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Imori, Denise and Guilhoto, Joaquim José Martins and Postali, Fernando Antonio Slaibe

University of São Paulo, University of São Paulo, University of São Paulo

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Denise Imori (*Department of Economics, FEA - University of São Paulo)*
Joaquim José Martins Guilhoto (*Department of Economics, FEA - University of São Paulo; REAL, University of Illinois; and CNPq Scholar*)
Fernando Antonio Slaibe Postali (*Department of Economics, FEA - University of São Paulo)*

Abstract

This paper aims to analyze the technical efficiency of farms in Brazil and its regions, based on the data from the 2006 Census of Agriculture. More specifically, it seeks to compare the technical efficiency of family farms in relation to business farms, considering the regional differences in the country. To do so, one simultaneously estimated, under different assumptions, stochastic production frontiers and inefficiency effects models. Thus, it was possible to measure the technical efficiency of farms, as well as analyze the influence of factors related to the production environment, allowing the indication of public policies aimed at improving the performance of producers. In the empirical estimation, it was observed, as expected, lower technical efficiency for family farms. In regional terms, with respect to the technical efficiency of business farms, the South region of Brazil stood out, also presenting, along with the Midwest region, the highest efficiency rates for family farms, on average. Regarding the influence of production environment, it was found that formal education and access to credit are noteworthy as important factors for the technical efficiency of Brazilian agriculture.

Keywords: Census of agriculture, Econometrics, Agriculture economics

JEL: D24, Q12, R11

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1. Introduction

Despite its modernization and consequent integration to markets (either as a supplier of inputs for the agro-industry or as a generator of foreign exchange), Brazilian farming is still characterized by the poverty that afflicts considerable number of its producers. Among these, the family farms are of special concern – these are producers which hold limited areas and often have in their small scale an obstacle to participate in the modernization process of Brazilian agriculture.

Still, beyond their already recognized historical and social roles, the family farms are important also from an economic standpoint. Thus, evaluating their production performance is an urgent matter. In order to take full advantage of available inputs and existing technology, the focus is on the technical efficiency of these agricultural producers. Moving from the assumption that, like the others, they are economic agents concerned with the optimization of their earnings, one should analyze the exogenous factors that affect its productive performance in order to develop public policies that are designed to minimize existing inefficiencies.

Another important point is that in a country such as Brazil, characterized by a vast and diverse territory under different aspects, it would be expected that the performance of agricultural producers, be they family farmers or not, is marked by inequalities at the regional level – the objective conditions of production vary for various reasons, intra-and inter-regionally. Therefore, this issue should also be considered when evaluating the technical efficiency of agriculture in the country.

1.2 Context

In 2005, according to Helfand *et al* (2008), the proportion of poor people in rural Brazil reached impressive 46% – almost two times higher than the poverty level found nationally. Since labor income represented 75% of total income in rural areas and having in view the low likelihood that the growth of transfers seen in recent years in the country is sustainable, in order to reduce poverty and rural inequality continuously, the essential implication is that public policy should aim to pro-poor sources of rural incomes. In this context, policies that contribute to the competitiveness of the family farms seem to be very important.[1]

In a context where resources are generally scarce and the opportunity to develop or adopt better technologies is still limited[2], the agricultural economy of the country and, in particular, the alleviation of rural poverty could greatly benefit from the analysis on the technical efficiency of rural establishments. The presence of significant levels of inefficiency suggests that there are opportunities for expanding production using the existing levels of inputs and technology.

In this framework, this work aims to address the central issue of technical efficiency of family farms. The Brazilian family farming, in addition to its traditional role in absorbing labor and producing food, has more recently been recognized as a relevant wealth generating complex, considering not only

[1] On July 24, 2006, Law No 11.326 was enacted, establishing guidelines for the formulation of the National Policy for Family Farming and Family Ventures, thus, providing the legal framework of the family farming. According to Law No 11.326, only farmers or rural entrepreneurs that simultaneously meet the following requirements can be considered "family farmers": a) Do not hold, on any account, area larger than four fiscal modules; b) Use predominantly labor of their own families in economic activities of their establishment; c) Have their income predominantly originating from economic activities linked to the establishment; d) Run their establishment with their family. Thus, following the current legal framework in Brazil, this study will use the above definition for family farming. The remaining establishments will be characterized as business farms.

[2] Productivity growth, as shown by Nishimizu and Page (1982), can be decomposed into technological change and technical efficiency. This decomposition makes it possible to study the sources of productivity growth from different perspectives. Specifically, while technological change evaluates the effect on productivity of adopting new production practices, technical efficiency can be interpreted as a relative measure of ability for a given technology. Thus, technological change relates to investments in research and technology, while efficiency gains are derived from technical improvements in the process of decision making, which is related to several variables, including, for example, experience and education.

the rural and regional economies, but the country as a whole (Guilhoto *et al*, 2010)[3]. Thus, the analysis of technical efficiency of family farms is highly appropriate, since, as pointed Abramovay (1997), its dynamism does not depend on supposedly "cultural" characteristics of its farmers, but on the same factors that affect the performance of farmers in general. Following the indications of Schultz (1980), it is of great importance to the rural establishments the incentives and possibilities that producers face in order to accomplish their agricultural potential. It is, therefore, an economically important point to examine and evaluate means whereby family farm's production efficiency can be enhanced.

Moreover, one cannot ignore that the family farmers are inserted in a scenario marked by historic land concentration in Brazil (Guanziroli *et al*, 2001). Illustrating the persistence of such context is the observation that in 2006 the family farms accounted for approximately 84.4% of the number of establishments in the country, but occupied only 24.3% of its agricultural area (IBGE, 2010). Given this context, the study of the potential of family farming was complemented by joint analysis of production of business establishments – so, following this approach, the measure of technical efficiency of family agricultural establishments has its results compared to those of business farms.

As indicated by Coelli (1995), in accordance with Ahmad (2011), partial measures of productivity, exemplarily the amount of output per area, exhibit the serious deficiency that they only consider one input – in this case, land – over all others, such as labor, capital, fuel, fertilizers, etc. Thus, employing these measures in the formulation of public policies possibly result in excessive use of inputs that were not considered in the evaluation of efficiency (Coelli, 1995). In this way, as corroborated by Alvarez and Arias (2004), measures of total factor productivity, which are ratios of aggregates of products and inputs, would be more appropriate to compare performance between establishments.

With this in mind, rather than partial measures of productivity, this study employed the methodology of stochastic frontier production functions – more specifically, as presented by Battese and Coelli (1995) – to assess the existence of possible differences in technical efficiency between business and family farms in Brazil and its regions.[4]

One of the main strengths of the methodology proposed by Battese and Coelli (1995), and employed in this study, is that it allows us to evaluate, simultaneously to the estimation of a stochastic production frontier, possible exogenous variables explaining the technical efficiency of producers in its so-called "model for technical inefficiency effects". As indicated by Abdulai and Eberlin (2001), this point is important in that a better understanding of the factors that may be associated with the inability of producers to achieve the efficient production frontier should aid the development of public policies favorable to their technical efficiency.

It is evident the necessity of considering regional differences inside Brazil in the analysis of the technical efficiency of agricultural establishments. In addition to the natural conditions, the territory of the country is heterogeneous by other factors such as those relating to its historical occupation (Buainain, 2007). Thus, when studying the performance of agriculture, both family and business types, especially keeping in view the nature of this activity, one should consider the problems and peculiarities of Brazilian regional diversity. This is a point that this paper intends to highlight, investigating the efficiency of both types of agricultural establishments in the Brazilian regions.

This paper also sought to deal with an issue that has been emphasized by the international literature about the technical efficiency of agriculture – especially that focused on family farmers – but (according to what one has knowledge at the time of this writing) not addressed, until then, by studies of the Brazilian case. It is the consideration of income earned in off-farm activities as part of the production

[3]According to Guilhoto *et al* (2010), in 2006 the GDP of Brazilian agribusiness exceeded the value of R$ 675 billion (in 2009 values), which corresponded to 24% of total national GDP. From this value, we observed that over 30% had their origin in the production of household establishments. Thus, the complex formed by the household farming, which includes production of family-run crops and livestock, and the sectors that relate to these rural activities, represented in 2006 approximately 7% of Brazilian economy in terms of value added.

[4] As indicated by Alvarez and Arias (2004), since the potential output calculated by estimating the stochastic production frontier, which is the denominator of the technical efficiency ratio, can be interpreted as an aggregate of inputs, we obtain the result that in a process of a single product – as considered in this study – the index of technical efficiency can be interpreted as a measure of total factor productivity.

valuation of farmers. As will be shown later, the study sought to contemplate this aspect through the estimation of a stochastic frontier model where the output variable includes wages earned in off-farm activities. The justification for considering the income earned in off-farm activities is based primarily on the following points (Paul *et al*, 2004; Chavas *et al*, 2005; Olson; Vu, 2007): i) such activities would use common inputs to rural production, and ii) affect the economic performance of producers. In this context, as stated by Guanziroli *et al* (2001) about the Brazilian family farming scenario, the possibility to generate income outside the family production unit is a factor that can determine the capacity of accumulation and thus the viability of any production system.

