Multi-output Technical Efficiency for Argentinean Dairy Farms Using Stochastic Production and Stochastic Distance Frontiers with Unbalanced Panel Data

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ABSTRACT

This paper uses stochastic production frontiers (SPF) and stochastic distance frontiers (SDF) to measure technical efficiency for a sample of dairy farms in Abasto Sur, Argentina. The data is a highly unbalanced panel including 46 farmers from 1997/98 to 2001/02 with a total of 82 observations. Four alternative models based on the Battese and Coelli framework are evaluated. Average technical efficiency across the four models ranges from 67.2% to 88.4% while the correlation coefficient for technical efficiency scores ranges from 0.632 to 0.976. There is significant technological regress, with an annual average of 16.8% and 17.7% for the two "best" models. The results indicate that alternative specifications can have a significant impact on the results, specifically on mean efficiency figures.

Key words: Argentina, dairy farms, panel data, stochastic production and stochastic distance frontiers, technical efficiency.

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INTRODUCTION

The current critical situation facing the Argentine dairy sector is in sharp contrast with the favorable conditions enjoyed during most of the 1990s. A major restructuring of the dairy farm sector in the early 1990s led to significant gains in milk output accompanied by a 6% average productivity growth rate between 1992 and 1999. However, as 1998 unfolded prices received by farmers started to drop and reached an annualized rate of decline equal to 16.6 % by the end of 2000. In addition, due to the recent economic problems in Argentina, crop production has become substantially more profitable than dairying. This has caused many Argentine dairy farmers to reduce grain and silage feeding, and return to a pasture-based system, which has had adverse effects on milk production and returns (Dobson, 2003). The deterioration and instability in farm returns has brought a great deal of uncertainty among producers making it very difficult for them to make business decisions.

The province of Buenos Aires plays an important role in the national production of milk representing approximately 27.8% of total output. Within this province, the Abasto Sur Region accounts for over 15% of the dairy farms and over 21% of total milk output in the province. This region is particularly sensitive to adverse market conditions because the prevailing production systems are intensive and highly specialized, compared to other dairy regions, thus making shifts to a different output mix more difficult. Also, this region tends to have higher average cost of production than other milk producing areas. Under these circumstances, attaining high levels of efficiency are of critical importance if farms are to remain in the dairy business and prosper (Arzubi and Berbel, 2002).

Technical efficiency measures for dairy farms have been reported for many countries in a wide range of studies. However, efficiency analyses for Argentina are rare and thus one purpose of this paper is to contribute to this limited literature. In addition, most of the studies that estimate technical efficiency at the farm level consider a single output frontier model. However, dairy farms, even in intensive systems, have several outputs (e.g., milk, meat, grains). This is evident from the extensive meta-analysis of the dairy farm efficiency literature in Moreira López (2006).

Fortunately, recent advances make it possible to accommodate multi-output multi-input technologies in a primal framework through the use of distance frontiers.

The purpose of this paper is to estimate technical efficiency for a multi-output technology using stochastic distance frontiers (SDF). Furthermore, we compare the results obtained from the SDF specification with those obtained from stochastic production frontiers (SPF) where output is equal to the sum of the gross returns generated from both milk and meat revenues. For this purpose, an unbalanced panel data for a sample of dairy farms in Abasto Sur, Argentina is used.

The paper is structured as follows: the second section discusses the SPF and the SDF models for unbalanced panel data; the third section presents the data and empirical models followed by a discussion of the results; and the last section contains some concluding remarks.

METHODOLOGY

Stochastic Production Frontier (SPF). Several papers using panel data for dairy farms focusing on technical efficiency measurement have been published. Studies using deterministic frontier models include the work by Bravo-Ureta (1986), Arias and Alvarez (1993), Turk (1995), Hallam and Machado (1996), Piesse, Thirtle and Turk (1996), Álvarez and González (1999), and Maietta (2000). Applications of stochastic production frontiers to farms using panel data include the papers by Battese and Coelli (1988), Bailey et al. (1989), Heshmati and Kumbhakar (1994), Kumbhakar and Heshmati (1995), Ahmad and Bravo-Ureta (1995 and 1996), Reinhard, Knox and Thijssen (1999), Cuesta (2000), and Moreira López et al. (2006).

