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AGRICULTURAL PRODUCTION IN BRAZIL AND ITS DETERMINANTS: AN ECONOMETRIC APPROACH FOR 2006 AND 2017

Produção agropecuária no Brasil e seus determinantes: uma abordagem econométrica para os anos de 2006 e 2017

Producción agrícola en Brasil y sus determinantes: un enfoque econométrico para los años 2006 y 2017

Maria Larissa Bezerra BATISTA – Universidade Federal de Pernambuco (UFPE)
ORCID ID: https://orcid.org/0000-0002-6273-059X
URL: http://lattes.cnpq.br/2920068640038677
EMAIL: maria.larissa25@gmail.com

Renata Benicio de OLIVEIRA – Universidade de São Paulo (USP)
ORCID ID: https://orcid.org/0000-0002-1929-0162
URL: http://lattes.cnpq.br/3553070487421917
EMAIL: renatabenicio086@gmail.com

Janaina da Silva ALVES – Universidade Federal do Rio Grande do Norte (UFRN)
ORCID ID: https://orcid.org/0000-0002-0182-3119
URL: http://lattes.cnpq.br/8841368848220253
EMAIL: janaina.alves@ufrn.br

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ABSTRACT

Agriculture is a sector of great importance for the Brazilian economy, since the beginning of its existence, and is configured, until today, as one of the most representative segments, in terms of dynamism and balance of external accounts based on the Current Account Balance (CAB), particularly the Trade Balance (TB). Thus, the purpose of this research is to analyze the determinants of agricultural production in Brazil, considering 2006 and 2017 and data from the Agricultural Census of the Brazilian Institute of Geography and Statistics (IBGE). In order to achieve this objective, the Panel Data econometric methodology was used, in which the value of agricultural production was considered as a dependent variable, while the employed personnel, the area of the establishment, the number of tractors and the regional dummies represented the explanatory variables. The results showed that the random effects model is the most adequate; all coefficients were statistically significant at the level of 1%, with the exception of the dummy in the Southern region, which was not significant; and 67.32% of variations in the value of production are explained by the set of independent variables. In addition, it appears that production in Brazil is more capital intensive. Therefore, it is concluded that greater action by the State is necessary, in the sense of expanding the technological access of producers, in an attempt to reduce the differences in the values of municipal production and to increase the agricultural product.

Keywords: Brazilian Agriculture; Panel Data; Production Function.

RESUMO

A agropecuária é um setor de grande importância para a economia brasileira, desde os primórdios de sua existência, e configura-se, até hoje, como um dos segmentos mais representativos, em termos de dinamismo e equilíbrio das contas externas a partir da Balança de Transações Correntes (BTC), particularmente a Balança Comercial (BC). Assim, a finalidade desta pesquisa é analisar os determinantes da produção agropecuária no Brasil, considerando os anos de 2006 e 2017 e os dados do Censo Agropecuário do Instituto Brasileiro de Geografia e Estatística (IBGE). Para que esse objetivo fosse alcançado, recorreu-se a metodologia econométrica de Dados em Painel, em que o valor da produção agropecuária foi considerado como variável dependente, enquanto o pessoal ocupado, a área do estabelecimento, o número de tratores e as dummies regionais representaram as variáveis explicativas. Os resultados apontaram que o modelo de efeitos aleatório é o mais adequado; todos os coeficientes foram estatisticamente significantes ao nível de 1%, com exceção da dummy da região Sul, que não foi significante; e 67,32% das variações no valor da produção são explicadas pelo conjunto das variáveis independentes. Além disso, depreende-se que a produção, no Brasil, é mais intensiva em capital. Portanto, conclui-se que é preciso maior atuação do Estado, no sentido de ampliar o acesso tecnológico dos produtores, na tentativa de reduzir as diferenças nos valores de produção municipal e elevar o produto agropecuário.

Palavras-chave: Agropecuária Brasileira; Dados em Painel; Função de Produção.

