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The opportunity for smallholder agricultural production growth: empirical evidence from Brazil

Smallholder farming is currently the most common farming structure worldwide, and it is essential for social, environmental, and economic development, especially in developing nations. This research sheds light on millions of family farmers in Brazil and provides an in-depth perspective on their technical efficiency. We employ the Stochastic Frontier Analysis (SFA), a parametric model that accounts for random shocks, to a unique and nationwide database. Such broad analysis has never been done before. As a main result, we found that smallholder production in Brazil can improve substantially without the need to expand agricultural land. Despite the contrasts of climate and infrastructure between the country regions, nearly all states have highly efficient smallholders, which highlights the potential for all farmers. This opportunity for sustainable production intensification is extremely important for a country that is a major agricultural exporter and still remains with a large part of the territory covered by forests, as well as to support millions of people who depend on this activity for survival. Based on the empirical results, increasing membership to cooperatives and the empowerment of female smallholders are the two main points that can benefit family farmers in Brazil and, therefore, should be the main targets of public policies.

Keywords: Family farm; Stochastic frontier; Cooperative; Efficiency.

A oportunidade para o crescimento da produção agrícola dos pequenos produtores: evidências empíricas do Brasil

A agricultura familiar é atualmente a estrutura agrícola mais comum em todo o mundo e é essencial para o desenvolvimento social, ambiental e econômico, especialmente nas nações em desenvolvimento. Esta pesquisa lança luz sobre milhões de agricultores familiares no Brasil e fornece uma perspectiva aprofundada sobre sua eficiência técnica. Empregamos a Análise de Fronteira Estocástica (SFA), um modelo paramétrico que contabiliza choques aleatórios, para um banco de dados único e nacional. Uma análise tão ampla nunca foi feita antes. Como principal resultado, descobrimos que a produção dos pequenos produtores no Brasil pode melhorar substancialmente sem a necessidade de expandir as terras agrícolas. Apesar dos contrastes de clima e infraestrutura entre as regiões do país, quase todos os estados têm pequenos produtores altamente eficientes, o que destaca o potencial para todos os agricultores. Essa oportunidade de intensificação sustentável da produção é de extrema importância para um país que é um grande exportador agrícola e ainda permanece com grande parte do território coberto por florestas, bem como para sustentar milhões de pessoas que dependem dessa atividade para sobreviver. Com base nos resultados empíricos, o aumento da adesão às cooperativas e o empoderamento das pequenas agricultoras são os dois principais pontos que podem beneficiar os agricultores familiares no Brasil e, portanto, devem ser os principais alvos das políticas públicas.

Palavras-chave: Agricultura familiar; Fronteira estocástica; Cooperativo; Eficiência.

Topic: **Desenvolvimento, Sustentabilidade e Meio Ambiente**

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INTRODUCTION

One of the main issues today is how to secure future demand for food, animal feed, and biofuels, as demand for these products grows exponentially (IFC, 2019). As stated by the Food and Agriculture Organization (RAPSOMANIKIS, 2015), smallholders are responsible for most agricultural products consumed in developing nations. In several countries, family farmers supply most of the export products, such as cocoa, coffee, cotton, and tea, while being key suppliers of horticulture and floriculture export goods. In the coming years, the contribution of smallholders is expected to become even more important for the agribusiness supply chain (IFC, 2019). The majority of farms worldwide, approximately 84%, are family farms that operate about 12% of total agricultural land and where about 2 billion people live (IFC, 2019; RAPSOMANIKIS, 2015).

Smallholders are extremely important for food supply all around the world. In 2015 the UN introduced the Sustainable Development Goals (SDGs), and one of them is to eradicate hunger and secure food supply with sustainable agriculture. Considering that, one objective is to strengthen small-scale food producers by helping them increase agricultural productivity and income by twice as much until 2030, in special females, family farmers, indigenous communities, fishers, and pastoralists (UN, 2015).

As in many countries, most farmers in Brazil are smallholders with 75% of the 17 million people employed in primary agricultural production working on small-scale farming units (Arias et al., 2017). Agribusiness is a cornerstone of the Brazilian economy, accounting for about 20% of the country's GDP in 2016. The country is the largest supplier of, for example, coffee, sugarcane, and tropical fruits in the world. Furthermore, smallholders are extremely important for the domestic market food supply (IBGE, 2006). Hence, we focus our analyses on smallholders in Brazil, considering their importance for the domestic and international food supply chain.