The stochastic production frontier model used in this study follows the Battese and Coelli framework (1992 and 1995), which has gained considerable popularity in recent years. According to Battese and Coelli (1992), the stochastic frontier production function can be written as:

$$Y_{it} = \exp\,(x_{it} \quad + v_{it} - u_{it}),$$

where Y_{it} denotes the output for the *i*-th farm in the *t*-th time period; x_{it} denotes a (*1xK*) vector of inputs and other explanatory variables for the *i*-th farm in the *t*-th time period; β is a (*Kx1*) vector of unknown parameters to be estimated; v_{it} is a random error assumed to follow a normal distribution with mean zero and constant variance $(v_i \sim iid\ N(0, \sigma_V^2))$ and u_{it} is a non-negative unobservable random error associated with technical inefficiency of the *i*-th farm.

Following Battese and Coelli (1992), u_{it} can be defined as:

$$u_{it} = \{\exp[-\eta(t-T)]\}u_i\ ,$$

where η is an unknown scalar to be estimated. Technical efficiency increases, remains constant or decreases over time, when the value of $\eta > 0$, η - 0 or $\eta < 0$ respectively.

The u_{it} term can have different specifications. Two frequently used specifications are the non-negative truncation of a normal distribution with mean μ and constant variance $(u_i \sim iid\ /N(\mu, \sigma_u^2)/)$ and the half normal distribution $(u_i \sim iid\ /N(0, \sigma_u^2)/)$.

Coelli *et al.* (2005) suggest that the choice of a more general distribution, such as the truncated-normal distribution, is usually preferable. However, this is ultimately an empirical issue and, therefore, in this paper the truncated-normal distribution is tested against the half-normal.

Kumbhakar, Ghosh and McGuckin (1991) and Reifschneider and Stevenson (1991) proposed stochastic frontier models in which the inefficiency effects (u_i) are expressed as an explicit function of a vector of firm-specific variables and a random error. Battese and Coelli (1995) introduced a model that is equivalent to the Kumbhakar, Ghosh and McGuckin (1991) specification, but relaxes some conditions concerning profit maximization and accommodates panel data.

Stochastic Distance Frontiers (SDF). Although the SPF has been widely used in the literature, a major limitation is that it only allows a single output. To overcome this issue, recent literature has introduced the SDF approach, which can accommodate multi-input multi-output technologies (e.g., Coelli and Perelman, 1996, 1999 and 2000).

The output-oriented distance frontier measures how output can be proportionally expanded holding inputs constant while remaining on the feasible production region. By contrast, the input-oriented distance frontier measures by how much the input vector can be proportionally contracted holding the output vector constant while operating on the feasible production region (Coelli, Rao and Battese,1998; Coelli and Perelman, 1999) . This paper will only focus on the output-oriented distance frontier.

Following Coelli and Perelman (1996) and Coelli, Rao and Battese (1998), if producers use a vector of *n* inputs to produce *m* outputs, then the output-oriented distance frontier is defined as follows:

$$D^O(x,y) = \min\{\theta : (y/\theta) \in P(x)\},$$

where *P(x)* is the set containing all output vectors *y* that are producible using *x*.

From an applied perspective, to compute the SDF it is necessary to specify an algebraic form to represent the relationship between inputs and outputs. Consistent with the Coelli and Perelman (1996) approach, a Cobb-Douglas output-oriented distance frontier (D^O) can be expressed as:

$$\ln D_{it}^O(x,y,t) - \ln y_{1it} = \beta_0 + \sum_{m=1}^{M-1} \beta_m \ln \frac{y_{mit}}{y_{1it}} + \sum_{k=1}^{K} \beta_k \ln x_{kit} \, .$$

where y_m is the production level of output *m* and x_k is the quantity of the *k*-th input used by firm *i* in time period *t*.