Having in mind what has been presented in this Introduction, it can be stated, more succinctly, that the present study has the motivation that improving the dimensioning of Brazilian agriculture, pointing out its strengths and limitations, is critical to the effectiveness of public policies and institutional innovations. Thus, the overall goal is the analysis of technical efficiency of agricultural establishments in Brazil, based on data from the Census of Agriculture of 2006, distinguishing family and business farms, and indicating factors that may explain differences in productive performance.

2. Methodology

This section presents the methodology used in this study to assess the technical efficiency of agricultural establishments in Brazil, as well as the effect exerted on it by exogenous factors. For a more complete explanation on microeconomic production theory, and on the development of the methodology of stochastic frontier analysis, see Kumbhakar and Lovell (2000).

2.1. Stochastic frontier production functions model

The stochastic frontier production model was independently proposed by Aigner, Lovell and Schmidt (1977) and by Meusen and van der Broeck (1977), in the following formulation:

$$Y_i = \exp(x_i\beta + V_i - U_i) \qquad (1)$$

In the above expression, Y_i represents the output of the ith firm, x_i is the vector corresponding to the inputs, β is the vector of unknown parameters,V_i is a symmetric random disturbance representing statistical noise and U_i is a non-negative random variable associated to the technical inefficiencies. The model defined above is called “stochastic frontier function” because the production values are delimited superiorly by the stochastic variable $\exp(x_i\beta+V_i)$ The random disturbances V_i may be positive or negative, so that the production according to the stochastic frontier varies in relation to the deterministic part of the model, $\exp(x_i\beta)$.

As indicated by Queiroz and Postali (2010), the economic logic of this model lies in the fact that the production process is subject to two random economically distinguishable disturbances, U_i e V_i. The term U_i reflects the assumption that the production of a firm cannot be above the level indicated by its frontier of potential production, given its inputs. In turn, the random disturbance V_i indicate that the production frontier may vary between companies or randomly over time for the same firm.

2.1.1. Stochastic frontier model incorporating a model for technical inefficiency effects

According to Kumbhakar and Lovell (2000), the analysis of production efficiency should have two components. The first is the estimation of a stochastic production frontier that would serve as reference to evaluate the technical efficiency of the producer. The objective of this first component would be to analyze the efficiency of producers using their inputs, under certain assumptions about their behavior. The other component emphasized by the authors and more recently widely in the literature regarding productivity, corresponds to the inclusion of another group of factors in the analysis, which are not outputs or inputs, but affect the performance of producers. The objective of this component is relating changes in performance of producers to variations in factors that are exogenous to their choice and that usually characterize the economic environment in which they operates. Note that the inclusion of these factors in the analysis allows us to analyze the role of public policies relating to technical efficiency (IGLIORI, 2005).

Following a significant volume of literature of empirical studies involving stochastic production frontiers, this study employed the methodology proposed by Battese and Coelli (1995). Accordingly, we describe below the stochastic frontier model incorporating a model for technical inefficiency effects as proposed in their article. However, we point out that our study used cross-section data, given the unavailability of Census data for family farming for the other years in which the research was published.

The authors consider the following of stochastic frontier production function for panel data:

$$Y_{it} = \exp(x_{it}\beta+V_{it}-U_{it}) \qquad (2)$$

In the above expression, Y_{it} denotes the output of the ith firm (i = 1, 2, ..., N) in the t-th period (t = 1, 2, ..., T), without the need for a balanced panel data. x_{it} is the vector (1 x k) of production inputs, which may include other control variables.β is the vector (k x 1) of parameters of the production frontier to be estimated. It is assumed that V_{it}s are i.i.d. random disturbances such that $V_{it} \sim (0,\sigma_V^2)$ and they are independently distributed of the U_{it} terms. In turn, U_{it}s are nonnegative random disturbances that represent technical inefficiencies of production and are assumed to be independently distributed. It is assumed that U_{it}s is obtained by truncation, at zero, of a normal distribution with mean $z_{it}\delta$ and variance σ^2, where z_{it} is a vector (1 x m) of explanatory variables of technical inefficiencies and δ is a vector (m x 1) of parameters to be estimated. Therefore, the inefficiency effect of stochastic frontier model, U_{it}, can be defined by the following specification:

$$U_{it} = z_{it}\delta + W_{it} \qquad (3)$$

The random variable W_{it} is defined by the truncation of a normal distribution with zero mean and unknown variance, σ^2, so that the truncation point is given by $-z_{it}\delta$, that is $W_{it} \geq -z_{it}\delta$ and $U_{it} \geq 0$.

Battese and Coelli (1995) propose to use the method of maximum likelihood estimation to obtain simultaneously the parameters of the stochastic frontier (β) and the model of inefficiency effects (δ). Therefore, it is used the parameterization of Battese and Corra (1977), replacing σ_V^2 and σ^2 by $\sigma_S^2 = \sigma^2+\sigma_V^2$ and $\gamma=\sigma^2/\sigma_S^2$ in the maximum likelihood function. The maximum likelihood function and its partial derivatives with respect to the estimation parameters of the model (β, δ, σ_S^2 and γ) are presented in Battese and Coelli (1993).

The technical efficiency (TE) of each firm in each period can be defined by the ratio Y_{it}/Y_{it}^*, where Y_{it}^* is output on the efficient frontier (i.e., when U_{it}=0). Tehrefore:

$$TE_{it}=\frac{\exp(x_{it}\beta+V_{it}-U_{it})}{\exp(x_{it}\beta+V_{it})}=\exp(-U_{it})=\exp(-z_{it}\delta- W_{it}) \qquad (4)$$

The prediction of technical efficiencies is based on its conditional expectation, given the assumptions of the model. This result is also presented in Battese and Coelli (1993).

2.2. Definition of regional areas

One may question the hypothesis that the technological structure of farmers and the effects of exogenous factors on their production are identical in all regions of Brazil, which is assumed when estimating the stochastic production frontier and its model for technical inefficiency effects using all observations in the country.

To overcome this potential problem, one can perform the estimations separately for each region, with the same parameters used for the national model. However, against such segregation of the analysis account the fact that, using it, the results regarding the technical efficiency indices become not comparable between regions. With those points in view, the present study aimed to address the issue about the regional heterogeneity through the inclusion of regional dummies in the specification of the model for technical inefficiency effects.

The regional definition used here differs from the usual division of the Brazilian space in great regions, aiming to aggregate similar municipalities in terms of the characteristics of their agriculture. Thus, five regions in the country were considered. In the North region, the municipalities of Legal Amazonia were included, with the important exception of those belonging to the state of Mato Grosso. Therefore, in the present work, the North region is composed of the municipalities of Rondônia, Acre, Amazonas, Roraima, Pará, Amapá, Tocantins, and western Maranhão. In the Northeast, the municipalities included those from the area of operation of the Superintendence for the Development of the Northeast (SUDENE), with the exception of those from Maranhão and already included in the North. Thus, within this work, the Northeast region includes the municipalities of eastern Maranhão, Piauí, Ceará, Rio Grande do Norte, Paraíba, Pernambuco, Alagoas, Sergipe, Bahi,a and northern Minas Gerais and Espírito Santo. The third region, Southeast, includes other municipalities of Minas Gerais and Espírito Santo, São Paulo, and Rio de Janeiro. The South region comprises all the municipalities of Santa Catarina, Paraná, and Rio Grande do Sul. Finally, the Midwest region includes the municipalities of Mato Grosso do Sul, Mato Grosso, and Goiás.[5]

3. Literature review

Since it was theoretically proposed in the late 1970s, the stochastic frontier model has been applied in several studies related to agriculture, under various assumptions and having as object of study the performance of producers in different countries and regions. This section presents a brief review of the empirical literature on the measurement of technical efficiency in agriculture.[6]

One of the studies that proposed the stochastic frontier model also showed its application to agriculture. Aigner, Lovell and Schmidt (1977) applied the model to aggregate data of agriculture for 48 U.S. states. The authors, however, found results that were not significantly different from those obtained by an “average response function”. In other words, it was found that in this case the stochastic frontier model did not provide substantial gains in the estimation of the production frontier, comparatively the application of the method of least squares.

The work that introduced the methodology that will be employed in the present study also showed its application to agriculture. Battese and Coelli (1995) studied the production of rice in the Indian village of Aurepalle using an unbalanced panel data. As a result of special interest, given their methodological proposition, Battese and Coelli obtained a negative parameter for the schooling variable in their model for technical inefficiency effects, which indicated that farmers with more years of schooling tended to be less inefficient. Moreover, the positive parameter for the age variable showed that older producers were more inefficient. Finally, the negative parameter for the temporal variable indicated the decline in inefficiency of producers over the period analyzed.

One of the first applications of the stochastic frontier model to the Brazilian agricultural sector was that of Taylor and Shonkwiler (1986). The authors aimed to compare the technical efficiency between recipients and non-recipients establishments of credit from the World Bank through the Integrated Development Program of the Forest Zone (Prodemata), aimed at small producers in this region of Minas Gerais. Therefore, the authors estimated both stochastic and deterministic production frontiers.

[5] The Federal District was disregarded from the database due to the peculiarity of its economic structure. According to the IBGE Regional Accounts, it was, in 2006, the State in which the corresponding agricultural sectors accounted for the lowest percentage of total value added – only 0.21% of this variable was due to rural production in the Federal District, in contrast with the participation of 15.69% in the rest of the Midwest region and 5.70% in the rest of Brazil.

