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STUDYING THE IMPACT OF MANAGERIAL ACTIVITIES ON THE TECHNICAL EFFICIENCY OF WISCONSIN DAIRY FARM

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ABSTRACT

The US dairy sector is facing structural changes including a geographical shift in dairy production and a tendency towards the implementation of more intensive production systems. These changes might significantly affect farm efficiency, profitability and the long-term economic sustainability of the dairy sector, especially in more traditional dairy production areas. Consequently, the goal of this study was to examine the impact of practices commonly used by dairy farmers and the effect of intensification on the performance of the farms. We used a sample of 273 Wisconsin dairy farms to estimate a stochastic production frontier simultaneously with a technical inefficiency model. The empirical results indicate that production exhibits constant returns to scale and that farm efficiency is positively related to farm intensification, the level of contribution of family labor in the farm activities, the use of a total mixed ration (TMR) feeding system and the administration of bovine somatotropin hormone (bST) to lactating cows.

Key Words: technical inefficiency, stochastic production frontier, intensification

INTRODUCTION

The US dairy sector is facing dramatic structural changes including a geographical shift in dairy production and a tendency towards the implementation of more intensive production systems. During the last decade, the more traditional dairy states have significantly decreased their number of dairy farms, and the western and southwestern states have rapidly increased their share in the dairy market (USDA, 2007; Barham et al., 2005; Cabrera et al., 2008). Under these circumstances, researchers have suggested that improvements in efficiency is one of the key factors for the survival of dairy farms in traditional production areas (Alvarez et al., 2008; Tauer, 2001; Tauer and Belbase, 1987).

Studying farm efficiency and the potential sources of inefficiency are therefore important from a practical as well as from a policy point of view. On the one hand, farmers could use this information to improve their performance. On the other hand, policymakers could use this knowledge to identify and target public interventions to improve farm productivity and farm income (Solís et al., 2009).

Previous literature on this topic can be divided into two groups. The first group of studies has focused on estimating the level of technical efficiency (**TE**) among samples of dairy farms. These studies have estimated production functions for sets of farms using either a non-parametric method (Charnes et al., 2000) or an econometric approach (Kumbhakar and Lovell, 2000). Studies using non-parametric methods include: Tauer (1998) who analyzed the productivity of New York dairy farms using the Malmquist productivity index; Jaforullah and Whiteman (1999) who examined the relationship between farm size and technical efficiency for a sample of dairy farms in New Zealand; and, Stokes et al. (2007) who calculated the efficiency of a small group of Pennsylvania dairy farms using Data Envelopment Analysis.

Studies using an econometric approach have focused on: studying the level of TE using cross-sections of dairy farms (Bravo-Ureta, 1986); evaluating the evolution of TE in panel data (Ahmad and Bravo-Ureta, 1996; Cuesta, 2000); decomposing productivity changes into technical change, efficiency change and scale change (Ahmad and Bravo-Ureta, 1995; Heshmati and Kumbhakar, 1994); performing regional comparisons of TE levels (Bravo-Ureta et al., 2008; Hailu et al., 2005); or computing TE levels using genetic indices as an additional input (Alvarez et al., 2005).

Conversely, the second group of studies has focused on analyzing the sources of inefficiencies. Among this group we found that: Tauer (2001) and Tauer and Mishra (2006) evaluated the efficiency and competitiveness of small scale dairy farms in the State of New York; Lawson et al. (2004) investigated the relationship between milk production efficiency and the incidence of reproductive disorders among a sample of Danish dairy farmers; and Murova and Chidmi (2009) evaluated the impacts of Government Programs on the efficiency of Dairy Farms in the US.

The present study belongs to the later group and adds to the literature by examining issues normally neglected in past studies; namely, the impact of practices commonly used by dairy farmers in the US and the effect of intensification on the performance of the farms. To reach our goal we implemented a version of the traditional Stochastic Production Frontier (**SPF**) framework which allows for a unified analysis of inefficiency effects. The empirical sample included detailed financial and production information for 273 Wisconsin dairy farms during the 2007 agricultural year. The main results provide estimates of the relative importance of inputs in dairy production and the effects of key factors on the efficiency of the farms. Specifically, we found that production exhibits constant returns to scale and that farm efficiency is positively linked with farm intensification, the level of contribution of family labor in the farm activities, the use of TMR feeding system and the administration of the hormone bST to lactating cows.