Lovell *et al.* (1995) indicate that in order to qualify as an output-oriented distance frontier equation (4) must fulfill the following regularity conditions: symmetry, monotonicity, positive linear homogeneity, non decreasing and convex in outputs (*y*), and decreasing in inputs (*x*). The convexity condition is important to ensure that the distance frontier displays diminishing marginal rates of technical substitution.

The homogeneity restriction can be empirically imposed by normalizing all outputs in the function by an arbitrary output (e.g., y_1), which yields the following (Lovell *et al.* 1994):

$$\ln \frac{D_{it}^O(x,y,t)}{y_{1it}} = \beta_0 + \sum_{m=1}^{M-1} \beta_m \ln \frac{y_{mit}}{y_{1it}} + \sum_{k=1}^{K} \beta_k \ln x_{kit} \, .$$

Equation (5) can be rewritten as:

$$\ln D_{it}^O(x,y,t) - \ln y_{1it} = \beta_0 + \sum_{m=1}^{M-1} \beta_m \ln \frac{y_{mit}}{y_{1it}} + \sum_{k=1}^{K} \beta_k \ln x_{kit} \, .$$

The level of inefficiency in the SDF can now be estimated by introducing the notion of a stochastic frontier (SF) into equation (6). In this manner, the distance from each observation to the SDF can be defined as inefficiency, which can be expressed as $-\ln D_{it}^0 = u_{it}$ (Coelli and Perelman, 1996) After appending a symmetric error term (v_{it}) to equation (6), the normalized TL output-oriented distance frontier can be rewritten as:

$$-\ln y_{1it} = \beta_0 + \sum_{m=1}^{M} \beta_m \ln \frac{y_{mit}}{y_{1it}} + \sum_{k=1}^{K} \beta_k \ln x_{kit} + v_{it} + u_{it} \, .$$

The maximum likelihood estimation of equation (7) will produce unbiased parameters and efficiency estimates for the stochastic output distance frontier.

Determinants of Inefficiency. The literature indicates that technical efficiency measures can be sensitive to the treatment given to the inefficiency term in stochastic frontier models (Wadud and White, 2000). Accordingly, the SPF and SDF models are estimated in this study with and without inefficiency effects, following the Battese and Coelli (1995) approach. The Battese and Coelli (1995) specification may be expressed in the same way as in equation (1), but now the u_{it} are non-negative random variables which are assumed to account for technical inefficiency in production and to be independently distributed as truncations at zero of the $N(m_{it}, \sigma_u^2)$ distribution, and m_{it} is: $m_{it} = z_{it}\delta,$

where z_{it} is a (*px1*) vector of variables which may influence the efficiency of a firm (e.g., age and level of education of the farmer, farm size, and location, among others), and δ is an (*1xp*) vector of parameters to be estimated.

The estimation of the technical efficiency is slightly different between the SPF and SDF approaches. In the former case, technical efficiency for the *i*-th farm is given by $TE=\exp(-u_i)$, where u_i is specified in equations (1) and (2) (Battese and Coelli, 1995). In the second case, the predicted value of the output distance for the *i*-th firm is given by $D^O = \exp(-u_i)$, where u_i is specified in equation (7) (Coelli and Perelman, 1996). In both cases, u_i cannot be measured directly because it only appears as part of the composed error term. Battese and Coelli (1988) and Jondrow *et al.* (1982) proposed a solution to this problem by modifying the conditional expectations of $\exp(-u_i)$ given the composed error term of the stochastic model (Battese and Coelli, 1995; Coelli and Perelman, 1996). All calculations can be done using the FRONTIER 4.1 software, which yields maximum-likelihood estimates for theparameters of the stochastic frontier model (Coelli, 1996).

Considering the above specifications, it is of interest to test if technical inefficiency is present in the model. This is equivalent to the null hypothesis that *y*=0. The parameter *y*, which must lie between 0 and 1, is equal to the ratio of the variance of the one sided error term to the total variance or $\gamma=\sigma_u^2/(\sigma_v^2+\sigma_u^2)$ (Battesse and Corra, 1977). The null hypotheses that the technical inefficiency effects are time invariant $(H_0{:}\eta=0)$ and that they have a half-normal distribution $(H_0{:}\mu=0)$, are also tested. Finally, in this paper, we attempt to account for the impact of the specification of the efficiency effects.

