Evaluation of Dairy Farm Technical Efficiency: Production of Milk Components as Output Measures

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Abstract

Under the Federal Milk Marketing Order (FMMO) and California milk pricing systems, minimum milk values are determined by the value of components important in dairy product manufacturing. This implies that milk values will vary across farms due to different solids composition (fat, protein and other solids) delivering to the same processing plant. Milk composition can be managed by farm operators by a number of management activities such as: breed choice, number of lactations to keep a cow in the milking herd, ration formulations, feeding management, whether to milk 2 or 3 times daily, and cow comfort. Given the milk pricing systems used for a majority of raw milk in the U.S., dairy farm operators are faced with an environment of maximize profits via a multi-output production function, (i.e., production of milk components). Previous analysis of dairy farm efficiency has typically used the total amount of milk produced (cwt of lbs) as a measure of output, not the production of its components. In this paper, we use hedonic aggregation functions to generate output indices in the evaluation of an input-oriented distance function.

We use data from the 2005 USDA Agricultural Resource Management Survey (ARMS)-Dairy Survey for this analysis. A unique feature of the 2005 survey is that it contains information on the annual amount of milkfat and protein produced by the milking herd. From this analysis we find that the estimated technical efficiency when using component amounts as output measures has less variance, but larger range, compared to the method using milk yield as output. A majority of dairy operations generate technical efficiency measures of more than 9.0 (with 1.00 being the possible maximum.

Keywords: Quality adjustment productivity, Technical Efficiency, Dairy Production.

I. Measuring the Output of U.S. Dairy Farms

Dairy producers whose processors participate in the Federal Milk Marketing Order (FMMO) and California fluid milk programs are faced with minimum milk value being based on milk solids density i.e., multiple-component pricing (MCP) system. A substantial proportion of minimum milk price depends on the valuation milk fat, protein, and other dairy solids contained in one hundred pounds of milk along with how the milk is used in the marketing orders. In other words, one hundred pounds of milk (e.g., a cwt) may have different values due to variations in components across farms, even for farms that sell their raw milk to the same processor. These component values are derived from wholesale manufactured dairy product prices whose yields are highly dependent on these components. The products used to determine component values include cheddar cheese, butter, nonfat dry milk and dry whey. The exact method used to determine minimum milk value depends on the product for which the raw milk is used as an input (Jesse and Cropp, 2008).

Since milk component composition determines milk value, these components and their anticipated values should be part of any examination of production decisions/outcomes observed for U.S. dairy farms. Many factors can affect milk composition, such as cattle breed, seasonality, number of previous lactations the cow has been in the milking herd, the number of times per day a cow is milked and feeding/ration decisions (Manchester and Blayney, 2001). In addition, genetic selection has had a significant impact on milk composition (Roibas and Alvarez, 2012). In 2012, average annual milk production for Holstein cows contained in the Dairy Herd Improvement Association (DHIA) data base was estimated to be 23,385 pounds while the Jersey breed yield was estimated to be 16,997 pounds (Kasbergen, 2013). In contrast to the total weight of milk produced, a Jersey cow typically has higher levels of milk components. The average percentage of fat and protein for Holsteins is 3.8% and 3.1%, respectively whereas Jersey cattle averaged 4.8% and 3.7% (Capper and Cady, 2012). In other words, when making production decisions, farmers may tradeoff between physical yield and the amount of milk solids.

Besides impacting milk composition by the breed choice, in the long-run

producers can also adjust management practices like the choice of feed. The simulation results from Bailey (2005) indicate that nutritional change can alter the percentage of fat by 1%. This is especially significant for herds that are below average in fat content.[1] Therefore, the total amount milk produced and the production of fat, protein and other solids are important factors influencing the allocation of inputs across dairy farm enterprise.

Previous evaluations of dairy farm productivity have typically used the volume of raw milk as the output measure without adjusting this physical quantity for differences in component yields. It is our contention that ignoring the true source of milk value will lead to the misspecification of any productivity evaluation. For instance, assume we have two farmers who use exactly the same amount of inputs to produce the same amount of milk by weight, but one farmer produces milk with higher density of components for whatever reason. Due to the component pricing of raw milk, farmers with higher component levels per cwt of milk will receive higher revenue than the producer whose milk has lower component amounts. The traditional method of estimating technical efficiency is not able incorporate this output difference caused by variable quality, i.e., component amounts. The bottom line is that the effective milk output measure should depend on not only on weight of the milk produced but also on the attributes of this milk. For this analysis we adjust our output measure by controlling for milk composition. This standardization makes it possible to adjust our productivity measurement based on milk quality not just quantity.

Figure 1 shows the distribution of the monthly Class III milk price coming from the value of the associated with fat, protein and other solids for milk with standard composition.[2] Class III milk under the FMMO system pertains to the pricing of milk used for cheese manufacturing. In 2005, on average milkfat and protein accounted for 94.8% of the value of Class III milk. Given data limitations we only have information on the amount of fat and protein produced in 2005

[1] Under the FMMO system, standard milk is defines as having 3.5% fat.
[2] Standard milk is composed of 3.5% fat with the skim portion being composed of 3.1% protein and 5.9% other solids.

Our objective of incorporating milk quality as a factor in milk output is to gain the unbiased estimation of a dairy operation's technical efficiency. To do so, we use hedonic functions to generate an aggregate output index with explicit incorporation of production of multiple components and then apply it to an input-oriented distance function to estimate dairy farm technical efficiency. An application of our multi-output efficiency analysis is illustrated by our use of the 2005 USDA Agricultural Resource Management Survey (ARMS)-Dairy Survey database. A unique feature of that year's ARMS data is that it contains information on milkfat and protein produced, which allows us to obtain the production of milk component composition.[3] When correcting for unobserved prices and demand shocks, the estimated technical efficiency has less variance, but larger range. More producers have efficiency greater than 0.9 when compared to the most efficient producers.

This analysis improves upon previous studies in several respects. From a methodical perspective, we use an aggregated hedonic function to generate an output index from multiple milk components. To our knowledge, such an analysis has not been undertaken for the U.S. dairy industry. A translog functional form is used as the basis of the hedonic function, which allows endogenous weights to differ between components produced. In terms of data, the ARMS data set contains detailed information of milk component production and input use specific to the dairy enterprise. Compared to analyses of productivity with quality-adjustment for other kinds of products, milk production has the advantage that we can identify all the attributes that affect the value of milk, since the multiple-component pricing system provides comprehensive indexes for evaluating milk quality. That is, we can create a standardized milk output of milk by controlling for difference of these components.

In Section 2 of this paper, the theoretical model of a multiple output distance function is developed. In Section 3, we provide an overview of the data used in the analysis. Section 4 is used to specify the empirical model and presents the empirical result. Finally, our conclusions and suggestions for future research are presented in

[3] The 2010 version of the ARMS data did not have this component information. It is unknown when the next dairy targeted ARMS survey will be undertaken. Dairy centered surveys were undertaken in 2010, 2005 and 2000.

Section 5.

II. How Can We Measure Technical Efficiency in Milk Component Production?

We use an input-oriented distance function to evaluate the technical efficiency of a sample of U.S. dairy farms. In the derivation of our technical efficiency measure we employ a hedonic output aggregator function to generate an output index with explicit incorporation of production of multiple components. The method we use allows us to estimate the parameters of the output aggregator simultaneously with the parameters of the distance function.