[6] For an extensive literature review on the technical efficiency of agricultural establishments, we suggest the following studies: Battese (1992), Bravo-Ureta and Pinheiro (1993), Thiam (2003), Bravo-Ureta *et al* (2007).

Through the stochastic frontier model, the authors estimated that the average efficiency for participants and non-participants were 0.714 and 0.704, respectively, not being significantly different.[7]

Directing attention to another region of the country, Igliori (2005) employed the methodology Battese and Coelli (1995) to analyze the technical efficiency of farmers of the Legal Amazon. For this, the author used data of 257 regions resulting from aggregating municipalities, based on the Census of Agriculture of 1996. Among the main results of the model for technical inefficiency effects estimated by Igliori (2005) is that the cost of transport to São Paulo negatively impacts the efficiency of agricultural producers in the Amazon, as expected by the theory of spatial economics, as the author points out. However, the distance from the nearest capital was significant and positively correlated with the efficiency term, what was opposed to the expected result. On the other hand, in agreement with the hypothesis of the presence of spatial agglomeration economies, it was found that the size of the population would positively impact the technical efficiency of producers, highlighting the role of local markets. This point was reinforced by the significant results concerning the total production of AMC and its past growth. The author also obtained favorable results for the existence of increasing returns to scale in terms of efficiency gains – these results, combined with those concerning the parameters of inputs in production frontier (which sum was close to 1), provide an interesting contrast between constant returns to scale for the production and increasing regarding the term of efficiency. Regarding the results for the spatially lagged variables, it was found that there were not strong evidences of spatial spillovers between regions inside Amazon. One possible reason for this result, according to the author, would be the large area occupied by each of considered regions, which would prevent a more systematic relationship between them. Finally, among the results of Igliori (2005), it is also worth noting that education was identified as negatively correlated to efficiency. This is a counterintuitive result, since it is expected that human capital shows positive impacts. The author suggests that a possible explanation for this would be the industrial composition of the regions. According to this argument, it may be supposed that regions with more educated populations begin to turn to industrial and service activities, so that the remaining agricultural sector would be intended only to supply local markets that do not face strong competition from other productive areas.

Marchand (2010) also addressed the issue of production efficiency in the Amazon. In this study, the author used data from the Census of Agriculture of 1996, by census tract, building up "representative establishments" by their size (15 classes) and land tenure status (4 possibilities). The author estimated only the stochastic frontier production function not worrying about the determinants of inefficiency effects.

More recently, Magalhães *et al* (2011) applied the methodology of Battese and Coelli (1995) to assess the determinants of technical inefficiency of 308 beneficiaries of the land reform program "Cédula da Terra" in five states in the northern region of the country, between the years 2002 and 2003. Among their results, Magalhães *et al* (2011) point out that labor was the factor that essentially determined production. The authors indicate that the small weight of land and other inputs would be consistent with the fact that they were studying establishments originated from a land reform program, which probably employ labor intensive technology, with low use of other inputs. Regarding the variables of the model for inefficiency effects, beyond the state dummies, only that for establishments' self-consumption was significant – its negative effect on efficiency would be consistent with the idea of this variable as an indicator of beneficiaries in initial stages of use of the resources provided by the project "Cédula da Terra". The non-significance of the other variables, however, also point to important elements to understand constraints on the production of the beneficiaries. In particular, according to the authors, they

[7] On the other hand, the estimation of a deterministic frontier indicated that the average efficiency for participants and non-participants were 0.185 and 0.059, respectively, being significantly different. Faced with this contradiction, the authors concluded that the results indicated undefined impacts on program participants. However, Battese (1992) points out that, given the relatively large standard deviations estimated for the random errors in the stochastic frontier model, it is possible that this was not statistically significantly different from the deterministic model. This would suggest that the results obtained with the deterministic frontiers would be more encouraging about the positive impact of the credit program.

were expending resources to obtain precarious technical assistance which, combined with generally low levels of education, did not provide good results to the establishments.

A very important aspect to be highlighted in the literature review of this section is that different authors with different subjects and databases have addressed the problem of measuring the performance of agricultural producers in quite different ways. The specification adopted in this paper was based on the literature concerning the technical efficiency of agriculture, but was also limited by the database, as shown below.

4. Database

The database and the construction of the variables that will be used in the empirical analysis of this study, using the methodology presented in section 3, constitute the object of attention of this section. We describe the construction of the variables for estimating both the stochastic production frontier as well its model for technical inefficiency effects. Throughout the description of the variables used, there is the worry to indicate how the literature predicts their behavior on empirical analyzes.

4.1. Construction of variables

The data used in this study were obtained by request from the Center for Agrarian Studies and Rural Development (NEAD) to IBGE, who tabulated the municipality-level data from the Census of Agriculture of 2006, detailing the family farms from the municipal total. For reasons of confidentiality, the data regarding survey questions that were answered by less than 3 establishments were not disclosed. Thus, we could not consider all municipalities that were investigated by the Census of Agriculture of 2006.

In this subsection, we will describe the work of constructing the variables used in the estimations of the production frontiers and inefficiency effects models. The estimates consider the existence of two representative establishments by Brazilian municipality: a family farm and a business farm.

4.1.1. Stochastic production frontier

The estimations used as output variable the total value of production of the establishments in 2006 and, alternatively, the sum of that value with the wages earned outside the establishment by rural producers. The total value of production includes that corresponding to livestock, crops and value-added from agribusiness. The addition of the wages earned in off-farm activities to the total value of production aims to deal with the point mentioned above, whereby the income from off-farms activities should be considered as a product under the justification that such activities use inputs common to rural production and affect the economic performance of family farmers (Paul *et al*, 2004). One should indicate, though, that this procedure implies the imposition of the hypothesis that both categories of activities (inside or outside the establishment) are considered as equally important by producers (Solís, 2005).

As production inputs, we considered four categories that are usual in the literature on technical efficiency of agriculture: labor, capital, land and other inputs. For the construction of the variable labor, we considered the guideline of Proger Rural, so it was measured in labor units employed by the establishment. As the capital, we considered the value of vehicles, tractors, machinery, and implements declared as assets by the producers. In the category of other inputs, we considered the expenses of establishments with fertilizers, soil amendments, seeds and seedlings, pesticides, animal medicines, salt and feed, and fuel. For land input, we considered the total area of establishments, which includes the area used for crops and pastures, but also occupied by woods and forests, water bodies for aquaculture, constructions, and degraded or useless land.

One should point out that the inclusion of woods and forests, as well as areas unsuitable for agriculture, in the inputs used by producers is not trivial. Possibly such inclusion affects the answer to the main question of this research study, which is the difference between the technical efficiencies of family farms in relation to business ones. The reason is that, on average, these areas represent a larger percentage of the total area of business establishments: 31%, against 26% for family farms. This difference, significant at 1%, suggests that the inclusion of these areas possibly reduces the efficiency measure of business producers, since – as compared to the case where such areas were excluded – one is increasing the amount of inputs used by them without proportional return for their production value.[8] However, it would be of interest in future studies to check this hypothesis by excluding, in the empirical analysis, the corresponding hectares of woods and forests or unsuitable land from the total area considered by the variable corresponding to the land input.

4.1.2. Model for technical inefficiency effects

The specification of the inefficiency effects model includes variables based on the literature concerning the technical efficiency of agriculture. Davidova and Gorton (2004) suggest that the variables that can influence the technical efficiency in this context are divided into two major groups: human capital and structural factors. Human capital variables include those such as formal and informal education, experience, training, and age of the producer. In turn, the structural factors would cover, among others, access to credit, land tenure status, and environmental variables. The specification used here sought to cover aspects related to the two groups, based on the study objectives and data availability.

The first assessed variable, of central interest to the present work, it was the dummy indicative of the family character of the establishment. Thus, we evaluated the hypothesis that, conditionally to the other variables included in the model, the category of the establishment (family or business) implies, on average, at different levels of technical efficiency.

The model also incorporated variables that are intended to indicate the effects of differences in the composition of output on the technical efficiency of agricultural establishments (Helfand, 2003). The proportions of the total area[9] of family or business farm in the municipality that were destined to livestock, to permanent crops or temporary crops were included as control variable – hence the category that was excluded from the specification corresponds to the area occupied by woods and forests, water bodies for aquaculture, construction, and degraded or useless lands.

In order to analyze the effect of human capital on the technical efficiency of agriculture, following the recommendation of Davidova and Gorton (2004), the model included a variable referring to formal education. This is the average years of schooling of people with more than 25 years in each municipality, as measured by the Population Census of 2000. Therefore, for reasons of data availability, we are not differentiating formal education of workers employed by family farms and business farms in the same municipality.

Education is usually postulated as having a positive impact on the technical efficiency of producers. According to Abdulai and Eberlin (2001), this view about the role of education on production comes from the fact that the reallocation of resources in response to changes in economic conditions requires: realizing that the change occurred; obtaining and analyzing information; developing valid conclusions from the information; and quick and decisive action. Besides the work of Abdulai and Eberlin (2001), some examples of empirical analyzes in which education showed positive impacts on the technical efficiency of agricultural establishments are Battese and Coelli (1995), Battese and Broca (1997), and Solis *et al* (2009).

