Economic Efficiency of U.S. Organic Versus Conventional Dairy Farms:

Evidence from 2005 and 2010

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Abstract

We estimate an input distance function for U.S. dairy farming to examine the competitiveness of organic and non-organic dairy production by system and size. Across organic/non-organic systems and size classes, size is the major determinant of competitiveness based on various measures of productivity and returns to scale.

Introduction

Over the past decade, organic milk production has expanded such that it now claims a consequential share of the U.S. milk produced. Estimates from the 2005 and 2010 U.S. Agricultural Resource Management Surveys (ARMS) show that organic milk production represented 0.7% and 4.1% of total U.S. milk production in those years, respectively. Expansion has occurred alongside increased organic milk demand. The *New York Times* has chronicled the evolution of U.S. organic milk production. Martin (2007) reported the addition of organic dairies associated with Horizon Organic and Wisconsin's Organic Valley in 2007. Zezima (2009) showed less favorable economic conditions for organic dairying in 2009. More recently, Neuman (2010) reported USDA's new pasture rules for all organic dairies, aimed at enforcing pasture grazing during the entire grazing season. Organic dairy farming has evolved such that it differs dramatically by size and region (McBride and Greene 2009).

Using ARMS data, we explore the extent of U.S. organic milk production in 2005 and 2010; estimate net return on assets, returns to scale (RTS), and technical efficiency (TE) associated with organic versus non-organic production by size; and compare financial

performance of organic with non-organic farms by size. Since we are estimating economic performance measures by system, we use a stochastic production frontier (SPF) approach following Morrison-Paul et al. (2004a,b) to analyze performance by group. Dairy systems are analyzed in a pooled analysis. We find that large farms economically outperform smaller farms in both organic and non-organic categories. We highlight financial, economic, and technical differences across organic compared to non-organic groupings by size, providing additional perspective to the McBride and Greene (2009) results.

Background

The 2007 U.S. Census of Agriculture indicates organic dairies sold milk valued at >$750 million. Certified U.S. organic milk production must be consistent with USDA guidelines. Animals cannot be provided antibiotics or growth hormones, but receive preventive veterinary care (Dimitri and Greene, 2002). They must have access to pasture, though extent of pasture access was unspecified until 2010 policy changes requiring that animals receive ≥30% of dry matter intake from pasture during a grazing season ≥120 days, depending upon region (Neuman 2010). Though the organic certification process has generally led to heavy pasture reliance, in some cases minimal pasture access had been provided. All feed must be grown organically. To convert to organic, cows must be fed a diet of ≥80% organic feed for 9 months, followed by 100% organic feed for 3 months. The alternative is to graze cows under a certified organic plan (Dimitri and Greene 2002).

A number of studies have compared characteristics of organic with non-organic milk production: farm size and production practices (Zwald et al. 2004); production efficiency (Reksen, Tverdal, and Ropstad 2005); and risk (Hanson et al. 2004). Few have compared the economics of organic with non-organic milk production, with most conducted outside the U.S. (e.g., Rosati and Aumaitre 2004). In the U.S., Butler (2002) compared net returns of

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California organic and non-organic milk production and Dalton et al. (2005) examined net returns associated with Maine and Vermont organic dairies. Both studies showed higher revenue per cow with organic relative to non-organic production, but no economic profit.

Three studies have used 2005 ARMS data to analyze organic dairy economics. Estimating a cost function, Mayen et al. (2009) found economies of scope in organic milk production, but not in non-organic production. Mayen et al. (2010) examined TE and self-selection into organic production, estimating a Cobb-Douglas SPF. Our work builds on theirs in several important ways: (1) we use all usable observations as discussed later in the Data and Methods section; (2) we analyze efficiency using an input distance function in a whole-farm context; and (3) we combine 2005 and 2010 ARMS dairy survey data for more observations in two time periods. McBride and Greene (2009) showed higher production costs for organic dairies, with additional production costs lower for pasture-based than non pasture-based operations. They did not estimate TE and RTS components of organic relative to non-organic production. They suggested new startups were unlikely unless they were of larger scale and/or pasture-based.