DATA AND EMPIRICAL MODEL

Table 1 shows the descriptive statistics for the dairy farms under study. Average milk production per farm per year is 1,028,372 liters (L) and ranges from 153,000 to 2,514,850 L. The average meat revenue per farm per year is US$ 30,984 with a minimum of US$ 901 and a maximum of US$ 167,199.(2) The range and standard deviation of average milk production and meat revenue indicate that there is considerable variation among farms. The average herd size for the sample is 212 cows, ranging from 54 to 514 cows. The average land area is 471 hectares, with a minimum of 109 and a maximum size of 1,403 hectares. The average use of other inputs per farm, *i.e. LB* (labor) and *CF* (concentrate feed), is 5.1 worker-equivalent and 359 metric tons per farm, respectively. This data was collected by surveying a sample of farmers over three agricultural years: 1997/98, 1999/2000 and 2001/02. The resulting data set is a highly unbalanced panel including 46 farmers with a total of 82 observations, 35 for 1997/98, 21 for 1999/2000 and 26 for 2001/02.

First, these data are used to estimate a Cobb-Douglas production frontier model where the dependent variable is the natural logarithm of annual gross revenues per farm (*Y*), which is equal to the sum of the revenues from milk and meat, measured in US dollars. The production frontier model can be written as: **(1.-)**

where the subscripts *i* and *t* refer to the *i*-th farm in the *t*-th time period. All the explanatory variables are annual figures expressed in natural logarithm and can be defined as follows: *CO* is the average number of dairy cows; *LD* is total land in hectares; *LB* is total labor measured in worker-equivalent; *CF* is concentrate feed in Tons; *OM* is total expenditures in the operation and maintenance of the milking equipment; *VE* is total expenditures in veterinary and medicine; DT_t is a set of dummy variables where t = 1, 2 and 3 (1=1997/98; 2=1999/2000; 3=2001/2002) and 0 otherwise; v_{it} and u_{it} are random variables as already defined; and s are unknown parameters to be estimated.

Equation (9) is a Battese and Coelli (1992) specification, which is formulated and estimated as Model 1. In this model, the inefficiency term has a half-normal distribution, is time invariant and does not incorporate explanatory variables in the one sided component. The Battese and Coelli (1995) specification is used to define Model 2, which incorporates a specification concerning the technical inefficiency term. Thus, Model 2 is the same as Model 1, but the technical inefficiency term is defined as: **(2.-)**

where *MC* is the ratio between cows in milk and total cows, *HL* is the ratio between hired and total labor, *RL* is a dummy variable equal to 0 if all land is owned and 1 if some (or all) land is rented, *TI* is a dummy variable defined as the summation of several factors that assume a value of 0 for no use and 1 otherwise. These factors are: milk cold equipment, milk production record keeping, artificial insemination, artificial calf rearing, use of farm supervisor and use of technical advisor. If the sum of all 6 variables is less than or equal to 3, then *TI* is equal to zero, otherwise it is equal to 1. w_{it} is a random variable, and the δ_S are unknown parameters to be estimated.

Models 3 and 4 incorporate the same variables as Models 1 and 2 except that output is now disaggregated into two, revenues from milk and revenues from meat, and a stochastic distance frontier is used. Like in the SPF models, the SDF uses a Cobb-Douglas framework, where the outputs are the natural logarithm of annual revenues per farm from milk (Y_{MK}) and from meat (Y_{MT}), both measured in US dollars. The SDF can be written as:
(3.-)

(1.-) $$Y_{it}=\beta_0+\beta_{CO}CO_{it}+\beta_{LD}LD_{it}+\beta_{LB}LB_{it}+\beta_{CF}CF_{it}+\beta_{OM}OM_{it}+\beta_{VE}VE_{it}+\sum\beta_{DT}DT_t+v_{it}-u_{it},$$