Evidence from around the world shows that smallholders' yield per hectare is close to the maximum output, i.e., these farmers manage to produce close to the maximum possible yield according to the amount of inputs used, resulting in higher productivity than their larger counterparts. For example, Rapsomanikis (2015) reported that smallholders' rice production in Vietnam reaches 9.3 tons/ha, against 5 tons/ha from other farms. Also, maize production of smallholders in Bolivia reaches 3.9 tons/ha, in contrast to 0.5 ton/ha from other farms. Therefore, policies targeting these producers are key to ensure food security (RAPSOMANIKIS, 2015). According to Ricciardi et al. (2018), small farmers usually have higher cropping concentration or better productivity than larger farms, with the latter also having the most significant rate of post-harvest loss.

The measurement of productive efficiency was introduced by Farrell (1957), who defined cost efficiency and how to decompose it into two components, i.e., one technical and one allocative. In the following years, influenced by Farrell's work, studies on efficiency and formulation of frontiers advanced quickly, with Data Envelopment Analysis (DEA) and Stochastic Frontier Analysis (SFA) becoming the most popular methods for this purpose. One of the main differences between the two methodologies is the non-parametric approach employed in DEA, as opposed to the parametric approach of the SFA model. In other words, DEA can be applied without previous information about the production function or about the inefficiency term allocation. Though, different from the SFA model, non-parametric approaches such as DEA do not consider random shocks (SILVA et al., 2018; CULLINANE et al., 2006).

According to Coelli et al. (1996), for analysis of agricultural economics, the stochastic frontier methodology is more appropriated. Since agricultural production is susceptible to variability, it is not reasonable to associate all variations from the frontier with inefficiency, as DEA assumes it. The SFA methodology has been successfully applied in several studies on agriculture worldwide. For example, Kagin et al. (2016) showed that small farms in Mexico have higher production per hectare and are more efficient than large production units. In Ghana, Villano et al. (2019) using SFA registered an average technical efficiency of 0.734 for smallholders using integrated crop-livestock systems. Peña et al. (2018), analyzing farmers in the Brazilian Amazon region applied hyperbolic distance functions combined with SFA and found that the desired outputs could be increased by 19.5% with simultaneous reduction of environmental degradation and inputs by 16.36%. According to Yang et al. (2018), in central China, the average technical efficiency of smallholders is 0.81.

Analyzes of technical efficiency are important to reveal any potential productivity gaps and guide how inputs need to be adjusted in order to maximize the outputs. This helps farmers to reduce production costs and increase financial security. Additionally, technical efficiency studies are essential to show whether there is an opportunity to increase production within the same area, i.e., increase yield without expanding agricultural land and thus improving environmental conservation. This is even more significant for countries that are major agricultural producers since increasing technical efficiency of farmers will also boost the economy of the country as a whole.

Brazil has a severe caveat concerning the collection and availability of data, e.g., the Agricultural Census is scheduled to take place every ten years, which is an enormous gap. Following 2006, there are only preliminary results for the 2016 Agricultural Census (published in 2017). Furthermore, in the new Census, the Government decided to reduce the detailing of the information collected and does not distinguish family farmers from industrial farmers, which impairs research and the development of new public policies targeting this sector.

In order to overcome this problem, we based our study on a unique database from the Brazilian Ministry of Agrarian Development (MDA) that provides detailed information about smallholders in Brazil. Studies relying on data from the MDA are scarce as the process of obtaining these data involves a lot of Government bureaucracy and restrictive policies. Employing the SFA methodology, the main goal of this research is to estimate the technical efficiency of smallholders throughout Brazil and examine whether there exists potential to increase production by improving efficiency. Further, as specific objectives, we aim to calculate and compare the efficiency between Brazilian regions, and between states. Also, the specific variables that most impact smallholder production function are identified and discussed to provide guidance for policymakers and stakeholders.

The results show the current potential for smallholder production growth and provide essential information to guide policymakers and help achieve the United Nations SDGs. As highlighted by Anang et al. (2014) if public support and investments are insufficient the growth of agricultural production can only be achieved with the expansion of agricultural lands. Our research is organized into four sections. The next section introduces the data source, as well as the variables and describes the methodological approach. We present the empirical results along with the discussion, in the third section. The final section summarizes our findings and gives suggestions for public policies and further studies.

METHODOLOGY

In Brazil, family farmers are required to maintain a record in the Ministry of Agrarian Development (MDA) to be eligible to receive support of public policies. This register includes filling a form, the DAP (Declaration of Aptitude to Pronaf), that contains social aspects of the producer and technical characteristics of the farm and is the data source of this study. The data was provided by the MDA in October 2014. Although the database does not provide information on inputs, such as fertilizers, seeds, and electricity, it contains important socio-economic variables and other technical information that are essential for the development and success of the agricultural activity, such as area, workforce, and diversification index.