Other studies, however, found an opposite relationship between formal education and technical efficiency of farmers. This is the case of Sherlund *et al* (2002), who studied the technical efficiency of small rice farmers in Côte d'Ivoire, finding greater technical efficiency among producers with less extensive formal education. One possible explanation for this result, the authors say, is that rural

[8] Although imprecise, an indicator of this is the fact that, according to the Census of Agriculture of 2006, woods and forests corresponded to 27% of the total area of agricultural establishments, but only 5% of their production value corresponded to the activities of forestry and vegetal extraction.

[9] In this paper, the control for the effects due to differences in the composition of the production was done by the proportions of the area since these is supposedly a structural feature of establishments. However, it should be indicated that it would also be possible that such control was performed by the proportion of the value of production that were due to these same activities. Preliminary analyses indicated that the results would not change significantly with the use of such alternative control.

production would be a secondary occupation for those with formal education in the context they analyzed so that their establishments would receive less attention and thus exhibit smaller technical inefficiency. As previously seen in the literature review, Igliori (2005) also found negative impact of formal education on technical efficiency, while Magalhães *et al* (2011) found it as not significant.

The specification of the model for inefficiency effects in this study also included an index on the background of producers as another human capital variable. We used the groups of years of management in the establishment indicated by producers in the Census of Agriculture of 2006. The construction of the index followed this criterion: "less than 1 year" in the charge of management was given the index value equal to 1; for "1 to less than 5 years", was attributed a value of 2; for "5 to 10 years", the assigned value were equal to 3 and, finally, "10 years and over" was given the value equal to 4. Note that the variable used is indicative both of the experience as the age of producers.

Again, there are divergent arguments in the literature and empirical evidence about the effect of variables related to age and experience on the technical efficiency of farmers. On the one hand, there is the classic hypothesis of Schultz (1964), whereby farmers identify their optimal combination of inputs and outputs, given a long enough period of time to learn their production processes – i.e. experience, according to Schultz, positively affects the technical efficiency of farms. On the other hand, several authors as Abdulai and Eberlin (2001) indicate that elderly producers are expected to be less adaptable to changes of scenario and to have lower physical strength, which is an important quality attribute of labor used in agricultural production – thus, age negatively influence the technical efficiency.

Thus, as expected, empirical applications obtained different results regarding the influence of these variables on technical efficiency. Olson and Vu (2007) found that producers with fewer years of management in their establishments would be more efficient, the opposite result of Wilson *et al* (2001). With regard to the age of producers, Battese and Broca (1997) found an inverse relationship of this variable and technical efficiency, while Hadley (2006) found a direct relationship. Liu and Zhuang (2000) and Abdulai and Eberlin (2001), besides the age of the producer, included in the model for inefficiency effects the square of that variable, in order to control for non-linear lifecycle effects. Both studies found that the technical efficiency of the farms would increase with the age of the producer until it reaches about 40 years old, decreasing thereafter. In addition, several other works that included the age of the producer as an explanatory variable in the model for technical inefficiency effects found it as not significant (e.g., Sherlund *et al*, 2002; Thiam, 2003; Paul *et al*, 2004; Solís *et al*, 2009).

In this study, among the structural factors (Gorton; Davidova, 2004), we sought to evaluate the effects of access to credit, land tenure status and environmental conditions on the technical efficiency of agricultural establishments.

As the variable referring to credit, the model for inefficiency effects employed the proportion of establishments in each municipality and in each category (family or business), which received funding in 2006 through various agents (banks, credit cooperatives, suppliers, integrator companies, other financial institutions, NGOs, relatives, etc.). [10]

The literature generally postulates that access to credit would have a positive influence on the technical efficiency of agriculture. According to Helfand (2003), constraints in credit markets could cause producers to choose combinations of inputs and outputs that would not seem great for establishments without those restrictions. Thus, credit restriction would decrease the efficiency of producers by limiting the adoption of innovations such as the use of more productive crop varieties and better inputs, as well as the acquisition of information necessary for better performance. As indicated by Liu and Zhuang (2000), in particular small producers in developing countries do not seem to adopt seemingly economically justifiable innovations because of their risk aversion – in these circumstances, access to credit, to mitigate risk, encourage the innovation and thereby promote increased technical efficiency. However, it is possible that credit has no effect on efficiency if it simply replaces other sources of funding, such as, for example, producers' saving (Abdulai; Eberlin, 2001), or if it is destined for consumption (Chavas *et al*, 2005).

[10] In the present work, access to credit is considered exogenous, following the practice commonly adopted in the literature of agricultural economics (e.g. Solís *et al*, 2009).

Empirical applications have found mixed results regarding the effect of access to credit on the technical efficiency of farmers. In the literature on the Brazilian case, Helfand and Levine (2004) found a positive effect on the efficiency, while Nogueira (2005) found negative and Magalhães *et al* (2011) have not found conclusive results. As examples of applications in other areas of the world, Liu and Zhuang (2000) and Abdulai and Eberlin (2001) found positive effect on efficiency and, on the other hand, Battese and Broca (1997) and Solís *et al* (2009) found no significant parameters for the variable corresponding to credit access in their works.

Regarding the land tenure status, the specification of the model for inefficiency effects employed in this work included the proportion of establishments in each municipality and in each category (family or business), which were owned by the producers, as opposed to they being renters, partners or occupants of the managed land. As pointed by Igliori (2005), the importance of such control stems from the fact that owners, renters, partners and occupants have different property rights and pay different prices for the use of the land, which may impact the technical efficiency of their establishments.

On this issue, on the one hand, there is the idea in the literature that land ownership would reduce the risks related to production and therefore increase the expected returns and encourage producers to invest in techniques that enable higher productivity (Gebremedhin; Swinton, 2003). On the other, one indicates that producers who are not owners have greater need for revenue to cover payments to the lands in which they produce, which could exert an incentive for greater efficiency of their properties (Solís *et al*, 2009).

As would be expected, then, the empirical applications have reached differing conclusions about the effect of the land tenure status on the technical efficiency of agricultural establishments. In the Brazilian case, while Helfand and Levine (2004) found that owners were less efficient in the Midwest region, Igliori (2005) did not obtain conclusive results analyzing the Amazon region. As other examples in the literature, Hadley (2006) found that owners would be more efficient than other producers, ceteris paribus, while Solís *et al* (2009) found opposite results in their empirical application and Battese and Broca (1997) obtained parameters that were not significant.

The specification of the model for inefficiency effects used in the present work tried to further control by some environmental factors that possibly affect the technical efficiency of agricultural production (Sherlund *et al*, 2002). All environmental variables are in municipal-level. They included, besides the altitude of the municipality (taken from IBGE's register of cities and towns in 1998), controls related to rainfall and temperature: these are estimates of annual averages in the 30 years that span from 1961 to 1990 conducted by the Institute of Applied Economic Research (IPEA) from the CRU CL 2.0 10' climate data base of the Climate Research Unit of the University of East Anglia (CRU-UEA).

Table 1 presents descriptive statistics for representative establishments that were considered in this work, for Brazil as a whole. Comparing, first, descriptive statistics concerning the specification of the production frontier, one realizes that representative business establishments presented, on average, much higher values for the output variables (value of production and wages earned in off-farm activities), and for those relating to inputs (labor, capital, other inputs, and area). It should be noted that, considering the partial productivity measure given by production per area, discussed in the Introduction, the family farms presented, on average, higher value: R$ 886.33 per hectare were produced, compared to R$ 549.58 per hectare in business establishments. Also in relation to the variables of the production frontier, we see in Table 1, there was great variation from the mean in the case of representative business establishments, which can be seen both from the high value of the standard deviation, as well from the minimum and maximum values of the variables.

Regarding the variables of the model for inefficiency effects, Table 1 indicates that representative family establishments had, on average, greater portions of their area dedicated to agricultural crops – as the portion allocated to livestock is not significantly different between the two categories of establishments, it follows that the business farms, on average, had higher proportions of area with woods and forests or useless for agricultural activities. Regarding the variable referring to the experience of farmers, we noticed that representative family farmers presented, in 2006, higher average years of management of their establishments. However, a smaller proportion of family farmers, by municipality, were named as owners of their lands, in comparison with business producers.

Descriptive statistics for the other regions, omitted here for space constraints, are presented in Imori (2011). They suggest a rather diversified scenario in the Brazilian agriculture. Thus, one should emphasize the need for assessments of technical efficiency of farms adopting methodologies that consider the complex relationships between inputs and outputs in the production processes, as well as the influences that various external factors may have on the production performance of producers.