MATERIALS AND METHODS

Stochastic Production Frontier and Inefficiency Analysis

To study the determinants of TE we used the SPF methodology developed by Aigner et al. (1977). The SPF method is based on an econometric (i.e., parametric) specification of a production frontier. Using a generalized production function and cross sectional data this method can be depicted as follows:

$$y_i = f(x_{ij};\beta) \cdot \exp(\varepsilon_i) \qquad [1]$$

where y represents output, x is a vector of inputs, β is a vector of unknown parameters and ε is the error-term. The subscripts i and j denote the farm and inputs, respectively.

In this specific formulation, the error-term is farm-specific and is composed of two independent components, $\varepsilon_i = v_i - u_i$. The first element, v_i, is a random variable reflecting noise and other stochastic shocks entering into the definition of the frontier, such as weather, luck, strikes, etc. This term is assumed to be an independent and identically distributed normal random variable with 0 mean and constant variance, iid [$N \sim (0,\sigma_v^2)$]. The second component, u_i, captures technical inefficiency (**TI**) relative to the stochastic frontier. The inefficiency term u_i is non-negative and it is assumed to follow a half-normal distribution (Kumbhakar and Lovell, 2000).

An index for TE can be defined as the ratio of the observed output (y) and maximum feasible output (y*):

$$\mathrm{TE_i} = \frac{y_i}{y_i\,*} = \frac{f(x_{ij};\beta) \cdot \exp(v_i - u_i)}{f(x_{ij};\beta) \cdot \exp(v_i)} = \exp(-u_i);\ \mathrm{TI_i} = 1 - TE_i \qquad [2]$$

Because y is always lower than or equal to y*, the TE index is bounded between 0 and 1. TE achieves its upper bound when a dairy farm is producing the maximum output feasible level (i.e., $y = y$*), given the input quantities. Jondrow et al. (1982) demonstrated that farm level TE can be calculated from the error term ε_i as the expected value of $-u_i$ conditional on ε_i, which is given by:

$$\mathrm{E}\left[u_i \middle| \varepsilon_i\right] = \frac{\sigma_u \sigma_v}{\sigma}\left[\frac{f(\varepsilon_i \lambda / \sigma)}{1 - F(\varepsilon_i \lambda / \sigma)} - \frac{\varepsilon_i \lambda}{\sigma}\right] \quad [3]$$

where: $\sigma^2 = \sigma_u^2 + \sigma_v^2$, $\lambda = \sigma_u / \sigma_v$, $f(\cdot)$ represent the standard normal density and $F(\cdot)$ the standard normal cumulative density functions. The maximum likelihood estimation of Eq. [1] provides estimators for the variance parameters σ_u^2 and σ_v^2. Thus, the TE measure for each farm is equal to:

$$TE_i = \exp\left(-\mathrm{E}\left[u_i \middle| \varepsilon_i\right]\right) \quad [4]$$

Caudill et al. (1995) extended this framework to analyze the extent to which certain variables influence the inefficiency term u_i. Specifically, these authors developed a model in which the determinants of inefficiency are evaluated using a multiplicative heteroscedasticity framework. That is:

$$\sigma_{ui} = \sigma_u \exp\left(Z_{mi}; \alpha\right) \quad [5]$$

where Z_{mi} is a vector of farm-management strategies that explain inefficiency and α are unknown parameters. Given that the inefficiency is assumed to follow a half-normal distribution a decrease in the variance will lead to increments in the efficiency level. In this approach, the parameters for the production frontier and for the inefficiency model are estimated jointly using the maximum likelihood technique (Caudill et al., 1995).

Empirical Model

The empirical analysis is based on the estimation of a Cobb-Douglas production function in which both the output and inputs are expressed in logarithmic form. Hence, the estimated coefficients reflect the output elasticities (Kumbhakar and Lovell, 2000). It is important to indicate that preliminary comparisons led to the rejection of the translog functional form.

In this model, the dependent variable is the total milk production sold measured in kg. Based on the literature and the data available, our empirical model included the following 6 inputs: *cow*, defined as the number of adult cows in the herd; *feed*, defined as the total cost of purchased feedstuffs in US $; *capital*, defined as the depreciation of buildings and land, and corresponds to 5% of the value of land use by the farm; *crop*, defined as the total expenses related to crop production measured in US $ (i.e., chemicals, fertilizers, lime, seeds and plant purchases, machinery depreciation, machinery hire expenses, machinery repair, fuel and oil expenses); *labor*, defined as the total labor including family and hired labor measured in US $; and, *livestock*, which includes breeding expenses, veterinary and medicines and other livestock expenses in US $.