Smallholders all around Brazil can create and update their DAPs in Government authorized places, which immediately sends the information electronically to the MDA system. Farmers are required to update their DAP every time there is a significant change in their production unit (e.g., expansion of agricultural land, hired workforce), or every three years. Therefore, the information obtained could have been inserted on the same day or up to three years ago. We carefully inspected the data set obtained to identify values distant from the average and irregular information. We excluded 140,500 DAPs, which only accounts for a very small portion of the data (about 3%), and the final data contains roughly 4.7 million observations. This is a national level database about smallholders that contains the most up-to-date information available in Brazil. A summary of each variable is given in Table 1.

Table 1: Summary statistics of smallholders' variables.

Variable	Description	Mean	Std. Dev.
Landowner	Dummy (0, 1)	0.6241	0.4843
Gender	HH* Dummy (zero male, one female)	0.3715	0.4832
Age	HH Age in years	44.8461	15.2108
Age^2	HH Age squared	2242.55	1474.936
Income	Annual agricultural income in BRL	18409.61	37683.41
Education	Ranked from 1 to 10: 1 – Illiterate, 2 – Literate, 3 – Primary education incomplete, 4 – Primary education completed, 5 – Secondary education incomplete, 6 – Secondary education completed, 7 – Technical course incomplete, 8 – Technical course completed, 9 – Degree incomplete, and 10 – Degree completed	3.3001	1.4855
Area	Farm area in hectares	19.0819	33.3318
$Area^2$	Farm area squared	1475.134	6674.321
Cooperative	Cooperative member. Dummy (0, 1)	0.0498	0.2175
Extension service	Received extension service. Dummy (0, 1)	0.0768	0.2663
Workforce	Number of family members and permanent employees	3.6979	1.7514
Diversification index	Simpson diversification index value	0.3534	0.2820
Region 1	North dummy (0, 1)	0.0944	0.2924
Region 2	Northeast dummy (0, 1)	0.6143	0.4867

Region 3	Southeast dummy (0, 1)	0.1189	0.3237
Region 4	South dummy (0, 1)	0.1422	0.3493
Region 5	Midwest dummy (0, 1)	0.0299	0.1705

*HH (Household head)

The *Landowner* is a dummy variable assuming one if the household head (HH) is the owner of the land and zero if not. *Gender* is a dummy variable assigned zero if the HH is male and one if female. *Age* represents the HH age in years. *Age²* represents the HH age squared. The HH formal education level is the variable of *Education*. The variable *Area* is the total farm size measured in hectares. *Area²* is the farm size squared. *Cooperative* is a dummy variable assuming one if the HH is part of a cooperative or farmer's organization and zero otherwise. *Extension service* is a dummy variable that assumes one for HH who obtained extension service assistance in the last twelve months and zero otherwise. *Workforce* represents the total of family members who live and depend on the farm income plus the number of permanent employees that work on the farm. The variable *Diversification index* measures the level of income diversification within the farm according to Simpson's Diversity Index (SIMPSON, 1949). *Region* 1 to 5 are dummy variables for the regions which assume one if the smallholder is located in that region and zero otherwise. Finally, *Income* is the annual gross farming income and is the output in our analysis. This variable considers sales incomes from farming activities such as agriculture, livestock, and forestry. Using revenue rather than yield is common in the literature, see Khanal et al. (2018) and Ma et al. (2018), and it permits to account for a combination of different farm activities income.

Stochastic Frontier Analysis

Two studies simultaneously developed and introduced the SFA model, one created by Aigner et al. (1977) and one stablished by Meeusen and van den Broeck (1977). The main suggestion was to account for the error component as two elements, a symmetrical one and a unilateral one. The first considers random variations or shocks that are out-of-control, such as the climate in the case of agriculture, while the second accounts for the inefficiency compared to the efficiency frontier (CONSTANTINO et al., 2017). We can express the model as:

$$Y_i = f(x_i; \beta)e^{\nu_i - u_i}$$

where Y_i is the production of the i-th smallholder; x_i is a vector of input variables. The coefficient β is a vector of parameters related to x_i to be calculated. ν_i is an iid $N(0, \sigma_v^2)$ random error term capturing exogenous factors out of farmer's control. u_i is an iid $N^+(0, \sigma_u^2)$ term related to inefficiency and assumed to have a half-normal distribution. Regarding agriculture productivity assessment the Cobb-Douglas production function is commonly applied in the literature (BATTESE et al., 1992) and was also employed in this study following Villano et al. (2019), Huy et al. (2019), and Khanal et al. (2018). The empirical model is as follows:

$$LnY_i = \beta_0 + \sum_{i=1}^{N} \beta_i \, LnX_i + \nu_i - u_i$$

where Y_i indicates the production of the i-th farmer. In this research particularly, the production is characterized as the annual gross farming income. The inputs are landowner, gender of the HH, age of the HH, age squared, education level of the HH, the total area of the farm in hectares, area squared, cooperative membership, access to extension services, workforce, diversification index, and region (region 5 is omitted because of collinearity). As previously mentioned, v_i and u_i are random shocks and measures of technical inefficiencies, respectively. The u_i term representing the technical inefficiency is specified by Battese et al. (1995) as:

$$u_i = z_i\delta + w_i$$

where z_i represents a vector of exogenous variables and δ is a vector of parameters to be computed. w_i is defined by the truncation of the $N(0, \sigma_u^2)$ distribution, hence $w_i > -z_i\delta$, and u being a non-negative truncation of the $N(z_i\delta, \sigma_u^2)$ distribution. The approach employs the maximum likelihood technique and simultaneously calculates the following variance parameters:

$$\sigma^2 = \sigma_v^2 + \sigma_u^2$$
$$\gamma = \sigma_u^2/(\sigma_v^2 + \sigma_u^2)\text{ , where } 0 \leq \gamma \leq 1$$

Finally, the technical efficiency TE_i fluctuates between 0 and 1, always holding the production level bellow or over the stochastic frontier $f(x_i;\beta)e^{v_i}$. TE_i is expressed as:

$$TE_i = \frac{Y_i}{f(x_i;\beta)e^{v_i}} = \frac{f(x_i;\beta)e^{v_i}e^{-u_i}}{f(x_i;\beta)e^{v_i}} = e^{-u_i}$$

RESULTS AND DISCUSSION

We performed the analyses using R 3.5.1 (R CORE TEAM, 2018) and the *frontier* package v1.1-2 (COELLI et al., 2017). The coefficients estimated for each variable are all statistically significant at 1% level as shown in Table 2. According to the results, the smallholder being part of a cooperative or farmer's association is what most positively influences the production function.

Our results corroborate with findings of Yang et al. (2018), Wongnaa et al. (2019), and Binam et al. (2004) which also reported a significant positive association between cooperative affiliation and technical efficiency in China, Ghana, and Cameroon, respectively. Further, according to FAO (2014) cooperation among small farmers is an important factor as it facilitates access to, for example, inputs and services, marketing, information, and consequently the entry into new markets. An explanation for the positive effect of this variable lies in the fact that smallholders often produce small quantities of a variety of crops, which makes it difficult for them to attract the attention of large buyers. However, when these farmers come together and combine their production, they gain access to larger markets, have easy access to bank loans, and can afford investments in machinery and technology to improve their productivity.

One example of the new opportunities that cooperatives create is the Purchase for Progress project of the United Nations World Food Programme (WFP), which negotiates future contracts to purchase food produced by smallholders through farmers' organizations (FAO, 2018). According to Ma et al. (2018), agricultural cooperatives are essential for smallholder farming systems in developing countries. The same authors report that efficiency of smallholders in China is superior for cooperative participants compared with non-participants. Unfortunately, for the last decades, policymakers have ignored the importance of cooperativism, and as stated by Herrera et al. (2017), currently only 5% of small agricultural producers in Brazil are members of cooperatives. Therefore, public policies need to target the creation of new cooperatives, the expansion of the existing ones, and motivate family farmers to join these organizations.

Table 2: Stochastic frontier analysis results.

Variable	Coefficient	Standard error
Landowner	0.4046***	0.00108
Gender	-0.4890***	0.00109
Age	0.0200***	0.00018
Age^2	-0.0001***	0.00000
Education	0.1400***	0.00038
Area	0.0161***	0.00003
$Area^2$	-0.00005***	0.00000
Cooperative	0.4279***	0.00247
Extension service	-0.2646***	0.00190
Workforce	-0.0025***	0.00029
Diversification Index	0.0437***	0.00182
Region 1	-0.6764***	0.00336
Region 2	-1.3735***	0.00308
Region 3	0.0588***	0.00329
Region 4	0.3403***	0.00325
Constant	9.8442***	0.00608
σ_u	1.30923	
σ_v	0.79834	
γ	0.72895	
Log-likelihood	-7151355.1	
Observations	4,691,912	

Note: *p < 0.1; **p < 0.05; ***p < 0.01.