2.1 The Hedonic Aggregator Function

Hedonic aggregator functions are used to create an aggregator of effective outputs of a multiple product firm. The hedonic aggregate output function used in this analysis can be represented via the following:

(1) $$\ln\psi(\mathrm{y}) = \sum_{i=1}^{M}\theta_i \ln y_i + \frac{1}{2}\sum_{i=1}^{M}\sum_{j=1}^{M}\gamma_{ij}\ln y_i \ln y_j$$

Where y is a vector of M outputs. To allow for the data to determine the exact shape of the aggregator function, we specify the function ψ(·) to be translog with respect to levels of components produced. This functional form was used by Kumbhakar and Hjalmarsson (1998) in their analysis of the electricity retail sector. This functional form is flexible and allows estimated coefficients to represent the relative weight of each output. For parameter identification purposes, we must impose parameter restriction. We assume the hedonic aggregate function to be symmetric ($\gamma_{ij} = \gamma_{ji}$) and homogenous of degree one ($\sum_{i=1}^{M}\theta_i = 1$ and $\sum_i \gamma_{ij} = 0$ for $\forall j$) with respect to outputs. For hedonic aggregate function with two outputs (M=2), the restrictions can be specified as follows:

$$\theta_1 + \theta_2 = 1; \gamma_{12=}\gamma_{21}; \gamma_{11} + \gamma_{21} = 0; \gamma_{12} + \gamma_{22} = 0$$

$$\Rightarrow \theta_2 = -\theta_1 \text{ and } \gamma_{11} = -\gamma_{12} = -\gamma_{21} = \gamma_{22}.$$

Hence, only two parameters (θ_1 and γ_{11}) need to be estimated to figure out the hedonic function. This specification will be applied in the empirical estimation section.

2.2 The Input Distance Function

Parametric and non-parametric distance functions are widely used when measuring technical efficiency due to their general ability to the distance function concept can be applied to multi-input or multi-output production technologies. In this analysis we define the input distance function as the maximum amount by which the input vector **x** could be radially reduced while remaining feasible to produce a given amount of output vector **y** (Coelli, Rao and O'Donnell, 1998).

(2) $$D_I(y,x) = \max\left\{\lambda : \frac{x}{\lambda} \in L(y)\right\}$$

Where $L(y) = \max\left\{\lambda : \frac{x}{\lambda} \in L(y)\right\}$ denotes the set of input vectors that are feasible to produce output vector **y**. The parameter λ represents ratio of actual inputs with the inputs in the frontier production and **x** represents the vector of inputs.

Figure 2 is used to show an example where two inputs, x_1 and x_2, are used to produce one output y. Hence, the input set, L(y), is the shaded space above the isoquant of output, Isoq-P(y). For a combination of inputs represented by point B (x_1^*, x_2^*), point A is achieved by projecting B from the origin along the isoquant which results in A is the corresponding fully efficient point.

The value of distance function is equal to the ratio $D_I(\mathbf{y},\mathbf{x}) = \lambda = \frac{OB}{OA}$. The parameter λ denotes the degree of inefficiency, since $\lambda - 1 = \frac{\mathrm{BA}}{\mathrm{OA}}$ is the percentage of input overused in order to produce a given amount of output. We can define the technical inefficiency as: $\mu \equiv ln\,\lambda \geq 0$, then

(3) $$D_I(y,x) = \lambda = e^u \Rightarrow \ln D_I(y,x) - u = 0$$

Imposing the assumption that $D_I(y,x)$ is homogenous of degree 1 in input **x**, we obtain:

(4) $$-\ln x_1 = \ln D_I(y,\tilde{x}) - u$$

Where $\tilde{x} = \left(\tilde{x}_2, \tilde{x}_3, ..., \tilde{x}_N\right) = \left(\frac{x_2}{x_1}, ..., \frac{x_N}{x_1}\right)$ and N is the number of inputs. We can represent the parametric distance function via the translog functional form. The stochastic version of this distance function with N inputs and M outputs can be represented via the following:

$$
\begin{aligned}
-\ln x_1 = \alpha_0 + \sum_{j=2}^{N} \alpha_j \ln \tilde{x}_j + 0.5 * \sum_{j=2}^{N}\sum_{k=2}^{N} \alpha_{jk} \ln \tilde{x}_j \ln \tilde{x}_k + \sum_{m=1}^{N} \beta_m \ln\left(y_m\right) \\
+ 0.5 * \sum_{m=1}^{M}\sum_{n=1}^{M} \beta_{mn} \ln\left(y_m\right) \ln\left(y_n\right) + \sum_{j=2}^{N}\sum_{m=1}^{M} \xi_{jm} \ln \tilde{x}_j \ln\left(y_m\right) + \varepsilon
\end{aligned}
\tag{5}
$$

Where ε=v-u. u and v are error terms. We assume error term u_i is independently and truncated normally distributed with mean η and variance σ_u^2, $u_i \sim N^+(\eta_i, \sigma_u^2)$. Following the method used by Battese and Coelli (1995), we set $\eta_i = \delta Z_i$, where Z_i is a vector of exogenous explanatory variables associated with technical efficiency. δ is a set of parameters to be estimated. The system noise error term v_i has the following distribution: $v_i \sim N(0, \sigma_v^2)$. We also assume the error terms u_i and v_i are independent.

When we incorporate hedonic aggregate output function as one of the outputs into the distance function, we obtain the following:

$$
\begin{aligned}
-\ln x_1 = \alpha_0 + \sum_{j=2}^{N} \alpha_j \ln \tilde{x}_j + 0.5 * \sum_{j=2}^{N}\sum_{k=2}^{N} \alpha_{jk} \ln \tilde{x}_j \ln \tilde{x}_k + \beta_1 \ln \psi\left(y\right) + \beta_2 \ln y_r + \sum_{j=2}^{N} \xi_{j1} \ln \tilde{x}_j \ln \psi\left(y\right) \\
+ \sum_{j=2}^{N} \xi_{j2} \ln \tilde{x}_j \ln y_r + 0.5 * \beta_{11} \ln \psi\left(y\right) \ln \psi\left(y\right) + \beta_{12} \ln \psi\left(y\right) \ln y_r + 0.5 * \beta_{22} \ln y_r \ln y_r - u + v
\end{aligned}
\tag{6}
$$

Where ψ(y) is aggregate output from milk components and y_r is output of revenue from livestock. Four inputs are incorporated, which will be specified in the following section.

2.3 Specification of Maximum Likelihood Estimation

Equation (1) and (6) are estimated simultaneously via the use of maximum likelihood (ML) methods. Similar as Belotti (2013) in their stochastic frontier analysis, the log-likelihood function for a single observation can be represented via the following:

(7) $$L_i = \left\{ -\frac{1}{2}\ln(2\pi) - \ln\sigma_s - \ln\Phi(\frac{\eta_i}{\sigma_s\sqrt{\gamma}}) + \ln\Phi\left[\frac{(1-\gamma)\eta_i - \gamma\varepsilon_i}{\left\{\sigma_s{}^2\gamma(1-\gamma)\right\}^{\frac{1}{2}}}\right] - \frac{1}{2}(\frac{\varepsilon_i + \eta_i}{\sigma_s})^2 \right\}$$

Where $\sigma_s = (\sigma_u^2 + \sigma_v^2)^{1/2}$, $\gamma = \sigma_u^2/\sigma_s^2$, $\eta_i = \delta Z_i$, $\varepsilon_i = v_i - u_i$ and $\Phi(\cdot)$ is the standard normal cumulative distribution function. Belotti (2013) also show that a measure of technical efficiency under the truncated normal distribution model via the following:

(8) $$TE_i = E\left\{\exp(-u_i \mid \varepsilon_i)\right\} = \left\{\frac{1-\Phi(\sigma_* - \frac{\eta_{*i}}{\sigma_*})}{1-\Phi(-\frac{\eta_{*i}}{\sigma_*})}\right\} * \exp(-\eta_{*i} + \frac{1}{2}\sigma_*{}^2)$$

Where $\eta_{*i} = \frac{-\varepsilon_i\sigma_u{}^2 + \eta\sigma_v{}^2}{\sigma_s{}^2}$ and $\sigma_* = \frac{\sigma_u\sigma_v}{\sigma_s}$.