(2.-) $$u_{it}=\delta_0+\delta_{MC}MC_{it}+\delta_{HL}HL_{it}+\sum\delta_{RL}RL_t+\sum\delta_{TI}TI_t+w_{it},$$

(3.-) $$-Y_{MKit}=\beta_0+\beta_{MT}\frac{Y_{MTit}}{Y_{MKit}}+\beta_{CO}CO_{it}+\beta_{LD}LD_{it}+\beta_{LB}LB_{it}$$
$$+\beta_{CF}CF_{it}+\beta_{OM}OM_{it}+\beta_{VE}VE_{it}+\sum\beta_{DT}DT_t+v_{it}+u_{it}$$

(2) All monetary terms are expressed in real terms, the base year is July 2004-June 2005.

where the subscripts *i* and *t* refer to the *i*-th farm in the *t*-th time period.

RESULTS

Table 3 shows the parameter estimates for the four models (Model 1 through Model 4) discussed in the previous section. All models exhibit highly significant parameter estimates in the production frontier part of the model with the exception of β_{VE} (veterinary expenses) in Model 1 (SPF without TE effects) and Model 3 (SDF without TE effects); and β_{MT} (meat sales over milk sales) in Model 4 (SDF with TE effects). On the inefficiency part of the model, specified in Models 2 (SPF) and 4 (SDF), again most parameter estimates are statistically significant with the exception of (RL (rented land) for model 4 and (TI (technological index) for both models.

Table 1. Descriptive Statistics for Argentinean Dairy Farms from Abasto-Sur.

Variable	Mean	Standard Deviation	Minimun Value	Maximum Value
Milk				
Liters year^{-1}	1,028,372	523,977	153,000	2,514,850
Gross revenue ($ year^{-1})[a]	266,602	158,722	30,695	793,129
Meat				
Gross revenue ($ year^{-1})[a]	30,984	32,332	901	167,199
Cows (Number)	212	89	54	514
Land (Ha)	471	270	109	1,403
Labor (worker-equivalent)	5.1	2.1	1.6	13
Concentrate feed (Ton year^{-1})	359	202	16	1,000
O & M milking equipment ($ year^{-1})[a]	5,721	3,720	0	18,769
Milk cows/total cows ratio	0.75	0.09	0.44	1.00
Hired labor/total labor ratio	0.91	0.10	0.54	1.00
Veterinary expenses ($ year^{-1})[a]	12,963	8,198	0	43,252
Dummy variables				
Time				
DT1 (1997/98)	0.427			
DT2 (1999/00)	0.256			
DT3 (2001/02)	0.317			
Rented Land				
No rent land	0.598			
Rent land	0.402			
Technological index				
Low technology	0.085			
High technology	0.915			

[a] Real US $. The reference year is July 2004-June 2005 or 2004/05.

Table 2. Summary for the parameters in models 1 through 4.

Variables	Model 1	Model 2	Model 3	Model 4
Constant	β_0	(0	(0	(0
Meat sales/Milk sales			(MT	(MT
Cows	(CO	(CO	(CO	(CO
Land	(LD	(LD	(LD	(LD
Labor	(LB	(LB	(LB	(LB
Concentrate feed	(CF	(CF	(CF	(CF
O & M milking equipment	(OM	(OM	(OM	(OM
Veterinary expenses	(VE	(VE	(VE	(VE
DT_2 (1999/00)[a]	(DT2	(DT2	(DT2	(DT2
DT_3 (2001/02)	(DT3	(DT3	(DT3	(DT3
Constant		(0		(0
Milk cows/total cows		(MC		(MC
Hired labor/total labor		(HL		(HL
Rented Landb		(RL		(RL
Technological Indexc		(TI		(TI

a The dummy for period 1, 1997/98, is excluded.
b The dummy for Rented Land, RL1 or no rent, is excluded.
[c] The dummy for Technological Index 1, TI_1 or low level, is excluded.