In second, the production function is positively affected when the smallholder owns the rural property. The positive impact of this variable reveals insecurity issues when the smallholder is not the owner of the land. This might be related to uncertainties associated with producing in a rural area that is on a lease or any other type of arrangement, which will affect the small farmer's decision regarding time and money spent in that area. Consequently, farmers in this situation often avoid large or long-term investments due to unstable future, even if it means maintaining a medium or low level of productivity.

Following, in third, is the smallholder Education level. The positive effect of education is documented in studies conducted by Dessale (2019) in Ethiopia, Yang et al. (2018) in China, and Mishra et al. (2018) in Cambodia. This positive impact can be explained due to the fact that education is related to better management practices, more knowledge about agricultural production, and better control of financial assets. Usually, farmers with higher education are more prone to implement practices that aim to improve productivity. Further, they tend to keep up with the latest developments and technologies. Contrarily to our results, Coelli et al. (2004) and Hasnah et al. (2004) analyze the case of Papua New Guinea and Indonesia and report a negative effect of schooling on efficiency. The authors explain that farmers with higher education are inclined to engage in off-farm employment and thus have limited time and attention to produce crops. The rural-urban migration flows cannot be neglected and need proper attention of public agents. Policies should promote higher education of smallholders while at the same time provide favorable conditions to encourage these farmers to continue the agricultural activity.

Likewise, the income diversification index presents a positive impact on the production function. Diversifying income sources is a great strategy adopted by farmers to create stability and become less susceptible to market volatility (BOSC et al., 2013; FAO, 2014). Additionally, authors report that it can reduce costs, increase sustainable production, and enhance food security even with climate change (BARRET et al., 2001; MERANER et al., 2015). Smallholders can diversify their income by producing multiple crops or performing other activities on the farm such as livestock production and agritourism. These results show that this is a great practice to be encouraged by public policies. The age variable presents a non-linear relationship, with the HH age and age squared presenting a positive and a negative effect on the production function, respectively. Our results corroborate with the theory of household life cycle which states that age only has a positive influence until determined limit when it starts to present the opposite effect (FISCHER et al., 2012; Jayne et al., 2003).

Lastly, the farm area also shows a non-linear relationship. Evidence regarding the effect of area on technical efficiency are mixed, researches of Ren et al. (2019) and Mango et al. (2015) report a positive effect while Dessale (2019) and Kagin et al. (2016) find a negative impact. Our results show that farm area increase only positively influences the production function until a certain point, and after that, it begins to affect negatively. This is understandable since smallholders usually have limited workforce and perform most tasks manually. Hence, increasing the farm area only increases production up to a point. After that, the area starts to get too big, and the smallholder does not have enough resources to work properly.

Among the variables negatively related to the production function, gender is the main one. The household head being a woman negatively impacts the production function, suggesting signs of gender inequality in Brazil. The study conducted by Etienne et al. (2019) report similar findings and adds that the asymmetric distribution of resources and responsibilities is related to cultural and social biases against women. Complementarily, Mango et al. (2015) found the same result in their study and associate it with the lack of access to productive resources by women. Mishra et al. (2017) stress that female agricultural producers in the Philippines achieve superior gains in rice yield, but are also charged higher fixed, seed, and workforce input prices, resulting in lower revenues. Further, female smallholders are biased by the fact that, in addition to all farming activities, they also perform most of the domestic work. Our results reflect this unfair extra burden that should not exist in society nowadays. The United Nations 2.3 SDGs also draw attention to this matter and state that women need to be one of the main target groups of public policies. Hence, rural women in Brazil need to receive more attention from policymakers in order to manage this issue and change this scenario.

Surprisingly, according to the results, there is a negative relationship between extension service and the production function. Studies such as Dessale (2019), Yang et al. (2018), and Mango et al. (2015) document the opposite influence of extension services on efficiency and highlight this variable as very important to promote technology adoption, learn production related information and improve productivity. We expected to find a positive effect for this variable in our study as well. Extension service is a mechanism for providing tailored knowledge and advice, that is extremely important to smallholders. This assistance can help farmers make better use of their resources, for instance water, area, and soil type, as well as disseminate affordable practices and technologies that can be implemented by family farmers and significantly improve production. Further, Stachiw (2019) highlights that extension service is important to guide smallholders on the safe use of pesticides and their potential damage to health.