III. Description of Dairy Farm Data

Our objective is to examine the productivity characteristics of U.S. dairy farms using the above modeling framework. We use the 2005 USDA Agricultural Resource Management Survey (ARMS)-Dairy Component for our analysis. The ARMS survey contains data on a nationally representative sample of U.S. dairy farms. It contains information about farm and operator characteristics, cost, returns, production and management activities (Dubman, 2000). A unique feature of the 2005 survey was that that it was collected with respect to total annual milk production but also the average component composition of that production. The presence of these measures of output enables us to generate an output index from multiple milk components.

Variables used in the estimation are listed in table 1. In the estimation of milk production technical efficiency, we employ three outputs measures (fat yield, protein yield and revenue from cattle sales) and four inputs measures (labor, feed, capital cost and other variable cost). Pasture-based dairy production has advantage in reducing feed cost and negative effect on milk yield (Dong, 2013), hence we incorporate a dummy variable for pasture-based dairy system, pasture25, which is 1 when the total forage ration from pasture during the grazing months is more than 25% and takes value 0

otherwise. Variables for production regions are also adopted. Eight farm production regions[4] are classified, which is specified in figure 1. Hence, we incorporate seven dummy variables for the production regions.

We notice that the size of dairy farms has significant variability across different production regions. Table 2 and table 3 presents the descriptive statistics of variables used in the estimation for the sample by herd size and by production regions. All the variables are normalized by the average number of active milking cows. The average herd size is 129 cows, for regions like Appalachia, Corn Belt, Lake State and Northeast, the number of milk cows are less than 100, while the herd size in Mountain and Pacific region are respectively 656 and 684. These different herd sizes may result in region-specific production management and output profiles across.

The annual per cow milk yield was found to be 19,455 lbs, fat yield was 716 lbs (3.65%) and 561 lbs (2.84%) of protein. Table 2 indicates that milk yield increases along with herd size, larger farms intend to have high level of milk output. However, as for milk components composition, farms with middle size have the highest percentage of fat and protein (3.68% and 2.89%), while farms with more than 750 cows have the lowest (3.44% and 2.74%). Table 3 shows that Pacific and Lake State regions have relatively high production levels compared to Appalachia and the Southern Plains. The distribution for milk components are different with milk production, which results that regions with higher level of milk yield may not be productive in milk components. For instance, Corn Belt ranks high in milk yield, while lower than average in component production.

There is also significant variability in the level of inputs used. The labor force devoted per cow in dairy production in 2005 is 98.43 hours with 24.98 hours from paid labor and 75.02 hours from unpaid labor. For Pacific and Southern Plain, labor hours are respectively 56.17 and 43.83 hours. Farms with less than 125 cows devote 112 hours of labor for each cow, which is more than two times for larger farms. The majority of labor force are unpaid labor like operator and family members, while large farms use paid labor for most of production.

[4] The production regions are classified as Appalachian, Corn Belt, Lake States, Mountain, Northeast, Pacific, Southern and Southern Plains.

Feed use is converted to the feeding of total digestible nutrients (TDN) according to conversion coefficients found in McGregor (1989). TDNs represent the sum of digestible fiber, protein, lipid, and carbohydrate components of a feedstuff or feed ration. TDN is directly related to digestible energy and is often calculated based on acid detergent fiber (ADF) content. The TDN of feed use for each cow on average is 1530.57 cwt, ranging from 416.64 cwt in Southern area to 4664.36 in Corn Belt and 4958.12 cwt in Southern Plain area. The allocation in purchased and homegrown feed is different across regions. For most regions, homegrown feed represents close to 2/3 of total TDNs fed. For the Mountain, Pacific and Southern Plain regions, the purchased represent approximately 50% of the amount of total feed. Those regions with a high proportion of purchased feed are with relatively large number of milking herds.

The capital cost includes expenditures on interest on operating capital, taxes and insurance, land and capital recovery of machinery and buildings used in dairy production. The average devoted per cow is $ 967.95. Capital cost decreases significantly as the herd size increases. For the Appalachian and Corn Belt regions capital cost are more than $1,000 dollars. For the Pacific and Southern Plain capital costs are $554.76 and $692.26.

Other variable cost is total of the variable expenses except for feed used per cow. It includes expenditures on bedding and litter, medical supplies and veterinary services, fuels and electricity, marketing containers, customer service, maintenance and repairs. The average cost is $642.35 and the variance is small across regions and herd size.

Table 4 and 5 presents characteristics of operators and dairy production and description about management practice. For operator and farm characteristic variables, most of the regional differences are not significant. Noticeably, the percentage of operators who have college degree varies from 11.81% in Corn Belt to 34.43% in Mountain. It also increases along with herd size, which may be correlated with adoption of technology and farm management skills. The dummy variable of Pasture-based equals one if more than 25% of the total feed is from pasture in pasture seasons of the year. The average of pasture-based is 0.3285, with relatively low value for Mountain and Southern regions (0.1241 and 0.1307). It is noticeable that farms with more than 360 milking cows mostly are not pasture-based (0.0963 and 0.0268).

There are more regional variances in the management practices of dairy production. For instance, adoption of technologies like milking seasonal dry-off varies from 0.0987 in Lake State to 0.7509 in Southern Plains. The use of udder washer is only 1.26% for Lake State, while for Pacific area is 61.14%. Those differences may contribute to the variation in technical efficiencies, which we will discuss later in this paper.

IV. Technical Efficiency of U.S. Dairy Farms

4.1 Estimation of Dairy Farm Distance Functions

We estimate the input distance function (eq. 6), which contains the hedonic aggregate function (eq. 1) whose value is used as our output measure. The parameters of the hedonic and input density functions are estimated simultaneously. The resulting parameter estimates are shown in Table 6. A majority of the parameters in the input distance function are statistically significant. In the hedonic function, the statistically significant coefficient for milkfat is 0.653 with standard error 0.252. Given the hedonic function symmetry and homogeneity restrictions, we can derive the parameter for protein is 0.347, for interaction term of fat and protein is -0.627 and for quadratic term of protein is 0.313[5].

4.2 Evaluation of Technical Efficiency

To compare our results with conventional methods of measuring technical efficiency, we estimate the input distance function using another two sets of outputs: (1) amount of milk yield (cwt/cow) and revenue from cattle ($/cow); (2) revenue from milk ($/cow) and revenue from cattle ($/cow).

The mean technical efficiency for the entire sample is 0.870 with a standard deviation of 0.074. Figure 3.1 is used to show the empirical distributions of technical efficiency. There is a significant right skewness of the efficiency values. We also estimate the kernel density for each herd size group and production region and present the

[5] By symmetric and homogenous restrictions specified in section 2.1, once estimate the parameters for Y_fat and Y_fat^2, we can obtain the rest parameters in hedonic aggregate function. Parameter for Y_protein = 1 – parameter for Y_fat; Parameter for Y_protein^2 = parameter for Y_fat^2; Parameter for Y_fat *Y_protein = –2* parameter for Y_fat^2.

results in Figures 3.2 and Figures 3.3. Table 7 is used to present a summary of the results of our technical efficiency measures by herd size. Farms with large number of milking herds tends to be more efficient. The minimum value of technical efficiency for farms with more than 750 cows is 0.924 and with a standard deviation is 0.009 which means that almost all large farms are relatively technical efficient in the sample. Farms with small scales have more variability in their technical efficiency measure. Table 8 is a summary of technical efficiency by production regions. The technical efficiency of Pacific region is the highest, followed by Southern and Southern Plains regions. Corn Belt region is relatively less efficient.

When comparing our result with ones from the other two conventional methods, we can see that in general, the mean of technical efficiency is relatively large and the standard deviation is relatively small. The skewness is negative and smaller, in other words, it's more right shifted. However, the difference is not that large and different across regions. For regions like Corn Belt, Mountain and Pacific, mean of TE using multi-output method is large than the other two methods, while for regions like Lake State and Southern, the difference is not significant. We conduct the logit model in the next section to investigate the influencing factors for the difference in the three methods.

