STOCHASTIC PRODUCTION FRONTIER AND TECHNICAL EFFICIENCY IN AGRICULTURE[1]

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ABSTRACT

The objective of this paper is to estimate the technical efficiency of a sample of representative producers in the Brazilian commercial agriculture, based on a stochastic production frontier model. The average technical efficiency obtained was 73.08% and, although this is a high ratio, it indicates that there it is still a possibility to increase productivity by improving technical efficiency. At the farm level, technical efficiency ranged from 41.47% to 93.09%. Tobit's model was used to investigate the influence of some human resources variables on the levels of technical efficiency. The results indicated that the most important variables were experience, private extension and alternative sources of information (radio).

Keywords: stochastic production frontier, technical efficiency, commercial agriculture.

1. Introduction

There is considerable agreement that an effective development strategy depends on the promotion of productivity and of growth of the agricultural sector. In this sense, the great challenge of the Brazilian

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agricultural sector, in the mid-sixties, was modernization.

Because of that, the agricultural sector modernization policy was adopted, mainly from mid-sixties. This policy prevailed in the following decades and was responsible for the transformation of the Brazilian agriculture. Along this process, policy instruments, such as rural credit, minimum prices, technical assistance and research were used. However, in the late eighties, this model of agricultural policy began showing signs of weariness, with a drastic reduction in the budgetary expenses destined to agriculture support programs (Barros, 1998).

In the nineties, a new institutional atmosphere, with a liberalizing economy and open to the international markets, emerges. Thus, the development of new mechanisms started being prioritized rather than the performance interventionist of the government.

This new scenario has a direct impact on agriculture, which now faces a new challenge: obtaining efficiency in the productive process. In that sense, identifying potential productivity gains originating from a more efficient use of technology becomes a fundamental issue. According to Alves (1993), given the existing limitations, the solution for the commercial sector of Brazilian agriculture, sensibly worsened in the nineties, is in the search for greater efficiency.

Recent literature has presented advances in obtaining efficiency estimates from the production functions estimates, using mainly the frontier production function. The econometric modeling of production frontier functions is usually a useful instrument to determine efficiency measures of the firms that are closer to the classical definition of production function. It corresponds to the maximum production that can be obtained from a certain input set, given the existing technology for the firms involved in the productive process.

Most of the literature about farm efficiencies has addressed to technical efficiency measures. Technical efficiency can be defined as the ability of a firm to find the maximum possible production with the available resources, whereas allocative efficiency refers to the ability to reach an optimal allocation of the existing resources.

Economic efficiency is the combination of technical and allocative efficiency (Farrell, 1957).

Some authors have also researched the relationship between efficiency measures and representative variables of human resources using the so-called two-step procedure. That is, initially, the efficiency is calculated. Then, a regression model is estimated in which efficiency is expressed as a function of human resources variables.

In Brazil, few studies have estimated the efficiency starting from the frontier function. Among these, one can indicate Taylor, Drummond & Gomes (1986) work, which analyzes technical and economic efficiency of a group of farmers through the estimate of a deterministic frontier production function; Taylor & Shonkwiller (1986), who estimated a stochastic production frontier function using the same data as Taylor, Drummond & Gomes 1986. These authors had the objective of verifying if farmers who received technical assistance from PRODEMATA program were more efficient than those who did not receive it. The farmers were from *Zona da Mata* area, in the State of Minas Gerais, and were characterized as traditional farmers. Tupy (1996) has also used the frontier methodology in order to estimate the economic efficiency of a group of poultry producers in Brazil. Gomes (1996) used a Cobb-Douglas deterministic frontier production function to estimate the technical efficiency of tomato producers in the irrigated area of Senador Coelho, in Petrolina. The efficiency measures found by these authors cannot be generalized to other types of producers who use other production technology.

This is precisely the context in which this study is situated. Its objective is determining the technical efficiency of Brazilian farmers in areas of modern (commercial) agriculture, trying to relate this measure with human resources variables.