Table 4 presents performance statistics for the alternative specifications evaluated using the generalized likelihood ratio test, which compares the likelihood function under the null and alternative hypothesis.(3) The first test focuses on the statistical significance of the *y* parameter (H_0:*y*=0) , which compares the stochastic frontier model versus the average production function. The closer *y* is to 1, the more significant the presence of technical inefficiency is (Battesse and Coelli, 1992; Coelli, 1996; Coelli *et al*. 2005). Hence, a value of 1.00 for reveals that 100% of the variation in observed output from the frontier is due to inefficiency.The *y* parameters shown in Table 3 range from 0.43 for Model 3 to 1.00 for Model 4, and the statistical test shows that this parameter is significantly different from zero for Models 1, 2 and 4 but not for Model 3.

The second step is to test the null hypothesis that the one-sided distribution is half-normal (H_0: μ=0) and this hypothesis is valid only for Models 1 and 3. The results indicate that the half-normal distribution is more compatible than the truncated-normal for the data under analysis. This result is consistent with several studies including Battese and Coelli (1992), Kumbhakar and Heshmati (1995), Ahmad and Bravo-Ureta (1996), Rezitis, Tsiboukas and Tsoukalas (2002), Cullinae and Song (2003), and Moreira *et al. (2006)*, among others.

The third step is to test the null hypothesis that technical efficiency is time invariant (H_0:η=0), which is relevant for Models 1 and 3. The null is accepted at the 5% level of significance indicating that technical efficiency is time invariant. Table 4 also shows a set of pair-wise log likelihood ratio tests to compare Models 1 and 2, and Models 3 and 4. The results show that Model 2 dominates Model 1, and Model 4 dominates Model 3. However, there is no way to contrast the performance of Models 2 and 4. In sum, the two dominant specifications are Model 2, which is a SPF approach with TE effects, and Model 4, which is a SDF also with TE effects.

To further compare the four models, descriptive statistics and correlation coefficients for technical efficiency are reported in Table 5. The average estimated technical efficiency between 1997/98 and 2001/02, ranges from 32.9% (Model 4) to 98.8% (Model 2). The minimum and the maximum technical efficiency for the two selected models (2 and 4) are: SPF approach (Model 2) 46.2% and 98.8%, and SDF approach (Model 4) 32.9% and 94.2%, respectively. In general, all models have a high correlation coefficient, ranging from a low of 0.632 for Models 2 and 4 to a high of 0.976 for Models 1 and 3. This result implies that all models rank farms closely with respect to their technical efficiency.

Table 3. Maximum Likelihood Parameter Estimates for Production Frontier Models (Models 1 and 2), and Stochastic Distance Frontier Output-Oriented Models (Models 3 and 4) (Standard errors in italic).

Variables	Parameter	Model 1	Model 2	Model 3[e]	Model 4
Constant	β_0	6.666 [a]***	7.160 ***	6.546 ***	7.247 ***
		0.376	*0.303*	*0.426*	*0.356*
Milk sales (Y_{MK})	(MK			<u>-0.957</u> [f]	<u>-0.965</u>
Meat sales (Y_{MT})	(MT			-0.043 *	-0.035
				0.033	*0.032*
Cows (CO)	(CO	0.516 ***	0.445 ***	0.550 ***	0.536 ***
		0.126	*0.111*	*0.128*	*0.101*
Land (LD)	(LD	0.212 ***	0.207 ***	0.178 ***	0.162 ***
		0.062	*0.051*	*0.068*	*0.058*
Labor (LB)	(LB	0.146 **	0.186 ***	0.136 **	0.145 **
		0.075	*0.067*	*0.078*	*0.070*
Concentrate feed (CF)	(CF	0.217 ***	0.176 ***	0.206 ***	0.137 **
		0.074	*0.066*	*0.075*	*0.065*
O & M milking equipment (OM)	(OM	0.071 ***	0.075 ***	0.074 ***	0.081 ***
		0.022	*0.017*	*0.022*	*0.016*
Veterinary expenses (VE)	(VE	0.017	0.022 *	0.016	0.028 **
		0.021	*0.016*	*0.022*	*0.015*
DT_2[b] (1999/00)	β_{DT2}	-0.440 ***	-0.402 ***	-0.450 ***	-0.431 ***
		0.050	0.053	*0.051*	*0.055*
DT_3 (2001/02)	β_{DT3}	-0.691 ***	-0.673 ***	-0.722 ***	-0.708 ***
		0.058	*0.054*	*0.062*	*0.053*
Constant	δ_0		3.075 ***		2.131 ***
			0.447		*0.315*
Milk cows/total cows (MC)	δ_{MC}		-0.027 ***		-0.017 ***
			0.005		*0.003*
Hired labor/total labor (HL)	δ_{HL}		-0.011 ***		-0.004 *
			0.004		*0.002*
Rented Land[c] *(RL)*	δ_{RL}		-0.335 ***		-0.066
			0.116		*0.045*
Technological level[d] *(TI)*	δ_{TI}		0.023		-0.068
			0.145		*0.122*
Log Likelihood Function		19.947	41.692	18.932	47.367
σ^2		0.052 ***	0.031 ***	0.052 ***	0.021 ***
		0.014	*0.011*	*0.014*	*0.005*
γ		0.454 ***	0.504 **	0.428 **	1.000 ***
		0.187	*0.233*	*0.202*	*0.007*