V. Conclusion and Discussion

Farm milk is a differentiated product given that its solids concentration is what determines value. That is, a cwt of milk produced by two dairy farms located next to each other whose milk is sold to the same processing plant could have substantially different value if their milks' component compositions differ. As such, we incorporate milk quality (i.e. fat and protein composition) as a factor in milk output to obtain an estimate of the technical efficiency measures for the products that determine production value. We use hedonic functions to generate aggregate output indices with explicit incorporation of the above two components. We then use an input-oriented distance function to estimate dairy farm technical efficiency. An application of the above analysis is the use of the 2005 USDA Agricultural Resource Management Survey (ARMS)-Dairy Survey. A unique feature of 2005's ARMS data is that it contains information on milk component density (e.g., fat and protein), which allows us to obtain the production of

milk component amounts.

We find in this paper that when adopting the multi-output method, the mean of technical efficiency is 0.87, with standard deviation 0.074. Technical efficiency was found to vary by size of the dairy herd as well as across regions. Farms with larger sized herds tends to be more efficient. Dairy farms with more than 750 cows were estimated to have an average technical efficiency of 0.92 and with a standard deviation 0.009. thus we find that almost all relatively large dairy farms are efficient compared to smaller operations. Dairy farms located in the Pacific region had the highest average efficiency rated compared to the Corn Belt which was found to be relatively inefficient. This result is obviously related to the observed herd size differences.

The above analysis is a first pass at trying to obtain a better understanding of dairy farm efficiency. We plan on undertaking the following activities:

- *Incorporate additional output categories*: In this analysis, we only account for the production of milk components and revenue from livestock as dairy farm outputs. Crop revenue will also be added to the list of output categories. Because of the existence of over order volume premiums we should also add the cwt of milk produced as an output.
- *Account for Off-Farm Income*. It is well known that income from off-farm employment can represent a significant proportion of dairy farm household income. We will expand the outputs to include off-farm income. This changes the technical efficiency focus from the dairy farm to the dairy farm household.
- *Update and Improve data quality*: In the 2005 ARMS data, the breed of cows used on dairy farm was not collected. Breed selection is critical when examining the per cwt value of milk and associated components. We need to incorporate breed information into the model in some manner such a variable impacting feed productivity. The year 2005 was only 5 years after Federal Order Reform. This short time period and the lifecycle of a typical dairy cow may mean that the dairy sector had not fully adjusted to the structural change represented by these reforms. If that is the case, then using more current data will provide more accurate estimates of dairy farm efficiency under the new FMMO milk pricing system.

- *Account for Regional Heterogeneity*: The empirical results indicate that technical efficiency varies across region. After controlling for herd size, do we still see such regional differences. This regional heterogeneity will be incorporate to allow for the output indices and efficiency frontier parameters to vary geographically.

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Table 1. List of Variables Used in Estimation.

Variable Name	Units	Description
Y_fat	cwt/cow	Quantity of fat produced per cow
Y_protein	cwt/cow	Quantity of protein produced per cow
Y_cattles	$/cow	Revenue from sales of cattles, including cull cows, all milk cows, herfers for herd replacement, cull bulls, breeding bulls and other dairy calves
X_labor	hrs/cow	Total hours of paid and unpaid labor
X_feed	cwt/cow	TDN's feed, including purchased and homegrown feed
X_capital	$/cow	Total cost on capital used per cow ($/cow), including expenditures on interest on operating capital, taxes and insurance, land and capital recovery of machinery and buildings used in dairy production
X_othercost	$/cow	Total of the variable expenses except for feed used per cow ($/cow). It includes expenditures on bedding and litter, medical supplies and veterinary services, fuels and electricity, marketing containers, customer service, maintenance and repairs
Pasture25	0/1	Dummy variable for pasture ration: =1 if forage ration from pasture ≥ 25% during grazing season; =0 otherwise
rBST	%	Percent of milking herd received rBST
$ProdReg_j$	0/1	Dummy variable for jth producrion region (j=1-7), list of production regions is shown is figure 3

Table 2. Descriptive Statistics of Variables Used in Estimation by Herd Size.

	Whole Sample	Herd Size			
		(0, 125)	[125, 360)	[360, 750)	>=750
	(N=1814)	(N=962)	(N=494)	(N=184)	(N=174)
Milk Yield (cwt/cow)	194.55	186.77	218.72	239.71	240.08
	(4.37)	(5.99)	(3.20)	(5.09)	(4.90)
Fat Production (cwt/cow)	7.1652	6.8811	8.1186	8.8979	8.3101
	(0.1211)	(0.1582)	(0.1763)	(0.1960)	(0.2129)
Fat Percentage (%)	3.6560	3.6578	3.6771	3.6904	3.4360
	(0.0555)	(0.5941)	(0.1064)	(0.0308)	(0.0671)
Protein Production (cwt/cow)	5.6092	5.3772	6.4032	6.8665	6.6339
	(0.1270)	(0.1250)	(0.1575)	(0.2261)	(0.4774)
Protein Percentage (%)	2.8423	2.8361	2.8892	2.8557	2.7385
	(0.0793)	(0.0847)	(0.1081)	(0.0886)	(0.1841)
Revene from Milk ($/cow)	3008.49	2878.93	3459.15	3680.96	3573.03
	(93.47)	(115.67)	(111.33)	(99.54)	(110.58)
Revenue from Cattles ($/cow)	323.16	338.98	262.72	236.11	292.05
	(23.06)	(27.13)	(22.12)	(14.33)	(43.21)
Labor (hrs/cow)	98.43	112.01	50.00	37.47	35.30
	(5.63)	(4.67)	(2.11)	(4.44)	(6.75)
Paid Labor Percentage (%)	24.98	17.14	48.71	68.46	77.07
	(3.94)	(2.93)	(4.58)	(3.32)	(2.96)
Unpaid Labor Percentage (%)	75.02	82.86	51.29	31.54	22.93
	(3.94)	(2.93)	(4.58)	(3.32)	(2.96)
Feed TDN (cwt/cow)	1530.57	810.95	769.74	23682.19	2753.99
	(1207.54)	(1816.93)	(236.75)	(2753.99)	(1512.28)
Pruchased Feed Percentage (%)	29.11	26.83	32.33	50.41	57.64
	(5.70)	(4.15)	(14.96)	(3.86)	(4.17)
Homegrown Feed Percentage (%)	70.89	73.17	67.67	49.59	42.36
	(5.71)	(4.15)	(14.96)	(3.86)	(4.17)
Capital Cost ($/cow)	967.95	1042.81	730.32	593.20	490.33
	(24.52)	(19.87)	(35.89)	(22.60)	(39.77)
Other Variable Cost ($/cow)	642.35	640.27	663.78	673.05	543.86
	(31.25)	(35.59)	(35.97)	(30.28)	(39.08)

Table 3. Descriptive Statistics of Variables Used in Estimation by Production Regions.