RESUMEN

La agricultura es un sector de gran importancia para la economía brasileña, desde el comienzo de su existencia, y está configurada, hasta hoy, como uno de los segmentos más representativos, en términos de dinamismo y saldo de cuentas externas en función de la Balanza de Transacciones Corrientes (BTC), particularmente la Balanza Comercial (BC). Por lo tanto, el propósito de esta investigación es analizar los determinantes de la producción agrícola en Brasil, considerando los años 2006 y 2017 y datos del Censo Agrícola del Instituto Brasileño de Geografía y Estadística (IBGE). Para lograr este objetivo, se utilizó la metodología econométrica de Panel Data, en la cual se consideró el valor de la producción agrícola. como variable dependiente, mientras que las personas empleadas, el área del establecimiento, el número de tractores y los maniquíes regionales representaron las variables explicativas. Los resultados mostraron que el modelo de efectos aleatorios es el más adecuado; todos los coeficientes fueron estadísticamente significativos al nivel del 1%, con la excepción de la variable ficticia en la región sur, que no fue significativa; y el 67.32% de las variaciones en el valor de producción se explican por el conjunto de variables independientes. Además, parece que la producción en Brasil es más intensiva en capital. Por lo tanto, se concluye que es necesaria una mayor acción del Estado, en el sentido de ampliar el acceso tecnológico de los productores, en un intento por reducir las diferencias en los valores de la producción municipal y elevar el producto agrícola.

Palabras clave: Agricultura Brasileña; Panel de Datos; Función de Producción.

1 INTRODUCTION

Over the last few decades, it has been observed that the participation of the agricultural sector in the global economic dynamism has shown a declining trend[1], while

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[1]This is a phenomenon that generally occurs when the economy is at an advanced level of development. On the other hand, at the beginning of this process, agricultural activity is responsible for sustaining the economy, promoting transformations in the productive structure as it develops (Raiher *et al*., 2016).

there has been considerable growth in other segments, such as industry and, mainly, services (Raiher *et al*., 2016). This issue can be attributed to the process of deindustrialization. Economic development is inherent to this process and is divided into three phases: (1) the agricultural segment drives growth; (2) as agricultural productivity increases, industry gains prominence and increases its share of income; and (3) the tertiary sector stands out based on the support provided to industry. This third stage is known as deindustrialization (Silva, 2014). However, despite the reduction in agricultural participation in the economic growth of the countries, agricultural activities continue to play a relevant role in economic terms, contributing to the supply of raw materials and food to the urban-industrial sector and by holding a high demand for inputs, machinery and equipment, which stimulate industrial production. In addition, foreign exchange from agricultural exports contributes to the balance of trade (Raiher *et al*., 2016).

In this context, it is important to understand the characteristics of the agricultural sector. This includes practices related to land cultivation (agriculture) and animal husbandry (livestock farming), thus encompassing not only the cultivation of food for human consumption, but also animal feed and the supply of inputs for industry, such as those for the production of energy, cellulose, textiles and rubber. Regarding the type of companies, the agricultural sector mainly includes those that are intensive in scale, which compete on the basis of costs and sell standardized products, the commodities. Thus, the main elements of sectoral competitiveness are the availability of natural resources and technology, which is progressively being used on rural properties. In this case, Brazil has advantages when compared to its foreign competitors due to its favorable climate and the large presence of arable land. Therefore, the main attraction of the agricultural enterprises of the nation is the low cost of production. In other ways, its crucial weakness is the existence of a deficient logistical infrastructure, which makes it impossible, in most cases, to increase production, due to the lack of capacity for flow and storage (Guimarães; Pereira, 2014).

Agriculture stands out in the Brazilian economy, as it is one of the most dynamic sectors in the country, given that, in addition to meeting the domestic demand for food and industrial inputs, the segment is one of those responsible for balancing external accounts, due to its significant share of total exports. In December 2018, national agribusiness exports totaled US$ 8.69 billion, setting a new record for that month. Due to this good performance, there was an increase in the share of agribusiness in the total value of Brazilian exports, from 39.4% (December - 2017) to 44.4% (December - 2018) (Amaral; Guimarães, 2017; Brasil, 2019).

In terms of the value of agricultural production, when observing the data from the agricultural censuses, published by IBGE (2007, 2019), it can be seen that, for 2006, in relation to employer agriculture, Brazilian production was 109,492,177.00 BRL, with the regions with the largest share in national production being the Southeast (37.54%), Central-West (23.46%) and South (20.84%). In addition, agricultural establishments belonging to the semiarid region recorded a share of only 5.47% of national production. In 2017, this value reached 355,889,076.00 BRL and, in percentage terms, the Central-West (32.46%) obtained the highest values, Southeast (29.42%) and South (21.96%) regions. When considering establishments in the Semi-arid region, these had a share equivalent to only 5.11%.

On the other hand, according to data from IBGE (2007, 2019), in the case of family farming, in 2006, the value of production in Brazil was 54,494,117.00 BRL, so that the South, Northeast and Southeast regions obtained the largest relative shares, with 38.73%, 24.60% and 21.61%, respectively. Furthermore, the value of production in the Semi-arid region corresponded to 15.45% of the total achieved by the country. In 2017, the value of national family production reached 106,472,475.00 BRL, with the most expressive percentages recorded by the South (41.28%) and Southeast (24.23%). Again, the semiarid region had a modest share, with a mere 10.86%.