Table 1 - Descriptive statistics, Brazil

		Family				Business			
		Mean	**SD**	**Min.**	**Max.**	**Mean**	**SD**	**Min.**	**Max.**
Production Frontier	**Production value (R$ thousand)**	20.20	74.77	0.62	4 909.29	157.23	403.15	1.09	13 333.68
	Off-farm income (R$ thousand)	0.69	1.24	0.00	21.82	4.71	6.86	0.00	199.72
	Labor (units)	2.99	0.85	1.09	23.10	6.18	10.03	1.33	490.25
	Capital (R$ thousand)	16.67	19.24	0.13	507.70	114.59	326.36	0.17	9 948.33
	Other inputs (R$ thousand)	4.33	12.79	0.01	591.40	64.44	442.07	0.04	18 432.71
	Area (hectares)	22.79	18.49	0.85	222.83	286.10	441.27	2.67	8 617.09
Model for inefficiency effects	**Area - Livestock (proportion)**	0.45	0.23	0.00	0.97	0.44	0.24	0.00	1.00
	Area – Temporary crops (proportion)	0.21	0.19	0.00	0.97	0.19	0.21	0.00	0.99
	Area – Permanent crops (proportion)	0.08	0.12	0.00	0.92	0.06	0.11	0.00	0.85
	Education (average years of schooling)	4.01	1.26	0.81	9.26	4.02	1.26	1.04	9.26
	Experience (groups of management years)	3.39	0.25	1.66	4.00	3.28	0.26	1.52	4.00
	Credit access (proportion)	0.20	0.15	0.00	0.87	0.20	0.15	0.00	1.00
	Land owners (proportion)	0.79	0.18	0.00	1.00	0.86	0.14	0.00	1.00
	Altitude (meters)	419.27	289.23	0.00	1 505.00	420.17	288.93	0.00	1 505.00
	Rainfall - average (mm/month)	114.77	35.84	28.87	254.24	114.73	35.73	28.87	254.24
	Temperature - average (°C)	22.79	3.03	14.38	28.04	22.78	3.02	14.38	28.04
	Observations	5 215				5 198			

Source: research data.

6.1. Parameter estimates and hypothesis testing

Following the recommendation of Battese and Broca (1997), we used a general specification for the model as a starting point and tested a simpler formulation within a formal framework for hypothesis testing. In this work, the most general form of the stochastic production frontier is a translog function.

The results of the maximum-likelihood estimates for the parameters of the stochastic production frontier and the model for technical inefficiency effects are shown in Table 2. Models I and II employed the sum of the value of production of the establishments and wages earned in off-farm activities as the output variable, adopting, respectively, the functional forms translog and Cobb-Douglas. In turn, the Models III and IV incorporate only the production value as output variable, also adopting the functional forms translog and Cobb-Douglas, in that order.

After obtaining these estimates by maximum-likelihood, we proceeded to carry out several tests of hypotheses in order to evaluate the alternatives considered for the production technologies. The results are shown in Table 3. The test groups 1, 2 and 3 made use of the likelihood ratio, λ. Through it, it is possible to compare the likelihood functions under alternative hypotheses (Solís, 2005). The test statistic is defined by:

$$\lambda = -2\ln[L(H_0)/L(H_1)] \qquad (6)$$

where H_0 and H_1 are the null and alternative hypothesis involved, respectively. If the null hypothesis, H_0, is true, then λ is asymptotically distributed as a chi-square random variable (or mixed chi-square) with the number of degrees of freedom equal to that of restrictions being tested (Battese; Coelli, 1995). If the null hypothesis involves $\gamma=0$, then λ has a mixed chi-square distribution, given that $\gamma=0$ is a value at the border of the parameter space for γ. The critical values for the tests in this case can be found in Kodde and Palm (1986).

Table 2 – Parameter estimates of the stochastic production frontier with model for inefficiency effects - Models I, II, III and IV

		Model I			Model II			Model III			Model IV		
		Parameter	**SD**		**Parameter**	**SD**		**Parameter**	**SD**		**Parameter**	**SD**	
Production Frontier	**Constant**	1.377	0.103	***	1.472	0.056	***	0.985	0.095	***	1.144	0.048	***
	Labor	0.589	0.072	***	0.454	0.018	***	0.660	0.075	***	0.488	0.019	***
	Capital	0.464	0.030	***	0.316	0.009	***	0.551	0.031	***	0.349	0.009	***
	Other inputs	-0.238	0.024	***	0.225	0.007	***	-0.255	0.025	***	0.220	0.007	***
	Land	0.257	0.031	***	0.127	0.009	***	0.253	0.033	***	0.146	0.009	***
	Labor*Labor	-0.105	0.020	***				-0.112	0.021	***			
	Capital*Capital	-0.012	0.005	**				-0.014	0.005	***			
	Other inputs*Other inputs	-0.008	0.003	**				-0.009	0.003	***			
	Land*Land	-0.018	0.005	***				-0.015	0.005	***			
	Labor*Capital	0.001	0.020					-0.011	0.021				
	Labor*Other inputs	0.075	0.016	***				0.071	0.016	***			
	Labor*Land	-0.006	0.018					0.005	0.019				
	Capital*Other inputs	0.036	0.006	***				0.039	0.006	***			
	Capital* Land	-0.043	0.008	***				-0.052	0.008	***			
	Other inputs*Land	0.070	0.006	***				0.076	0.006	***			
Model for inefficiency effects	**Constant**	0.450	0.281	***	0.588	0.275	**	0.334	0.300	***	0.376	0.327	
	Family dummy	0.604	0.036	***	0.388	0.031	***	0.400	0.033	***	0.204	0.033	***
	Area - Livestock (proportion)	-0.290	0.062	***	-0.297	0.060	***	-0.362	0.062	***	-0.387	0.074	***
	Area – Temporary crops (proportion)	-0.313	0.076	***	-0.399	0.078	***	-0.483	0.077	***	-0.590	0.085	***
	Area – Permanent crops (proportion)	-0.561	0.105	***	-0.621	0.107	***	-0.797	0.113	***	-0.882	0.129	***
	Education	-0.263	0.013	***	-0.282	0.013	***	-0.312	0.015	***	-0.342	0.015	***
	Experience	-0.068	0.042		-0.102	0.045	**	-0.095	0.042	**	-0.131	0.051	**
	Credit access (proportion)	-0.558	0.102	***	-0.605	0.099	***	-0.582	0.108	***	-0.696	0.121	***
	Land owners (proportion)	-0.087	0.069		0.073	0.074		-0.179	0.072	**	-0.007	0.072	
	Altitude	0.000	0.000	***	0.000	0.000	***	0.000	0.000	***	0.000	0.000	***
	Rainfall - average	-0.002	0.000	***	-0.001	0.000	***	-0.002	0.000	***	-0.001	0.000	***
	Temperature - average	0.062	0.008	***	0.070	0.008	***	0.089	0.009	***	0.102	0.010	***
	North	0.102	0.058	*	-0.050	0.058		-0.037	0.057		-0.204	0.062	***
	Northeast	-0.022	0.046		-0.251	0.045	***	-0.141	0.046	***	-0.383	0.049	***
	Southeast	0.048	0.042		-0.061	0.040		0.006	0.040		-0.118	0.044	***
	Midwest	-0.162	0.054	***	-0.307	0.059	***	-0.200	0.056	***	-0.402	0.061	***
	σ^2	0.432	0.009	***	0.455	0.009	***	0.487	0.010	***	0.519	0.011	***
	γ	0.170	0.023	***	0.167	0.025	***	0.182	0.024	***	0.198	0.025	***
	Log-likelihood	-10079.32			-10392.01			-10627.46			-10933.35		

Source: research data. Significance levels: * 10%, ** 5%, *** 1%.

Remarks about the regional classification: North – Amazon municipalities, except those belonging to Mato Grosso; Northeast – SUDENE municipalities, except those from Maranhão that were included in the North; Southeast – municipalities of Minas Gerais and Espírito Santo not included in the Northeast, in addition to those of São Paulo, and Rio de Janeiro; South – municipalities of Santa Catarina, Paraná and Rio Grande do Sul; Midwest – municipalities of Mato Grosso do Sul, Mato Grosso and Goiás.

Additional remarks: estimates obtained by maximum-likelihood; output variable: production value of the agricultural establishment (Models III and IV) plus wages earned in off-farm activities (Models I and II).

Table 3 – Hypothesis testing of stochastic production frontier models

Test	Null hypothesis	Test Statistic	Conclusion
1) Cobb-Douglas x Translog			
Model I x Model II	$\beta_{ij}= 0, \forall$ i,j	625.38	Reject H_0
Model III x Model IV		611.79	Reject H_0
2) No inefficiency effects in the production function			
Model I		1729.27	Reject H_0
Model II	$\gamma = \delta_0=\delta_1=\ldots=\delta_{19}=0$	1939.11	Reject H_0
Model III		1701.44	Reject H_0
Model IV		1968.47	Reject H_0
3) Variables in the inefficiency effects model have no effect on the level of technical inefficiency			
Model I		1729.27	Reject H_0
Model II	$\delta_1=\delta_2=\ldots=\delta_{19}=0$	856.42	Reject H_0
Model III		1701.44	Reject H_0
Model IV		2046.09	Reject H_0
4) Spearman correlation			
Model I x Model II		0.973	
Model III x Model IV	Same ranking of	0.977	
Model I x Model III	technical	0.974	
Model I x Model without inefficiency effects	efficiencies	0.399	
Model III x Model without inefficiency effects		0.415	

Source: research data.

In short, besides the statistical significance of the parameter γ indicating that the stochastic production frontier approach proved to be more appropriate than the model of average production function, results of tests of hypotheses presented in Table 3 indicate that: i) the translog functional form provided a better representation of the production frontier than the Cobb-Douglas specification; ii) the model for inefficiency effects was to be incorporated into estimations; iii) the levels of the explanatory variables actually affect jointly the estimated technical efficiencies; iv) choosing the output variable did not affect the ranking of the estimated technical efficiencies. Taking up this in mind, the following analysis will focus on the results of the estimations obtained under Models I and III, which adopted a translog functional form for the production frontier, included the model for inefficiency effects of Battese and Coelli (1995) and considered different variables representing output (sum of the value of production of establishments plus wages earned in off-farm activities and only the value of production, respectively).