However, the negative effect found in our analysis corroborates with the results of Taubadel et al. (2014) in Chile. Likewise et al. (2019) report that the total of visits by extension agents has no significant result on farmers' efficiency in Vietnam. As stated by Binam et al. (2004), there are many reports of poor performance in the operation of extension services due to bureaucracy, mismanagement, lack of program structure, and other common issues in publicly operated and staff-intensive systems. The negative effect of this variable can be explained due to mismanagement and lack of coordination to implement a public extension service nationwide, which resulted in a poor performing program for smallholders in Brazil.

Subsequently, the workforce variable negatively impacts the production function as well. In this study, the workforce is the sum of family members who live and depend on the farm income plus the number of permanent employees that work on the farm. Some researchers argue that larger household sizes mean more workforce available to that farm unit, which improves its functionality (TAUBADEL et al., 2014; WONGNAA et al., 2019). Nonetheless, our results corroborate with Mango et al. (2015), who noted that larger family units increase pressure on the, already restricted, supplies available to the family and appear to worsen poverty, consequently expenses with proper inputs, such as better seeds and fertilizer, becomes less tangible. We believe this to be the case of Brazilian smallholders and that the negative effect of the variable workforce demonstrated in the analysis is due to the decrease in resources as the family size increases. Policymakers could develop awareness campaigns about family planning and birth control targeting the poorest smallholders in order to release the pressure and guarantee enough resources for them.

Considering the continental size of Brazil, small agricultural producers in different parts of the country face distinct scenarios, and that is reflected in the efficiency scores. As shown in Fig. 1, smallholders' efficiency ranges from 0.0002 to 0.8865 illustrating the existence of an enormous gap and revealing signs of inequality.

The mean technical efficiency in the country is 0.4501 (Table 3). Family farmers with technical efficiency up to 0.25 account for 15% (689,934 smallholders), ranging from 0.251 to 0.50 account for 42% (1,990,225 smallholders), ranging from 0.501 to 0.75 account for 41% (1,939,943 smallholders) and more than 0.751 account for 2% (71,810 smallholders). It is well known that agricultural activity suffers from instability due to several conditions such as weather, fires, and pests, and for this reason, it is not reasonable to consider that all variations from the efficiency frontier are related to inefficiency. Our results indicate that, on average, smallholders' production in Brazil has tremendous potential to grow by means of better management of the existing resources. There are thousands of highly efficient family farmers countrywide. Smallholders produce almost 40% of the gross value of agricultural outputs in Brazil (IBGE, 2006), and this contribution can be much larger with no expansion of agricultural lands. This capacity of increasing its production is fundamentally essential to sustain the country's agricultural relevance and still preserve one of the most significant and most extensive forests in the world. Our results verify the statement of Arias et al. (2017) that Brazil is capable to continue increasing agricultural production while being environmentally sustainable and without depleting natural capital.

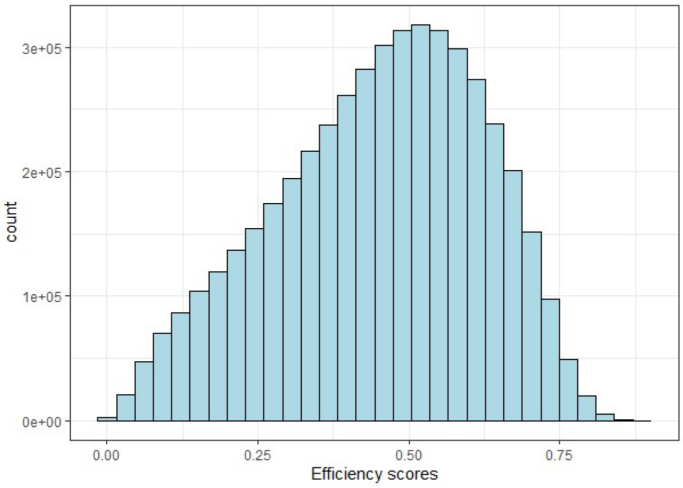

Figure 1: Histogram of efficiency scores in Brazil.

Table 3: Efficiency scores in Brazil.

