cost Function

Hypothesis	Statistic*	Significance**
A. Technology		
(1) $H_o : Cobb-Douglas$	2063.4	< 0.0001
(2) $H_o : Homothetic$	626.6	< 0.0001
B. Technical Inefficiency		
(1) $H_o : d_1 = d_3 = d_9 = d_{10} = d_{11} = 0$ (Overall)	46.8	< 0.0001
(2) $H_o : d_1 = 0$ (Traditional Region)	3.2	0.075
(3) $H_o : d_3 = 0$ (Purchased Feed Proportion)	4.5	0.035
(4) $H_o : d_9 = 0$ (Small Farm)	12.0	0.0005
(5) $H_o : d_{10} = 0$ (Specialization)	24.7	< 0.0001
(6) $H_o : d_{11} = 0$ (Cow Mortality Rate)	9.0	0.003
C. Allocative Inefficiency		
(1) $H_o : q_{120} = q_{320} = q_{121} = q_{321} = q_{123} = q_{323} = q_{126} = q_{326} = q_{127} = q_{327} = 0$ (Overall)	92.9	<0.0001
(2) $H_o : q_{121} = q_{321} = 0$ (Traditional Region)	22.6	<0.0001
(3) $H_o : q_{123} = q_{323} = 0$ (Purchased Feed Proportion)	13.0	0.002
(4) $H_o : q_{126} = q_{326} = 0$ (Experience)	6.2	0.044
(5) $H_o : q_{127} = q_{327} = 0$ (Coop)	6.0	0.050

$* -2(L_R - L_U) \sim c_q^2$

** Pr > ChiSq

Table 5: Dairy Sector Short and Long Run Scale Elasticity Under Different Efficiency Assumptions (Standard Error in Parentheses)

	Model 1: $VC(w, y, K)$	Model 2: $VC(qw, y, K)$	Model 3: $VC(qw, y, K, f(z))$	Model 4: $VC(q(z)w, y, K, f(z))$
Herd Size (Obs)	*Short Run Scale Elasticity*			
Herd < 30 (52)	1.759 (0.847)	2.340 (1.115)	3.879 (2.917)	3.243 (2.038)
50 < Herd ≥ 30 (138)	1.627 (0.985)	2.081 (1.653)	1.467 (10.400)	3.938 (10.694)
100 < Herd ≥ 50 (195)	1.234 (0.316)	1.465 (0.384)	1.777 (0.657)	1.752 (0.647)
200 < Herd ≥ 100 (122)	1.084 (0.287)	1.250 (0.336)	1.427 (0.482)	1.466 (0.530)
500 < Herd ≥ 200 (62)	0.862 (0.115)	0.969 (0.130)	1.050 (0.157)	1.100 (0.186)
1000 < Herd ≥ 500 (33)	0.746 (0.107)	0.819 (0.116)	0.867 (0.134)	0.902 (0.150)
2000 < Herd ≥ 1000 (13)	0.705 (0.091)	0.771 (0.096)	0.812 (0.108)	0.865 (0.134)
Herd ≥ 2000 (5)	0.612 (0.081)	0.662 (0.079)	0.689 (0.090)	0.712 (0.077)
Herd Size (Obs)	*Long Run Scale Elasticity*			
Herd < 30 (52)	2.097 (0.819)	2.560 (1.058)	3.953 (2.743)	3.317 (1.930)
50 < Herd ≥ 30 (138)	1.962 (0.956)	2.320 (1.590)	1.665 (10.047)	4.000 (10.126)
100 < Herd ≥ 50 (195)	1.572 (0.310)	1.731 (0.381)	1.996 (0.635)	1.947 (0.621)
200 < Herd ≥ 100 (122)	1.415 (0.276)	1.522 (0.325)	1.670 (0.463)	1.688 (0.503)
500 < Herd ≥ 200 (62)	1.200 (0.110)	1.257 (0.123)	1.314 (0.148)	1.346 (0.171)
1000 < Herd ≥ 500 (33)	1.086 (0.100)	1.121 (0.111)	1.146 (0.130)	1.167 (0.144)
2000 < Herd ≥ 1000 (13)	1.048 (0.085)	1.081 (0.091)	1.099 (0.103)	1.137 (0.125)
Herd ≥ 2000 (5)	0.961 (0.082)	0.988 (0.089)	0.990 (0.093)	1.000 (0.074)

Table 6: Pairwise Correlations of Variable Hypothesized to Affect Dairy Farm Efficiency
(Significance in Parentheses >0.1 not shown)

	z1 (traditional)	z3 (feedpr)	z6 (exp)	z7 (coop)	z9 (small)	z10 (spec)	z11 (mort)	herd
Z1 (traditional)								
Z3 (feedpr)	-0.158 (0.000)							
Z6 (exp)		-0.097 (0.015)						
Z7 (coop)								
Z9 (small)	0.124 (0.002)	-0.306 (0.000)		-0.098 (0.015)				
Z10 (spec)	-0.144 (0.000)	0.545 (0.000)	-0.157 (0.000)		-0.219 (0.000)			
Z11 (mort)		0.067 (0.097)						
herd	-0.140 (0.001)	0.354 (0.000)	-0.086 (0.032)		-0.357 (0.000)	0.339 (0.000)		

Table 7: Predicted Long Run Scale Elasticity and Cost Inefficiency by Herd Size, Purchased Feed and Milk Revenue Proportions

(Mean Technical, Allocative and Cost Inefficiency in Proportions)

	SCELR	TI	AI	CI
herd < 50	3.814	0.174	2.251	2.426
200 < herd ≥ 50	1.847	0.275	2.280	2.555
2000 < herd ≥ 200	1.266	0.354	2.359	2.713
herd ≥ 2000	1.000	0.380	2.540	2.920
feedprop < 0.25	2.792	0.194	2.410	2.603
0.45 < feedprop ≥ 0.25	2.612	0.246	2.312	2.558
0.60 < feedprop ≥ 0.45	2.137	0.272	2.245	2.517
0.90 < feedprop ≥ 0.60	2.307	0.281	2.243	2.524
feedprop ≥ 0.90	1.762	0.298	2.230	2.528
mkrevprop < 0.6	2.385	0.149	2.322	2.470
0.7 < mkrevprop ≥ 0.6	3.799	0.215	2.302	2.517
0.8 < mkrevprop ≥ 0.7	1.996	0.269	2.290	2.560
0.9 < mkrevprop ≥ 0.8	1.739	0.319	2.258	2.578
mkrevprop ≥ 0.9	2.088	0.355	2.259	2.613

Table 8: Predicted Long Run Scale Elasticity and Cost Inefficiency by Experience, Location, Farm Type, Use of Cooperatives

(Mean Technical, Allocative and Cost Inefficiency in Proportions)

	SCELR	TI	AI	CI
exp < 14	1.926	0.274	2.326	2.600
21 < exp ≥ 14	2.427	0.270	2.264	2.533
28 < exp ≥ 21	2.248	0.258	2.302	2.560
36 < exp ≥ 28	1.922	0.247	2.299	2.547
75 < exp ≥ 36	3.200	0.244	2.249	2.492
traditional	3.103	0.193	2.070	2.262
non-traditional	2.148	0.275	2.343	2.618
Small farm	3.250	0.191	2.251	2.442
Other farm	1.528	0.319	2.320	2.639
coop	2.530	0.266	2.247	2.514
non-coop	1.988	0.244	2.363	2.607