	All Regions (N=1814)	Appalacian (N=204)	Corn Belt (N=287)	Lake States (N=360)	Mountain (N=113)	Northeast (N=441)	Pacific (N=219)	Southern (N=105)	Southern Plains (N=85)
Herd Size (cows)	129.27	84.77	93.11	83.86	659.94	87.83	683.98	373.45	343.61
	(12.76)	(4.64)	(6.81)	(5.99)	(1639.914)	(4.43)	(66.24)	(59.27)	(48.82)
Milk Yield (cwt/cow)	194.55	173.58	198.64	193.04	199.50	194.68	223.01	179.23	175.82
	(4.37)	(5.07)	(18.61)	(5.38)	(31.40)	(6.45)	(4.59)	(7.40)	(7.19)
Fat Production (cwt/cow)	7.1652	6.3250	6.6628	7.2264	7.3904	7.4179	8.1180	6.2573	6.1888
	(0.1211)	(0.2168)	(0.7674)	(0.2345)	(0.4282)	(0.2420)	(0.1775)	(0.4471)	(0.3768)
Fat Percentage (%)	3.6560	3.5757	3.4117	3.7089	3.6398	3.7466	3.6456	3.4756	3.4822
	(0.0555)	(0.0593)	(0.2566)	(0.0552)	(0.3879)	(0.0264)	(0.0796)	(0.1343)	(0.1756)
Protein Production (cwt/cow)	5.6092	3.1413	5.1997	5.6965	6.1685	6.0217	6.5452	5.2186	4.7219
	(0.1270)	(0.2053)	(0.6456)	(0.2325)	(0.2782)	(0.2047)	(0.3229)	(1.4771)	(0.4556)
Protein Percentage (%)	2.8423	1.7215	2.6070	2.9244	3.0456	3.0355	2.9176	2.9751	2.5815
	(0.0793)	(0.1126)	(0.2464)	(0.0704)	(0.3729)	(0.0581)	(0.1253)	(1.0181)	(0.2428)
Revene from Milk ($/cow)	3008.49	2755.32	2940.71	2971.11	2889.49	3120.33	3245.19	3260.48	2692.37
	(93.47)	(78.65)	(254.01)	(91.61)	(521.29)	(105.70)	(63.36)	(76.57)	(118.49)
Revenue from Cattles ($/cow)	323.16	414.01	394.64	338.40	351.38	259.41	284.33	180.90	211.75
	(23.06)	(119.70)	(83.11)	(29.95)	(188.32)	(23.96)	(34.06)	(23.69)	(33.26)
Labor (hrs/cow)	98.43	89.92	110.70	103.51	61.02	102.24	34.77	47.17	51.17
	(5.63)	(6.78)	(15.83)	(6.59)	(66.56)	(5.63)	(3.98)	(14.77)	(9.01)
Paid Labor Percentage (%)	24.98	30.19	19.51	23.47	50.33	21.49	56.17	38.69	43.47
	(3.94)	(3.71)	(2.36)	(1.67)	(32.69)	(2.61)	(1.97)	(12.29)	(4.53)
Unpaid Labor Percentage (%)	75.02	69.81	80.49	76.53	49.67	78.51	43.83	61.31	56.53
	(3.94)	(3.71)	(2.36)	(1.67)	(32.69)	(2.61)	(1.97)	(12.29)	(4.53)
Feed TDN (cwt/cow)	1530.57	1090.73	4664.36	526.40	1064.57	1376.86	874.59	416.64	4958.12
	(1207.54)	(546.94)	(6300.34)	(2217.90)	(2728.39)	(4608.25)	(356.08)	(272.14)	(2142.97)
Pruchased Feed Percentage (%)	29.11	35.91	28.44	20.88	60.28	30.91	59.85	71.92	66.68
	(5.70)	(4.07)	(2.92)	(3.41)	(41.64)	(3.95)	(3.69)	(10.27)	(5.80)
Homegrown Feed Percentage (%)	70.89	64.09	71.56	79.12	39.72	69.09	40.15	28.08	33.32
	(5.71)	(4.07)	(2.92)	(3.41)	(41.64)	(3.95)	(3.69)	(10.27)	(5.80)
Capital Cost ($/cow)	967.95	1101.79	1097.60	1010.30	748.75	906.28	554.76	692.26	783.91
	(24.52)	(44.53)	(54.24)	(26.63)	(632.89)	(34.01)	(40.09)	(131.62)	(41.41)
Other Variable Cost ($/cow)	642.35	596.35	629.99	605.99	522.65	748.49	520.69	581.93	528.54
	(31.25)	(67.55)	(30.44)	(23.31)	(90.64)	(62.20)	(23.41)	(30.60)	(39.35)

Table 4. Descriptive Statistics of Dairy Production Characteristics by Herd Size.

	Whole Sample	Herd Size			
		(0, 125)	[125, 360)	[360, 750)	>=750
	(N=1814)	(N=962)	(N=494)	(N=184)	(N=174)
Operator and Farm Characteristics					
Age of Operator	51.12	50.88	52.37	51.30	51.25
	(0.79)	(1.01)	(1.33)	(0.85)	(0.85)
College Education (%)	14.81	13.40	18.42	25.83	24.43
	(4.57)	(4.40)	(7.40)	(3.60)	(4.99)
Years in Dairy Production	23.42	23.44	24.18	22.17	19.58
	(0.69)	(0.80)	(2.33)	(1.26)	(1.16)
Pasture-based (1/0)	0.3285	0.3756	0.1785	0.0963	0.0268
	(0.0356)	(0.0359)	(0.0739)	(0.0233)	(0.0146)
Rented Land (%)	30.97	29.27	37.60	40.15	33.54
	(1.66)	(1.98)	(1.84)	(5.23)	(4.77)
Mangement Practices					
Use of rBST (%)	7.92	4.83	18.91	25.15	18.65
	(1.49)	(1.83)	(3.70)	(3.22)	(3.20)
Veterinary (1/0)	0.6827	0.6246	0.8975	0.9311	0.9265
	(0.0352)	(0.0481)	(0.0217)	(0.0169)	(0.0300)
Nutritionist (1/0)	0.7198	0.6769	0.8690	0.9408	0.9108
	(0.0302)	(0.0437)	(0.0153)	(0.0191)	(0.0238)
Seasonal dry-off (1/0)	0.2215	0.2089	0.2383	0.2315	0.5030
	(0.0671)	(0.0667)	(0.0802)	(0.0445)	(0.0545)
Milking automatic takeoffs (%)	37.11	24.03	86.07	91.73	88.63
	(2.14)	(2.56)	(5.67)	(2.13)	(4.08)
Udder Washer (%)	6.02	1.67	12.62	41.37	60.96
	(1.78)	(1.44)	(1.98)	(8.54)	(7.70)

Table 5. Descriptive Statistics of Dairy Production Characteristics by Production Regions.

	All Regions (N=1814)	Appalacian (N=204)	Corn Belt (N=287)	Lake States (N=360)	Mountain (N=113)	Northeast (N=441)	Pacific (N=219)	Southern (N=105)	Southern Plains (N=85)
Operator and Farm Characteristics									
Age of Operator	51.12	52.99	50.29	50.68	52.31	51.53	52.13	52.77	53.85
	(0.79)	(1.26)	(1.71)	(1.44)	(1.03)	(1.58)	(1.21)	(2.22)	(2.59)
College Education (%)	14.81	19.52	11.81	11.52	34.43	18.47	19.72	15.47	25.81
	(4.57)	(3.56)	(2.61)	(2.99)	(6.13)	(5.58)	(3.52)	(5.35)	(7.91)
Years in Dairy Production	23.42	24.90	22.76	23.17	21.56	24.61	21.02	18.72	23.29
	(0.69)	(1.48)	(2.16)	(1.41)	(2.62)	(1.51)	(1.23)	(1.31)	(2.01)
Pasture-based (1/0)	32.85	38.06	30.86	28.56	12.41	42.94	22.51	13.07	37.18
	(3.56)	(5.06)	(4.81)	(7.14)	(23.37)	(6.73)	(6.23)	(6.16)	(6.77)
Rented Land (%)	30.97	31.86	38.26	29.55	31.39	28.39	36.84	19.91	27.99
	(1.66)	(2.10)	(4.18)	(3.41)	(4.42)	(3.44)	(3.68)	(6.72)	(4.21)
Mangement Practices									
Use of rbST (%)	7.92	5.89	10.00	6.31	7.73	10.13	6.23	6.75	4.17
	(1.49)	(1.16)	(2.65)	(1.40)	(8.56)	(3.74)	(1.38)	(2.67)	(2.39)
Veterinary (1/0)	0.6827	0.7005	0.6642	0.6247	0.7319	0.7429	0.8557	0.7540	0.7220
	(0.0352)	(0.0393)	(0.0421)	(0.0489)	(0.2892)	(0.0559)	(0.0455)	(0.1001)	(0.0501)
Nutritionist (1/0)	0.7198	0.5560	0.7279	0.6934	0.7558	0.7787	0.7614	0.8014	0.6147
	(0.0302)	(0.0413)	(0.0514)	(0.0468)	(0.3798)	(0.0459)	(0.0375)	(0.0852)	(0.0562)
Seasonal dry-off (1/0)	0.2215	0.6424	0.3059	0.0987	0.4015	0.1926	0.4574	0.7222	0.7579
	(0.0671)	(0.0359)	(0.0727)	(0.0263)	(0.1492)	(0.0397)	(0.0478)	(0.1086)	(0.0809)
Milking automatic takeoffs (%)	37.11	41.63	33.89	34.95	42.26	29.68	91.25	67.42	55.75
	(2.14)	(4.63)	(5.52)	(4.15)	(16.19)	(5.32)	(3.48)	(12.50)	(0.0569)
Udder Washer (%)	6.02	7.63	1.51	1.26	31.38	3.34	61.14	39.46	12.17
	(1.78)	(3.17)	(0.71)	(0.48)	(75.45)	(1.76)	(6.27)	(15.17)	(6.71)

Table 6. Model Parameter Estimates.