Data and Methods

This study uses data from the 2005 and 2010 ARMS Phase III dairy version, conducted by the USDA's National Agricultural Statistics Service and Economic Research Service. The 2005 (2010) dataset provides 1,812 (1,939) usable responses from 24 (26) states[1], including 348 (594) organic dairies. Thus, we have a total of 3,751 observations, 942 of which are organic. The ARMS collects information on farm size, type and structure; income and expenses; production practices; and farm and household characteristics. Because this design-based survey uses stratified sampling, weights or expansion factors are included for

each observation to extend results to the dairy farm population of the largest U.S. dairy states, representing 90% of U.S. milk production.

A Model to Assess Technical and Scale Efficiency

A parametric input distance function approach is used to estimate performance measures, including RTS and TE. Following Morrison-Paul et al. (2004a,b), the input distance function is denoted as $D^I(X,Y,R)$, where X refers to inputs, Y to outputs, and R to other farm efficiency determinants. For the analysis, three outputs developed from the ARMS for dairy farms are: Y_{CROP} = value of crop production, Y_{LIVE} = value of livestock production, and Y_{OFF} = off-farm income, which is total off-farm income less unearned income. Inputs are costs of: X_{LAB} = labor; X_{CAP} = capital; X_{MISC} = miscellaneous including feed, fertilizer, and fuel; and X_{OLND} = quality adjusted land. Thus, our analysis is whole-farm, rather than dairy-enterprise based as with McBride and Greene (2009) and Mayen et al. (2010). This is a significant distinction considering the roles of off-farm income, other farm enterprises, and homegrown feed, which is valued at its actual production cost using the whole-farm approach rather than at its market price using enterprise measures.

The input distance function represents farms' technological structure in terms of minimum inputs required to produce given output levels, as farmers typically have more short-term control over input than output decisions (Morrison-Paul et al. 2004a,b). Also, Morrison-Paul and Nehring (2005) found output-oriented models to have limitations—a less good fit—when output composition differences are important, as is the case in this dairy survey, designed to include very small organic dairies along with large conventional dairies to get population estimates. See Morrison-Paul and Nehring (2005), and Dorfman and Koop (2005), for ARMS applications of distance functions.

To account for differences in land characteristics, state-level quality-adjusted values for the U.S. estimated in Ball et al. (2008) are multiplied by pasture plus non-pasture acres to construct a stock of land by farm. That is, the estimated state-level quality-adjusted price for each farm is multiplied by actual acres of pasture and non-pasture and a service flow computed based on a service life of 20 years and interest rate of 6%. See Nehring et al. (2006) for a fuller description. Ignoring land heterogeneity, including urbanization effects on productivity and agronomic (i.e., water holding capacity, organic matter, slope, etc., of land) and climatic information incorporating the differing crop and pasture patterns used in dairying, would result in biased efficiency estimates (Ball et al. 2008; Nehring et al. 2006).

Estimating $D^I(X,Y,R)$ requires imposing linear homogeneity in input levels (Färe and Primont 1995), which is accomplished through normalization (Lovell et al. 1994); $D^I(X,Y, R)/X_1 = D^I(X/X_1,Y, R) = D^I(X^*,Y, R)$.[2] Approximating this function by a translog functional form to limit *a priori* restrictions on the relationships among its arguments results in:

(1a) $\ln D^I_{it}/X_{1,it} = \alpha_0 + \Sigma_m \alpha_m \ln X^*_{mit} + .5 \Sigma_m \Sigma_n \alpha_{mn} \ln X^*_{mit} \ln X^*_{nit} + \Sigma_k \beta_k \ln Y_{kit}$

   $+ .5 \Sigma_k \Sigma_l \beta_{kl} \ln Y_{kit} \ln Y_{lit} + \Sigma_q \phi_q R_{qit} + .5 \Sigma_q \Sigma_r \phi_{qr} R_{qit} R_{rit} + \Sigma_k \Sigma_m \gamma_{km} \ln Y_{kit} \ln X^*_{mit}$

   $+ \Sigma_q \Sigma_m \gamma_{qm} \ln R_{qit} \ln X^*_{mit} + \Sigma_k \Sigma_q \gamma_{kq} \ln Y_{kit} \ln R_{qit} + v_{it} = TL(X^*,Y, R) + v_{it}$, or

 (1b) $-\ln X_{1,it} = TL(X^*,Y, R) + v_{it} - \ln D^I_{it} = TL(X^*,Y, R) + v_{it} - u_{it}$,

where i denotes farm; t the time period; k,l the outputs; m,n the inputs; and q,r the R variables. We specify $X_{1 = }X_{OLND}$ as land, so the function is specified on a per-acre basis, consistent with much of the literature on farm production in terms of yields.

