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Technical efficiency and farm size: an analysis based on the Brazilian agriculture and livestock census[1]

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Abstract. This paper analyzes the relationship between technical efficiency and farm size, considering different classes of area and efficiency levels in Brazil. Stochastic Frontier Production was used to obtain the technical efficiency and the Quantile Regression was used to identify their determinants. Microdata from the 2006 Brazilian Agriculture Census were used. It was found a positive and non-linear relationship between farm size and efficiency in all area classes. However, the more efficient the producers, the weaker the relationship, which indicates that such producers were less dependent on the land factor. In addition, irrigation, technical assistance and cooperatives membership were the factors which contributed most to increasing efficiency, especially for the less efficient producers.

Keywords: Farm size, agriculture and livestock, stochastic frontier, technical efficiency, quantile regression.
JEL codes: Q10, Q15, C21

1. INTRODUCTION

Most studies on the productivity of the agriculture and livestock sector have pointed to an inverse relationship between farm size and productivity (Mazumdar, 1965; Berry, Cline, 1979; Sen, 1966), which could lead to a policy of land reordering so as to increase the productive performance of the entire sector. However, recent results have been contradictory, especially when the omission of relevant variables related to the characteristics of the producer, involving the human, physical and social capital of the farms, is taken into account. In addition, most of the studies use partial productivity measures, which are considered insufficient for analysing the importance of farm size and its influence on productive performance.

Since the beginning of studies in the field of agricultural economics, the relationship between farm size and productivity has been of great interest

[1] The authors thank the Brazilian Institute of Geography and Statistics (IBGE) for allowing access to the 2006 Agriculture and Livestock Census microdata.

(Bagi, 1982). However, this debate has not yet yielded a definitive solution, given the divergent results found in both the national literature and that of different countries. This issue is still relevant as it has direct implications for the role of agrarian reform policies if conditions are to be created to reduce inequality and generate economic growth in rural areas.

In the first studies, it was generally accepted that there was an inverse relationship between these variables, or in other words, the productivity of a farm decreases as its size increases (Mazumdar, 1965; Berry, Cline, 1979; Sen, 1966). However, especially from the 90's onwards, researches rejecting this hypothesis began to appear more frequently (Newell *et al.*, 1997; Rios, Shively, 2005). For Teryomenko (2008), the emergence of more advanced methodologies and superior quality data contributed to this deeper analysis of the theme, and also allowed for the inclusion of specific control variables which can directly affect the relationship between productivity and size.

One of the pioneering studies which identified the inverse relationship between productivity and size was undertaken by Mazumdar (1965) when analyzing two districts in the state of Uttar Pradesh, India. His justification for the inverse relationship is based on the fact that small farms use family labor more intensively. According to Mazumdar (1965), this is due to their economic incentive, as the motivation to put more effort into the work is greater for family members than for hired workers. In addition, hired labor requires more supervision, which could raise costs. Studies by Sen (1966), Benjamin (2002) and others have also analysed this approach.

Another explanation for this inverse relationship is proposed by Deolalikar (1981), who broadened the debate on the subject by incorporating the significance of technical progress. He argues that this inverse relationship is only observed where agriculture uses traditional farming techniques, that is, the hypothesis that small farmers are more productive is only valid when agriculture uses a low technological level.

Feder's (1985) study rejects the hypothesis that a labor market failure has greatest responsibility for the inverse relationship between productivity and size. For him, as family labor is a fixed resource on each farm, if there are no failures in capital or land markets and if each farm operates to maximize profits, then market forces would lead to an optimal solution. This solution implies that, if the market worked perfectly, each family would use the resources that were necessary to maintain ideal production, which would be proportional to the size of the family. Thus, the labor/land relationship would be the same across farms, and productivity would not be affected by farm size. However, this scenario changes when credit market failures are assumed because the amount of capital available to each family would depend on the amount of collateral (property land) it could offer.

Dyer (1997) and Havnevik and Skarstein (1997) argue that small farms present greater productivity of the land in the short term only, as in the long term, this would tend to fall. According to them, the reason for the fall in productivity is the more intensive use of land in the effort to maintain labor productivity at the same level. Thus, as more people worked on the farm and considering that small farms would have fewer resources to invest in preserving the fertility of the soil, then the productivity of the soil would decrease in the long term, thereby reducing the productivity of the land.

As argued by Helfand and Levine (2004), the type of measure used to represent productivity could also produce distinct results for the relationship with farm size. In this same sense, a study by Moreira *et al.* (2007) set out to investigate the inverse relation for Brazilian agriculture and livestock farms, using two measures for productivity: a partial measure, based on the productivity of the land, and the other based on total factor productivity (TFP). The results identified an inverse relationship between productivity of the land and farm size for the five Brazilian macro regions. However, when total factor productivity was analysed, only the Northern, Northeastern and Southeastern regions presented an inverse relationship between size and productivity of agriculture and livestock farms.

Helfand *et al.* (2015) investigated the relationship between farm size and TFP growth based on information from the 1985, 1995-96, and 2006 Agriculture and Livestock Censuses. They used aggregated data at municipal level and considered five classes of area: 0-5 ha, 5-20 ha, 20-100 ha, 100-500 ha and more than 500 ha. Based on a Stochastic Frontier Production approach, they identified a decline in the technical efficiency of the representative farms analysed in all groups, which contributed to lower TFP growth between 1985 and 2006. They also saw that the medium-sized farms belonging to the 20-100 and 100-500 ha groups presented the lowest rate of TFP growth in practically all Brazilian regions.

Thus, the results found in the literature show that the relationship between productivity and farm size is still a controversial issue. In addition, more recent literature presents the use of more complete measures to represent productive performance, such as the technical efficiency of the farm, which reduce the possibility of bias in favor of small farms and other measurement errors, which could occur when using partial productivity measures[2].

Against such a background, this study set out to determine the relationship between technical efficiency and farm size, by controlling productive heterogeneity in relation to the different classes of area and efficiency levels in rural Brazil in 2006. In addition, the study also allowed for the identification of the main determinants of the productive performance of farms when different efficiency ranges were considered.

When identifying the main determinants of the productive performance of farms, such as total area, total financing, access to cooperatives, irrigation technology and others, the consideration of different levels of technical efficiency makes a significant contribution to the existing literature. This analysis is relevant because, if a low performance farm is to increase its yield, a greater investment in factors other than those which would guarantee the maintenance of efficiency of farms with greater productivity may be necessary. Thus, agricultural policies could be more efficient in reducing inequality between small and large producers if they also considered the efficiency of the farms and not just the type of producer.

It is also believed that the relationship between performance and farm size could be altered according to the level of efficiency of the producer, thereby showing the farm's greater or lesser dependence on the land. It should be noted that research with a focus on Brazil is generally based on aggregate data at state or municipal level, or by choosing representative farms for different area groups in a municipality[3]. This research used microdata from the 2006 Agriculture and Livestock Census, as they allow for broad characterizations, and the minimization of possible bias caused by the aggregation of data at municipal or state levels[4].

This study is divided into 3 sections, along with the Introduction. Section 2 presents the methodology and source of the data used to reach the proposed objective. Section 3 presents and discusses the results of the research, while Section 4 presents the conclusions of the study.

[2] According to Lima *et al.* (2017), it is understood by technical efficiency how an optimal combination of inputs is employed in the productive process in order to obtain the maximum product. This means that this efficiency deals with the relationship between the inputs and the total final product, so it can be considered a more complete measure for productivity. For the estimation of the technical efficiency scores the Stochastic Production Frontier approach was used, as presented in section 2.1.

[3] Helfand and Levine (2004), Rada and Valdes (2012), and others.

[4] Microdata (data at farm level) of the 2006 Agriculture and Livestock Census were accessed in a reserved room at the IBGE headquarters in Rio de Janeiro, with prior approval for the research project.