In view of the above, studies aimed at understanding the determinants of agricultural production in Brazil are relevant, since they can help guide public policy measures. However, the importance of this research can also be expressed by its contribution to academia, given that it encourages further research in the area, considering that this is a vast field, in addition to including current data, made available by the most recent Agricultural Census (2017) by IBGE. Regarding the problem of this work, it is related to the need to know the determining factors of the level of agricultural production in Brazil.

In this sense, the general objective of this work is to analyze the determinants of Brazilian agricultural production in the period from 2006 to 2017, while the specific objectives are: to present the panorama of the agricultural sector in Brazil, showing, briefly, its behavior over time; and to estimate an agricultural production model using the Panel Data methodology.

Finally, this paper is structured in five sections, the first one refers to this introduction, presenting a brief contextualization of the subject and the proposed objectives; the second corresponds to the theoretical framework, which is divided into two subsections, one addressing agricultural progress from the beginnings to the present day and the other describing some empirical works highlighted in the literature on this subject; the third concerns the methodology, exposing the data used and the method applied (Panel Data); the fourth refers to the results and discussions; and the fifth is intended for the final considerations.

2 THEORETICAL FRAMEWORK

2.1 Overview of agriculture in Brazil

Since the dawn of civilization, the agricultural sector has been one of the foundations of the Brazilian economy, having evolved from monocultures to modernized agriculture, and it employs sustainable mechanisms, such as the integration of crops and livestock and direct planting, which contributes to increasing productivity levels. When observing the trajectory of the national economy, it is possible to infer that it is characterized by a cyclical profile, whose wealth is dependent, in given periods, on a specific product originating from agriculture. In other words, Brazilian progress happened based on cycles, which are directly related to some agricultural product, such as the cycles of sugar cane (1530), cattle (1534), coffee (1727), rubber (1870), silk production (1848), soybeans (1923), industrial poultry farming (1960s) and industrial pig farming (1970s) (Brazil, 2018).

Thus, Furtado (2007) shows that agricultural colonization in Brazil offered great financial results and created attractive prospects for the economic use of its lands. Castro (2016) agrees with these arguments, emphasizing that the economic trajectory of Brazil has been associated with the dynamics of agricultural products since colonization. The occupation of the territory itself occurred, in large part, as a result of the expansion of the area occupied by various agricultural activities, such as those mentioned in the previous paragraph. The relevance of this segment in the development of the economy occurred due to favorable aspects, such as the size of the territory and the lack, in general, of severe winters. However, there were also disadvantages regarding the quality of the soil, which commonly had low natural fertility. According to these characteristics, the growth of the agricultural enterprise was based on the occupation of immense extensions of land and the low productivity of crops.

For many centuries, agricultural activities were carried out in a rudimentary manner, with little introduction of technological innovations. Agriculture was sustained mainly by a production system that was extremely labor-intensive and low-cost. Given the emphasis on modernizing the industrial sector, this trend continued for many years, changing only from

1960 onwards, when this system began to undergo an accelerated transformation, stimulated by public policies that gradually incorporated the principles of the so-called "Green Revolution[2]" in the rural area of Brazil. This was a period, therefore, marked by the beginning of a new economic pattern based on the hegemony of the import substitution model, responsible for promoting the creation of Agro-Industrial Complexes (CAIs) (Castro, 2015).

Among the principles of the Green Revolution, the one related to the insertion and diffusion of technological innovations in the field of agricultural activities stands out (Castro, 2015). The transformation of agriculture then occurred from the mid-1960s, when it was introduced into the environment of Brazilian modernization and development (Barreto; Almeida, 2009). This modernization was based, above all, on the insertion of new technologies that, through structural transformations, diversification and organization of productive factors, resulted in productivity gains (Moreira; Teixeira, 2014).

Throughout the 1970s, Brazilian agriculture showed significant dynamism, since agricultural production increased very quickly, increasing the supply of raw materials; the modernization of the sector intensified and made it possible to open a domestic market for industrial production; and the inclusion of new areas for production promoted the incorporation of the national economy into previously isolated spaces (Kageyama; Graziano da Silva, 1983). Thus, the industrialization process of agriculture provided its definitive integration with the rest of the economy (Graziano da Silva, 1997). Still, Cano (2011) emphasizes that as agriculture modernizes, part of the direct employment generated by the primary segment is expelled, but other indirect urban jobs are created, such as occupations in tertiary activities, agroindustrialization or in the production goods industry.