Returning to the analysis of parameter estimates of the stochastic production function, shown in Table 2, for Models I and III, we can point out that one should be careful in interpreting the estimated parameters, since they have little meaning per se for the translog function. The calculation of elasticities for each input would actually be of greater interest (Abdulai; Eberlin, 2001). The values of these elasticities calculated at the midpoint of the value of inputs are presented in Table 4, using the parameters of the stochastic production frontiers estimated for Models I and III.

Table 4 - Elasticities of production frontier in relation to inputs

	Model I	Model III
Labor	0,509	0,549
Capital	0,272	0,290
Other Inputs	0,322	0,328
Land	0,136	0,164

Source: research data.

In both models I and III, the higher elasticity of the production frontier, in the average value of inputs, referred to labor, followed by that of other inputs and that of capital. Table 4 indicates the percentage variation of the land, in turn, would be accompanied by lower percentage change in the better response production, as elasticity for that input proved to be less high.

As pointed out by Barnes (2008), the measure of returns to scale can be obtained by summing these partial elasticities. In the case of Model I, we obtained a sum equal to 1.238, whereas for Model III it was equal to 1.330. Thus, in both models, the sum obtained was greater than unity, indicating increasing returns to scale at the midpoint of the value of inputs. This suggests that, on average, agricultural establishments were operating in suboptimal size (Thiam, 2003).

6.2. Technical efficiencies

This section is dedicated to analyzing the results of the estimation of technical efficiencies of representative establishments, obtained from the stochastic production frontiers under Models I and III. Such estimations were performed according to the expression (4). First, we analyze the results for Brazil as a whole, which are then segmented by region.[11]

Table 5 shows the distribution of technical efficiencies estimated by Models I and III, for Brazil as a whole, distinguishing between representative family and business establishments. It can be observed that the choice of variable regarding the output (sum of the production value of the establishment and wages obtained in off-farm activities or just the production value) brings changes that are not negligible as regards the distribution of technical efficiencies estimated considering each type of agricultural establishments. Note that under Model III, which does not consider wages earned in off-farm activities as part of their output, a larger number of representative family establishments presented technical efficiencies corresponding to superior intervals (compared to what was observed under the Model I) at the expense of technical efficiencies estimated for representative business establishments.

Under both models, however, family farmers had a lower average technical efficiency than business farmers. The average technical efficiency indices of representative family establishments were 0.54, under Model I, and 0.60, under the Model III. This indicates that, on average, with the same levels of inputs and technology, the sum of production value of establishments and wages earned in off-farm activities, in the case of Model I, or the production value, in the case of Model III, could be increased in 46 percentage points and 40 points, respectively. These results, therefore, suggest that substantial gains could be achieved by family farmers, given the existing levels of inputs and technology employed by producers. In turn, the representative business establishments presented average technical efficiency indices of 0.74 and 0.71 in Models I and III, in that order.

Table 5 - Distribution of technical efficiencies, Brazil

	Model I				Model III			
	Family		Business		Family		Business	
	No	%	No	%	No	%	No	%
< 0.1	0	0.00	0	0.00	0	0.00	0	0.00
[0.1 - 0.2[	78	1.50	0	0.00	56	1.07	4	0.08
[0.2 - 0.3[	812	15.57	13	0.25	570	10.93	105	2.02
[0.3 - 0.4[	883	16.93	187	3.60	775	14.86	363	6.98
[0.4 - 0.5[	601	11.52	544	10.47	603	11.56	559	10.75
[0.5 - 0.6[	591	11.33	627	12.06	449	8.61	538	10.35
[0.6 - 0.7[	719	13.79	539	10.37	588	11.28	472	9.08
[0.7 - 0.8[	779	14.94	615	11.83	813	15.59	703	13.52
[0.8 - 0.9[	717	13.75	1724	33.17	1150	22.05	1666	32.05
[0.9 - 1.0]	35	0.67	949	18.26	211	4.05	788	15.16
Mean	0.54		0.74		0.60		0.71	
SD	0.21		0.18		0.22		0.19	
Minimum	0.13		0.25		0.12		0.17	
Maximum	0.94		0.96		0.95		0.95	

Source: research data.

[11] It should be noted again that the regional classification used in the work is different from the usual division by great Brazilian regions.

Figure 1[12] shows the estimated technical efficiencies for representative family (left) and business establishments (right), by means of Models I and III, respectively. As would be expected given the high value of the Spearman correlation between Models I and III, shown in Table 3, the representations show up very similar – representative family or business establishments of each municipality often presented in both models indexes of technical efficiency residing at close intervals.

The North region is one that has the lowest average technical efficiency considering the family farms, under Models I and III – under both, we obtained the result that over 70% of family farmers had technical efficiency below 0.50. Regarding business establishments in the North, although more efficient than family farms, they too could achieve substantial gains of output under both Models I and III – the estimated average technical efficiencies of these two models were, respectively, 0.60 and 0.57. Figure 1 highlights, however, that representative business establishments corresponding to some municipalities in northwest Rondônia, northern Pará and Amapá obtained technical efficiency indices above 0.80.

For the Northeast region, we observed that its family farms could also achieve substantial gains in output, given their inputs levels and production technology, since they showed low technical efficiencies estimates, on average: 0.46 and 0.53 under Models I and III, respectively. As for representative business establishments, it was found that, under the estimates of both Models I and III, the Northeast region had, on average, the lowest technical efficiencies. Also, it should also be indicated that this was the only region in which, according to the results of Model III, the average efficiency of representative family establishments was not inferior to that of business establishments – they presented average technical efficiency level of 0.52 (under Model I, 0.56). According to Figure 1, especially representative business establishments regarding municipalities of São-Francisco valley Bahia and east Piauí presented low technical efficiencies according to the estimates of Models I and III. On the other hand, it is observed that the representative business establishments corresponding to areas closer to the coast showed considerably higher technical efficiencies under both models – especially in the states of Bahia and Pernambuco, where many of these establishments have obtained technical efficiency indices above 0.80.

The Southeast region was in middle position regarding its estimated technical efficiencies for representative family establishments, both under the Model I, as under the Model III – their average ratios were 0.58 and 0.64, respectively. Regarding the technical efficiency estimates for representative business establishments, one can indicate that the average value presented by the Southeast was lower only than in the South region (0.85 under Model I, 0.83 under Model III). According to Figure 1, the representative business establishments imbued with technical efficiencies higher than 0.90 in the Southeast corresponded for municipalities located mainly in the areas of northeast of São Paulo, south of Minas Gerais (besides Uberaba and Uberlândia, in this state), and south of Rio de Janeiro.

As for the South and Midwest regions of the country, one can indicate that such regions have obtained technical efficiency indices to their family farms whose means were not statistically different, but were higher than in other regions of the country, considering both Models I and III – the South had averages of 0.64 and 0.69, respectively, while the Midwest had averages of 0.66 and 0.71. For business establishments, as pointed out in the preceding paragraph, the South presented the highest average technical efficiency in the country – under both models, 0.89. It is noteworthy, in this region, the large proportion of municipalities whose representative business establishments had efficiency rates higher than 0.90: 54.20%, according to the Model I, 46.06%, according to the Model III. According to Figure 1, these municipalities were located, in the South region, especially in the western areas of their states. As for the Midwest, this region was found in an intermediate position for the technical efficiency of their representative business establishments (0.82 under Model I, 0.78 under Model III). Figure 1 indicates that the efficiency ratios above 0.80 corresponded mainly to municipalities of Mato Grosso do Sul and southern areas of the states of Mato Grosso and Goiás

[12] In these Figures, the blank areas of the Brazilian territory correspond to municipalities whose data required for estimating the stochastic production frontier and the model for inefficiency effects were not available in the database used in the present work.