2. Frontier production function and technical efficiency measure

In this study, the frontier production function is considered as:

$$Y_j = f(X_{ij}; B)e^{\varepsilon_j}$$
$$i = 1,2,...N \qquad (1)$$
$$j = 1,2,...N$$

Where Y_j is the agricultural output from j, X_{ij} is the amount of input i used by firm j and β is a parameters vector, $\varepsilon_j = v_j - u_j$ is the composed error term. The components u_j and v_j are thought to be independent, being v_j the random error with normal distribution $\left(v \sim N\left(0, \sigma_u^2\right)\right)$ and u_j is the error term which captures inefficiency. A great advantage of this model is the introduction of a composed error term, one representing the measure and exogenous shock errors out of the production unit control (v_j), and another concerning the inefficiency measure (u_j).

If $u_j = 0$, the firm is in the production frontier, obtaining maximum production given the input level it uses. If $u_j > 0$, the firm is inefficient and produces less because of this inefficiency. If the error term u_j is not in the model, the model is an average function, used in most econometric studies of production function and criticized by Farrell (1957) and other authors. If error v_j is not included, the model becomes a deterministic frontier.

We must point out that an important matter in stochastic frontier models is concerned with the assumption regarding the distribution of error term u_j. Most of the existing literature has chosen the half-normal distribution, as suggested by Aigner, Lovell & Schmidt (1977).

In order to measure efficiency empirically, we first estimate stochastic frontier production and, then, use the approach introduced by Jondrow et al (1982) in order to separate the frontier diversion in random and efficiency components.

As for half-normal distribution, Jondrow et al. (1982) showed that the assumptions which were made about the statistical distribution of v_j and u_j mentioned above, enable the calculation of the conditional meaning of u_i given ε_j , such as:

$$E(u_j \mid \varepsilon_j) = \sigma^* \left[\frac{f\left(\varepsilon_j \lambda / \sigma\right)}{1 - F\left(\varepsilon_j \lambda / \sigma\right)} - \frac{\varepsilon_j \lambda}{\sigma} \right] \tag{2}$$

where f and F are, respectively, the standard normal density functions andthestandard normal distribution and $\delta^* = \delta_u^2 \delta_v^2 / \delta^2$.

Thus, equation (2) provides us with u_j and v_j after the substitution of ε, σ, λ by their estimates. Once the u_j estimates are calculated, it is possible to calculate the technical efficiency measure for each of the farms, as well as the mean technical efficiency measure.

The technical efficiency measure is given by:

$$TE_j = Y_j \big/ Y^*_j \tag{3}$$

where Y*j is the frontier production level, i.e., when inefficiency (*uj*) equals zero, then, $Y^*_j = f(X_i;\beta)e^{v_j}$ e $Y_j = f(X_i;\beta)e^{v_j - u_j}$

$$TE_j = f(X_i;\beta)e^{v_j - u_j} \big/ f(X_i;\beta)e^{v_j} \tag{4}$$

That is, $TE_j = e^{-uj}$ (5)

The maximum technical efficiency equals 1. In that case the firm is producing in the frontier, i.e., $Y^*_j = Y_j$.

The technical efficiency of the farm has been estimated along several empirical works, starting from *1-E(u_j/ε)*. However, Battesi & Coelli (1988) warn that, when the function is expressed in its logarithmical form, such as the one adopted in this work, the correct measure of technical efficiency is $e^{(-uj)}$. The mean technical efficiency also derived by Battesi & Coelli (1988) is:

$$TE = 2[1 - F(\delta_u)]\exp\frac{1}{2}\delta^2_u \qquad (6)$$

3. Empirical model and data

The Cobb-Douglas functional form was used to estimate the stochastic production frontier. We must point out that this functional form has been widely used in agricultural efficiency analysis. Additionally, in one of the few studies which examine the impact of distinct specifications regarding the functional form adopted, Kopp & Smith (1980) found a very low impact of the adopted functional form on the estimated efficiencies.

The model to be estimated is:

$$Y_j = \beta_0 T^{\beta_1} L^{\beta_2} M^{\beta_3} e^{\varepsilon_j} \qquad (7)$$

Which, in its logarithmical form, is:

$$\ln Y_j = \ln \beta_0 + \beta_1 \ln T + \beta_2 \ln L + \beta_3 \ln M + \varepsilon_j \qquad (8)$$

Where $\boldsymbol{Y_j}$ is the agricultural production value of farm j; $\boldsymbol{T}$ is the area or land explored (in hectares); $\boldsymbol{L}$ is labor (days/man); $\boldsymbol{M}$ represents expenses with seeds, insecticides and fertilizers, machines and equipment maintenance; and ε_j is the composed error term, $v_j - u_j$.