As indicated, SPF also allows for a unified analysis of inefficiency effects. The variables included in the inefficiency model were: *milking system*, a set of dummy variables representing each alternative system; namely: flat barn, pit parlor and pipeline (pipeline was the omitted variable); *housing*, a dummy variable equals 1 for farms that use free stall housing; *milking frequency*, a dummy variable equals 1 for the farms with a milking frequency equal to 2; bST, the percentage of the cows under bovine somatotropin treatment; and, *family labor*, the ratio of family labor to total labor measured in US $. Following Tauer (2001) we controlled for size using the number of cows in the herd. Finally, to study the impact of intensification on efficiency we included 3 additional variables: *feed/cow*, defined as the ratio of purchased feedstuffs to the number of cows (a similar approach can be found in Alvarez et al. (2008) and Kompas and Chu (2006)); TMR, a dummy variable equal to 1 for the farm that uses the TMR feeding system; and, *pasture*, a dummy variable equal to 1 for farms that use pasture feeding systems. This last variable was included to measure the impact of extensive production on TE. Table 1 presents descriptive statistics for all the variables included in the analysis.

Data

The data used in this study consisted of detailed farm-level information for dairy farms participating in the Agriculture Financial Advisor (AgFA) program managed by the Center for Dairy Profitability at the University of Wisconsin-Madison. The aim of the AgFA program is to collect, analyze and store high quality financial and production information for dairy farms in the State of Wisconsin. More information on the AgFa program can be found at http://cdp.wisc.edu/AgFA.htm.

The empirical sample included 273 dairy farms and the collected information corresponded to the 2007 agricultural year. The dairy farms in the sample were highly specialized with most of their output coming from dairy sales. All the farms were located in the State of Wisconsin which has traditionally been one of the top states in terms of milk production and dairy farming in the US. The climate in Wisconsin is typically Continental with cold and snowy winters, and warm summers. Annual rainfall is above 800 mm, and temperatures average about 19 ºC during summer and -8 ºC during the winter. About two-thirds of the annual precipitation falls during the growing season. The rainfall and temperature during the 2007 agricultural year was within the historical averages. Thus, the estimated results presented here are not expected to be biased due to climate variability.

RESULTS AND DISCUSSION

Table 2 presents the maximum likelihood parameter estimates for the estimated production frontier model. Because all input variables are measured in logarithmic form, the estimated coefficient values represent the partial output elasticities. Following Caudill et al. (1995) we tested the estimated heteroscedastic model against the traditional homoscedastic specification using a likelihood ratio test. The results of this test suggested that the homoscedastic model should be rejected in favor of the heteroscedastic framework implemented in this study.

All output elasticities are positive and statistically significant with the exception of capital. Of all input variables, *cow* has the highest impact on the productivity level with an elasticity equals to 0.77. That is, a 1% increase in the number of cows in the herd results in an estimated increase in milk production of 0.77%. The next highest elasticity is for *crop* (0.09), followed by *feed* (0.07), *livestock* (0.07) and *labor* (0.03).

The scale elasticity (i.e., the sum of all output elasticities) is 1.007 revealing the presence of constant returns to scale (**CRS**). A likelihood ratio test confirms this outcome. In general terms, CRS suggests that, for the sample of studied dairy farms, there is no proportional relationship between the size of the farms and the level of output produced. Kompas and Chu

(2006) further explained that CRS implies that the level of productivity depends on improvements in technology and efficiency, and not necessarily on the size of the farm.

Table 3 shows that the mean TE in the sample is 88%. That is, an average farm in the sample could in principle increase its level of milk production by 12% using the current input quantities. Table 3 also presents the distribution of TE scores. This table shows that approximately 83% of the farmers achieved TE levels of 80% or higher. These results are not surprising because the studied farms are very specialized and they are located in one of the top dairy states in the US. It is worth noting that the average level of efficiency obtained here is comparable to the averages presented by Bravo-Ureta et al. (2007) in their meta-regression analysis of TE in agriculture. These authors reported an 84% average TE for stochastic frontier studies focusing on dairy farms in developed countries.