Distance from the frontier, $-\ln D^I_{it}$, is characterized as the technical inefficiency error $-u_{it}$. Equation (1b) was estimated as an error components model using maximum likelihood methods. The one-sided error term u_{it}, distributed as exponential, is a nonnegative random variable independently distributed with truncation at zero of the $N(m_{it},\sigma_u^2)$ distribution,

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where $m_{it}=R_{it}\delta$, R_{it} is a vector of farm efficiency determinants (assumed to be the factors in the R vector), and δ is a vector of estimable parameters. The random (white noise) error component v_{it} is assumed to be independently and identically distributed, $N(0,\sigma_v^2)$. Estimated using SPF techniques, TE is characterized assuming a radial contraction of inputs to the frontier (constant input composition).

Productivity impacts (marginal productive contributions, MPC) of outputs or inputs can be estimated by the first order elasticities, $MPC_m = -\varepsilon_{DI,Ym} = -\partial\ln D^I(X,Y,R)/\partial\ln Y_m = \varepsilon_{X1,Ym}$ and $MPC_k = -\varepsilon_{DI,X*m} = -\partial\ln D^I(X,Y,R)/\partial\ln X*_k = \varepsilon_{X1,X*k}$. MPC_m indicates the increase in overall input use when output expands (should be positive, like a marginal cost or output elasticity measure), and MPC_k indicates the shadow value (Färe and Primont 1995) of the kth input relative to X_1 (should be negative, like the slope of an isoquant). Similarly, MPCs of structural factors, including soil texture (TEXT), water holding capacity (WATHCA), and pasture acres (PAST) can be measured through the elasticities, $MPC_{Rq} = -\varepsilon_{DI,Rq} = -\partial\ln D^I(X,Y,R)/\partial R_q = \varepsilon_{X1,Rq}$. If $\varepsilon_{X1,Rq} <0$, increased R_q implies less input is required to produce a given output, and vice versa.

Scale economies are calculated as the combined contribution of the M outputs Y_m, or the scale elasticity $SE = -\varepsilon_{DI,Y} = -\Sigma_m\partial\ln D^I(X,Y,R)/\partial\ln Y_m = \varepsilon_{X1,Y}$. That is, the sum of the input elasticities, $\Sigma_m \partial\ln X_1/\partial\ln Y_m$, indicates the overall input-output relationship, and thus RTS. The extent of scale economies is thus implied by the shortfall of SE from 1; if SE<1, inputs do not increase proportionately with output levels, implying increasing RTS. Previous studies on dairy farm efficiency using ARMS have found significant economies of size (Tauer and Mishra 2006; Mosheim and Lovell 2009; Mayen et al. 2010).

Finally, TE "scores" are estimated as $TE = \exp(-u_{it})$. Impacts of changes in R_q on TE can also be measured by the corresponding δ coefficient in the inefficiency specification for - u_{it}. PASTURE is a dummy variable indicating cows receive >25% of their forage needs from pasture during the grazing season. ORGANIC is a dummy variable indicating the operation is either organic or transitioning to organic. It is assumed that the inefficiency effects are independently distributed and u_{it} arise by truncation (at zero) of the exponential distribution with mean μ_{it}, and variance σ^2.

Input endogeneity has been a concern in the estimation of input distance functions; if found, biased estimates result. Some studies have used instrumental variables to correct the problem, while others have argued either that (1) it was not problematic in their studies because random disturbances in production processes resulted in proportional changes in the use of all inputs (Coelli and Perelman 2000, Rodriguez-Alvarez 2007) or (2) no good instrumental variables existed, thus endogeneity was not accounted for (Fleming and Lien 2010). We estimate instruments for each of the inputs. The Hausman test was used to test for endogeneity. Since endogeneity was found, the predicted values are used as instruments in the SPF.