2. METHODOLOGY

The strategy adopted to achieve the objectives proposed in the research was based on two procedures. The first was using the Stochastic Frontier Production[5] technique to obtain the efficiency levels of Brazilian agriculture and livestock farms for the country as a whole, and for each area class: minifundium, small, medium, and large[6]. In the second stage of the research, the Quantile Regression[7] technique was used to identify the explanatory power of the variables[8] understood as determinants of technical efficiency, considering different efficiency ranges. The two methods are presented below.

2.1. Stochastic Frontier Production

The main aim of the Stochastic Frontier model is to estimate a production function, where it is expected to obtain maximum production from a combination of factors at a given technological level. However, there is no guarantee that an efficient combination of factors which maximize production is used, as there could be technical inefficiencies in the use of these factors. This implies that the farm could be producing below the maximum production frontier. Thus, the amount by which the production of this farm falls short of the production frontier provides a logical measure of technical inefficiency.

According to Taylor and Shonkwiler (1986), the stochastic nature of the model is directly related to the possible existence of factors which cause deviations from the production frontier and could escape the farmer's control, such as climatic variations, pests and diseases. In contrast to deterministic frontier models, where random variations are incorporated into the measure of technical inefficiency, the specification of stochastic frontier models includes a random error component to explain such variations.

In this study, as data refer to the 2006 Agriculture and Livestock Census microdata, that is, data at farm level, the basic form of the stochastic frontier production function is given by:

$$Y_i = f\left(X_i;\beta\right) e^{(v_i - u_i)}, \text{ where } i = 1, 2, 3, \ldots, n \quad (1)$$

where Y_i represents the production obtained by the i-th farm; X_i is the vector of the production factors used,

[5] For more detail see Coelli *et al.* (2005) and Hadley (2006).

[6] The criteria used to classify Brazilian agriculture and livestock farms in each area group are presented in Section 3.3.

[7] For more detail on the method, see Koenker and Basset (1978).

[8] The variables used are presented in Section 3.3.

β the vector of parameters to be estimated; and v_i and u_i are the error terms. The v_i random error component explains production measurement errors due to climatic variations, the presence of unobservable inputs in production, and errors in the observation and measurement of data. The u_i error component represents the restriction of the level of production to values equal to or lower than those of the frontier, therefore characterizing the technical inefficiency of the agriculture and livestock farm. The parameters are frequently estimated via Maximum Likelihood methods.

Given the above, the first step in the empirical application of the method is to define the functional form of the stochastic frontier, as pointed out by Coelli and Battese (1996). Different functional forms are used in the application of output analysis; however, according to Hanley and Spash (1993), the Cobb-Douglas function is preferable to other forms if there are three or more independent variables in the model, as they involve less loss of degrees of freedom. In this study, the number of independent variables is greater than three, hence the Cobb-Douglas function was used.

Chambers (1988) identified certain advantages in using the Cobb-Douglas: 1) simplicity in estimating the parameters because in logarithmic forms, the Cobb-Douglas function is linear in parameters; 2) regression coefficients provide the production elasticities which can be compared to each other; 3) because it is a homogeneous function, the sum of the regression coefficients determines the returns to scale; and, 4) when compared to the transcendental logarithmic functional form (translog), the Cobb-Douglas function has a small number of parameters for estimation as it is less susceptible to the common problems of multicollinearity in estimating the production function.

Thus, by incorporating dummy variables for states and total area groups, the logarithmic form of the stochastic frontier function can be represented by:

$$lnY_i = \sum_{i=1}^{n} ln\beta_i X_i + \sum_{h=1}^{26} E_h + \sum_{g=1}^{3} G_g + v_i - u_i \tag{2}$$

where Y_i is the total value of production of the i-th farm, in reals, in 2006; X_i is the vector of the factors of production considered[9]; E_h are dummies to represent the Brazilian states; G_g are dummies to represent the area groups; and β_i is a vector of the parameters to be estimated, which define the production technology. It should be noted that it was necessary to include dummies to capture the fixed characteristics of each area group or state, and to try to control possible spatial autocorrelation, so as to obtain an estimate of efficiency free from these effects[10].

The estimated model assumed that the v_i random error component has a normal distribution, independent and identically distributed (*iid*), truncated at zero, with variance $\sigma_v^2\left[v \sim iidN\left(0,\sigma_v\right)\right]$ and captures the stochastic effects beyond the control of the productive unit, such as measurement errors and climate, for example; and u_i is responsible for capturing the technical inefficiency of the i-th farm, that is, the part of the error which constitutes a downward deviation in relation to the production frontier, and are non-negative random variables. This unilateral (non-negative) term can follow half-normal, truncated normal, exponential or gamma distributions with mean $\mu > 0$ and variance σ_u^2 (Aigner *et al.*, 1977; Greene, 1980).

Initially, it was expected to find a positive relationship between the factors of production considered and the gross value of production, showing a directly proportional relationship between an increase in these factors and an increase in the value of agriculture and livestock production. However, the possibility of finding negative signs for these coefficients was not ruled out.

It should be noted that, because of the existing heterogeneity between farms, the standard errors were estimated using the bootstrap resampling method[11], considering 50 replications. In this way, the degree of reliability in the inferences made on the basis of the estimated statistical results is greater.

Given a vector of production factors, X_i, potential $\left(Y_i^*\right)$ is defined as the maximum production obtained in the absence of technical inefficiency throughout the productive process and is represented by:

$$Y_i^* = e^{\left(X_i\beta + v_i\right)} \tag{3}$$

Thus, the estimated technical efficiency of the i-th farm can then be defined as the ratio between its observed production and potential production, also known as frontier production, given the technology available, and is formulated as follows:

$$TE_i = \frac{Y_i}{Y_i^*} = \frac{e^{\left(x_i\beta + v_i - u_i\right)}}{e^{\left(x_i\beta + v_i\right)}} = e^{-u_i} \tag{4}$$

[9] The variables used are presented in Section 3.3.

[10] It should be noted that area dummies are only included in the estimated frontier for Brazil as a whole, as the other frontiers are specific to each area group.

[11] For more details on the procedure, see Song *et al.* (2012).

where the technical efficiency score (TE_i) is a value between zero and ($0 \le TE_i \le 1$), where zero represents full inefficiency and 1, total efficiency. After estimating the stochastic frontier model, the technical efficiencies of the sample farms were estimated using conditional expectation, $E\left[\exp\left(-U_i | V_i - U_i\right)\right]$, as suggested by Battese and Coelli (1988)[12].

Aigner *et al.* (1977) suggested that the maximum likelihood estimates of the model parameters should be obtained in terms of parametrization, where $\sigma^2 = \sigma_v^2 + \sigma_u^2$ and $\lambda = \frac{\sigma_u}{\sigma_v}$. A value greater than 1 for λ means that the variance of the technical inefficiency (u_i) is greater than the stochastic error term (v_i) and vice versa when λ is less than 1.

2.2. Determinants of technical efficiency in different ranges of efficiency

After estimating the technical efficiency scores via the stochastic frontier method, the second stage of the analysis involves identifying the main factors which influence the efficiency of the productive units. The quantile regression method is used to identify the main determinants of technical efficiency, when different efficiency ranges are taken into consideration. This method is feasible since the explanatory power of the independent variables over the dependent variable could be distinct at different points in the distribution of the sample analysed, depending on the dispersion and heterogeneity of the sample. Thus, using estimation techniques based on least squares may not be the most correct way to obtain the coefficients of a model. So, for the present study, the estimated equation is given by:

$$Q_\theta(LnTE_i | Z_i) = f\left(Z_i; \beta_\theta\right) \tag{5}$$

where $LnTE_i$ is the logarithm of technical efficiency of the i-th farm; Z_i is the vector of the determinant characteristics considered[13] and β_θ, the vector of parameters to be estimated in the θth quantile. Equation (5) was estimated in five quantiles (0.10, 0.25, 0.50, 0.75, 0.90), with the dependent variable being the efficiency in each range, or conditional quantile, of the error distribution of the stochastic function (Equation 4).

