

1 **Determinants of Technical Efficiency among Dairy Farms in Wisconsin.** By Cabrera et al.,  
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3 technical efficiency is related to practices commonly used by dairy farmers and the effect of  
4 intensification on the performance of the farms. The empirical analysis showed that at a  
5 commercial level the administration of bovine somatotropin hormone to lactating cows increases  
6 milk production. In addition, farm efficiency is positively related to farm intensification, the  
7 level of contribution of family labor in the farm activities, the use of a total mixed ration feeding  
8 system and the milking frequency.

9

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## Determinants of Technical Efficiency among Dairy Farms in Wisconsin

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23

24      **ABSTRACT**

25            The US dairy sector is facing structural changes including a geographical shift in dairy  
26          production and a tendency towards the implementation of more intensive production systems.  
27          These changes might significantly affect farm efficiency, profitability and the long-term  
28          economic sustainability of the dairy sector, especially in more traditional dairy production areas.  
29          Consequently, the goal of this study was to examine the impact of practices commonly used by  
30          dairy farmers and the effect of intensification on the performance of the farms. We used a sample  
31          of 273 Wisconsin dairy farms to estimate a stochastic production frontier simultaneously with a  
32          technical inefficiency model. The empirical analysis showed that at a commercial level the  
33          administration of bovine somatotropin hormone to lactating cows increases milk production. In  
34          addition, we found that production exhibits constant returns to scale and that farm efficiency is  
35          positively related to farm intensification, the level of contribution of family labor in the farm  
36          activities, the use of a total mixed ration (TMR) feeding system and the milking frequency.

37      **Key Words:** technical inefficiency, stochastic production frontier, intensification

38

39            **INTRODUCTION**

40            The US dairy sector is facing dramatic structural changes including a geographical shift  
41          in dairy production and a tendency towards the implementation of more intensive production  
42          systems. During the last decade, the more traditional dairy states have significantly decreased  
43          their number of dairy farms, and the Western and Southwestern states have rapidly increased  
44          their share in the dairy market (USDA, 2007; Barham et al., 2005; Cabrera et al., 2008). Under  
45          these circumstances, researchers have suggested that improvements in efficiency is one of the

46 key factors for the survival of dairy farms in traditional production areas (Alvarez et al., 2008;  
47 Tauer, 2001; Tauer and Belbase, 1987).

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

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

65 Consequently, the present study implements a stochastic frontier model to evaluate the  
66 determinants of technical efficiency among dairy farms in the State of Wisconsin. This research  
67 adds to the literature by examining issues normally neglected in past studies; namely, the impact  
68 of practices commonly used by dairy farmers in the US and the effect of intensification on the

69 performance of the farms. To reach our goal we implemented a version of the traditional  
70 Stochastic Production Frontier (**SPF**) framework which allows for a unified analysis of  
71 inefficiency effects. The empirical sample included detailed financial and production information  
72 for 273 Wisconsin dairy farms during the 2007 agricultural year. The main results provide  
73 estimates of the relative importance of inputs in dairy production and the effects of key factors  
74 on the efficiency of the farms. Specifically, we found that the studied dairy farms exhibits  
75 constant returns to scale and that farm efficiency is positively linked with farm intensification,  
76 the level of contribution of family labor in the farm activities, the use of TMR feeding system  
77 and the milking frequency. In addition, the commercial dairy farms included in the analysis show  
78 that the administration of the hormone bST to lactating cows positively affects production.

79

## 80 MATERIALS AND METHODS

### 81 *Stochastic Production Frontier and Inefficiency Analysis*

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

86

$$87 y_i = f(x_{ij}; \beta) \cdot \exp(\varepsilon_i) \quad [1]$$

88

89 where  $y$  represents output,  $x$  is a vector of inputs,  $\beta$  is a vector of unknown parameters and  $\varepsilon$  is the  
90 error-term. The subscripts  $i$  and  $j$  denote the farm and inputs, respectively.

