Determinants of Technical Efficiency among Dairy Farms in Wisconsin. By Cabrera et al., page 000. Data from 273 Wisconsin dairy farms were used to examine the extent to which technical efficiency is related to practices commonly used by dairy farmers and the effect of intensification on the performance of the farms. The empirical analysis showed that at a commercial level the administration of bovine somatotropin hormone to lactating cows increases milk production. In addition, 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 feeding system and the milking frequency.

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Determinants of Technical Efficiency among Dairy Farms in Wisconsin

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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 analysis showed that at a commercial level the administration of bovine somatotropin hormone to lactating cows increases milk production. In addition, we found 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 milking frequency.

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 has focused on estimating the level of technical efficiency (**TE**) among samples of dairy farms. To do so, these studies have used either a non-parametric method such as Data Envelopment Analysis (e.g., Tauer, 1998; Jaforullah and Whiteman, 1999; Stokes et al., 2007; among others) or an econometric approach such as stochastic (production, cost or profit) frontier models (e.g., Heshmati and Kumbhakar, 1994; Cuesta, 2000, Alvarez et al., 2005; Bravo-Ureta et al., 2008; among others). These two methodologies have also been used to analyze the potential sources of inefficiencies (e.g., Lawson et al., 2004; Tauer and Mishra, 2006; Murova and Chidmi, 2009). However, Kumbhakar and Lovell (2000) argue that stochastic frontier models seem to be the most appropriate approach in studies related to the agricultural sector due to its ability to deal with stochastic noise, accommodate traditional hypothesis testing, and allowing for single step estimation of the inefficiency effects

Consequently, the present study implements a stochastic frontier model to evaluate the determinants of technical efficiency among dairy farms in the State of Wisconsin. This research 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 the studied dairy farms 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 milking frequency. In addition, the commercial dairy farms included in the analysis show that the administration of the hormone bST to lactating cows positively affects production.

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**):

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

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:

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

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:

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

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:

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

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 5% of the value of land used plus building depreciation to 15 years of useful life; *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 $. In addition, to account for differences in production based on the use of grow hormones we included the control variable *bST* which is defined as the percentage of the cows under bovine somatotropin treatment.

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; and, *family labor*, the ratio of family labor to total labor measured in US $. 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.

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 equal to 0.78. That is, a 1% increase in the number of cows in the herd results in an estimated increase in milk production sold of 0.78%. The next highest elasticity is for *crop* (0.08), followed by *livestock* (0.06), *feed* (0.06) and *labor* (0.02). In addition, the control variable *bST* is also positive and statistically significant. This result confirms previous research on the positive impact of bST on milk production (e.g., Bauman et al., 1999) and suggests that commercial farms could consider the use of bST as a mean to improve production.

The scale elasticity (i.e., the sum of all output elasticities) is 1.001 revealing the presence of constant returns to scale (**CRS**). To corroborate this result we used a likelihood ratio test, which confirmed the presence of CRS. 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 scale of the farm.

Table 3 shows that the mean TE in the sample is 0.88 (i.e., 88%) with a standard deviation equal to 0.08. That is, an average farm in the sample could in principle increase its level of milk production sold 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. 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. Due to the inverse relationship between TI and TE (see Eq. [2]) the interpretation of the estimated parameters is performed with respect to their effect on TE. That is, a negative effect on TI has a positive impact on TE. This approach is common practice in the literature and facilitates the comparison of our results with previous studies

An important goal of this study was to evaluate the association between intensification and farm efficiency. The empirical results show that the intensification variable *feed/cow*, 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. 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).

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 due to its negative effect on feed efficiency (Bargo et al., 2002; Dartt et al., 1999; Kolver and Mueller, 1998).

The empirical results clearly show 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.

Milking frequency was also found significantly associated with TE. Specifically, farms milking their cows more than 2X per day are more efficient than those with a milking frequency of just 2X. This result agrees with the literature. Indeed, Erdman and Varner (1994) report that 3 and 4 daily milking frequencies have, respectively, 3.5 and 4.9 kg/d per cow additional milk produced. In addition, Dahl et al. (2004) reported that more frequent milking in early lactation stages has also been found to improve milk production efficiency.