	Mean	Min.	Max.	Std. Dev.
Brazil	0.4501	0.0002	0.8865	0.1711
North	0.4575	0.0005	0.8797	0.1532
Rondônia (RO)	0.5068	0.0032	0.8430	0.1509
Acre (AC)	0.4211	0.0016	0.8735	0.1634
Amazonas (AM)	0.4578	0.0005	0.8797	0.1615
Roraima (RR)	0.4215	0.0104	0.8559	0.1785
Pará (PA)	0.4508	0.0013	0.8477	0.1419
Amapá (AP)	0.4287	0.0193	0.8180	0.1548
Tocantins (TO)	0.4481	0.0007	0.8303	0.1591
Northeast	0.4484	0.0006	0.8865	0.1741
Maranhão (MA)	0.5116	0.0012	0.8669	0.1465
Piauí (PI)	0.4402	0.0017	0.8678	0.1556
Ceará (CE)	0.4052	0.0008	0.8744	0.1758
Rio Grande do Norte (RN)	0.4517	0.0006	0.8865	0.1760
Paraíba (PB)	0.3747	0.0008	0.8685	0.1861
Pernambuco (PE)	0.4689	0.0006	0.8814	0.1777
Alagoas (AL)	0.5019	0.0018	0.8648	0.1636
Sergipe (SE)	0.4969	0.0012	0.8525	0.1540
Bahia (BA)	0.4447	0.0010	0.8701	0.1757
Southeast	0.4463	0.0002	0.8568	0.1828
Minas Gerais (MG)	0.4030	0.0005	0.8568	0.1829
Espirito Santo (ES)	0.5439	0.0012	0.8313	0.1262
Rio de Janeiro (RJ)	0.5675	0.0003	0.8353	0.1404
São Paulo (SP)	0.5270	0.0002	0.8565	0.1608
South	0.4551	0.0002	0.8574	0.1602
Paraná (PR)	0.4616	0.0003	0.8545	0.1567
Santa Catarina (SC)	0.4784	0.0009	0.8521	0.1607
Rio Grande do Sul (RS)	0.4419	0.0002	0.8574	0.1606
Midwest	0.4539	0.0003	0.8595	0.1625
Mato Grosso do Sul (MS)	0.4460	0.0003	0.8394	0.1659
Mato Grosso (MT)	0.4280	0.0028	0.8595	0.1665
Goiás (GO)	0.4826	0.0095	0.8290	0.1471
Federal District (DF)	0.5256	0.0202	0.8428	0.2001

Brazil has five regions with twenty-six states and a Federal District. As shown in Fig. 2, the mean production efficiency between regions is resembling. Nonetheless, the highest mean efficiency of 0.4575 found in the North region is still below values documented in other countries such as Chile (0.89), China (0.81), and Zimbabwe (0.75) (ETIENNE et al., 2019; TAUBADEL et al., 2014; YANG et al., 2018). Additionally, according to the results, the Southeast region has the lowest mean technical efficiency closely followed by the Northeast region, which is concerning since more than 70% of Brazilian family farmers are located in these two regions (HERRERA et al., 2017). Different from other countries of OECD, Brazil spends only a small share of investments in the agricultural sector, especially services and innovation. Lack of infrastructure affects agrologistics and farmers' access to markets, elevating the costs and reducing productivity (ARIAS et al., 2017).

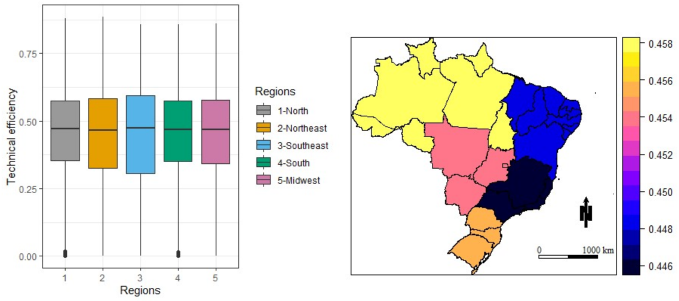

Figure 2: Box plot and map of Brazilian regions' mean efficiency scores.

As we can see in Fig. 3, even states in the same region present significant differences. All states in the North and Northeast areas have technical efficiency below 50%, except for Rondônia, Maranhão, and Alagoas states. The Paraiba state (Northeast), one of the poorest in the country, presents the lowest average efficiency, only 0.374, while other states in the same region achieved scores of 0.51 and 0.50. The Rio de Janeiro state has the highest mean efficiency in Brazil, 56.7%. Differently, in the same region, the Minas Gerais state presents an average efficiency of 0.40.