The explanatory variables specified in the model have frequently been used in the estimation of agricultural production frontiers (Taylor, Drummond & Gomes, 1986; Taylor & Shonkwiller, 1986, and Bravo-Ureta & Pinheiro, 1997).

After estimating the Cobb-Douglas production frontier, the next step is using the methodology proposed by Jondrow et al. (1982) in order to decompose ε_j in v_j e u_j. After obtaining the u_j estimate, we can calculate the technical efficiency of each farm.

In order to satisfy public policies, identifying the sources of these efficiencies is useful. It can be done through the investigation of the relationship between the technical efficiency levels and some representative variables of human resources.

Bravo-Ureta & Pinheiro (1997) used the Tobit model in order to estimate the influence of representative variables of human resources on the efficiency levels found, since technical efficiency (dependent variable) will only be a value between 0% and 100%.

In the Tobit model, as showed by Greene (1997), a least squares is not adequate to estimate the parameters. Because of that, a maximum likelihood method is used.

Greene (1991) argues that, in cases in which there is a truncation both at the bottom and at the top limit, the *two-limit tobit* is adequate.

The following empirical model was estimated:

$$TE_j = \beta_0 + \beta_1 Esc + \beta_2 Exp + \beta_3 Ext + \beta_4 Epriv + \beta_5 Radio + \xi \quad . \quad (9)$$

Variables Esc, Exp e Ext, Epriv and Radio represent, respectively, schooling of the person in charge of the agricultural property, experience, contact with public rural extension services, contacts with private extension, and information access through radio programs. In equation 9, the dependent variable is the technical efficiency ratio. The independent variables are all binary, and their value is 1 if they are the equal or above the mean sample, and 0, if they are under it. They are defined in the following way:

Schooling (Esc): This variable was measured in number of school years of the person in charge of the agricultural property. Its value is 1 if the number of school years of study is above 8, and zero, otherwise;

Experience (Exp): this variable was measured according to the number of years the person in charge of the agricultural property is in business. Its value is 1 if the number of years is above 10, and zero, otherwise;

Public extension (Ext): this variable was measured according to the number of contacts the person in charge of the agricultural property had with the public extension service. It value is 1 if the number of contacts is above 14, and zero, otherwise;

Private extension (Epriv): this variable was measured in the same way as the public extension variable. However, here, its value is 1 if the number of contacts is above 1, and zero, otherwise;

Radio: this variable equals 1 if the person in charge of the agricultural property has access to information through radio, and zero, otherwise.

The data used in this study are primary and they were generated by a sample of 330 farms in Brazilian agricultural areas (Araújo et al., 1990). The areas chosen for the study and the respective number of interviews applied to each one of them are: i) Carazinho, RS (36 interviews: ii) São Gabriel d'Oeste, MS (25 interviews); iii) Rondonopolis, MT (26 interviews); iv) Rio Verde, GO (21 interviews).

These areas are representative of commercial agriculture characterized by the use of modern production techniques and by their market targeting. The "municipio" of Rio Verde is marked by high technology commercial agriculture in large scale. Many farmers from that area are from Southern states of Brazil and are, therefore, grain – and most especially soybean – producers. Rondonopolis has a very intensive capital agriculture with a reduced use of labor. São Gabriel d'Oeste also presents agriculture of intensive capital, explored in large scale and based on soybean crop like Rondonopolis. Carazinho has a technically improved agricultural sector with a relatively high mechanization rate and a small use of labor. Moreover, its production scale is higher than that of other areas of Rio Grande do Sul and is principally oriented to the production of grains, mostly soybean and corn.

4. Results

A Cobb-Douglas function was first estimated ordinary least squares. Then, the Cobb-Douglas stochastic production frontier was estimated through the maximum likelihood method (Table 1).

The results show a good adjustment of the Cobb-Douglas production function. The estimated parameters are significant at the 1% level, except for labor, which is significant at the level of 5%. The adjusted R^2 is high, 89%, and the F test is significant at the level of 1%. The variables used explain, therefore, approximately 90% of production.

Table 1 - Cobb-Douglas production function and Cobb-Douglas Stochastic Production Frontier Function parameters estimate for the Sample of Commercial Farmers in Brazil.