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

98        An index for TE can be defined as the ratio of the observed output ( $y$ ) and maximum  
 99 feasible output ( $y^*$ ):  
 100

$$101 \quad TE_i = \frac{y_i}{y_i^*} = \frac{f(x_{ij}; \beta) \cdot \exp(v_i - u_i)}{f(x_{ij}; \beta) \cdot \exp(v_i)} = \exp(-u_i); \quad TI_i = 1 - TE_i \quad [2]$$

102  
 103        Because  $y$  is always lower than or equal to  $y^*$ , the TE index is bounded between 0 and 1.  
 104 TE achieves its upper bound when a dairy farm is producing the maximum output feasible level  
 105 (i.e.,  $y = y^*$ ), given the input quantities. Jondrow et al. (1982) demonstrated that farm level TE  
 106 can be calculated from the error term  $\varepsilon_i$  as the expected value of  $-u_i$  conditional on  $\varepsilon_i$ , which is  
 107 given by:  
 108

$$109 \quad E[u_i | \varepsilon_i] = \frac{\sigma_u \sigma_v}{\sigma} \left[ \frac{f(\varepsilon_i \lambda / \sigma)}{1 - F(\varepsilon_i \lambda / \sigma)} - \frac{\varepsilon_i \lambda}{\sigma} \right] \quad [3]$$

110

111 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  
112 standard normal cumulative density functions. The maximum likelihood estimation of Eq. [1]  
113 provides estimators for the variance parameters  $\sigma_u^2$  and  $\sigma_v^2$ . Thus, the TE measure for each farm is  
114 equal to:

115

116 
$$TE_i = \exp(-E[u_i | \varepsilon_i]) \quad [4]$$

117

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

122

123 
$$\sigma_{ui} = \sigma_u \exp(Z_{mi}; \alpha) \quad [5]$$

124

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

130

131 ***Empirical Model***

132 The empirical analysis is based on the estimation of a Cobb-Douglas production function  
133 in which both the output and inputs are expressed in logarithmic form. Hence, the estimated

134 coefficients reflect the output elasticities (Kumbhakar and Lovell, 2000). It is important to  
135 indicate that preliminary comparisons led to the rejection of the translog functional form.

136 In this model, the dependent variable is the total milk production sold measured in kg.  
137 Based on the literature and the data available, our empirical model included the following 6  
138 inputs: *cow*, defined as the number of adult cows in the herd; *feed*, defined as the total cost of  
139 purchased feedstuffs in US \$; *capital*, defined as 5% of the value of land used plus building  
140 depreciation to 15 years of useful life; *crop*, defined as the total expenses related to crop  
141 production measured in US \$ (i.e., chemicals, fertilizers, lime, seeds and plant purchases,  
142 machinery depreciation, machinery hire expenses, machinery repair, fuel and oil expenses);  
143 *labor*, defined as the total labor including family and hired labor measured in US \$; and,  
144 *livestock*, which includes breeding expenses, veterinary and medicines and other livestock  
145 expenses in US \$. In addition, to account for differences in production based on the use of grow  
146 hormones we included the control variable *bST* which is defined as the percentage of the cows  
147 under bovine somatotropin treatment.

148 As indicated, SPF also allows for a unified analysis of inefficiency effects. The variables  
149 included in the inefficiency model were: *milking system*, a set of dummy variables representing  
150 each alternative system; namely: flat barn, pit parlor and pipeline (pipeline was the omitted  
151 variable); *housing*, a dummy variable equals 1 for farms that use free stall housing; *milking*  
152 *frequency*, a dummy variable equals 1 for the farms with a milking frequency equal to 2; and,  
153 *family labor*, the ratio of family labor to total labor measured in US \$. Finally, to study the  
154 impact of intensification on efficiency we included 3 additional variables: *feed/cow*, defined as  
155 the ratio of purchased feedstuffs to the number of cows (a similar approach can be found in  
156 Alvarez et al. (2008) and Kompas and Chu (2006)); TMR, a dummy variable equal to 1 for the

157 farm that uses the TMR feeding system; and, *pasture*, a dummy variable equal to 1 for farms that  
158 use pasture feeding systems. This last variable was included to measure the impact of extensive  
159 production on TE. Table 1 presents descriptive statistics for all the variables included in the  
160 analysis.

161

162 **Data**

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

169 The empirical sample included 273 dairy farms and the collected information  
170 corresponded to the 2007 agricultural year. The dairy farms in the sample were highly  
171 specialized with most of their output coming from dairy sales. All the farms were located in the  
172 State of Wisconsin which has traditionally been one of the top states in terms of milk production  
173 and dairy farming in the US.