Furthermore, over the last four decades (1970 to 2010), agriculture has faced several challenges related to the demands of society. Considering that, until the 1970s, much of food security was ensured through imports, the main obstacles faced by the segment were related to the need to ensure the supply of food at a reasonable price, especially for urban areas, which received a large influx of migrants from rural areas; to assist in the progress of the Brazilian countryside, creating jobs, generating income and contributing to the well-being of the rural population; to guarantee the occupation and preservation of natural resources; and to create exportable surpluses, generating foreign

[2] The Green Revolution is characterized, according to Albergoni and Pelaez (2007, p. 32), as a "new technological model of agricultural production that implied the creation and development of new activities for the production of inputs (chemical, mechanical and biological) linked to agriculture", with the purpose of increasing the level of production and, consequently, the supply of food and the eradication of hunger.

exchange to promote other economic sectors. Thus, at this time, structural changes began to be made in the sector, which contributed to food self-sufficiency in the following decades, with the exception of wheat. The elements that made it possible to introduce modern technologies into production mechanisms and determined a considerable increase in food supply, without the need for proportional expansion of the area, were competitive production and the provision of natural resources in the Cerrado, as well as the investments of the federal government in the creation of a minimum infrastructure, in Science, Technology and in Agricultural policy tools, such as rural credit (Martha Júnior *et al*., 2010).

In this sense, Brazilian agriculture has been modernizing, and this issue is seen as the increasing incursion of technological innovations and transformations in the relations between capital and labor. Thus, it has been propagated as a model that changes economic conditions, favoring the increase in large-scale production. Thus, modern agriculture is based on the use of new technologies, large-scale production, dependence on elements that are external to the property, integration with industry, production flow in other countries and the geographic mobility of productive and financial capital, with its consolidation and expansion taking place in a context of territorial modernization (Matos; Pessôa, 2011).

Silva and Botelho (2014) therefore state that the current agricultural panorama in Brazil is marked mainly by the strength of agribusiness and its high productivity, both for domestic supply and for export, resulting from high investments in modern technologies, characterized as capital intensive. This is one of the aspects of the modernization of the sector, and it is conditioned by technological devices as a driving force for development.

2.2 Agricultural production: empirical review

In the literature, there are a number of studies that address the determinants of agricultural production. One of them is that of Alvim and Stulp (2015), who conducted a study to verify the relevance of the production factors land, labor, tractors, livestock and working capital on the value of agricultural production in Rio Grande do Sul. To this end, the variables of value of agricultural production were used as the dependent variable, and labor in the primary sector, number of tractors, variable expenses, crop area, pasture area and livestock as the explanatory variables, extracted from the IBGE Agricultural Censuses of 1975, 1995-96 and 2006. The methodology used consisted of adopting Panel Data. The results indicated the existence of an intensification in the use of capital in the activities of this sector, aiming at increasing its productivity and profitability. Based on this, they concluded that the technological development observed in recent years has led agricultural activity to increase the use of capital, to the detriment of labor.

Pintor and Piacenti (2016) defined as the objective of their work the analysis of the determining factors of the production frontier of rice, corn and soybean crops in the states of the North and Northeast regions of Brazil, from 1999 to 2012. To reach their objective, they used the Panel Data methodology, in which the dependent variable corresponded to the harvested agricultural area and the independent variables were equivalent to the rural credit demanded by agriculture; the Gross Value Added (GVA) of agricultural production; the price of commodities; number of employees in the agricultural sector; number of establishments in the agricultural sector; quantity of tractors sold; monetary value of agribusiness exports; dummy variable[3], which assumes the value one for Bahia and zero for the other states; dummy variable, one for Maranhão and zero for the other states; dummy variable, one for Pará and zero for the rest; dummy variable, one for Piauí and zero in the others; and dummy variable one for Tocantins and zero for the others. These data were taken from the IBGE, BACEN, the United Nations Conference on Trade and Development (UNCTAD), the Annual Report of Social Information (RAIS) of the Ministry of Labor and Employment (MTE), the National Association of Automotive Vehicle Manufacturers (ANFAVEA) and the Ministry of Agriculture, Livestock and Supply (MAPA).

Regarding the results, they found that 81.95% of the harvested area of rice, corn and soybeans in the North and Northeast are explained by the set of explanatory variables described, and that Bahia, Maranhão, Pará, Piauí and Tocantins are the states that have the largest productions and the greatest impact on the regions. They concluded that the expansion of the agricultural frontier of the crops analyzed in the regions considered made it possible to open a new market, since the market relations in which they were expanded were still incipient. The estimated econometric model proved this fact itself, since the variables of the number of employees and GVA of production were statistically significant, demonstrating the increase in income resulting from agricultural activity (Pintor; Piacenti, 2016).