Variables	Average Function	Stochastic frontier function
Constant	7.73880*	7.81800*
	(0.6442)	(0.6079)
Land	0.49547*	0.48408*
	(0.07184)	(0.06548)
Labor	0.12015**	0.15310*
	(0.05456)	(0.05918)
Modern Input expenditure	0.27048*	0.27695*
	(0.05858)	(0.05141)
F Test	302.23*	---
Quasi function Coefficient	0.886	0.914
F (RCE) Test	5.76*	
Wald (RCE) Test		3.43***
Adjusted R^2	0.89*	--
λ		1.7943**
		(0.80231)
σ		0.4886*
		(0.07694)
σ_v^2		0.05658
σ_u^2		0.18214
MLFL		-38.73136
n=108		

Source: Research Data

Note: * significant at the level of 1%.. ** Significant at the level of 5%. . ***Significant at the level of 10%. MLFL - Maximum likelihood function logarithm. The values in parentheses are standard-diversion.

As the Cobb-Douglas production function is estimated in its logarithmical form, the estimated coefficients express production elasticity with respect to inputs. The results are coherent, both as to expected signs and as to the importance of each input in the explanation of production.

Regarding the production frontier results, one can verify that the estimated coefficients are very similar to the those of the average function model, except for the constant term and the labor variable coefficient, that are greater in frontier function estimate. This demonstrates that the frontier function does not represent a completely neutral displacement in relation to the average function.

As for the estimation of the stochastic frontier function, the parameter $\lambda=\delta_u/\delta_v$ is particularly important. In the estimated model, λ = 1.7949 and is statistically significant, what implies that error term u_j dominates v_j, i.e., the difference between the observed production and the frontier production is due to inefficiency. Parameter $\gamma= \lambda^2/(1+\lambda^2)=\delta_u^2/\delta^2$ measures the effect of inefficiency in the variation of the observed production (Bravo-Ureta & Pinheiro, 1997). In the present study, γ equals 0.76, which means that 76% of the production change is due to technical inefficiency.

Once the stochastic frontier production function has been estimated and the u_j estimate has been obtained through Jondrow et al.'s (1982) methodology, it is possible to calculate the technical efficiency of each farm as well as the mean technical efficiency. Table 2 shows the frequency distribution of the technical efficiency estimate for the group of modern farmers in Brazil.

The results demonstrate that the level of technical efficiency ranges from 41.47% to 93.09%. The mean technical efficiency for this sample of farms is 73.08%. This reveals that it is possible to increase production by using available technology better. The farmers of this sample fail to use this technology.

Table 2.Technical efficiency frequency distribution

Efficiency level (%)	Number of producers
> 90	1
>85<90	14
>80<85	21
>75<80	20
>70<75	15
>65<70	9
>60<65	8
>55<60	6
>50<55	6
>45<50	3
>40<45	5
Total	108
Mean	73.08%
Maximum	93.09%
Minimum	41.47%

Source: Research data

An indication of variables that influence, or have some relationship with the determined technical efficiency levels, is doubtlessly, an important contribution. Hence, the Tobit model results, presented in Table 3, relate the levels of technical efficiency with some variables that are generally used: schooling, public and private extension, experience, and radio.

Although the signs of the estimated parameters were as expected, only experience, private extension and radio variables were statistically[4] significant. That is, the differences found in the levels of technical efficiency are explained by these variables. As suggested by Hussain et al. (1994), the test of joint significance of the variables was based in the Chi-square statistics. The value of the calculated Chi-square was above the 10% level of the table, what leads one to conclude that the estimated parameters are together different from zero.

[4] A correlation matrix of the variables used in the model is attached demonstrating that the variables are not correlated.

Table 3. Tobit model parameters estimates with the variables: experience. schooling, public extension and private extension.

Variable	Coefficients	Standard -diversion
Intercept	65.1144 *	2.9988
Experience	3.2581***	2.5555
Schooling	0.3094^{NS}	2.4441
Public extension	0.9675^{NS}	3.4725
Private extension	8.2288*	2.7580
Radio	5.9232**	2.5713
LFMV	-421.1149	
Chi Square	13.56**	
N	108	

*Note: * significant at the level of 1%. ** Significant at the level of 20%. ***Significant at the level of 10%.* NS Non- significant . MLFL - Maximum likelihood function logarithm

The results are coherent with other studies about the influence of these variables on technical efficiency. As to schooling, the empirical evidences do not establish a clear standard. Some studies find positive and statistically significant effects. Among them are the papers of Belbase & Grabowski (1985); Kalirajan & Shand (1986). However, some other works did not determine the schooling effect, such as Bravo-Ureta & Evenson (1994) e Kalirajan (1991).