174

175 **RESULTS AND DISCUSSION**

176 Table 2 presents the maximum likelihood parameter estimates for the estimated  
177 production frontier model. Because all input variables are measured in logarithmic form, the  
178 estimated coefficient values represent the partial output elasticities. Following Caudill et al.  
179 (1995) we tested the estimated heteroscedastic model against the traditional homoscedastic

180 specification using a likelihood ratio test. The results of this test suggested that the  
181 homoscedastic model should be rejected in favor of the heteroscedastic framework implemented  
182 in this study.

183 All output elasticities are positive and statistically significant with the exception of  
184 *capital*. Of all input variables, *cow* has the highest impact on the productivity level with an  
185 elasticity equal to 0.78. That is, a 1% increase in the number of cows in the herd results in an  
186 estimated increase in milk production sold of 0.78%. The next highest elasticity is for *crop*  
187 (0.08), followed by *livestock* (0.06), *feed* (0.06) and *labor* (0.02). In addition, the control variable  
188 *bST* is also positive and statistically significant. This result confirms previous research on the  
189 positive impact of bST on milk production (e.g., Bauman et al., 1999) and suggests that  
190 commercial farms could consider the use of bST as a mean to improve production.

191 The scale elasticity (i.e., the sum of all output elasticities) is 1.001 revealing the presence  
192 of constant returns to scale (**CRS**). To corroborate this result we used a likelihood ratio test,  
193 which confirmed the presence of CRS. In general terms, CRS suggests that, for the sample of  
194 studied dairy farms, there is no proportional relationship between the size of the farms and the  
195 level of output produced. Kompas and Chu (2006) further explained that CRS implies that the  
196 level of productivity depends on improvements in technology and efficiency, and not necessarily  
197 on the scale of the farm.

198 Table 3 shows that the mean TE in the sample is 0.88 (i.e., 88%) with a standard  
199 deviation equal to 0.08. That is, an average farm in the sample could in principle increase its  
200 level of milk production sold by 12% using the current input quantities. Table 3 also presents the  
201 distribution of TE scores. This table shows that approximately 83% of the farmers achieved TE  
202 levels of 80% or higher. It is worth noting that the average level of efficiency obtained here is

203 comparable to the averages presented by Bravo-Ureta et al. (2007) in their meta-regression  
204 analysis of TE in agriculture. These authors reported an 84% average TE for stochastic frontier  
205 studies focusing on dairy farms in developed countries.

206 The results of the TI model are presented at the end of Table 2. Due to the inverse  
207 relationship between TI and TE (see Eq. [2]) the interpretation of the estimated parameters is  
208 performed with respect to their effect on TE. That is, a negative effect on TI has a positive  
209 impact on TE. This approach is common practice in the literature and facilitates the comparison  
210 of our results with previous studies

211 An important goal of this study was to evaluate the association between intensification  
212 and farm efficiency. The empirical results show that the intensification variable *feed/cow*,  
213 defined as the ratio of feed purchased per cow on the farm, has a negative and statistically  
214 significant coefficient implying that an increase in the intensification of a farm leads to  
215 improvements in the efficiency levels. These results agree with the outcomes presented by  
216 Alvarez et al. (2008) and Kompas and Chu (2006) for dairy farms in Northern Spain and  
217 Australia, respectively.

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

225 which could be translated into better intake and consequently improved milk production (Soriano  
226 et al., 2001).

227 The use of pasture, a practice commonly associated with extensive farming, although not  
228 statistically significant, had a negative relationship with TE. Numerous studies have documented  
229 that pasture systems result in lower milk yields due to its negative effect on feed efficiency  
230 (Bargo et al., 2002; Dartt et al., 1999; Kolver and Mueller, 1998).

231 The empirical results clearly show that a higher proportion of family labor over the total  
232 labor leads to increase TE. This result agrees with Carter (1984) who argued that, in agricultural  
233 production, family members seek to maximize family welfare rather than individual welfare and  
234 consequently, provide a higher effort toward production.

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

241 The set of dummy variables included to measure the influence of the milking systems on  
242 TE are not statistically significant suggesting that there are no significant differences on TE  
243 between the 3 studied parlor technologies (i.e., flat barn, pit parlor and pipeline). We would  
244 expect that pit parlor, a technology associated with modern dairy practices (Wronski et al., 2007;  
245 Wagner et al., 2001), would show higher TE over older systems such as pipeline or flat barns.