According to Buchinsky (1995), estimated parameters are interpreted by the marginal effect (*MEg*) of each explanatory variable in each specific conditional quantile, given by the partial derivative of each regressor of Equation 5:

$$ME_g = \frac{\partial Q_y(q | Z)}{\partial z_j} \tag{6}$$

In terms of the variables represented by dummies, the *MEg* should be interpreted as the response of the conditional q-th quantile of efficiency to the change of the j-th element of the vector Z of the independent variables from zero to 1. This means that, for the dummy variables, the marginal effect is obtained by the difference of the probabilities of Z being equal to 1 or equal to zero, as described in the equation below:

$$ME_g = P\left[Q_y = y \mid Z_j = 1\right] - P\left[Q_y = y \mid Z_j = 0\right] \tag{7}$$

The Wald test is applied to verify if the coefficients estimated in each quantile are, in fact, statistically different from each other. According to Hao and Naiman (2007), when variance and covariance are estimated, this test allows one to verify the equality hypothesis between pairs of coefficients in each quantile $\beta_i^{(p)}$ and $\beta_i^{(q)}$, corresponding to the same variance, but between quantiles p and q using the Wald statistic:

$$Wald(W) = \frac{\left(\beta_j^{(p)} - \beta_j^{(q)}\right)^2}{\beta_j^{(p)} - \beta_j^{(q)}} \tag{8}$$

The Wald statistic follows the χ^2 distribution with q degrees of freedom, considering q the number of hypotheses tested jointly or with F distribution, where $F = \frac{1}{q}W$, with q degrees of freedom in the numerator and d degrees of freedom in the denominator (Cameron, Trivedi, 2009).

Thus, by estimating the quantile regression (5), it is possible to identify the power of determination, if it exists, of the explanatory variables in groups of the sample differentiated by bands, or quantiles, of efficiency. Thus, the way each group responds to changes in these variables is verified, and not just the effect in relation to the sample mean. This analysis is interesting considering that the estimated efficiency could present great productive heterogeneity, given the peculiarities of each state and/or area class. In addition, it also allows one to investigate whether the relationship between productive performance and farm size changes at each level of efficiency.

It should also be noted that, as in the previous stage, the heterogeneity of the productive units was considered

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[12] See study by Battese and Coelli (1988), for more detail on the technical efficiency estimator used.

[13] The variables used are presented in Section 3.3.

in the estimation process. The standard errors were estimated via the bootstrap resampling method, in order to give greater reliability to the inferences made on the basis of the estimated statistical results.

2.3. Source and treatment of data

Information about the variables used in the present study is based on microdata from the 2006 Agriculture and Livestock Census, accessed directly from the headquarters of the Brazilian Institute of Geography and Statistics (IBGE). The microdata had to be selected and treated, so that the final base drawn up would be suited to the analyses undertaken. As the study set out to determine the relationship between technical efficiency and farm size (area), farms where areas were undeclared were excluded (255,019 observed). Farms located in urban areas were equally excluded (192,350 observed), as were those in special sectors such as slums, barracks, shelters, ports, indigenous villages, asylums, etc. (117,530 observed), thereby maintaining those exclusively of the sector.

Farms belonging to settlements were also excluded (139,496 observed), in order to avoid possible errors in measuring the variables. Although the enumerators were instructed to consider each settler's plot as a farm, in several cases the area of the whole settlement was considered a single farm, as the agricultural work was undertaken in a collective manner.

In addition, the sample included only those farms owned by an individual producer. Those classified as condominiums, consortiums or partnerships, cooperatives[14], corporations or limited liability companies, public utility institutes, whether government (federal, state, or municipal) or otherwise (190,838 observed) were not considered, because even if characteristics define a single person as being responsible for them, in practice, they have multiple owners. Likewise, farms where the type of producer was not identified (20,440 observed) were excluded.

After selections and transformations had been made, 915,673 observations were deleted (17.7% of the original sample), leaving a final sample composed of 4,259,963 agriculture and livestock farms. In order to obtain a more accurate estimate of the relationship between productivity and farm size, the microdata were organized into four classes according to farm size (minifundium, small, medium, and large), classified by IBGE in accordance with fiscal modules[15]. It should be noted that all aggregations, data generated and analyses were performed using the STATA® software.

As seen in previous subsections, the first step in obtaining the efficiency scores was the estimation of the production frontier function. For this, the 2006 gross production value (*prodval*), in reals, was defined as the product variable[16]. The factors of production were defined by the following variables: productive area (*prodarea)*, comprising the sum, in hectares, of the areas of cropland, livestock and agroforestry, representing a proxy for the land factor; total value, in reals, of the assets of the property (*valprop*), as a proxy for capital goods; sum of the number of family and contracted labor units (*laboru*)[17] as a proxy for the labor factor; (*totinput*), referring to the sum of expenses with soil amendments, fertilizers, pesticides, veterinary medicine, seeds and seedlings, salt/feed, fuel and energy, as a proxy for inputs; and the number of livestock units (*stocku*) (equivalent to the total number of animals on farms), as a proxy for livestock.

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[14] The exclusion of cooperatives does not mean that their members were excluded as they were included as individual producers if they had agriculture and livestock farms.

[15] The Fiscal Module (FM) is an agrarian unit of measure expressed in hectares, fixed for each municipality, considering the type of exploration predominant in the municipality, income from the predominant exploration, other types of exploration in the municipality which, although not predominant, are significant depending on the income or area used; and the concept of family property. The measure represents the minimum area required for rural properties to be considered economically viable, ranging in size from 5 to 110 hectares, depending on the municipality. The fiscal module serves as a parameter for the classification of rural property in the municipality in terms of size, in accordance with Law 8,629, dated February 25, 1993, and rural properties can be classified as: a) minifundia, with a size of up to 1 fiscal module; B) small properties, with an area of between 1 and 4 fiscal modules; C) medium-sized properties, with a size greater than 4 and up to 15 fiscal modules; and D) large properties, with an area greater than 15 fiscal modules.

[16] The choice to use the total gross value of production in each farm was due to the limitation of the microdata of the Agricultural Census, regarding the information about the productive inputs. That is, although the Census presents detailed information about the production value of each commodity, it is not possible to identify the amount of some inputs (labor, capital and others inputs) used in each crop specifically. In this way, it was not possible to estimate production stochastic frontiers for each agricultural product.

[17] According to the methodology of the 2006 Agriculture and Livestock Census, a family labor unit was obtained by adding the number of people, men or women, with ties of kinship, of 14 years of age or older, including the person running the farm, to half of the number of people with ties of kinship, less than 14 years of age, plus the number of employees with 'another status' aged 14 years or over, plus half the number of employees with 'another status' under 14 years of age. The hired labor unit was obtained by adding the number of men and women: permanent employees aged 14 years and over, to half the number of permanent employees under 14 years of age, plus partner employees of 14 years and above plus half of the number of employees of less than 14 years of age, plus the result of dividing the number of daily wages paid in 2006 by 260, plus the result of dividing the number of contract days by 260 (IBGE, 2006).

Tab. 1. Descriptive statistics of variables used in the analysis, per agriculture and livestock farm size.