Some authors have affirmed that the allocative effect of education is the most significant one. Pudasaini (1983) estimated the effect of education in agriculture in Nepal. The author found results which corroborate what was mentioned above, i.e., the allocative effect of education was much more significant than the worker effect. In other words, education contributes more to the improvement of allocation ability than to technical efficiency. Huffman (1974) also found results that corroborates these findings. Ram (1980) determined that education and extension services have a positive effect on allocative efficiency of producers in India.

Bravo-Ureta & Pinheiro (1993) pointed out that in the empirical works they have done to investigate the influence of human capital on the efficiency levels, the larger relation refers to extension and access to information.

In fact, extension services have a more explicit objective of spreading more adequate production techniques. That is, by being in contact with extension services, producers have more access to technical knowledge and can produce more efficiently.

One must point out that in this study, private extension was the significant variable that explained efficiency levels. The influence of public extension was not significant. This result, however, does not seem to be contradictory or surprising, particularly when one considers that the sample taken for the study came from modern farmers. About this, Alves e Contini (1992) remark that private extension gained importance with technological development and is specialized in passing it on. They also affirm that, in Brazil, in the Mid-western, Southeastern and Southern regions, the presence of private extension, represented by some modern input firms, agribusiness, cooperatives, and planning-specialized companies, is a reality. Hence, public extension stops being the technology-spreading agent and loses, in this aspect, to private initiatives, specially in areas of advanced agriculture.

An interesting aspect that must be pointed out is the high significance of the radio variable to explain technical efficiency levels. This variable has not been intensively exploited by empirical work, but is an important result which shows the power that mass communication has performed.

Finally, the experience variable was also important to explain technical efficiency levels. This reinforces the argument presented in by the *learning-by-doing* literature, which is that *learning by doing* is an important source of knowledge acquisition that should be considered in the analysis.

5. Conclusion

This paper used the stochastic production frontier method to estimate the technical efficiency of a representative group of producers of Brazilian modern agriculture.

The results obtained in the present study showed a possibility of having a production increase by improving efficiency, since the average level of technical efficiency was of 73.08%. This level cannot be considered low, however it indicates that productivity can still be increased by improving efficiency. This result is important, since it shows that in the short run, additional gains can be achieved by an improvement in the performance of the sample of farmers. The technical efficiency levels range between 41% and 93%, but most producers have a technical efficiency of 70-80%.

A model establishing a relationship between the influence of variables such as schooling, private extension, public extension, experience and radio, was tested and provided useful results for future estimates of better parameters of possible variables that could help improving these farmers' performances. The latter variable represents information access to radio programs. The model presented interesting results. Among the analyzed variables, private extensicn, experience and alternative sources of information (radio), were important to explain the level of technical efficiency.

Producers who established a broad contact with private extension services had higher technical efficiency levels. This confirms the important role played by private extension in Brazilian commercial agriculture of grains. When the producers purchased the inputs, they possibly had access to important information about the best way of using it, and this has resulted in higher efficiency levels.

The analysis of the importance of cumulative knowledge through experience, has also been indicated by the analysis, i.e., more experienced producers had a better performance from a technical perspective. The importance of alternative sources of knowledge about technical efficiency was also showed by the analysis. Finally, when it comes to schooling, the present work has not identified a statistically significant relation of this variable and the level of technical efficiency. One of the possible explanations for this empirically documented fact is that education has a greater impact on allocative efficiency. Hence, studies investigating the impact of this variable on allocative efficiency would doubtlessly be an important contribution.

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Attachments

Correlation Matrix

	Experience	Schooling	Radio	Extention	Private Extension
Experience	1.000				
Schooling	-0.1508	1.000			
Radio	0.2558	-0.2782	1.000		
Extention	-0.0605	-0.0803	-0.2101	1.000	
Private Extension	-0.3455	-0.0201	-0.2584	0.1986	1.000