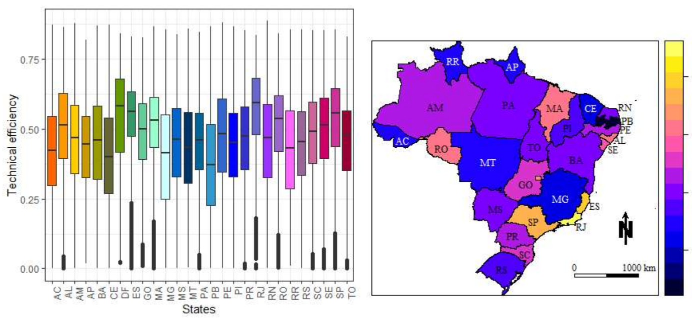

Figure 3: Box plot and map of Brazilian states' mean efficiency scores.

Inequality is a well-known problem in Brazil. The agro-ecological conditions among regions are very distinct, for example, the Northeast suffers from dryland conditions and in this region, the agricultural production of more than 80% of family farmers is insufficient to take them out of poverty. Differently, in the South and Southeast regions only a small percentage of smallholders are poor (ARIAS et al., 2017). However, according to our results, there are highly efficient family farmers in every state, showing that it is possible for others to reach this same level.

As stated by Arias et al. (2017), despite the distinct climate conditions, two other facts contribute to the contrasting scenarios. First, the share of family farmers' members of cooperatives in the South and Southeast is higher than in other regions of Brazil, which contributes to access to markets, inputs, technology, and gains of scale. Secondly, the poor quality of extension services provided in the Northeast, as well as in the rest of the country, fails to transfer the knowledge and technology necessary to overcome the agro-ecological constraints and other difficulties these farmers face.

Two promising strategies to improve the quality of soil, recover degraded areas and increase ecological production intensification are crop diversification and combination of farming practices (COSER et al., 2018). The last is one of the focuses of the Brazilian Agricultural Research Corporation (EMBRAPA), which in the past decades has been leading research about crop-livestock-forestry systems and can certainly help increase efficiency and strengthen smallholders in the country. Although, it will all depend on high quality and reliable extension service, which is recently undergoing a restructuring process.

Finally, it is essential to highlight that the problem involving food security has three main aspects: efficiency boost, demand reduction, and food supply chain management. According to Garnett (2014), agricultural efficiency increase faces the supply side problem and can be achieved by, for example, planning and controlling the fertilizers applied, using drip irrigation, and giving better destination for agricultural waste, such as energy production. Our results are one step further to help achieve one of the UN SDGs, by demonstrating that it is possible to drastically increase family farmers’ agricultural production in Brazil with sustainability.

CONCLUSIONS

In the past decades, the number of smallholders in Brazil has been increasing. So far public policies have favored commercial farmers and the production of agricultural commodities. Family farmers can achieve higher efficiency levels compared to industrial farms and account for a large part of the agricultural output in Brazil. We exam a large and unique database containing information of millions of smallholders countrywide. Our findings reveal that the mean technical efficiency in the country is only 45%, which reveals an enormous potential to increase smallholder production in Brazil by improving efficiency.

Regarding the main variables related to smallholders' production function, we found that cooperative membership, landowner, and education are positively associated with the production function. The first one especially concerns since only five percent of these farmers are members of cooperatives or farmer's association. This research reveals how important it is for policymakers to focus on the strengthen of existing cooperatives and impulse the creation of new ones. Additionally, policies should work on facilitating smallholder farm acquisition in order to boost productivity. According to the results, female household head, extension service, and workforce negatively impact the production function. A sign of gender inequality raises severe concerns about cultural and social biases against women in rural areas. These gender differences should not exist and need to be tackled by public policies. Further, assistance from public agents is widely reported as an important instrument for the development and success of family farmers. The poor quality of extension services provided in Brazil needs to be carefully assessed and reformulated to fulfill its objectives.

Lastly, we aimed to compare technical efficiency between regions and between states in Brazil. Our results demonstrate that family farmers have a gigantic potential to increase their production with better use of existing resources and no expansion of agricultural lands, revealing a great opportunity for them. The North region has the highest mean technical efficiency, while the Southeast region has the lowest. Among the states, Rio de Janeiro and Paraiba presented the highest and lowest mean efficiency, respectively. Despite the differences between regions, there are highly efficient smallholders all over the country, which demonstrates that it is possible for others to reach this level. This higher efficiency comes with the implementation of better public policies. This research has limitations since we do not include input variables such as fertilizers and seeds due to the serious data shortage in Brazil. However, the technical information about the farm and the socio-economic variables about the millions of smallholders included in our analysis are of great importance for the outcome and efficiency of agricultural activity as well.

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