Variables	Mini (N=3,283,982)		Small (N=694,133)		Medium (N=208,806)		Large (N=72,962)		Total (N=4,259,963)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
prodval(R$)	10,189	218,338	37,304	412,398	98,849	702,204	430,706	3,700,359	26,157	571,345
valprop (R$)	51,794	466,192	285,477	965,981	1,021,292	2,435,663	4,954,006	1,18e+07	221,372	1,848,835
totinput (R$)	2,065	193,793	10,014	102,411	36,867	688,611	246,885	7,307,546	9,260	984,657
finance (R$)	829,94	9,036	3,845	20,343	13,018	91,645	58,949	806,783	2,914	108,409
prodarea (ha)	7.60	10.20	49.59	43.64	206.74	167.32	1,158	1,993	43.91	305.57
totarea (ha)	10.36	13.51	69.7	54	286	214	1,716	3,102	62.76	468
laboru (units)	2.52	5.84	2.89	4.26	3.77	13.07	6.62	19.42	2.71	6.67
stocku (units)	6.88	21.55	34.02	58.75	124.15	175.46	593.11	1,140	27.09	176
tech (%)	*0.16*	*0.367*	*0.375*	*0.484*	*0.452*	*0.498*	*0.588*	*0.492*	*0.217*	*0.412*
irrig (%)	*0.06*	*0.24*	*0.069*	*0.25*	*0.073*	*0.26*	*0.08*	*0.27*	*0.062*	*0.24*
storage (%)	*0.16*	*0.366*	*0.298*	*0.458*	*0.27*	*0.444*	*0.248*	*0.432*	*0.189*	*0.392*
coop (%)	*0.397*	*0.489*	*0.474*	*0.499*	*0.424*	*0.494*	*0.411*	*0.492*	*0.411*	*0.492*
rural (%)	*0.895*	*0.307*	*0.801*	*0.399*	*0.696*	*0.46*	*0.661*	*0.474*	*0.866*	*0.341*
exper10 (%)	*0.626*	*0.484*	*0.707*	*0.455*	*0.645*	*0.479*	*0.586*	*0.492*	*0.64*	*0.48*
school (%)	*0.542*	*0.498*	*0.653*	*0.476*	*0.571*	*0.495*	*0.499*	*0.5*	*0.561*	*0.496*
tenant (%)	*0.0505*	*0.219*	*0.0328*	*0.178*	*0.0398*	*0.196*	*0.0321*	*0.176*	*0.0468*	*0.211*
partner (%)	*0.0348*	*0.183*	*0.00767*	*0.0872*	*0.00606*	*0.0776*	*0.00356*	*0.0596*	*0.0284*	*0.16*
occupier (%)	*0.105*	*0.307*	*0.0236*	*0.152*	*0.0181*	*0.133*	*0.00796*	*0.0889*	*0.0858*	*0.28*

Note: SD=Standard deviation.
Source: Drawn up by authors based on microdata from the 2006 Agriculture and Livestock Census.

It was also necessary to consider Brazil's regional differences in the analysis of the technical efficiency of farms as Brazilian territory is heterogeneous not just in terms of natural conditions but also in terms of factors such as historical occupation. With that in mind, regression was estimated considering fixed effects at state level in order to control this spatial heterogeneity. To do so, a dummy (E_h) for each unit of the federation was included in the model, which was given a value of 1 when the farm belonged to that unit of the federation and 0, otherwise.

In terms of the analysis of the determinants of productive efficiency, total farm area (*totarea)*, in logarithm, its quadratic term (*totarea2),* was included in the model, as well as the main variable, to see if the effect of farm size was non-linear. In addition, in order to control the heterogeneities due to the specific characteristics of the farmer or farm, the following variables[18] were also considered: access to technology, represented by the *irrig* dummy was given a value of 1 if the farm had access to irrigation; access to public institutes and bodies, defined by the variables total amount financed (*finance*), in logarithm; and access to technical assistance, represented by the dummy *tech* was given a value of 1, if the farm had access to any type of technical assistance, either occasionally or regularly; presence of a storage unit on the farm, represented by the dummy *storage* was given a value of 1 if the farm had a storage unit; participation in information networks via participation in cooperatives and/or class entities such as farmers' unions, associations or movements, represented by the *coop* dummy was given a value of 1 if the person in charge of the farm participated in cooperatives and/or class associations; residence of the farm head in a rural area, represented by the dummy *rural* was given a value of 1, if the head of the farm lived in the rural area, which for purposes of the study, are considered proxies for the presence of social capital on the farm; and variables related to human capital, such as the years of experience of the head as administrator of the farm, represented by the dummy *exper10* was given a value of 1, if the head had spent more than 10 years administering the farm, and schooling (*school).* As for the latter, it should be emphasized that it is a measure of little schooling, indicating whether the farm head became literate as an adult, did or did not have complete primary education or had no formal education whatever, but can read and write. It is thus expected that this will have a negative impact on the productive efficiency of the farms. This choice was

[18] The variables were selected using studies by Helfand and Levine (2004), Rada and Valdes (2012) and others.

made because it is basically the most frequent situation among farm heads. Finally, the status of the producers in relation to the land (*tenant, partner, occupier*) were considered dummies with the status of owner used as a basis. Table 1 presents the descriptive statistics per farm size of the variables considered in the analyses.

The data presented in Table 1 show that output value, value of goods, costs of inputs and total amount financed increase according to the size of the farm. The minifundia contain a mean of 7.6 ha of productive area, which is about 7 times smaller than that of the small farms (49.59 ha). When compared to medium and large properties, the average productive area of the minifundia was about 27 and 152 times smaller, respectively.

It was seen that access to technical assistance increases as farm size increases, as only 16% of the minifundia had access, while for large farms this percentage reached almost 60%. As regards access to irrigation technologies, it was seen that access is still limited for Brazilian farms, as the mean percentages varied from 6% for the minifundia to 8% for large farms.

On the question of social capital on the farm, in terms of participation in cooperatives and/or class entities such as producers' unions, associations or movements, it was seen that those responsible for small farms were the most participative. This was followed by the medium and large farms and the minifundia. In addition, about 70% of those in charge of farms classified as small had 10 years' experience or more as farm head. This was the highest percentage. Large farms presented the lowest percentage, namely 58.6%. As regards schooling, most farm heads had low levels (up to primary level completed), corresponding to 65%, 57% and 54% respectively, of the heads of the small and medium farms and minifundia. For the large farms, 50% of farm heads presented this level of schooling.

3. RESULTS AND DISCUSSION

3.1. Stochastic Frontier Production

As shown in Section 3, five stochastic frontier production functions were estimated, one referring to Brazil as a whole and the other four to different groupings of farms according to area: minifundia (minis), small, medium and large. It should be noted that the specified functional form was that of Cobb-Douglas and the parameters were obtained via maximum likelihood.

The results of the stochastic frontier estimates are presented in Table 2. It must be remembered that, as all variables were transformed into their natural logarithm, the estimated coefficients refer to the elasticities of the factors of production and should be interpreted in percentage terms. To better visualise the expression, the coefficients of fixed effects for the federal units were omitted. In terms of adjustment to the model, the Wald statistic result indicated that the null hypothesis of joint insignificance of the variables was rejected at a level of 1%, in all functions, which showed that the models estimated were adequate.

One of the advantages of using the Cobb-Douglas functional form in its log-linear form is that it is possible to identify the returns to scale of the production function by means of the direct sum of the elasticities of the productive factors (CHAMBERS, 1988). Thus, it was seen that the sum of the elasticities was 1.02 for the function estimated for Brazil, that is, the returns from the technology used are close to the constant returns to scale. In terms of returns of the specific functions for the minis, small, medium and large farms, the sum of elasticities was 1.02, 1.07, 1.00, 1.07, respectively, without any great differences in the returns of the factors of production even when considering farms of different sizes (Tab. 2).

From the results presented in Table 2, it was seen that the effect of the productive area differed for the different-sized groups of farms. The largest elasticities for this factor were seen at the limits of the medium and large farms, which indicates that a 10% increase in area was associated with a 2.64% and 2.91% increase in production values, respectively. This result suggests that such farms, even those with a larger total area than the others, are still basically dependent on the land factor in the productive process. For the small farms, productive area was the factor which least contributed to production value.