a * 10% level of significance, ** 5% level of significance, ***1% level of significance. A one-sided *t*-test was used in the production function, σ^2 and γ parameters. A two-sided *t*-test was applied in all other parameters.
b The dummy for period 1, DT_1 = 1997/98, is excluded.
c The dummy for Rented Land, RL_1 or no rent, is excluded.
d The dummy for Technological Index, TI_1 or low level, is excluded.
e All output SDF (Models 3 and 4) parameters have been multiplied by -1 to be comparable with the SPF results (Models 1 and 2).
f Underlined parameters are calculated by homogeneity conditions.

(3) The generalized likelihood ratio statistic is given by $\lambda = 2 [\ln \{L(H_1)\} - \ln \{L(H_0)\}]$, where $L(H_1)$ and $L(H_0)$ are the values of the likelihood function under the alternative and null hypotheses. The value of λ has a chi-square distribution with a number of degrees of freedom equal to the number of restrictions imposed.

Table 4. Specifications Test for all Models.

Null Hypotheses *H0*	χ^2 **Statistic**	χ^2 **0.95 value**	**Decision**
$\gamma = 0$[a]			
Model 1	3.22	2.71 (1 *d.f.*)	Reject *H0*
Model 2	46.71	11.91 (6 *d.f.*)	Reject *H0*
Model 3	2.45	2.71 (1 *d.f.*)	Accept *H0*
Model 4	59.32	11.91 (6 *d.f.*)	Reject *H0*
Model 1 vs. Model 2[b]			
$\lambda=\delta_0=\delta_{MC}=\delta_{HL}=\delta_{RL}=\delta_{TI}=0$	43.49	12.59 (6 *d.f.*)	Reject H_0
Model 3 vs. Model 4[b]			
$\lambda=\delta_0=\delta_{MC}=\delta_{HL}=\delta_{RL}=\delta_{TI}=0$	56.87	12.59 (6 *d.f.*)	Reject H_0

a This statistic has a mixed χ^2 distribution.
b Read as Restricted model versus Unrestricted model.

Several dairy farm studies that use a stochastic frontier model report average technical efficiencies close to the results of this paper (e.g., Battese and Coelli (1988) 71%; Bailey et al. (1989) 78%; Kumbhakar, Biswas and Bailey (1989) 79%; Bravo-Ureta and Rieger (1990) 84%; Bravo-Ureta and Rieger (1991) 83%; Dawson and Woodford (1991) 86%; Heshmati and Kumbhakar (1994) 82%; Kumbhakar and Heshmati (1995) 85%; Ahmad and Bravo-Ureta (1996) 81%; Reinhard, Knox and Thijssen (1999) 89%; Cuesta (2000) 78%; and Álvarez and Arias (2004) 70%).