Pintor *et al*. (2016) established as the central purpose of their research to verify the impact of rural credit on the growth of the GVA of agriculture in the municipalities of the Western mesoregion of Paraná, considering 2000 to 2012. For this, the methodology used

[3] Dummy variables for Bahia, Maranhão, Pará, Piauí and Tocantins were included in the model, separately, to capture the impacts of the main rice, corn and soybean producing states on the harvested area of these crops in the North and Northeast regions (Pintor; Piacenti, 2016).

was Panel Data, in which the dependent variable was represented by the GVA of agricultural production, while the group of explanatory variables was constituted by the rural credit demanded by agriculture; harvested agricultural area; estimated soybean production costs per bag (60 kg); average exchange rate; dummy variable, with value one if the municipality is part of the Foz do Iguaçu microregion and zero if it is not; dummy variable, one if the municipality is part of the Toledo microregion and zero otherwise; and dummy variable, one if the municipality is part of the Cascavel microregion and zero for the rest. The data were extracted from IBGE, BACEN, Institute of Applied Economic Research (IPEA) and Secretariat of Agriculture and Supply (SEAB) of Paraná.

The results showed that, considering the fixed effects model, the independent variables explain 84.67% of the variations in the GVA of agricultural production. Furthermore, the rural credit coefficient presented the expected sign, but was not statistically significant, despite the increase recorded in rural credit for the period in the Western mesoregion, of 340%. Thus, they concluded that the variation in the harvested area, the soybean production costs per bag and the exchange rate contributed effectively to the GVA of agricultural production. Also, they highlighted that the variation in the exchange rate is related to the variations in production costs, since its increase tends to cause reductions in the GVA, since this fact leads to a greater increase in production costs than in the increase in the prices of agricultural products (Pintor *et al*., 2016).

Benevides *et al*. (2018) proposed to evaluate the productivity of agricultural factors, based on an analysis of Total Factor Productivity (TFP) in agriculture in the large producing countries from 1990 to 2003, which were: Germany, Brazil, China, United States, France, India, Japan, Mexico, Russia and Turkey. To accomplish this objective, the Panel Data econometric method was used, through the estimation of a Cobb-Douglas function, with the dependent variable being the gross value of agricultural production and the independent variables considering the agricultural area, capital (number of tractors in use) and labor (labor in agriculture, measured in man-years), taken from the World Bank database. The results found showed that, based on the estimation carried out by random effects, capital presented a positive and significant coefficient, revealing that the availability and use of machinery are a determining element of the level of agricultural production.

In addition, the coefficient of the labor force variable was also positive and statistically significant, with this effect being greater in countries that do not have modern agricultural technologies. Besides, the variable representing the land factor was insignificant, thus contradicting the literature. Finally, they concluded that agricultural factor productivity was high in the countries that held the highest production during the 14 years studied, and that, among all the variables, China had the highest TFP throughout the entire period, followed by the United States. In opposition, factor productivity in Brazil was similar to that of Turkey and India (Benevides *et al*., 2018).

Based on the studies cited in this subsection, it is essential to highlight the advances that this research proposes for the topic in question. This work aims to fill a gap related to the scarcity of studies that address the role of agricultural production in Brazilian municipalities and the variables that influence its expansion. As well, it introduces a more recent period to the analysis, based on data made available by IBGE in the last Agricultural Census (2017).

3 METHODOLOGY

3.1 Study area, variables and data source

The study area of this work comprises 5,041 Brazilian municipalities, considering that, of the 5,571 existing municipalities, 531 did not have their records released by the IBGE for all the selected variables or presented values in only one of the years. The variables considered in this study are the value of municipal agricultural production (obtained from the sum of the values of plant and animal production), the number of people employed (employed personnel) in the agricultural establishments of the municipality, the total area of all agricultural units in the municipality and the total number of tractors present in these establishments.

Besides, in order to capture the individual effects of each region on national agricultural production, five regional dummies were added, covering municipalities belonging to the major regions of the country and the Semi-arid region. In the case of the former, they assume a value of one when they belong to the region and zero otherwise. In relation to the latter, they obtain a value of one when they are not part of the Semi-arid region and a value of zero otherwise. Thus, four dummies were created for the major regions of Brazil, with the reference being the North region; and a dummy for location in the Semi-arid region. The inclusion of a variable that captures the productive differences resulting from the Semi-arid climate is important, given that it is unfavorable to agricultural production and affects a large area of the country, being present in more than half of the Northeast region and part of Minas Gerais, as pointed out by Silva *et al*. (2019). In this sense, Chart 01 shows the studies that inspired the choice of each variable.