The variable used as proxy of the capital factor, *valuecap*, presented a positive sign and was statistically significant in all functions estimated. As expected, the highest elasticity seen for this factor was in the model referring to the large farms. The capital factor also contributed most to production value for this group of producers, which indicates that a 10% increase in the value of improvements, buildings and other facilities would raise the GPV by 3.43%, on average.

To represent the labor factor, the sum of family and hired workers on each farm was considered. On analysing the model estimated for rural Brazil as a whole, it was seen that of all the productive factors, this variable presented the highest elasticity, thereby playing a significant role in the formation of the national GPV. As regards the models estimated for each farm group, it was seen that the effect of labor in generating the value of production was highest for the minifundia, small and medium producers, and this factor also presented the

Tab. 2. Stochastic Frontier Production for Brazilian minifundia, small, medium and large farms.

	Brazil	**Mini**	**Small**	**Medium**	**Large**
Lnprodarea	0.203***	0.201***	0.203***	0.264***	0.291***
	(0.0010)	(0.0013)	(0.0031)	(0.0077)	(0.0102)
Lnvalprop	0.207***	0.194***	0.235***	0.234***	0.343***
	(0.0011)	(0.0011)	(0.0032)	(0.0056)	(0.0089)
Lnlaboru	0.372***	0.339***	0.402***	0.355***	0.310***
	(0.0015)	(0.0016)	(0.0036)	(0.0044)	(0.0092)
Lntotinput	0.245***	0.220***	0.312***	0.287***	0.261***
	(0.0005)	(0.0007)	(0.0018)	(0.0030)	(0.0062)
Lnstocku	-0.0123***	0.0606***	-0.0866***	-0.137***	-0.133***
	(0.0006)	(0.0009)	(0.0014)	(0.0019)	(0.0037)
Small	0.139***	-	-	-	-
	(0.0023)				
Medium	0.336***	-	-	-	-
	(0.0044)				
Large	0.637***	-	-	-	-
	(0.0071)				
Constant	5.374***	5.895***	4.550***	5.140***	3.874***
	(0.0333)	(0.0519)	(0.0637)	(0.0904)	(0.1180)
Usigma	1.635***	1.540***	1.704***	2.016***	2.224***
	(0.0014)	(0.0017)	(0.0035)	(0.0057)	(0.0108)
Vsigma	0.164***	0.260***	-0.175***	-0.352***	-0.351***
	(0.0021)	(0.0023)	(0.0067)	(0.0086)	(0.0233)
Lambda	9.969	5.923	9.737	5.727	6.336
Wald Test	1.06E+10	3.96E+09	409,325	319,197	136,178
Nº Obs.	4,259,963	3,283,982	694,133	208,886	72,962

Note: *** significant at 1%; Standard deviation in brackets.
Source: Drawn up by authors based on microdata from the 2006 Agriculture and Livestock Census.

highest returns for these groups. Such a result is not surprising, as these types of farm, especially the minifundia, are, in most cases, associated with lower levels of investment, capital stock and have other limitations and, thus, using more labor is one of their main strategies for increasing agricultural income in the short term.

As for input expenses, represented by the variable *totinput*, it was seen that, as expected, higher costs for inputs in productive processes are related to the higher production values of the farm, especially for small farms, which presented the highest elasticity for this factor of production.

A positive relationship was only seen in the minifundia between the variable representative of the livestock on the farm (*stocku*), and production value in the minifundia. A 10% increase in livestock was associated with a 0.6% higher GPV, on average. For the other functions, what was found was contrary to what was expected. However, it must be stressed that, when using the number of animals on the farm as a proxy for the livestock factor, as an independent variable, the importance of this factor in the productive process could be camouflaged, as it does not provide any information on how the livestock is used, or on the characteristics of this stock. If livestock is improperly used by the farm, such as in densities beyond the capacity of the farm, problems involving insufficient feeding and even disease could lead to lower production values.

Tab. 3. Mean technical efficiency of farms, per size.

Size	Technical Efficiency
Minifundia (<1 FM)	0.334
Small (1 to 4 FM)	0.304
Medium (>4 to 15 FM)	0.272
Large (>15 FM)	0.289

Source: Drawn up by authors based on microdata from the 2006 Agriculture and Livestock Census. FM=Fiscal module.\

Another significant result from Table 2 is the *Lambda* parameter estimate obtained by dividing the inefficiency variance (*Usigma*) by the variance of the random error component (*Vsigma*) which allows one to test the presence or absence of technical inefficiency. Values greater than 1 found in all the functions estimated indicate that most of the error is due to inefficiency, that is, discrepancies seen between the products and the optimal frontiers are primarily due to technical inefficiency.

After estimating the production frontiers for each area group selected, technical efficiency scores were obtained (Tab. 3).

With regard to technical efficiency, the mean values show that those agriculture and livestock farms classified as minifundia were technically more efficient than farms of other sizes. It is also seen that small farms were more efficient than either the medium or large. These results suggest an inverse relationship between farm size and technical efficiency. This issue is discussed in greater detail in the following section.

In addition, since the value 1 (one) represents an absence of technical inefficiency, the low values seen in all the size classes considered indicate that farms were still quite inefficient, despite the differences between them.

3.2. Determinants of technical efficiency of agriculture and livestock farms per efficiency level

After obtaining the efficiency scores, the quantile regression technique was used to verify the determinants of the productive efficiency of the representative farms, considering five quantiles or efficiency groups (0.10; 0.25; 0.50; 0.75; and, 0.90). It is important to highlight that, in addition to identifying the relationship between the variables used and productive efficiency, these results also allow one to verify the variation in the power of determination of these variables on the performance of the producers for different levels of efficiency, represented by each quantile of the sample. The results are shown in Tables 4, 5 and 6.

To check if the effects of the variables selected are in fact heterogeneous in relation to the quantiles of the sample, the Wald test was carried out. The result calculated for the F statistic of the models estimated for the total sample (Brazil), minifundia, small, medium and large farms were significant at 1%, and thus the null hypothesis of equality of parameters was rejected. This means that the explanatory power of the variables with respect to technical efficiency changes, depending on the level (range) of efficiency of the farms, indicates that the estimation via quantile regression is more adequate, to the detriment of estimation by least squares or any other method.

It should be remembered that, as specified in Equation 5, total farm area was included as a determinant of efficiency with a view to statistically verifying the relationship between productive performance and farm size. However, as seen in the literature on the subject (Helfand, Levine, 2004; Teryomenko, 2008), the relationship between productive performance and farm size can be non-linear. Thus, a quadratic term of the area was added to statistically test this hypothesis of non-linearity (Tabb. 4, 5 and 6).

The results in Table 4 present a negative and significant relationship between technical efficiency and total area for less (q10 and q25) and more efficient (q75 and q90) farms for Brazil. The positive result found for the medium-sized farms (q50) confirms how important it is to analyse the determinants, taking existing heterogeneities between different levels of efficiency into consideration. Estimates based solely on the sample mean can omit relevant information about the effect of area (and other determinants) on the productive performance of the farm. In addition, a nonlinear relationship between these variables was only seen in farms with higher levels of technical efficiency, which indicates that the increase in area reduces the efficiency of the farm up to a minimum level, after which farm productivity increases. Helfand and Levine (2004) found a similar result when analysing determinants of technical efficiency of farms in Midwestern Brazil.

As regards the other variables, it was seen that irrigation technology (*irrig*), the presence of storage units on the property (*storage*) and the fact that the producer was a member of some type of cooperative (*coop*) exerted a significant and positive effect on technical efficiency, especially of those farms associated with lower levels of efficiency (q10 and q25).