The effect of time (*DTs*) on output is significant for all periods (β_{DT2} and β_{DT3}) and for both selected models (2 and 4). For Model 2, the year-to-year rate of technological change is -20.1% (1999/00 over 1997/98) and -13.5% (2001/02 over 1999/00). The simple average annual rate of technological change over the 1997/2002 period is -16.8%. Model 4 has a similar technological change pattern than Model 2, with a year-to-year rate of -21.6% (1999/00 over 1997/98) and -13.8% (2001/02 over 1999/00), with a simple average annual rate over the 1997/2002 period of -17.7%.

Ideally, one would have rates of technological change from other studies of the Argentine dairy sector in order to have a benchmark for comparison. However, no such data are available. Nevertheless, the literature typically reports technological progress rather than regress as found in this study. However, Battese and Tessema (1993) also report technological regress (38% per year) for a panel of farms from three Indian villages.

CONCLUDING REMARKS

This paper uses stochastic production frontier models (SPF) and output-oriented stochastic distance frontier models (SDF) to measure technical efficiency for a sample of dairy farms in Abasto

Table 5. Correlation coefficient and Descriptive Statistics for Technical Efficiency from Four Alternatives Models.

A. Correlation Coefficient				
Model/Model	1	2	3	4
1	1.000			
2	0.733	1.000		
3	0.976	0.741	1.000	
4	0.710	0.632	0.722	1.000
B. Descriptive Statistics				
Model	1	2	3	4
1997/98	0.885	0.897	0.885	0.678
1999/00	0.878	0.859	0.879	0.672
2001/02	0.886	0.888	0.886	0.664
Average	0.883	0.884	0.884	0.672
Low	0.717	0.462	0.730	0.329
High	0.953	0.988	0.952	0.942

Sur, Argentina. The data is a highly unbalanced panel including 46 farmers from 1997/98 to 2001/02. Four alternative specifications of the Battese and Coelli (1992 and 1995) framework are evaluated. The two preferred models incorporate inefficiency effects as in Battese and Coelli (1995). Average technical efficiency across the four models evaluated ranges from 67.2% to 88.4%, while the correlation coefficient for technical efficiency scores ranges from 0.632 to 0.976. The analysis reveals a significant rate of technological regress (an annual average of 16.8% and 17.7% for the selected SPF and SDF models, respectively).

The results indicate that alternative specifications of the Battese and Coelli (1995) framework can have a significant impact on the results, specifically on mean efficiency values. However, a key conclusion of this paper is that SPF and SDF models exhibit similar patterns with respect to the estimated production function parameters. Thus, if the interest is on ranking farms according to their level of technical efficiency then the evidence here indicates that the simpler single (aggregate) output technology does quite well. However, the technical efficiency measures are relatively lower for the SDF than SPF models (67.2% and 88.4%, respectively).

RESUMEN

V. H. Moreira López, B. E. Bravo-Ureta, A. Arzubi, y E. Schilder. Eficiencia Técnica en Predios Lecheros de Argentina con Múltiples Productos Usando Fronteras Estocásticas de Producción y Distancia en Panel de Datos Desbalanceado.

Este trabajo usa fronteras estocásticas de producción (FEP) y fronteras estocásticas de distancia (FED) para medir la eficiencia técnica de una muestra de predios lecheros de Abasto Sur, Argentina. Se dispone de un panel de datos altamente desbalanceado, incluyendo 46 agricultores entre 1997/98 a 2001/02 con un total de 82 observaciones. Se evalúan cuatro especificaciones alternativas del modelo propuesto por Battese y Coelli (1995). El rango del promedio de eficiencia técnica entre los cuatro modelos evaluados es 67,2% a 88,4%, mientras el coeficiente de correlación para los índices de eficiencia técnica va desde 0,632 a 0,976. Existe un significativo retroceso tecnológico, con un promedio anual de 16,8% y 17,7% para los “mejores” modelos. Los resultados indican que la especificación econométrica puede tener un impacto significativo en los resultados, específicamente en los promedios de eficiencia técnica.

Palabras claves: Argentina, datos de panel, eficiencia técnica, fronteras estocásticas de producción y de distancia, predios lecheros.

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