246 Furthermore, our analysis also showed that the type of housing did not have significant  
247 impact on TE. It could be argued that free stall housing, a modern dairy farming strategy, may

248 have a positive effect on efficiency because it facilitates herd management and cow comfort.  
249 However, our sample that included many small farms using a variety of bedded pack designs  
250 alternative to free stalls, indicated that these house systems could be as efficient as free stalls  
251 depending on the detailed management provided.

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

264 The parlor system and housing would also be expected to be positively correlated to the  
265 number of cows in the farm (Wronski et al., 2007; Gribble, 2003). To test this hypothesis, we run  
266 an alternative TI model including variable *cow*. Both alternative specifications displayed similar  
267 outcomes (i.e., non-statistical significance for housing and milking parlor). Additionally, the  
268 variable *cow* showed also not to be significant in explaining the farm TE. This latter result is  
269 important for Midwest and Northeast US and for Canadian farms, in which herd size increase  
270 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 insights in the understanding the potential future of this sector in more traditional dairy states. Ball (2009) showed that during the last decade

294 more traditional dairy states in the US have decreased their level of productivity while Western  
295 and Southwestern states are displaying significantly improvements. Even though improving the  
296 TE of milk production in Wisconsin is possible, the question if this level of improvement would  
297 make Wisconsin dairy producers as efficient or competitive as producers in other US regions  
298 remains an area for further research. To answer this query, a study of a larger scope will be  
299 needed using detailed farm level information for representative farms in different geographical  
300 locations.

301       Lastly, although some of the variables included in the inefficiency model displayed non-  
302 statistical significance effects in explaining TI, they show some interesting signs and tendencies.  
303 Thus, the relationship between TE and milking systems, and housing facilities merits further  
304 research using a larger sample of farms in alternative environments. In addition, we envision that  
305 with increased awareness of the environmental impacts of dairy production as well as more  
306 stringent environmental regulations that have been put in place, activities such as manure  
307 management and other environmental managerial activities will become essential in the day-to-  
308 day dairy farm activities. Consequently, studying the impact of environmental management  
309 practices on TE could be an area for future refinement of the model implemented here.

310

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408 **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) <sup>1</sup>	0.53	0.95	0	1
Pasture (dummy) <sup>2</sup>	0.24	1.77	0	1
Milking system (dummy) <sup>3</sup>				
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) <sup>4</sup>	0.92	0.30	0	1
Family labor (%)	37	1.01	0	100
Housing (dummy) <sup>5</sup>	0.38	1.28	0	1
Feed/cow (ratio)	777	0.46	96	2,027

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410 <sup>1</sup>Use of TMR = 1411 <sup>2</sup>Use of pasture = 1412 <sup>3</sup>Pipeline is the omitted variable413 <sup>4</sup>Two times daily milking frequency = 1414 <sup>5</sup>Free stall housing = 1

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

Variables <sup>1</sup>	Coefficient	St. Dev.
<i>Frontier</i>		
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
<i>Inefficiency model</i>		
TMR (dummy) <sup>2</sup>	-0.513*	0.275
Pasture (dummy) <sup>3</sup>	0.393	0.246
Milking system (dummy) <sup>4</sup>		
Flat barn	0.293	0.553
Pit parlor	0.528	0.404
Milking frequency (dummy) <sup>5</sup>	0.928*	0.564
Family labor (%)	-0.008**	0.003
Feed/cow (ratio)	-0.002***	0.000
Housing (dummy) <sup>6</sup>	0.172	0.386
Constant	-3.113***	0.708
$\lambda = \sigma_u/\sigma_v$	1.28	
$\sigma_v$	0.09	
Log-likelihood	191	

417

418 \*P &lt; 0.10; \*\*P &lt; 0.05; \*\*\*P &lt; 0.01

419 <sup>1</sup>Dependent variable is the total milk production sold measured in kg.420 <sup>2</sup>Use of TMR = 1421 <sup>3</sup>Use of pasture = 1422 <sup>4</sup>Pipeline is the omitted variable423 <sup>5</sup>Two times daily milking frequency = 1424 <sup>6</sup>Free stall housing = 1

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426 **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%
<i>Mean TE</i>		88%
<i>St. Dev. TE</i>		0.08

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