Tab. 4. Determinants of technical efficiency according to Brazilian levels of efficiency.

Variables	BRAZIL				
	q10	q25	q50	q75	q90
Lntotarea	-0.229***	-0.0006	0.0071***	-0.0081***	-0.0116***
	(0.0027)	(0.0011)	(0.0004)	(0.0003)	(0.0003)
Lntotarea2	-0.0268***	-0.0087***	-0.00261***	0.0007***	0.0011***
	(0.0006)	(0.0002)	(7.69e-05)	(4.26e-05)	(3.36e-05)
Lnfinance	0.156***	0.0415***	0.0152***	0.0053***	0.0011***
	(0.0012)	(0.0002)	(0.0001)	(5.41e-05)	(6.42e-05)
Irrig	1.160***	0.477***	0.221***	0.135***	0.0900***
	(0.0123)	(0.0024)	(0.0008)	(0.0010)	(0.0008)
Storage	2.068***	0.499***	0.155***	0.0449***	-0.0011
	(0.0088)	(0.0019)	(0.0007)	(0.0006)	(0.0007)
School	-0.107***	0.0191***	0.0371***	0.0175***	0.0006
	(0.0064)	(0.0016)	(0.0005)	(0.0004)	(0.0005)
Coop	1.375***	0.339***	0.0641***	0.0013***	-0.0142***
	(0.0106)	(0.0021)	(0.0007)	(0.0005)	(0.0004)
Rural	1.624***	0.755***	-0.0520***	-0.0646***	-0.0394***
	(0.0097)	(0.0127)	(0.0016)	(0.0008)	(0.0006)
exper10	1.014***	0.299***	0.0404***	-0.0051***	-0.0092***
	(0.0070)	(0.0018)	(0.0006)	(0.0005)	(0.0006)
Tech	0.455***	0.360***	0.188***	0.0917***	0.0412***
	(0.0091)	(0.0021)	(0.0008)	(0.0005)	(0.0005)
Tenant	1.140***	0.616***	0.238***	0.118***	0.0919***
	(0.0209)	(0.0039)	(0.0017)	(0.0012)	(0.0011)
partner	1.539***	0.668***	0.253***	0.118***	0.0705***
	(0.0122)	(0.0036)	(0.0022)	(0.0012)	(0.0016)
occupier	1.296***	0.443***	0.137***	0.0487***	0.0220***
	(0.0080)	(0.0032)	(0.0013)	(0.0010)	(0.0010)
constant	-7.996***	-3.338***	-1.294***	-0.772***	-0.531***
	(0.0090)	(0.0135)	(0.0021)	(0.0010)	(0.0008)
Nº Obs	4,259,963	4,259,963	4,259,963	4,259,963	4,259,963

Note: *** significant at 1%; Standard deviation in brackets.
Source: Drawn up by authors based on microdata from the 2006 Agriculture and Livestock Census.

The results estimated for each group of producers in relation to farm size (minifundium, small, medium, and large) are presented in Tables 5 and 6. In terms of total farm area, it was seen that, irrespective of the type of producer, those farms related to intermediate efficiency quantiles (q25, q50 and q75) presented a positive relationship between productive performance and farm size, with the greatest effect of this variable seen for medium-sized producers. Another interesting result is that, as the producer reaches higher levels of technical efficiency, the effect of total area decreases, which indicates that this farm is becoming less dependent on the land factor. Other studies, such as those by Tauer and Mishara (2006), Alvares and Arias (2004), Gonçalves *et al.* (2008) and Kumbhakar *et al.* (1991) also found a positive relationship between these variables.

However, in the case of the minifundia and small groups, it was seen that for producers related to lower levels of efficiency (q10), an increase in total area was associated with a reduction in their technical efficiency. This result is surprising, as it questions whether land redistribution policies are effective in improving the productive performance of poorer farmers, and the results seen in the present study indicate that they are not. In addition, the hypothesis of non-linearity between efficiency and total area was also confirmed in the four groups analyzed.

It was seen that an increase in the total financing variable (*Lnfinance*) increased the technical efficiency of all farms analysed, especially those in the larger area class. In the same vein, Magalhães *et al.* (2011) report that credit is a productive factor which reduces technical inefficiency, as it allows for greater access to and better use of resources, so that, in effect, it increases the productivity of the property.

That the effect of financing is greatest for large producers can be explained by the fact that these farmers are associated with better levels of schooling and greater access to technical assistance services, which can lead to more efficient use of the resources acquired. Of the different levels of efficiency analysed, it was seen that less efficient producers (q10) were the main beneficiaries of the increase in the total amount of financing, which was also true in terms of irrigation. This shows the importance of increasing the availability of rural credit as a means towards reducing part of the existing heterogeneities in the Brazilian agriculture and livestock sector.

On considering the effects of the other determinants of technical efficiency, the coefficients estimated for the *irrig* variable indicated that farms which used irrigation technology were associated with higher levels of efficiency in all groups of producers analysed. A similar result was found by Khai and Yabe (2011), when analysing determinants of the technical efficiency of rice producers in Vietnam for the 2005/06 crop. In addition, in all cases, this technology was more important for increasing the productive performance of producers belonging to the lowest quantile of efficiency (q10), especially those classified as small.

The variable representative of the number of storage units on the farms (*storage*) was statistically significant and positive for all four groups analysed, which indicates that an increase in storage units is associated with an increase in technical efficiency, with the exception of the most efficient quantile (q90) of large farms. However, it was found that, in general, the effect of this variable is smaller for minifundia and small producers.

The relationship between schooling and technical efficiency of farms was found to be positive and significant for almost all levels of efficiency in all the groups considered. It must be remembered that this variable should be interpreted as an indicator of a low level of schooling, as it indicates the percentage of farmers who either became literate as adults or who had completed or did not complete primary schooling or had no schooling whatever but could read and write. Therefore, the result that was found indicates that such producers were associated with greater productive performance. Although this result was the opposite of what was expected for Brazilian agriculture and livestock farming, it could indicate that experience in production could have a greater effect than the schooling itself.

Among the variables used to identify the contribution of social capital to the productive performance of farms, the fact that the farmer participated in cooperatives and/or class entities such as unions, associations or producer movements (*coop*) contributed to higher levels of efficiency irrespective of farm size, with the exception of those farms associated with the highest levels of technical efficiency (q90), as at these levels the estimated coefficient was negative. This result is interesting because it shows that the benefits arising out of cooperation could be limited to those farms already using their productive inputs efficiently, while they are highly advantageous for relatively inefficient producers, given the high coefficient seen for the lower efficiency quantile (Q10), in all class sizes considered. The importance of organizing farmers into cooperatives was also seen by Galawat and Yabe (2012) when they identified that farmers who joined associations or cooperatives incurred less profit loss, and achieved greater efficiency. According to Baron (2007), participation in associative organizations increases rural producers' access to information, technology and rural extension services, and thereby contributes to greater efficiency in farming.

The fact that the head of the farm lived in the rural area (*rural*) was related to higher levels of technical efficiency solely for the minifundia and small producers, relating to quantiles q10 and q25, and medium-sized farmers, relating to quantile q10, when compared to farms where the head resided in an urban environ-

Tab. 5. Determinants of technical efficiency per efficiency levels for minifundia and small farms.