The results of the TI model are presented at the end of Table 2. Following common practice, the interpretation of the parameters is performed with respect to their effect on TE, which means that the estimated coefficients are analyzed as if they displayed the inverse sign. In addition, Figure 1 depicts the influence of selected variables on the TE level of the farms using scatter plots.

An important goal of this study was to evaluate the association between intensification and farm efficiency. The empirical results show that the intensification variable, defined as the ratio of feed purchased per cow on the farm, has a negative and statistically significant coefficient implying that an increase in the intensification of a farm leads to improvements in the efficiency levels. The lower-right plot in Figure 1 confirms this result by clearly showing that TE increase with intensification. These results agree with the outcomes presented by Alvarez et al.

(2008) and Kompas and Chu (2006) for dairy farms in Northern Spain and Australia, respectively.

Another common practice implemented by more intensive farms is the use of the TMR. This feeding strategy blends all feedstuffs into a complete ration with the required level of nutrients. Our results show that TMR is positively associated with higher levels of TE. This result could be explained by the fact that cows receiving TMR have limited opportunity of sorting out individual ingredients of the diet, which allows greater flexibility to feed the right amounts for particular stages of lactation and production levels. Thus, the use TMR would result in a consistency of ingredients that improve fermentation and digestibility by rumen bacteria, which could be translated into better intake and consequently improved milk production (Soriano et al., 2001).

Conversely, the use of pasture, a practice commonly associated with extensive farming, although not statistically significant, had a negative relationship with TE. Numerous studies have documented that pasture systems result in lower milk yields (Bargo et al., 2002; Dartt et al., 1999; Kolver and Mueller, 1998), which decrease feed efficiency, and might affect TE.

The parameter for the use of bST is negative and statistically significant, indicating that the use of bST positively affects TE. This result was expected due to the reported ability of bST to increase milk production by 3 to 5 kg/d (Bauman et al., 1999). Bauman et al. (1999) indicated that bST also improves the overall lactation yield and lactation persistence. To support this additional milk synthesis, feed intake must increase, but because the feed requirements for body maintenance remain unchanged, the use of bST improves the efficiency in the conversion of feed to milk.

The estimated coefficient as well as the lower-left plot in Figure 1 shows that a higher proportion of family labor over the total labor leads to increase TE. This result agrees with Carter (1984) who argued that, in agricultural production, family members seek to maximize family welfare rather than individual welfare and consequently, provide a higher effort toward production.

The set of dummy variables included to measure the influence of the milking systems on TE are not statistically significant suggesting that there are no significant differences on TE between the 3 studied parlor technologies (i.e., flat barn, pit parlor and pipeline). We would expect that pit parlor, a technology associated with modern dairy practices (Wagner et al., 2001), would show higher TE over older systems such as pipeline or flat barns. We conjecture then that most important than the parlor system is the efficiency of the management, which will determine the efficiency of the milking system and impact the overall TE.

Similarly, milking frequency was not found significantly associated with TE. The literature reports that 3 and 4 daily milking frequencies have 3.5 and 4.9 kg/d per cow additional milk produced (Erdman and Varner, 1994); nonetheless, additional milk frequencies are also associated with additional labor and additional feed intake requirements, which, depending on market conditions and specific farm characteristics, would determine this practice to be more or less efficient.

Our analysis also showed that the type of housing did not have significant impact on TE. It could be argued that free stall housing, a modern dairy farming strategy, may have a positive effect on efficiency because it facilitates herd management and cow comfort. However, our sample that included many small farms using a variety of bedded pack designs alternative to free stalls, indicated that these house systems could be as efficient as free stalls depending on the detailed management provided.

Finally, the size of the farm, measured as the number of cows in the herd, was found not statistically significant as a determinant of TE. However, the sign for the parameter of number of cows as well as the tendency depicted in the upper-left plot in Figure 1 suggest that TE levels increase with the farm size. An explanation for the divergence between the econometric model and the graph could be that size is correlated with intensification, but the effect of size on TE could have already been picked up in the efficiency model by the variables related with intensification.