Chart 01 – Variables used and studies that inspired their choice

Variable	Acronym	Studies that inspired the choice of the variable
Production value (in thousands BRL)	V_p	Alvim and Stulp (2015); Pintor and Piacenti (2016); Pintor *et al*. (2016) ; Benevides *et al*. (2018)
Employed personnel (number of people)	Employed	Alvim and Stulp (2015); Pintor and Piacenti (2016); Benevides *et al*. (2018)
Area of establishments (in hectares)	Area	Alvim and Stulp (2015); Pintor and Piacenti (2016); Pintor *et al*. (2016); Benevides *et al*. (2018)
Number of tractors in establishments (units)	Tractors	Alvim and Stulp (2015); Pintor and Piacenti (2016); Benevides *et al*. (2018)
Regional dummies	DNE (for the Northeast), DSE (for the Southeast), DS (for the South), DCO (for the Center-West), DNSA (for location in a non-Semi-arid region)	Painter and Piacenti (2016); Pintor *et al*. (2016)

Source: Prepared by the authors (2024).

It is important to note that there are other important variables that impact the value of production, but some of them are not found in both censuses considered, so the variables were selected according to economic theory and empirical literature and availability in both censuses. These data refer to the years 2006 and 2017 and were collected from the Agricultural Census - 2006 (IBGE, 2007) and the Agricultural Census – 2017 (IBGE, 2019), through the IBGE Automatic Recovery System (SIDRA), given that these are the most recent Censuses available. Additionally, since the analysis carried out covers two years, the variable concerning the value of production was deflated, based on the General Price Index - Internal Availability (IGP-DI) recorded in December 2019, published by IPEA (2020).

The main descriptive statistics of the variables value of agricultural production, employed personnel, area of the establishment and number of tractors on the establishment for the Brazilian municipalities considered in this study, in relation to 2006 and 2017, are presented in Table 01. As can be seen from their standard deviations, the information present in the dataset is very heterogeneous, which is expected, according to the wide diversity of climates and biomes that characterize the Brazilian territory, in addition to the differences related to urbanization levels, inequalities and other aspects.

Regarding agricultural production, in 2006, Nova Lima (MG) recorded the lowest value, with 110,850.00 BRL, while the highest, equivalent to 1,081,713.04 BRL, was achieved by Bofete (SP). In 2017, however, the lowest production, in monetary terms, corresponding to 327,620.00 BRL, was obtained by Alumínio (SP), while the highest, 3,656,855.35 BRL, was achieved by Rio Verde (GO).

In terms of employed personnel, in 2006, the municipality with the fewest people employed in agricultural establishments was Xangri-lá (RS), with only 10 workers. On the other hand, Cametá (PA) had the largest number of workers in agricultural units, with a total of 39,883 employees. In 2017, Guarujá (SP) took the position of Xangri-lá, with 18 workers, while Cametá maintained its position, this time with 48,246 employees.

Regarding the area of agricultural establishments, in 2006, the municipality with the smallest area was Embu-Guaçu (SP), with a mere 18 hectares, while Corumbá (MS) recorded the largest extensions of land allocated to agricultural units, with a total of 5,000,982 hectares. In 2017, however, the smallest area was recorded in Santo André (SP), with only 18 hectares, while Corumbá continued to comprise the largest area observed, 4,810,916 hectares.

Table 01 – Descriptive statistics of the variables related to the value of production and its determinants (2006 and 2017)

Variables	Minimum		Average		Maximum		Standard Deviation		Coefficient of Variation (%)	
	2006	2017	2006	2017	2006	2017	2006	2017	2006	2017
Production value (in thousands BRL)	110.85	327.62	38,076.31	102,821.41	1,081,713.04	3,656,855.35	63,072.2	200,199.58	165.65	194.71
Employed personnel (number of people)	10	18	3.060	2,786	39,883	48,246	3,271.54	2,994.52	106.91	107.48
Area of the establishment (in hectares)	18	18	64,228.84	67,642.03	5,000,982	4,810,916	132,415.14	144,408.52	206.16	213.49
Number of tractors (units)	3	3	162.55	243.17	2,584	4,646	236.69	346.31	145.61	142.41

Source: Prepared by the authors, based on data from the IBGE Agricultural Census (2006 and 2017).

Regarding the number of tractors, in 2006, 57 municipalities, almost all of which were in the North and Northeast regions, had only three tractors. However, only the municipality of São Lourenço do Sul (RS) had 2,584 tractors. In 2017, there was a reduction in the number of municipalities that had three tractors, falling to 30 municipalities. In contrast, Canguçu (RS) became the municipality with the largest presence of tractors among its agricultural units, with a total of 4,646, followed by São Lourenço do Sul, with 4,361. This result highlights the disparity that exists between municipalities and regions in Brazil, with regard to access to modernization, which, apparently, has been expanding slowly over the last 12 years, possibly indicating the presence of a still very rudimentary agriculture.