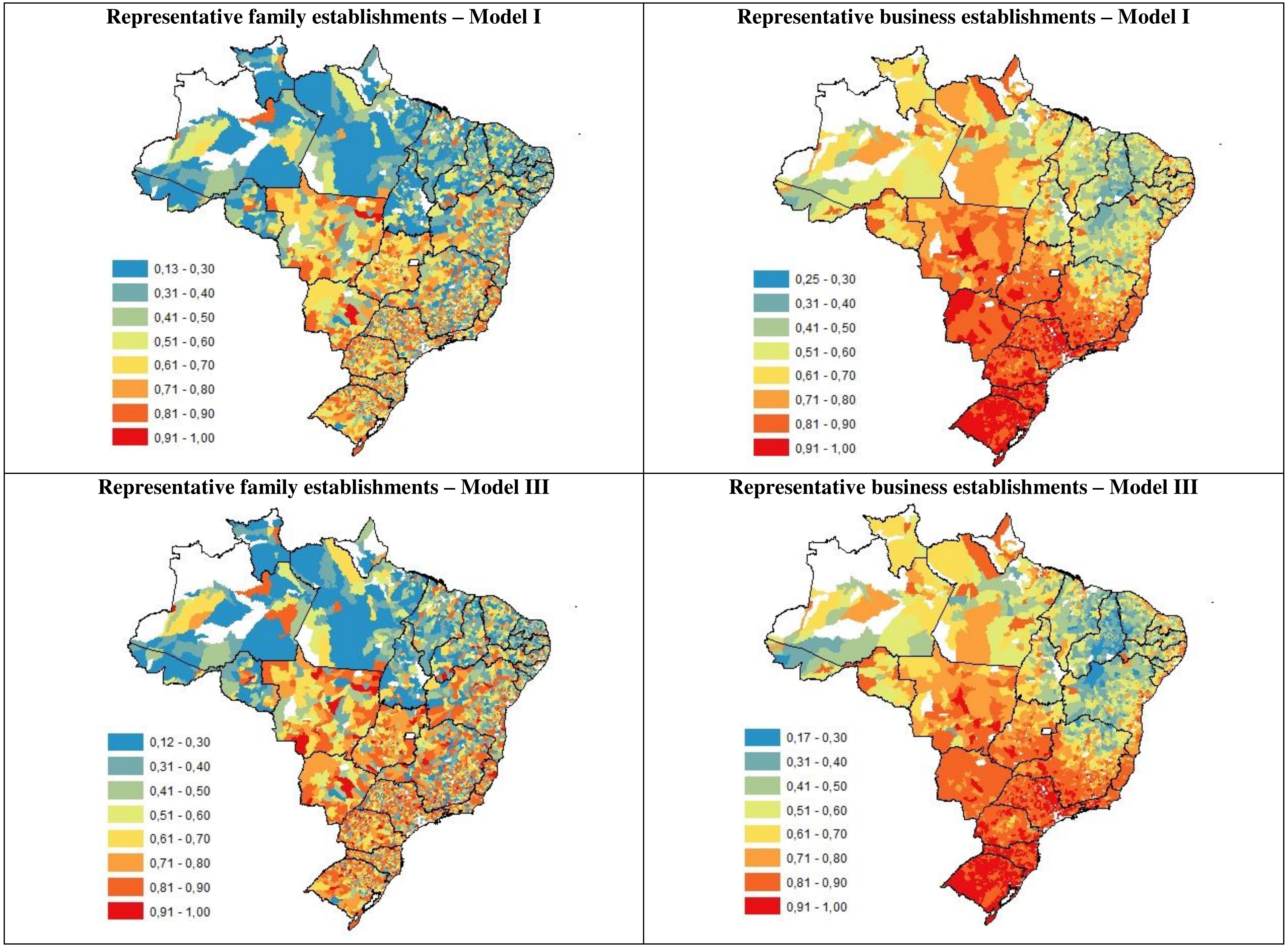

Figure 1 – Technical efficiency estimates of representative family (left) and business establishments (right), Model I (above) and III (below)

6.3. Model for inefficiency effects

We analyze now the estimated parameters for the models for technical inefficiency effects, included in Models I and III, whose results were presented in Table 2. In interpreting the effects of these variables, it should be indicated that, since in the model for inefficiency effects of Battese and Coelli (1995) the dependent variable is the element relating to the inefficiency error term (U_i), a negative parameter indicates that the respective variable favors technical efficiency.

First, we evaluate the effects of the explanatory variables that are not dummies. Regarding the composition of production, the results for both Models I and III indicate that, over the category of area use that was omitted from the specification employed here – namely, woods and forests, or land useless for agriculture – increasing the proportion of the area for any of the other activities (livestock, temporary crops or permanent crops) has positive and statistically significant effect on the technical efficiency of farms. This is an understandable result: everything else constant, the allocation of a greater proportion of the area for activities whose production more greatly contribute to the composition of the output variables of Models I and III would lead to greater technical efficiency measures.

The parameter refering to formal education was estimated to be negative and significant in the models for inefficiency effects of both Models I and III. This indicates that an increase in the number of years of schooling of the adult population of a given municipality would lead to greater technical efficiency of their agricultural establishments. This is a strong indication that, in agreement with what was theorized by much of the literature, also in the Brazilian agriculture education would act as a driver of technical efficiency, providing that the processes for capturing information and making decisions by producers to be faster and well done (e.g., Battese; Coelli, 1995; Battese; Broca, 1997; Abdulai; Eberlin, 2001; Solís *et al*, 2009).

About the other component of human capital included in the model for inefficiency effects of the present work, the background of producers (consolidated in groups according to their years of management of their establishments), presented significant parameter (at 5% level of significance) only in Model III. That is, only in the model which did not consider wages earned in off-farm activities as part of the output variable of the stochastic frontier, the farmers' background was significant and positively related to technical efficiency of agricultural establishments. Thus, in the empirical application of Model III of this paper, there is evidence that the positive effect of experience on the producers' technical efficiency exceed unfavorable aspects that accompany their increasing age (Wilson *et al*, 2001). However, the parameter on the producers' background was not significant in the model for inefficiency effects included in Model I, which considered wages earned in off-farm activities as part of the output variable – it is not an isolated case in the empirical literature on the technical efficiency of agriculture (e.g., Sherlund *et al*, 2002; Thiam, 2003; Paul *et al*, 2004; Solís *et al*, 2009).

One possible explanation for the lack of significance of the parameter referring to the producers' background in the estimation of only Model I would be that getting salaries in off-farm activities – embodied in the output variable of that model – would be more substantial among younger producers. Possibly, such producers have more frequent access to jobs, both in rural establishments directed by others, and in urban areas, which expands its product as considered by Model I and, given the used inputs, also its technical efficiency. With this, the significant positive relationship observed in Model III between technical efficiency and producers' background would be less evident. The issue clearly deserves a more thorough study, which, however, is beyond the scope of this work.

Regarding access to credit, the estimation results of Models I and III suggested that it has positive influence on technical efficiency in the empirical application of this work, since the estimated parameter for its variable had a negative sign in the respective models for inefficiency effects. Thus, as indicated by Helfand (2003), it seems that, in fact, in Brazil, access to credit would lead establishments to choose the most appropriate combinations of inputs and outputs, facilitating the employment of superior crop qualities and acquisition of information necessary for a better performance. This is a result, although not unanimous (e.g., Battese; Broca, 1997; Solís *et al*, 2009), also found in empirical applications concerning other regions (e.g., Liu; Zhuang, 2000; Abdulai; Eberlin, 2001).

Similar to the results obtained for variable on producers' background, the parameter of the variable referring to the land tenure status was significant only in the model for inefficiency effects corresponding to Model III. In this model, where the wages earned in off-farm activities are not considered as components of outputs, the significant and positive relationship between the percentage of land owners in municipalities and technical efficiency suggested to be valid the idea that land ownership reduces risks and encourages investment in techniques that enable higher productivity (Gebremedhin; Swinton, 2003). However, the empirical application developed under the Model I, in which the output variable was considered as the sum of wages earned in off-farm activities and the production values, did not find a statistically significant relationship between land tenure status and technical efficiency, which constitutes a recurrent result in literature (e.g., Battese; Broca, 1997; Igliori, 2005).

Again, therefore, as was the case for the variable related to producers' background, we have obtained statistically significant parameter for the variable on land tenure status only in Model III. A tentative explanation is that in the existence of property title, producers would devote more intensively themselves to productive activities related to their establishments, which enlarges their product against producers who present different status with respect to the land. Thus, one could observe a significantly positive relationship between technical efficiency and land ownership in the estimation of Model III. However, a more careful analysis of the issue – although very interesting – is beyond the scope of this work.

The parameters of the variables that were included in the model for inefficiency effects as environmental controls were statistically significant in both Models I and III, suggesting that these factors actually influence the technical efficiency of Brazilian agriculture. Thus, on average, in Brazil, higher altitudes are associated with lower technical efficiencies. One possible explanation for this is the difficulty that rough terrains, commonly associated with higher altitudes, hinder the proper use of mechanization, so that the capital of the farms located in these areas may be underutilized. As to other environmental controls, it was observed that, on average and considering the country as a whole, higher temperatures are associated with lower technical efficiencies, with the opposite being true for rainfall.

Having performed the analysis of the estimated parameters for level variables in the model for inefficiency effects, we now evaluate the effects arising from the dummies on the technical efficiencies of agricultural establishments in the empirical analysis of this study. First, we analyze the results for the variable of central interest to the study, namely, a dummy indicating the family (=1) or business (=0) character of the representative establishment. Table 2 shows, for both Models I and III, positive and statistically significant maximum-likelihood parameters for the dummy indicative of family character in the model for inefficiency effects. The results therefore suggest that, conditionally to the other variables in the model for inefficiency effects, the family character is negatively related to technical efficiency of agricultural establishments.

Concerning the relationship between the heterogeneity of each region[13] and the technical efficiency of their agricultural establishments, an important point is the examination of Figure 1, which mapped the indexes of technical efficiency estimates from the stochastic production frontiers of Models I and III in comparison with the results obtained for the parameters relating to the regional dummies in their models for inefficiency effects. It should be emphasized that, unlike the technical efficiency indices illustrated by Figure 1, the measured relationships between the variables in the model for inefficiency effects, including the regional dummies, and the performance of productive establishments are conditional to the other factors considered in the model. As will be seen below, this observation is particularly important in the case of the Brazilian Northeast.