In addition to endogeneity concerns associated with SPF inputs, selection bias may be of concern. Since organic producers self-select into organic production, they may have been more or less productive than non-organic farmers regardless of whether or not they had opted to produce organic milk. Mayen et al. (2010) corrected for organic dairy selection bias by using propensity score matching, while McBride and Greene (2009) corrected for it by estimating the inverse Mills ratio in a first-stage probit equation and including it in a second-stage profit equation. Both drop some farms from their analyses, such as "mixed" (produce both organic and non-organic milk) and transitional (converting from non-organic to

organic). Our probit selection equation included similar variables to those used by McBride and Greene (2009). The inverse Mills ratio was significant in the SPF, suggesting selection bias. Thus, it was included in the SPF as a correction for organic selection bias.

Using ARMS Data to Estimate an SPF

Since complex stratified sampling is used with ARMS, inferences regarding variable means for regions are conducted using weighted observations. As discussed by Banerjee et al. (2010), the ARMS is a multiphase, non-random survey, so classical statistical methods may yield naïve standard errors, causing them to be invalid. Each observation represents a number of similar farms based upon farm size and land use, which allows for a survey expansion factor or survey weight, effectively the inverse of the probability that the surveyed farm would be selected for the survey. As such, USDA-NASS has an in-house jackknifing procedure that it recommends when analyzing ARMS data (Cohen et al. 1988; Dubman 2000; Kott 2005), which allows for valid inferences to the population. Thus, econometric estimation of SPF models presents unique challenges when using ARMS data. The SAS QLIM procedure was used to estimate SPF models. We use the jackknife replicate weights in SAS to obtain adjusted standard errors. A property of the delete-a-group jackknife procedure is that it is robust to unspecified heteroscedasticity.

The USDA version of the delete-a-group jackknife divides the sample into 15 nearly equal and mutually exclusive parts. Fifteen estimates of the statistic (replicates) are created. One of the 15 parts is eliminated in turn for each replicate estimate with replacement. The replicate and the full sample estimates are placed into the jackknife formula:

(2)   Standard Error $(\beta) = \{14/15\sum_{k=1}^{15}(\beta_k - \beta)^2\}^{1/2}$

where β is the full sample vector of coefficients from the Frontier 4.1 program results using the replicated data for the "base" run. β_k is one of the 15 vectors of regression coefficients for each of the jackknife samples. The t-statistics for each coefficient are computed by dividing the "base" run vector of coefficients by the vector of standard errors of the coefficients.

Farm Categories for Comparison

Eight combinations of size and organic status are compared in this study. Farms are first divided into organic and non-organic categories, based upon whether the farm sold organic milk or it was transitioning to organic. Since our self-selection inverse Mills ratio was non-significant in the SPF, we are able to make direct comparisons of efficiency measures based upon self-identification of organic status. Given the wide range in the size distribution of intensive non-organic farms, this category is further broken into the following size categories for organic: <65 cows, 65 – 189 cows, and ≥190 cows; and for non-organic: <100 cows, 100-499 cows, 500-999 cows, 1,000-2,499 cows, and ≥2,500 cows. These size categories allow for comparisons of productivity, financial, and environmental measures by size and organic status. The resulting categories can be compared on the basis of not only TE and SE, but also on other economic and productivity measures.

Results

Stochastic Frontier Results

Table 1 shows stochastic frontier estimates. Other than for livestock, measures of outputs have the correct signs, but all are non-significant. Coefficients for inputs have the expected negative signs. The δ_U sign is positive and significant. The coefficient for PASTURE is significant and negative, indicating that pasture reliance (relative to intensive) increases input usage for a given output level. In addition, the productive impact of pasture ($\gamma_{YLIVE,PAST} = 0.0102$) is significant, though reversed in sign, indicating that increased pasture

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use decreases the productive contribution of (increases the inputs required for) livestock. Neither ORGANIC nor the inverse Mills ratio is significant, so we have no evidence that productivity results are influenced by selection bias. We also find positive, significant $\beta_{YCROP,YCROP}$ coefficients, suggesting increasing RTS in all models. These results show not only the importance of scale efficiency, but also provide support for the model. From Table 2, note that MPCs of outputs and inputs have the correct signs, positive for outputs and negative for inputs, though few are significant.