On average, it is noted that the values of all variables, except for the one related to employed personnel, increased from 2006 to 2017. Of particular note is the change in the value of production, which almost tripled during this period, rising from 38,076.31 BRL (2006) to 102,821.41 BRL (2017).

3.2 Panel Data

To achieve the objectives of this study, an econometric panel data model was estimated using *R* software, version 3.6.1. Thus, as demonstrated in equation (1), the dependent variable is represented by the value of production (Vp), while the set of explanatory variables is formed by the total number of people employed in the agricultural establishments of the municipality (Employed), by the total area of these establishments (Area), by the total number of tractors in the establishments (Tractors) and by the regional dummies, in which DNE corresponds to the Northeast, DSE is equivalent to the Southeast, DS represents the South, DCO refers to the Midwest and DNSA refers to the absence of a Semi-arid climate. Following the studies by Pintor and Piacenti (2016), Pintor *et al*. (2016) and Benevides *et al*. (2018), all variables were logarithmized.

$$lnVp = \beta_0 + \beta_1 lnEmployed + \beta_2 lnArea + \beta_3 lnTractors + DNE + DSE + DS + DCO + DNSA \quad (1)$$

Baltagi (2005) explains that the Panel Data method allows the analysis of information, related to families, firms or other agents, combining time series and cross-section. When the same individuals are observed in all years considered, the panel is called balanced; otherwise, the panel is unbalanced. In the case of this study, the balanced panel was chosen in order to observe the changes that occurred in the production functions of the municipalities between the two years analyzed.

The use of the Panel Data method has several advantages, such as the consideration of heterogeneity among individuals, the identification of changes over time and the observation of the effects derived from the implementation of policies (Baltagi, 1995). The general equation of this technique is described in equation (2), in which Y_{it} corresponds to the value of the dependent variable for unit i at time t; X_{jit} is equivalent to the value of the j-th regressor for unit i at time t (where j = 1,..., K); and ε_{it} represents the error term for the i-th unit at t (Greene, 2000):

$$Y_{it} = X_{it}^{j}\beta + \varepsilon_{it} \tag{2}$$

Pinto, Silva and Coelho Junior (2017) explain that the Panel Data model can be specified in three ways: pooled regression, fixed effects (FE) and random effects (RA). The first type of model consists of an estimation using ordinary least squares (OLS), but it weights the data in a stacked manner, disregarding the heterogeneity between observations and the temporal changes that have occurred. Regarding the other types of models, Benevides *et al*. (2018) explain that they assume that the intercept varies between observations, while the coefficients of the regressors are constant for each individual, considering that both remain constant over time. However, the second type treats the intercept as a fixed but unknown parameter, as it captures the specificity in the behavior of each observation analyzed; while the third type interprets the linear coefficient as random.

Thus, the fixed and random effects models are expressed in equations (3) and (4), respectively, where β_0 corresponds to the population intercept, ε_i corresponds to the measurement error between observations and u_i represents the random portion of the error, under the assumption that the residuals are not correlated with any regressors of the equation (Benevides *et al*., 2018):

$$Y_{it} = \propto_i + \beta_{1it} + \cdots + \beta_{nit}x_{kit} + \varepsilon_{it} \tag{3}$$

$$Y_{it} = \bar{\beta}_0 + \beta_{1it} + \cdots + \beta_n x_{kit} + \varepsilon_{it} + u_{it} \tag{4}$$

Regarding the choice of the most appropriate model, this must be proven using the Chow and Hausman F-tests and the Breusch-Pagan Lagrange Multiplier test, known as the LM-test; as proposed by Pintor and Piacenti (2016), Pintor *et al*. (2016) and Pinto, Silva and Coelho Junior (2017).

The Chow F-test determines which model, pooled or with fixed effects, is most appropriate for the data set used. To do so, it divides the sample into two parts and compares the results obtained in several estimated regressions, observing the differences between them. If these are (not) significant, it is concluded that there was (no) structural change (Nascimento, 2012). In this sense, the Chow test has the null hypothesis that the intercept is stable over time, that is, the pooled model is preferable when compared to the fixed effects model. Conversely, the alternative hypothesis states that the linear coefficient is constant throughout the period analyzed, so that the model with fixed effects is more appropriate (Pinto; Silva; Coelho Junior, 2017).