Table 2 shows that, first, for Model I, we obtained a positive and significant at 10% level parameter for the dummy on the North region in the model for inefficiency effects. Therefore, given the indicated controls, the agricultural establishments in the North were on average less efficient than those in the South (omitted in the specification). In turn, the parameter for the dummy of the Midwest region in

[13] It should be noted again that the regional classification adopted in the present work is different from the usual division by Brazilian great regions. Details of this classification, as well as its justification can be found in Section 2.2.

the model for inefficiency effects of Model I was estimated as negative and statistically significant. Thus, given the controls, one can understand that the estimated technical efficiency for establishments in the Midwest, on average, was higher than for the South.

Also from Table 2 it can be inferred that the results differed as to regional heterogeneities in Model III, which considers as the output variable only the production value of establishments (as opposed to its sum with wages earned in off-farm activities, employed in Model I). The main difference compared to the results obtained in Model I refers to the statistical significance of the negative parameter for the dummy on the Northeast region in the model for inefficiency effects. Thus, in the case where one considers only the value of production as output variable, the Northeast region, given the factors of the model for inefficiency effects – i.e. conditionally to presenting values equal to those of the South region for variables concerning the composition of production, education, producers' background, land tenure status, access to credit and environmental aspects – would be more positively related to technical efficiency of agriculture in relation to the South region. Also, unlike what was observed for Model I, the parameter of the dummy on the North region was not significant in the results for Model III. Moreover, also in Model III, the agricultural establishments of Midwest region showed up, on average and given the controls in the model for inefficiency effects, more efficient than those of the South region.

From the results above, thus, we can highlight that the highest technical efficiency levels were presented, on average and given the controls in the model for inefficiency effects, by the agricultural establishments in the Midwest region, which was verified in both Models I and III. This is not a surprising result since, especially among business producers, agricultural production in this region, the Brazilian frontier of agricultural expansion (Baer, 2008), is guided primarily in technology-intensive and high market value commodities, especially soybeans (NEAD, 2010). We should point out that, in the previous section of this paper, it was seen that the average technical efficiencies that were estimated for the Midwest region, under both models, were not superior to those of the South, both in the case of family and of business production. It is noteworthy, therefore, that obtaining significant and negative results for the parameter of the dummy on the Midwest in the models for inefficiency effects indicates higher efficiency in this region, conditionally to the other factors considered in the model for inefficiency effects.

With respect to the North region, it was found that their agricultural establishments had on average and conditionally to the other factors, lower estimated efficiency than the South region of the country under Model I, but not under Model III. One possible explanation for this result would mean that the average engagement of producers in off-farm activities is less pronounced in the North, which would relatively decrease its output variable as considered by Model I. Such justification attempt may also be indicated for the case of the Northeast, which presented, on average and given the controls, agricultural establishments with greater technical efficiency in accordance with the Model III, but not according to Model I. This is a result that deserves attention, since it breaks the frequent association between productive inefficiency and that Brazilian region – however, as well as its implications, this result should be considered carefully.

As can be seen in Figure 1, in fact the technical efficiencies estimated under Model III proved to be low for the representative establishments belonging to the Northeast region, both for family farmers, as for business farmers. However, one should reinforce the point that the results for the parameters of the dummies in the model for inefficiency effects were obtained through estimation that was conditional on other factors in the model for inefficiency effects. The result that in Model III the parameter of the dummy on the Northeast region in the model for inefficiency effects was negative and significant indicates that, given the other controls in the model, the Northeast would present agricultural establishments more technically efficient than those in the South region of the country. It can be indicated, therefore, that the low average technical inefficiencies in the Northeast region, indicated by Figure 1, can be explained by their disadvantage in terms of human capital and structural factors that influence the performance of farmers. In other words, we have that, if the objective conditions of agricultural production in the Northeast, such as described by the controls of the model for inefficiency effects, were equal to those observed by producers in the South, establishments in Northeast would present, on average, greater technical efficiency than the southerners. It would certainly be of great interest further investigation of this result, which, however, is beyond the scope of this work.

It is also possible to regionally distinguish the effect of family character of agricultural establishments on the technical efficiency through a specification of the model for inefficiency effects in which interactions between dummies for the family character of establishments and regions were included. The results of these estimates, omitted here for space constraints, are presented in Imori (2011).[14]

7. Final remarks

Given that a large proportion of the poor population lives in rural areas in Brazil, we can consider the development of agriculture as a major possibility to alleviate poverty. Although the development of new technologies to increase productivity can be considered as optimal option, it takes time and may require considerable investments. Thus, an alternative would be to take maximum advantage of available inputs and existing technology by improving the technical efficiency of farmers. With this in view, the broad objective of this study was to analyze the technical efficiency of agricultural establishments in Brazil, based on data from the Census of Agriculture of 2006. In particular, we sought to evaluate the difference between the efficiencies of family and business farmers in the country – this point is important because, despite being marked by several restrictions on production, family farming plays very important roles, from historical, social and economic standpoints. One should also indicate that large regional differences are presented by family farmers in Brazil. This led to the concern of regionally analyzing the performance of these producers. This study used the model of stochastic production frontier as presented by Battese and Coelli (1995). Thus, it was possible to simultaneously estimate stochastic frontiers – in relation to which the technical efficiencies are measured – and assess how exogenous factors affect the producers' performances, so that it was possible to analyze the role of public policies on technical efficiency.

A main point among the results obtained in the study is that family farmers presented, on average, low performance relatively to business farmers. Also conditionally, considering factors related to human capital and structural conditions of production, the family character was related to lower technical efficiency. That is, those factors that affect agriculture as a whole, such as considered in this study, could not fully explain the difference in efficiency between groups of producers, both in Brazil and in their regions. This implies that public policies aimed at increasing the competitiveness of the farming family front of business producers, by improving their technical efficiency, should preferably be designed in a specific way for these producers. In this context, it seems necessary to analyze and deal with likely market failures that are hindering the access of family farmers to inputs of better quality and higher value crops, in order to strengthen local economies.

Among the variables considered in the model for inefficiency effects, we highlight the effect observed for the formal education of the municipalities to which the representative establishments corresponded. Thus, we have that public policies focused on formal education of the general population significantly and positively affect the technical efficiency of the rural sector. It may be pointed out that, especially in a scenario marked by modernization of agriculture, it becomes urgent to quickly and decisively obtain and analyze information, so that investment in education should be considered a central element in a strategy designed to improve performance of rural production.

In the context of modernization of Brazilian agriculture, we highlight the implication of the obtained result for the variable on the credit access in the model for inefficiency effects for the design of public policies: there was a significant and positive relationship between access to credit and technical efficiency of farms. The development and availability of adequate lines of credit can be indicated as central to the competitiveness of producers, especially in markets of competitive and modern productions.

[14] Among the main results, we have that in Model III, given controls of the model for inefficiency effects, excepting those located in the North region, in average family farms in the South are more technically efficient than those of other regions the country (in line with what would be expected given the historical development of family farming in the country), while their business farms are less efficient, given the controls presented at the expression of the model for technical inefficiency.

An important aspect for the development of public policies is given by its implications at the regional level. As indicated throughout this work, agriculture presents historical, social and economic aspects, as well as performances, varying among Brazilian regions, so it is expected that public policies aimed at the rural sector have different effects regionally. In particular, one should point out that such policies may actually accentuate regional disparities found between the performances of farmers. On the other hand, the results at the regional level obtained in this study indicate that the possibility of increasing technical efficiency through public policies that improve conditions for productive context, such as given by the factors considered in the model for inefficiency effects, is especially great for municipalities in the area of SUDENE. This is an important result, since it indicates objective instruments to increase outputs, given the available inputs and technology, in a region where on average technical efficiencies are lower than those of other regions.

Beyond such considerations on the quantitative and qualitative results, this paper indicated possibilities for future studies, mainly based on constraints faced by its analysis. Among these limitations, there are those resulting from the restrictions imposed by the available database. As important point is that the results in this study are based on cross-section data. Another limitation due to the unavailability of data corresponds to the fact that variables suggested by the literature as related to technical efficiency of agriculture could not be considered in the model for inefficiency effects, so that its effects could not be evaluated empirically. Among these variables, one can highlight those related to access to technical assistance and participation in associations.

Another possibility for future research concerns the question of the relationship between the off-farm activities and the performance of producers, which is a subject of recent attention in the literature. Although this work has contemplated this point with a considerably limited approach (partly due to single output technology that was considered here), relevant questions were raised, which leads to interest in future work to more deeply explore such point.

An important observation to be made, finally, concerns the question about the sustainability of the alternative indicated in this work to the problem of rural poverty, namely, improving the performance of farmers, especially those of family character. Although increasing technical efficiency could in the short term compensate for push factors in poorer rural areas, easing the dynamics of emptying of labor, one should ask whether such an increase would be a sufficient and sustainable balance in the long term, especially as the opportunity costs for members of the family group increase with new opportunities in urban centers, especially the young people. Clearly, it is desirable to create better opportunities for producers and their families, so then other questions arise: "how to integrate the rural labor to urban markets, so that is not insecure? What are the prospects for agricultural production, especially typically family crops?" Among others, these questions are necessary for future studies about the Brazilian family farming.

Even with limitations, some of which were already pointed out, it is thought that the present work has contributed to the discussion on the technical efficiency of Brazilian agricultural producers, as well as exogenous factors that affect its economic performance, providing support for the design of public policies more carefully aimed at minimizing the inefficiencies existing in the rural sector of Brazil and its regions.

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