Variables	MINI					SMALL				
	q10	q25	q50	q75	q90	q10	q25	q50	q75	q90
Lntotarea	-0.638***	0.0941**	0.120***	0.0045	-0.0215**	-0.199***	0.0106***	0.0065***	-0.0053***	-0.0080***
	(0.112)	(0.0476)	(0.0191)	(0.0090)	(0.0108)	(0.0023)	(0.0011)	(0.0004)	(0.0002)	(0.0002)
Lntotarea2	0.0817***	-0.0106*	-0.0143***	0.0018	0.0050***	-0.0393***	-0.0144***	-0.0029***	0.0009***	0.0011***
	(0.0147)	(0.0062)	(0.0024)	(0.0011)	(0.0013)	(0.0010)	(0.0004)	(0.0001)	(5.53e-05)	(6.29e-05)
Lnfinance	0.0984***	0.0403***	0.0145***	0.0044***	0.0004***	0.149***	0.0366***	0.0137***	0.0050***	0.0013***
	(0.0016)	(0.0005)	(0.0002)	(0.0001)	(0.0002)	(0.0015)	(0.0003)	(9.13e-05)	(6.45e-05)	(8.00e-05)
Irrig	0.591***	0.422***	0.157***	0.0744***	0.0353***	1.182***	0.468***	0.244***	0.160***	0.110***
	(0.0149)	(0.0063)	(0.0021)	(0.0016)	(0.0017)	(0.0121)	(0.0023)	(0.0012)	(0.0011)	(0.0011)
storage	3.285***	0.590***	0.184***	0.0638***	0.0115***	1.802***	0.429***	0.139***	0.0395***	-0.0019**
	(0.0465)	(0.0061)	(0.0018)	(0.0015)	(0.0014)	(0.0117)	(0.0026)	(0.0008)	(0.0007)	(0.0008)
School	0.0778***	0.0980***	0.0511***	0.0107***	-0.0096***	-0.133***	0.0217***	0.0367***	0.0217***	0.0067***
	(0.0157)	(0.0090)	(0.0027)	(0.0014)	(0.0013)	(0.0064)	(0.0021)	(0.0006)	(0.0004)	(0.0005)
Coop	1.667***	0.495***	0.0925***	0.0102***	-0.0168***	1.284***	0.271***	0.0496***	-0.0038***	-0.0148***
	(0.0418)	(0.0094)	(0.0024)	(0.0012)	(0.0012)	(0.0133)	(0.0025)	(0.0009)	(0.0006)	(0.0006)
Rural	1.634***	0.525***	-0.0474***	-0.0537***	-0.0298***	1.620***	1.892***	-0.0247***	-0.0636***	-0.0434***
	(0.0338)	(0.0174)	(0.0026)	(0.0014)	(0.0013)	(0.0089)	(0.0726)	(0.0016)	(0.0011)	(0.0009)
exper10	1.364***	0.580***	0.0611***	-0.0037***	-0.0097***	0.907***	0.214***	0.0322***	-0.00331***	-0.0062***
	(0.0242)	(0.0111)	(0.0022)	(0.0010)	(0.0012)	(0.0080)	(0.0026)	(0.0010)	(0.0006)	(0.0006)
Tech	0.456***	0.438***	0.203***	0.0856***	0.0324***	0.411***	0.293***	0.167***	0.0897***	0.0451***
	(0.0178)	(0.0063)	(0.0025)	(0.0012)	(0.0014)	(0.0099)	(0.0022)	(0.0010)	(0.0005)	(0.0006)
Tenant	0.206***	0.472***	0.185***	0.103***	0.128***	1.344***	0.554***	0.225***	0.110***	0.0840***
	(0.0315)	(0.0204)	(0.0057)	(0.0044)	(0.0050)	(0.0140)	(0.0031)	(0.0014)	(0.0012)	(0.0017)
partner	0.367***	0.315***	0.114***	0.0581***	0.0456***	1.616***	0.596***	0.235***	0.110***	0.0651***
	(0.0574)	(0.0240)	(0.0082)	(0.0061)	(0.0102)	(0.0139)	(0.0027)	(0.0014)	(0.0010)	(0.0015)
occupier	0.476***	0.154***	-0.0241***	-0.0238***	-0.0034	1.355***	0.400***	0.130***	0.0465***	0.0179***
	(0.0326)	(0.0085)	(0.0045)	(0.0048)	(0.0049)	(0.0096)	(0.0032)	(0.0014)	(0.0010)	(0.0008)
constant	-9.180***	-4.072***	-1.656***	-0.849***	-0.525***	-7.600***	-4.178***	-1.241***	-0.761***	-0.538***
	(0.208)	(0.0808)	(0.0372)	(0.0175)	(0.0214)	(0.0072)	(0.0716)	(0.0017)	(0.0010)	(0.0009)
Nº Obs	3,283,982	3,283,982	3,283,982	3,283,982	3,283,982	694,133	694,133	694,133	694,133	694,133

Note: *** significant at 1%, ** significant at 5%; Standard deviation in brackets.
Source: Drawn up by authors based on microdata from the 2006 Agriculture and Livestock Census.

ment, keeping other attributes constant. The greater effect of this variable for minifundia and small farms was expected, as a large number of them involve family farming where, as Guanziroli *et al.* (2001) reported, productive performance depends more on the physical ability of family members to perform the agricultural tasks needed for production, and so the head of the farm participates directly in the work. Nevertheless, the negative relation found for large farms is not surprising in the sense that, when living in an urban location, the big producer has greater access to information about the market, banking institutions to obtain credit and other services.

On the question of the experience of farm heads (*exper10*), the estimated coefficient was statistically significant and presented a positive relation with technical efficiency for the first quantiles (q10, q25 and q50) for all four groups of producers. For these farms, producers with more than 10 years' experience in managing the property were more productive than those with less experience, which indicates that with experience the producer uses inputs more efficiently. Other studies, such as those undertaken by Abdulai *et al.* (2013) and Oyewol (2009), have also found a significant and positive relationship between productive efficiency and experience. However, for the most efficient farms (q90) in each group considered, the results indicated a negative relationship between experience and technical efficiency.

The impact of technical assistance (*tech*) as a determinant of productive performance was also statistically

Tab. 6. Determinants of technical efficiency per efficiency levels for medium and large farms.