Comparisons by Category

Table 3 presents farm characteristics and economic measures by organic status and size. The category representing the largest number of farms is the non-organic category with <100 cows; the smallest category is that of organic farms with ≥190 cows. The Non-organic 100 ≤ Cows < 500 farms produced the most milk, while Organic <65 Cows farms produced the least. Pasture use decreased for both organic and non-organic farms as farm size increased; the highest usage was 1.72 acres/cow for Organic <65 Cows and the least was for Non-organic ≥2,500 Cows, at 0.03 acres/cow. Milk per cow generally increased with size for both organic and non-organic farms; organic farms produced less milk per cow than non-organic farms.

Purchased feed costs per cow were lowest for smaller-scale operations, likely because of increased pasture and homegrown feed use. As a result, within size category, differences were not shown by organic status. Variable cost per hundredweight of milk produced was highest for small organic farms, decreasing with size within that system. Variable costs per hundredweight of milk produced also declined with size for non-organic farms. Net return on assets was highest for large-scale non-organic farms. Larger-scale operations showed higher debt relative to assets; they were more highly leveraged.

Technical efficiency increased with size in the organic category, but not for non-organic farms. Returns to scale increased with size for both organic and non-organic farms, showing evidence of economies of size in U.S. milk production.

Conclusions

The ARMS design allowed us to sort dairy farms into organic / non-organic systems and expand the observations to the U.S. dairy farm population to examine relative competitiveness. Our frontier estimates are robust in correcting for endogeneity, selectivity bias, and survey design. Hence we can legitimately make statistically valid inferences to the population of dairy farms surveyed in 2005 and 2010. The general conclusion is that, in terms of economic viability, size of operation matters. Large farms economically outperformed smaller farms in most system / organic status categories, evidenced by RTS and profitability measures. And we find that our organic farms grouped as less than 65 cows and 65 to 190 cows are competitive with nonorganic farms with less than 500 cows. However, industrial organic farms of greater than 190 cows experienced low returns.

Despite finding differences in a number of productivity measures and RTS, differences in TE were not great among farms by organic status or size. This is not too surprising, considering (1) those with lower milk production per cow are expected to be generally lower-input (though variable cost per cwt milk comparisons do not substantiate this), and (2) with significant exit of dairy farms, few new entrants, and the assumed lack of economic profit associated with an industry that is "close" to purely competitive, firm survival within this developed industry requires attention to TE, regardless of scale or system.

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Future research will further examine differences in 2005 and 2010 dairies, recognizing that the economic environment in which organic dairy farms were operating in 2010 was different from that in 2005. We will also look further into differences by system, i.e., pasture-based versus confined systems.

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Footnotes

1. States and designated regions included are Northeast: ME, NY, PA, VT; Lake States: MI, MN, WI; Corn Belt: IL, IN, IA, MO, OH; Appalachia: KY, TN, VA; Southeast: FL, GA; Southern Plains: TX; Northern Plains: KS (2010 only); Mountain West: AZ, CO (2010 only), ID, NM; Pacific: CA, OR, WA.

2. By definition, linear homogeneity implies that $D^I(\omega X, Y, R) = \omega D^I(X, Y, R)$ for any $\omega > 0$; so if ω is set arbitrarily at $1/X_1$, $D^I(X, Y, R)/X_1 = D^I(X/X_1, Y, R)$.