Variable	Estimate	Std. Err.	Variable	Estimate	Std. Err.
Hedonic Aggregate Output Function $\psi(y)$			*Input Distance Function (Cont.)*		
Y_fat	0.6526**	0.2516	$\psi(y)$ * X_othercost	0.1767***	0.0466
Y_fat ^2	0.3134	0.4170	Y_cattles	-0.5008*	0.0294
Input Distance Function			Y_cattles ^2	-0.0086	0.0071
Constant	0.2377***	0.0496	Y_cattles * X_feed	0.0137	0.0164
X_feed	0.2067***	0.0331	Y_cattles * X_capital	-0.0144	0.0221
X_capital	0.2398***	0.0419	Y_cattles * X_othercost	-0.0170	0.0182
X_othercost	0.5046***	0.0354	Y_cattles * $\psi(y)$	0.0015	0.0359
X_feed ^2	0.0240**	0.0121	Pasture25	-0.0139	0.0197
X_capital ^2	0.0592**	0.0239	rBST	-0.0314	0.0385
X_othercost ^2	0.0456***	0.0129	Appalacian	-0.0101	0.0334
X_feed * X_capital	-0.0740***	0.0266	Corn Belt	0.0245	0.0261
X_feed * X_othercost	-0.0623***	0.0232	Lake States	-0.0030	0.0225
X_capital * X_othercost	0.0018	0.0299	Mountain	0.1343***	0.0380
$\psi(y)$	-0.5612***	0.0902	Northeast	0.2989***	0.0298
$\psi(y)$ ^2	-0.2281***	0.0570	Southern	0.0504	0.0460
$\psi(y)$ * X_feed	0.1373**	0.0435	Southern Plains	0.2915***	0.0410
$\psi(y)$ * X_capital	-0.2067***	0.0598			

Note: Log likelihood = -186.63

*=statistically significant at 10%; **=statistically significant at 5%; ***=statistically significant at 1%.

By symmetric and homogenous restrictions in hedonic aggregate function, parameter for Y_protein is 0.3474, for Y_fat*Y_protein is -0.6268 and for Y_protein^2 is 0.3134.

Table 7. Summary Statistics of Technical Efficiency by Herd Size.

Herd Size	TE Type	Mean	Std. Dev.	Skewness	Min	Max
All Samples	Quality	0.8703	0.0744	-1.3856	0.5113	0.9731
	Quantity	0.8659	0.0765	-1.3710	0.4974	0.9728
	Revenue	0.8615	0.0795	-1.3542	0.4683	0.9718
(0, 125)	Quality	0.8298	0.0721	-1.3266	0.5113	0.9483
	Quantity	0.8250	0.0748	-1.2782	0.4974	0.9449
	Revenue	0.8194	0.0781	-1.2150	0.4683	0.9491
[125, 360)	Quality	0.9113	0.0281	-1.5766	0.7771	0.9534
	Quantity	0.9067	0.0306	-1.5330	0.7637	0.9512
	Revenue	0.9033	0.0324	-1.7821	0.7370	0.9494
[360, 750)	Quality	0.9427	0.1467	-1.8432	0.8678	0.9673
	Quantity	0.9400	0.1596	-1.7112	0.8626	0.9666
	Revenue	0.9378	0.1694	-1.8754	0.8498	0.9663
>=750	Quality	0.9566	0.0094	-1.1706	0.9236	0.9721
	Quantity	0.9545	0.0102	-1.1934	0.9181	0.9728
	Revenue	0.9526	0.0114	-1.4216	0.9098	0.9717

Note: Output sets for each TE Type:
Quality: Yield of milkfat, yield of protein and revenue of cattles; Quantity: Yield of milk and revenue of cattles; Revenue: revenue of milk and revenue of cattles.

Table 8. Summary Statistics of Technical Efficiency by Production Regions.

Region	TE_type	Mean	Std. Dev.	Skewness	Min	Max
All Regions	Quality	0.8703	0.0744	-1.3856	0.5113	0.9731
	Quantity	0.8659	0.0765	-1.3710	0.4974	0.9728
	Revenue	0.8615	0.0795	-1.3542	0.4683	0.9718
Appalacian	Quality	0.8607	0.0721	-1.9538	0.5451	0.9583
	Quantity	0.8566	0.0725	-1.8586	0.5472	0.9570
	Revenue	0.8515	0.0747	-1.7113	0.5360	0.9568
Corn Belt	Quality	0.8553	0.0774	-1.0896	0.5729	0.9657
	Quantity	0.8506	0.0799	-1.1006	0.5662	0.9647
	Revenue	0.8461	0.0815	-1.0224	0.5590	0.9646
Lake States	Quality	0.8652	0.0733	-1.3637	0.5599	0.9652
	Quantity	0.8612	0.0746	-1.3367	0.5555	0.9638
	Revenue	0.8565	0.0783	-1.3593	0.5331	0.9632
Mountain	Quality	0.8672	0.0767	-0.4979	0.6742	0.9731
	Quantity	0.8624	0.0792	-0.5044	0.6817	0.9728
	Revenue	0.8548	0.0861	-0.4864	0.6583	0.9718
Northeast	Quality	0.8639	0.0721	-1.3952	0.5113	0.9673
	Quantity	0.8590	0.0751	-1.3645	0.5096	0.9666
	Revenue	0.8547	0.0781	-1.3944	0.4683	0.9663
Pacific	Quality	0.9133	0.0543	-2.0461	0.6797	0.9686
	Quantity	0.9094	0.0564	-2.0582	0.6496	0.9676
	Revenue	0.9074	0.0554	-1.9610	0.6666	0.9670
Southern	Quality	0.8982	0.0566	-1.6484	0.7040	0.9676
	Quantity	0.8943	0.0588	-1.7438	0.6882	0.9665
	Revenue	0.8907	0.0619	-1.8232	0.6803	0.9653
Southern Plains	Quality	0.8916	0.0929	-2.2488	0.5395	0.9659
	Quantity	0.8872	0.0957	-2.2770	0.4974	0.9642
	Revenue	0.8824	0.1009	-2.1741	0.4939	0.9638

Note: Output sets for each TE Type:
Quality: Yield of milkfat, yield of protein and revenue of cattles; Quantity: Yield of milk and revenue of cattles; Revenue: revenue of milk and revenue of cattles.