Variables	MEDIUM					LARGE				
	q10	q25	q50	q75	q90	q10	q25	q50	q75	q90
Lntotarea	0.185	1.214***	0.344***	0.0413*	-0.0276	-0.0698	0.331**	0.326***	0.0789***	0.0097
	(0.231)	(0.142)	(0.0424)	(0.0232)	(0.0199)	(0.325)	(0.165)	(0.0846)	(0.0243)	(0.0303)
Lntotarea2	-0.0139	-0.114***	-0.0310***	-0.0013	0.0042**	-0.0090	-0.0341***	-0.0235***	-0.0042**	0.0003
	(0.0225)	(0.0136)	(0.0040)	(0.0021)	(0.0018)	(0.0234)	(0.0119)	(0.0059)	(0.0017)	(0.0021)
Lnfinance	0.148***	0.0566***	0.0220***	0.0070***	0.0009***	0.184***	0.0673***	0.0234***	0.0068***	0.0004
	(0.0030)	(0.0008)	(0.0004)	(0.0002)	(0.0002)	(0.0080)	(0.0015)	(0.0007)	(0.0005)	(0.0004)
Irrig	0.732***	0.432***	0.156***	0.0826***	0.0379***	0.469***	0.380***	0.155***	0.0788***	0.0506***
	(0.0416)	(0.0139)	(0.0063)	(0.0051)	(0.00474)	(0.0428)	(0.0313)	(0.0120)	(0.0072)	(0.0075)
storage	4.866***	0.782***	0.228***	0.0742***	0.0175***	4.202***	0.692***	0.168***	0.0330***	-0.0054
	(0.0815)	(0.0121)	(0.0045)	(0.0025)	(0.0029)	(0.290)	(0.0294)	(0.0062)	(0.0039)	(0.0052)
School	0.142***	0.0969***	0.0354***	1.57e-05	-0.0102***	0.108**	0.0046	-0.0121	-0.0099	-0.0121*
	(0.0248)	(0.0160)	(0.0046)	(0.0022)	(0.0027)	(0.0432)	(0.0292)	(0.0119)	(0.0074)	(0.0064)
Coop	1.611***	0.655***	0.150***	0.0311***	-0.0085***	2.433***	0.748***	0.190***	0.0373***	-0.0089*
	(0.0963)	(0.0187)	(0.0052)	(0.0030)	(0.0023)	(0.361)	(0.0493)	(0.0138)	(0.0062)	(0.0046)
Rural	0.443***	-0.0218	-0.0902***	-0.0496***	-0.0214***	-0.0352	-0.208***	-0.120***	-0.0349***	-0.0072
	(0.0348)	(0.0181)	(0.0042)	(0.0026)	(0.0036)	(0.0552)	(0.0362)	(0.0102)	(0.0043)	(0.0045)
exper10	1.137***	0.798***	0.0812***	-0.0158***	-0.0303***	1.006***	0.801***	0.129***	0.0207***	-0.0017
	(0.0639)	(0.0282)	(0.0033)	(0.0026)	(0.0023)	(0.112)	(0.0464)	(0.0110)	(0.0063)	(0.0039)
Tech	0.410***	0.652***	0.277***	0.115***	0.0426***	0.655***	1.142***	0.435***	0.154***	0.0469***
	(0.0383)	(0.0149)	(0.0049)	(0.0031)	(0.0024)	(0.137)	(0.0576)	(0.0118)	(0.008)	(0.0065)
Tenant	0.252***	0.551***	0.184***	0.0805***	0.0656***	0.0715	0.342***	0.182***	0.0901***	0.0619***
	(0.0822)	(0.0347)	(0.0084)	(0.0064)	(0.0057)	(0.219)	(0.0433)	(0.0222)	(0.0135)	(0.0134)
partner	0.421***	-0.167	0.0505	0.0488***	0.0672***	0.177	0.122	0.197***	0.176***	0.134**
	(0.141)	(0.163)	(0.0472)	(0.0159)	(0.0171)	(0.296)	(0.236)	(0.0583)	(0.0297)	(0.0557)
occupier	1.054***	0.0271	-0.191***	-0.0456**	0.0282***	0.441	-0.315	-0.279***	-0.0448	0.0864*
	(0.0968)	(0.0593)	(0.0311)	(0.0196)	(0.0087)	(0.362)	(0.229)	(0.104)	(0.0392)	(0.0522)
constant	-11.71***	-7.439***	-2.576***	-1.063***	-0.524***	-10.83***	-5.555***	-3.028***	-1.326***	-0.681***
	(0.583)	(0.364)	(0.110)	(0.0613)	(0.0535)	(1.073)	(0.570)	(0.293)	(0.0888)	(0.106)
Nº Obs	208,886	208,886	208,886	208,886	208,886	72,962	72,962	72,962	72,962	72,962

Note: *** significant at 1%, ** significant at 5%, * significant at 10%; Standard deviation in brackets.
Source: Drawn up by authors based on microdata from the 2006 Agriculture and Livestock Census.

significant and presented the relationship expected for all models and efficiency levels estimated. In addition, it was seen that the greatest effect of this variable was seen for more inefficient farms (q10 and q25), which shows the relevance of the Technical Assistance and Rural Extension services for the country, especially for those producers facing greater challenges to convert productive inputs into production (or production value) itself. According to Anderson and Feder (2004) and Christoplos (2010), this is due to the role of technical assistance in encouraging the adoption of new technologies, which give producers access to more modern production factors. In addition, the flow of information generated by this service also contributes to raising the human capital of the producer, and has a direct impact on managerial skills, and as a result provides welfare gains in the countryside.

Finally, the effect on levels of productive efficiency of the employment status of the farm head in relation to the land was analysed. It is important to note that since the status of owner was used as a basis, a negative relationship found for a given status would indicate that a non-owner producer would be less efficient than an owner producer. The results show that, for all groups analysed, producers with the status of tenant, partner or occupier (in some cases) were relatively more efficient than owners. This result was not expected, as properties with definitive tenure have greater guarantees for acquiring credit and other services, as land is considered a tangible guarantee for loan repayment (BESLEY, 1995). In addition, the owner's incentive to invest long-term in innovation technology, which could contribute to increasing productive efficiency, is greater and, thus, it was expected that such producers would be related to better productive performance.

4. CLOSING REMARKS

The literature presents divergent results for the relationship between productive performance and farm size. Hence, the aim of this research was to verify this relationship, considering different size classes of Brazilian farms, using microdata from the 2006 Agriculture and Livestock Census. In addition, the study identified the main determinants of the productive performance of these properties considering each area group (minifundium, small, medium, large) in separate production frontiers.

The results of technical efficiency, obtained by estimating the stochastic frontier production function, indicated that the level of technical efficiency presented a negative and non-linear relationship with farm size solely for those minifundia and small producers related to the 10% less efficient and the 90% more efficient farms. This result is surprising because it questions the effectiveness of land redistribution policies in increasing the productive performance of small farmers, as the results shown here indicate that this would be true only for those who already had better productive performances. For medium-sized and large farms, there was a positive and significant relationship between technical efficiency and total area. The quadratic term was also significant and negative, and confirms the non-linear relationship between size and productive performance. This means that an increase in medium and large farm areas is directly associated with an increase in efficiency; however, from an optimal level onwards, that relationship becomes negative.

As for the other explanatory variables, which determine the productive efficiency of the representative units, it was seen that factors, such as access to irrigation technology, technical assistance, presence of storage units on the farms and membership of cooperatives and/or class entities and others, were crucial in increasing the productive performance of Brazilian farms, especially those related to low levels of technical efficiency. In this sense, the formulation of public policies for increasing the supply of such resources and services is vital, especially for small farmers. Greater availability of credit, for example, could contribute to more efficient use of resources available, and thus bring the production of the property closer to the optimal frontier of production.

However, if the inefficiencies seen in Brazilian agriculture and livestock rearing are to be reduced, much more is needed than merely providing greater access to production factors. Policies should concentrate on issues which allow for a more adequate use of these factors. For example, there is no point in enabling the rural producer to buy more inputs if he does not know that when they are improperly or excessively used, they can have negative effects on agriculture and livestock production. Thus, policies on technical assistance, qualification of the workforce, improvement of the managerial capacity of farm heads, among others, could reduce the levels of inefficiency on farms, with minimum change in the quantity of production factors, as they make for a more rational use of these factors.

In addition, the government should also encourage the setting up of cooperatives by producers, as this allows less efficient producers to have easier access to markets and new technologies, as well as managing to get better business deals. Such policies are crucial for increasing the productive performance of agriculture and livestock farms and to ensuring greater equity between small and large Brazilian producers.

In general, the results found indicate that land redistribution alone would not be sufficient to reduce rural inequalities. According to the estimates obtained, this may not be the most effective mechanism, since even if there are producers with relatively large properties, if they are using it efficiently a reduction of their land would lead to a worse balance than the one presented by scenario of land concentration. This analysis reinforces the argument that there may be efficient producers of all sizes, and in this case, applied public policies on determinants of productivity may be more effective, and less costly, to reduce inequality between small and large farms, if compared to agrarian reform.

As suggestions for future research, it becomes relevant to expand the analysis to verify the productive heterogeneity between each Brazilian region separately. Although the present research has controlled the bias caused by fixed characteristics of each region, detailed analysis could demonstrate to what extent the relationship between productive performance and farm size is sensitive to technology and / or other regional particularities. One of the paper's limitations was to consider each farm size class associated with a specific technology. It would be interesting to consider the existence of a meta-frontier of production, that is, to consider the possibility of having an optimal technology available to all producers. This investigation would also allow us to identify how far family farmers are from the optimal technology and what is the impact of this on the relationship between their productive performance and the farm size.

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