Table 1. Input Distance Function Parameter Estimates, 2005-2010 Frontier

Variable	Parameter (t-test)
α_0	10.3634 (3.75)***
α_{XLAB}	-1.9551 (-1.17)
α_{XMISC}	-0.8293 (-1.29)
α_{XCAP}	-0.1567 (-0.21)
β_{YCROP}	0.0359 (0.13)
β_{YLIVE}	-0.0207 (-0.08)
β_{YOFF}	0.1553 (0.52)
$\beta_{YCROP,YCROP}$	0.0250 (1.85)*
$\beta_{YLIVE,YLIVE}$	0.0277 (1.38)
$\beta_{YOFF,YOFF}$	-0.0037 (-0.62)
$\beta_{YCROP,YLIVE}$	-0.0282 (-2.32)**
$\beta_{YCROP,YOFF}$	-0.0041 (-1.42)
$\beta_{YLIVE,YOFF}$	-0.0052 (-0.32)
$\gamma_{YLIVE,TEXT}$	-0.0078 (-1.10)
$\gamma_{YLIVE,WATHCA}$	0.0003 (0.03)
$\gamma_{YLIVE,PAST}$	0.0102 (2.56)**
$\alpha_{XLAB,XLAB}$	0.1781 (0.40)
$\alpha_{XMISC,XMISC}$	-0.0559 (-0.48)
$\alpha_{XCAP,XCAP}$	-0.0724 (-0.76)
$\alpha_{XLAB,XMISC}$	0.3249 (1.29)
$\alpha_{XLAB,XCAP}$	-0.0102 (-0.03)
$\alpha_{XMISC,XCAP}$	0.1112 (0.46)
$\alpha_{XPASTURE}$	-0.5709 (-4.02)***
$\alpha_{XORGANIC}$	0.1369 (0.62)
α_{XIMR}	0.1634 (0.41)
$\delta_v^{\,2}$	0.3774 (10.77)***
$\delta_u^{\,2}$	0.5283 (4.53)***

Notes: *** Significance at the 1% level (t=2.977), ** Significance at the 5% level (t=2.145), and * Significance at the 10% level (t=1.761).
Source: USDA Agricultural Resource Management Study. USDA (2005, 2010).
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Table 2: MPC's for Outputs and Inputs and Return to Scale (t-statistics in Parentheses)

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MPC$_{YCROP}$	*0.064*	*(1.79)***	MPC$_{XLAB}$	*-0.035*	*(-0.03)*
MPC$_{YLIVE}$	*0.380*	*(2.41)***	MPC$_{XMISC}$	*-0.705*	*(-1.01)*
MPC$_{YOFF}$	*0.001*	*(0.11)*	MPC$_{XCAP}$	*-0.166*	*(-1.44)*
RTS	*0.446*	*(2.99)****	MPC$_{XOLND}$	*-0.094*	*(-0.08)*

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Notes: *** Significance at the 1% level (t=2.977). ** Significance at the 5% level (t=2.145).
* Significance at the 10% level t =1.761).
Source: USDA Agricultural Resource Management Study. USDA (2005).
The t-statistics are based on 1,804 observations using weighting techniques described in Dubman's CV15 program.

Table 3. Characteristics of Farms Including Technical Efficiency and Returns to Scale, by Organic Status and Size, 2005 and 2010 ARMS Dairy Survey.

Item	Group							
	Organic <65 Cows	Organic 65≤ Cows <190	Organic ≥190 Cows	Non-organic <100 Cows	Non-organic 100≤ Cows <500	Non-organic 500≤ Cows <1,000	Non-organic 1,000≤ Cows <2,500	Non-organic ≥2,500 Cows
No. Observations	616	255	71	1,112	1,183	256	190	68
No. Farms	3,666	1,549	290	63,520	26,307	3,033	1,806	531
% Value of Production	0.7	0.8	1.1	19.3	31.8	12.9	20.3	13.2
Cows per Farm	39.3	94.2	659.0	49.6	177.8	639.3	1,408.7	4,090.4
Pasture Acres per Cow	1.72	1.22	0.67	0.69	0.36	0.07	0.09	0.03
Milk per Cow, lbs/yr	12,252.0	13,084.6	16,207.9	18,005.1	20,709.7	23,792.6	23.658.4	23,404.1
Cost Purch Feed / Cow	778.92	737.94	1,561.67	789.55	1,080.35	1,408.77	1,547.91	1,567.47
Variable Cost per cwt Milk	26.49	16.15	15.27	15.42	10.61	8.96	9.00	8.66
Net Return on Assets	0.049	0.058	0.034	0.040	0.050	0.077	0.098	0.126
Household returns	0.071	0.075	0.022	0.059	0.067	0.102	0.126	0.159
Milk Price per cwt	21.30	22.50	20.10	16.20	16.00	16.00	15.60	14.90
Debt-Asset Ratio	0.14	0.15	0.26	0.11	0.17	0.27	0.31	0.38
Technical Efficiency	0.65	0.72	0.76	0.66	0.69	0.63	0.54	0.48
Returns to Scale	0.47	0.50	0.54	0.46	0.50	0.53	0.53	0.57