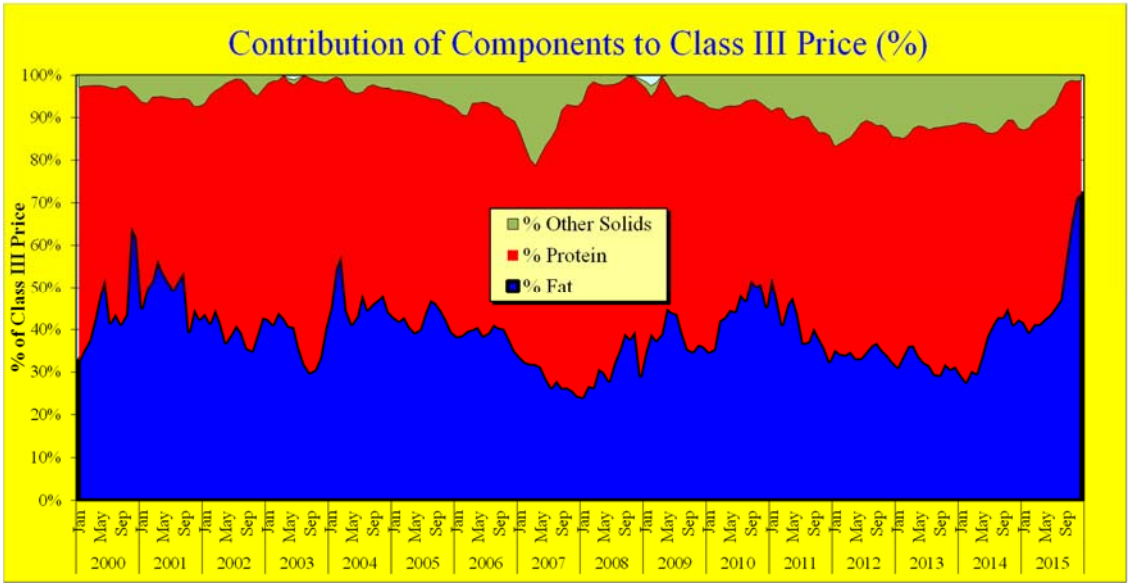


Figure 1. Contribution of Components to Class III Milk Price

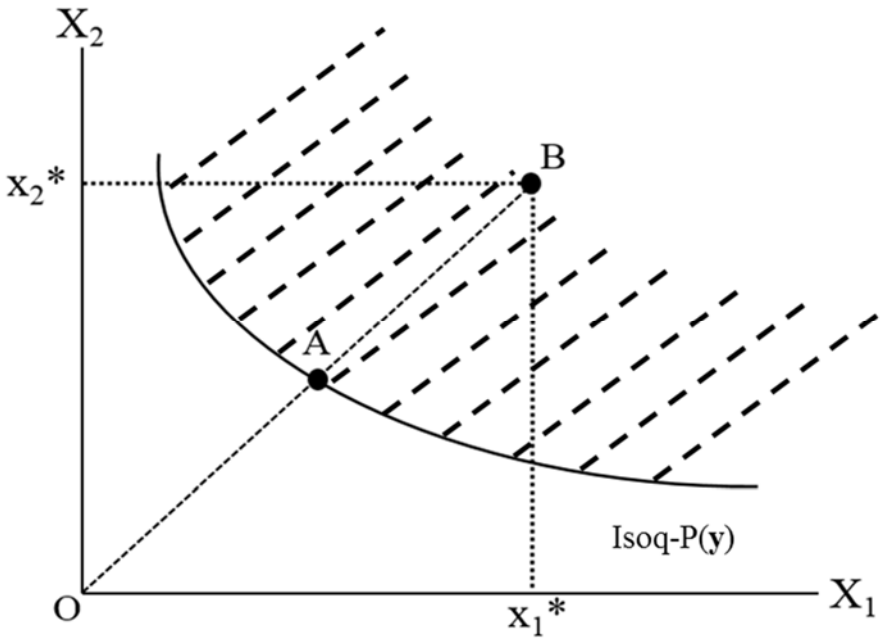
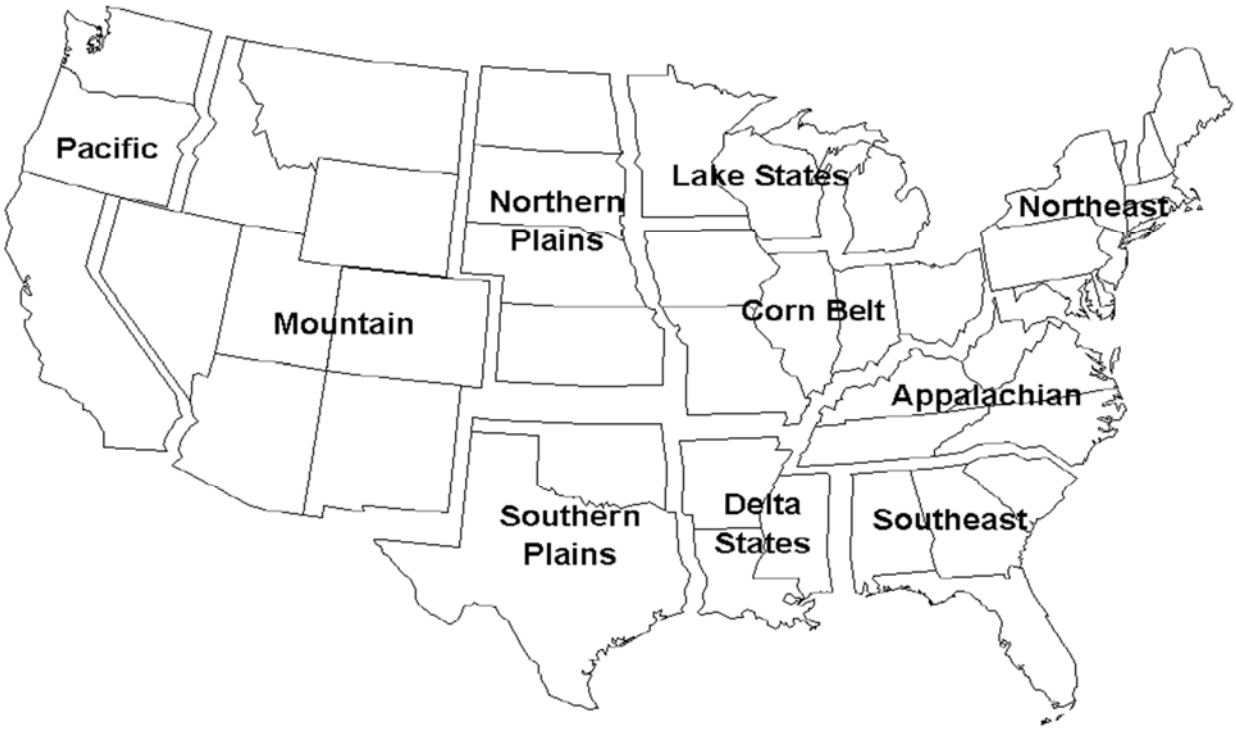


Figure 2. Input Distance Function and Technical Efficiency



Region 1, Appalachian

Kentucky, Tennessee, Virginia

Region 2, Corn Belt

Illinois, Indiana, Iowa, Missouri, Ohio

Region 3, Delta States

Region 4, Lake States

Michigan, Minnesota, Wisconsin

Region 5, Mountain

Arizona, Idaho, New Mexico

Region 6, Northeast

Maine, New York, Pennsylvania, Vermont

Region 7, Northern Plains

Region 8, Pacific

California, Oregon, Washington

Region 9, Southeast

Florida, Georgia

Region 10, Southern Plains

Texas

Figure 3. U.S. Farm Production Regions[6]

[6] Source: Agricultural Prices 2008 Summary, P231; ARMS dataset covers eight production regions except delta states and northern plains