CONCLUSIONS

This study examined the impact of practices commonly used by dairy farmers in the US and the effect of intensification on the performance of the farms using a SPF and a sample of 273 Wisconsin dairy farms. The empirical results showed that the variable with the highest impact on production is the number of cows on the farm followed by the total expenditure in crops, feeding, livestock and labor. In addition, we found that there was no proportional relationship between the size of the farms and the level of output produced, which implies that the level of productivity depends on improvements in technology and efficiency, and not on the size of the farm.

The average level of TE in the sample was 88%, which suggests that opportunity exists to expand milk production using the current level of inputs and the technologies already available. With respect to the sources of technical efficiency, we found that farm efficiency was positively related to farm intensification, the level of contribution of family labor in farm activities, the use of a total mixed ration (TMR) feeding system and the administration of bST to lactating cows.

Although some of the variables included in the inefficiency model have non-statistical significance effect in explaining TI, they show some interesting signs and tendencies. Thus, the relationship between TE and milking systems, milking frequency and housing facilities merits further research. In addition, we envision that with increased awareness of the environmental impacts of dairy production as well as more stringent environmental regulations been put in place, activities such as manure management and other environmental managerial activities will become essential in the day-to-day dairy farm activities. Consequently, studying the impact of environmental management practices on TE could be an area for future refinement of the model implemented here.

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Table 1. Descriptive statistics for Wisconsin dairy farms (n=273, 2007 agricultural year)

Variable (unit)	Mean	CV	Min.	Max.
Milk (kg)	1,335,408	1.31	171,172	1,2185,328
Cow (n)	133	1.16	23	998
Feed ($)	122,917	1.53	2,650	1,249,075
Capital ($)	90,848	0.90	11,833	541,322
Crop ($)	159,759	1.02	4,977	1,115,004
Labor ($)	74,315	1.35	3,377	649,892
Livestock ($)	56,314	1.95	559	788,063
TMR (dummy)[1]	0.53	0.95	0	1
Pasture (dummy)[2]	0.24	1.77	0	1
Milking system (dummy)[3]				
Pipeline	0.67	0.70	0	1
Flat Barn	0.08	3.47	0	1
Pit Parlor	0.25	1.74	0	1
Milking frequency (dummy)[4]	0.92	0.30	0	1
bST (%)	14	1.82	0	100
Family labor (%)	37	1.01	0	100
Housing (dummy)[5]	0.38	1.28	0	1
Feed/cow (ratio)	777	0.46	96	2,027

[1]Use of TMR = 1
[2]Use of pasture = 1
[3]Pipeline is the omitted variable
[4]Two times daily milking frequency = 1
[5]Free stall housing = 1

Table 2. Production frontier estimates (n=273, 2007 agricultural year)

Variables[1]	Coefficient	St. Dev.
Frontier		
Constant	7.6903***	0.2172
Cow (n)	0.7671***	0.0385
Feed ($)	0.0709***	0.0207
Capital ($)	-0.0105	0.0193
Crop ($)	0.0864***	0.0195
Labor ($)	0.0269**	0.0115
Livestock ($)	0.0669***	0.0132
Inefficiency model		
Cow (n)	-0.0002	0.0018
TMR (dummy)[2]	-0.4916*	0.2759
Pasture (dummy)[3]	0.2859	0.2524
Milking system (dummy)[4]		
Flat barn	0.3489	0.5601
Pit parlor	0.5885	0.4133
Milking frequency (dummy)[5]	0.8104	0.6577
bST (%)	-0.0129**	0.0060
Family labor (%)	-0.0074*	0.0038
Feed/cow (ratio)	-0.0013**	0.0005
Housing (dummy)[6]	0.1561	0.3913
Constant	-3.0245***	0.8111
$\lambda = \sigma_u/\sigma_v$	2.33	
σ_v	0.17	
Log-likelihood	189	

*P < 0.10; **P < 0.05; ***P < 0.01
[1]Dependent variable is the total milk production sold measured in kg.
[2]Use of TMR = 1
[3]Use of pasture = 1
[4]Pipeline is the omitted variable
[5]Two times daily milking frequency = 1
[6]Free stall housing = 1

Table 3. Distribution of technical efficiency (TE) scores

TE Interval (%)	Number of Farms	Percentage of Farms in TE Interval
0-49	0	0.0%
50-59	2	0.7%
60-69	11	4.0%
70-79	33	12.1%
80-89	87	31.9%
90-100	140	51.3%
Mean TE		*88%*

Figure 1. Scatter plots between selected managerial strategies and technical efficiency (TE)