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 (Wronski et al., 2007; Wagner et al., 2001), would show higher TE over older systems such as pipeline or flat barns.

Furthermore, 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.

We conjecture that the non-statistical significance found in this study for the parlor system and housing could be explained by the fact that the other management strategies included in the TI model (i.e., farm intensification, milking frequency and the type of labor) are more important in explaining the overall farm efficiency among the studied farms. However, it is worth noticing that the literature on this subject present mixed results. On the one hand, Wronski et al. (2007), Bewley et al. (2001a) and Wagner et al. (2001) argue that the milking systems and housing are positively correlated with the farm efficiency. On the other hand, Tauer, (1993) found that Stanchion barns were as efficient as milking parlors. Hallan and Machado (1996) argue that there is little evidence to believe that higher levels of facilities, machinery or equipment (related with milking parlors and free stall housing) are associated with increased efficiency. And, Bewley et al. (2001b) reported that differences in dairy housing types were not a major predictor of labor efficiency.

The parlor system and housing would also be expected to be positively correlated to the number of cows in the farm (Wronski et al., 2007; Gribble, 2003). To test this hypothesis, we run an alternative TI model including variable *cow*. Both alternative specifications displayed similar outcomes (i.e., non-statistical significance for housing and milking parlor). Additionally, the variable *cow* showed also not to be significant in explaining the farm TE. This latter result is important for Midwest and Northeast US and for Canadian farms, in which herd size increase would not always be the answer to reach economic sustainability.

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 outcome of this research offers valuable information on the determinants of TE among farms in traditional dairy areas. However, the future of this sector in more traditional dairy states is still unknown. In the rest of this section we highlight the main outcomes of this study along with some suggestions for further research.

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. Farms supplementing their cows with bST also show higher level of production. We also 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, from a technical standpoint, opportunity exists to expand milk production using the current level of inputs and the technologies already available in the area. These results suggest that dairy farms in Wisconsin can improve their productivity and efficiency if they take advantage of more efficient farm practices. We know from our results that using bST, more intensive production systems or > 2X milking improve production and technical efficiency. However, we do not know if these strategies might attain higher economic efficiency. The study of economic efficiency merits careful consideration and could be an area for future refinement of the study implemented here.

On the other hand, our results offer some insides in the understanding the potential future of this sector in more traditional dairy states. Ball (2009) showed that during the last decade more traditional dairy states in the US have decreased their level of productivity while Western and Southwestern states are displaying significantly improvements. Even though improving the TE of milk production in Wisconsin is possible, the question if this level of improvement would make Wisconsin dairy producers as efficient or competitive as producers in other US regions remains an area for further research. To answer this query, a study of a larger scope will be needed using detailed farm level information for representative farms in different geographical locations.

Lastly, although some of the variables included in the inefficiency model displayed non-statistical significance effects in explaining TI, they show some interesting signs and tendencies. Thus, the relationship between TE and milking systems, and housing facilities merits further research using a larger sample of farms in alternative environments. In addition, we envision that with increased awareness of the environmental impacts of dairy production as well as more stringent environmental regulations that have 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	12,185,328
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
bST (%)	14	1.82	0	100
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
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	7.829***	0.225
Cow (n)	0.779***	0.036
Feed ($)	0.059***	0.020
Capital ($)	-0.007	0.018
Crop ($)	0.082***	0.019
Labor ($)	0.024**	0.011
Livestock ($)	0.062***	0.013
bST (%)	0.001***	0.000
Inefficiency model		
TMR (dummy)[2]	-0.513*	0.275
Pasture (dummy)[3]	0.393	0.246
Milking system (dummy)[4]		
Flat barn	0.293	0.553
Pit parlor	0.528	0.404
Milking frequency (dummy)[5]	0.928*	0.564
Family labor (%)	-0.008**	0.003
Feed/cow (ratio)	-0.002***	0.000
Housing (dummy)[6]	0.172	0.386
Constant	-3.113***	0.708
$\lambda = \sigma_u / \sigma_v$	1.28	
σ_v	0.09	
Log-likelihood	191	

*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	3	1.1%
60-69	10	3.7%
70-79	34	12.4%
80-89	89	32.6%
90-100	137	50.2%
Mean TE		*88%*
St. Dev. TE		*0.08*