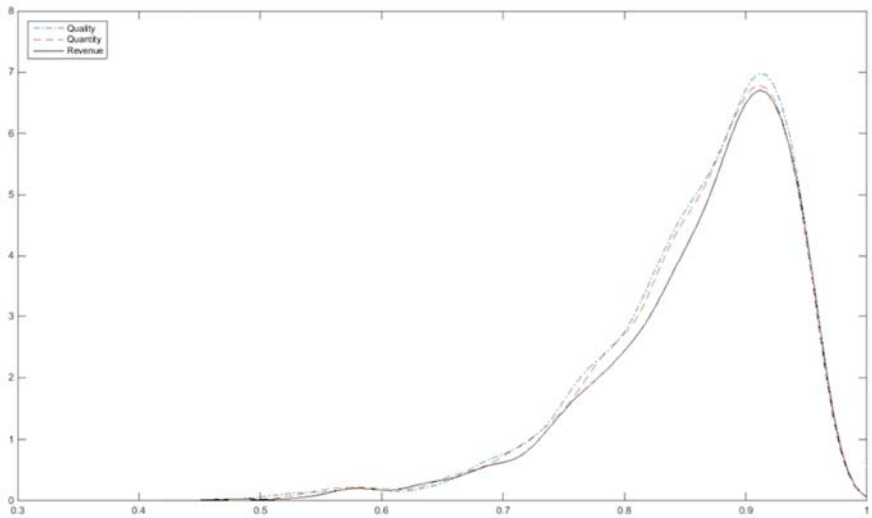


Figure 4.1. Kernel Density Estimation of Technical Efficiency

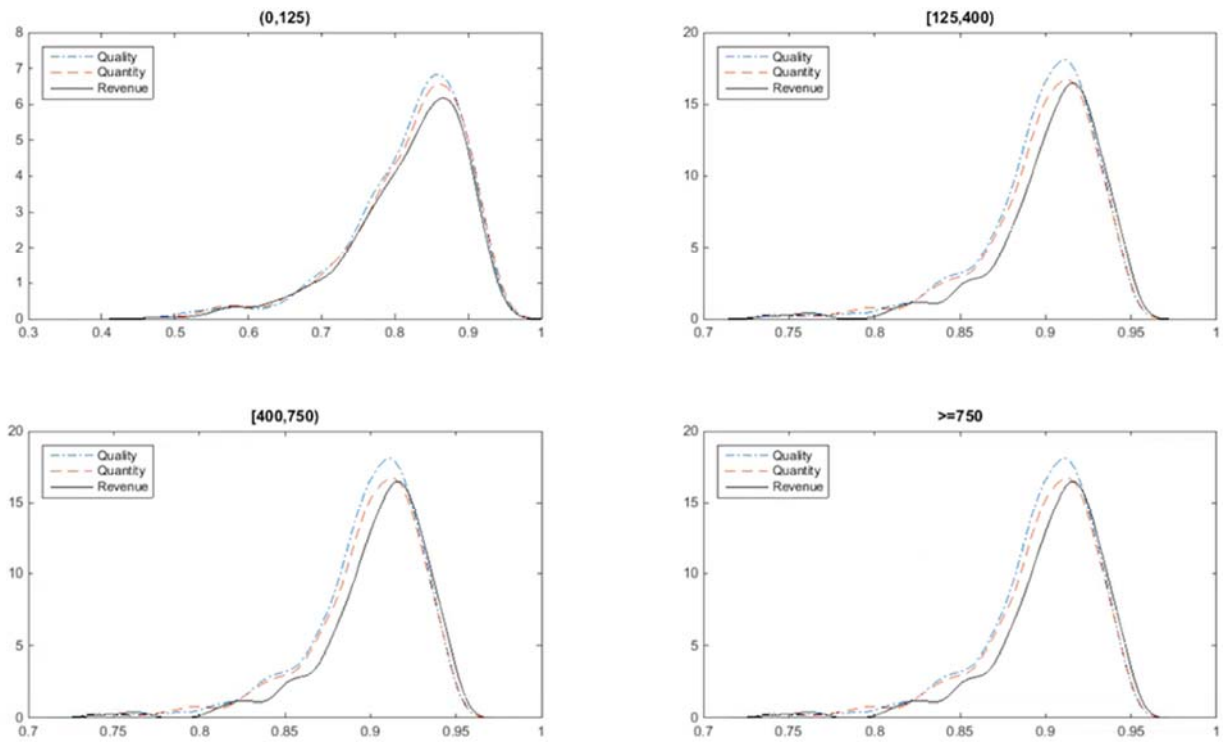


Figure 4.2. Kernel Density Estimation of Technical Efficiency
for Each Herd Size Group

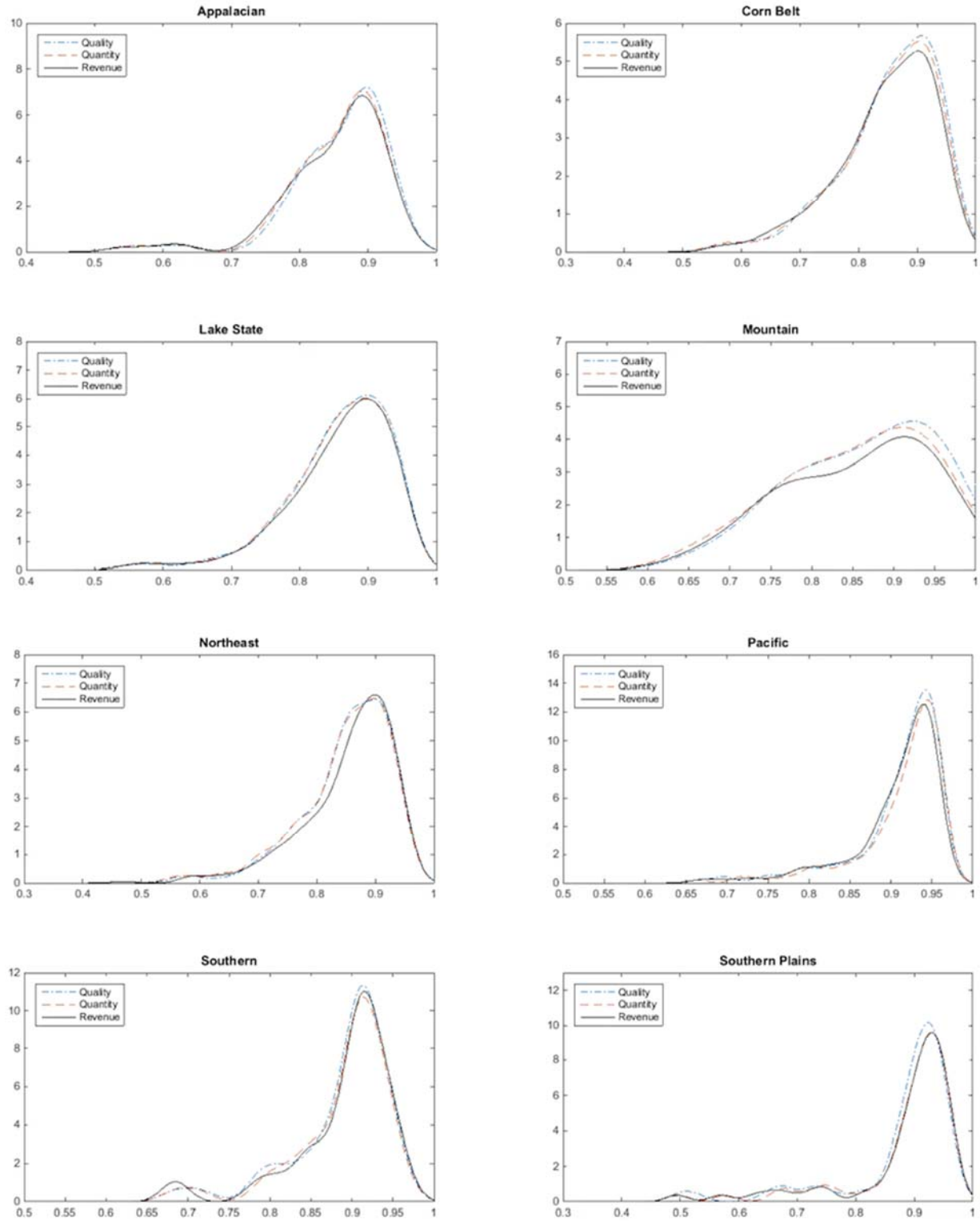


Figure 4.3. Kernel Density Estimation of Technical Efficiency for Each Production Regions