The Hausman test follows an asymptotic distribution χ^2 , with k degrees of freedom, and has as its null hypothesis (H_0) the statement that the estimators of the fixed effect model and the random effect model do not differ substantially, while the alternative hypothesis (H_a) consists of the existence of a correlation between the residuals and the regressors, thus implying the inadequacy of the RA model (Gujarati; Porter, 2011). These hypotheses are based on the fact that, if the effects of the agents are not correlated with the regressors, the RA estimator is consistent and efficient, while the parameters estimated by the FE model will be consistent but inefficient. However, if the individual effects present a correlation with the angular coefficients, the parameters of the FE model will be consistent and efficient, while those of RA will be inconsistent (Sousa; Leite Filho, 2008).

The LM-test aims to identify the best model, between the pooled regression and the random effects model, based on the individual variance of the error terms. Thus, its null hypothesis understands that such variance equals zero, so that the stacked data model is more appropriate, while the alternative hypothesis interprets it as different from zero, thus evidencing that the random effects model is more appropriate (Pinto; Silva; Coelho Junior, 2017).

Finally, it is important to emphasize some issues regarding the hypothesis violation tests, since in order to ensure greater robustness of the model, hypothesis verification tests were performed in order to test for the existence of multicollinearity, autocorrelation and heteroscedasticity, as well as to observe the distribution of the residuals. Regarding multicollinearity, the Variance Inflation Factor (VIF)[4] was used, which indicates the presence of high multicollinearity when the values obtained are above 10 (Hair *et al*., 2009). Regarding heteroscedasticity, the Breusch-Pagan and White tests were adopted. Their null hypotheses consist of homoscedasticity, while the alternative hypotheses indicate heteroscedasticity. Regarding autocorrelation, the Durbin-Watson test was performed, whose null hypothesis corresponds to the non-existence of autocorrelation, while the alternative hypothesis states the opposite. Since the presence of heteroskedasticity was detected, the Newey-West method, which consists of extending the White's test of consistent standard errors for heteroskedasticity, was adopted to correct it (Gujarati; Porter, 2011). The significance level adopted in this work is equivalent to 1%. The results of the models and tests are presented in the next section.

[4] The Variance Inflation Factor (VIF) is calculated as follows: $\frac{1}{1-R_j^2}$, where $R^2{}_j$ corresponds to the R^2 obtained in an auxiliary regression (Fávero *et al*., 2009).

4 RESULTS AND DISCUSSION

In order to verify the influence of the factors land, capital, labor and region on the value of agricultural production in Brazil, an econometric equation was estimated, as described in equation (1) of the methodology, using the Panel Data technique. Regarding the hypothesis violation tests, initially, the Variance Inflation Factor (VIF) was adopted to detect the presence of multicollinearity in the data set. The results revealed that the degree of collinearity between the variables is low, making it possible, therefore, to isolate the individual effects of each parameter on the dependent variable. Regarding the distribution of the residuals, the p-value of the Jarque-Bera test was below the significance level of 1%, which, therefore, implied the rejection of the null hypothesis, regarding the normality of the distribution of the residuals. However, when analyzing the histogram, it can be stated that, asymptotically, the residuals are normally distributed, that is, $N\sim(0, \sigma^2)$.

Regarding autocorrelation, the Durbin-Watson test revealed its non-existence, given that the p-value measured was greater than the adopted significance level, which implied the non-rejection of the null hypothesis, according to they, there is no autocorrelation. Subsequently, to verify the equality of the variances of all the units analyzed, the Breusch-Pagan and White heteroscedasticity tests were used, whose p-values were lower than the significance level, consequently rejecting the null hypotheses of homoscedasticity and indicating, therefore, the presence of heteroscedasticity. So, the Newey-West test was used to correct this violation.

Thus, three models were estimated: one with fixed effects, another with random effects and a pooled regression, the results of which are presented in Table 02. As can be seen, the p-values of the Chow and LM-tests were lower than the adopted significance level (1%), thus rejecting the null hypotheses that the pooled model is preferable to the fixed and random effects model, respectively. Furthermore, the p-value of the Hausman test was also lower than 1%, thus rejecting the null hypothesis that the generalized least squares (GLS) estimates are consistent and indicating that the fixed effects model is more appropriate.

However, Wooldridge (2015, p. 444) warns of the possibility that the Hausman test may be flawed in rejecting the null hypothesis. The author explains that this error occurs when “the sampling variation is so large in the estimates of the fixed effects model that it cannot be concluded whether practically significant differences are statistically significant[5]." As can be seen, the coefficients of the variables are similar in both models, but the parameter related to employed personnel had a different sign than expected and the adjusted R^2 obtained was negative in the fixed effects model. In this context, and considering the high variation in the data, expressed by the descriptive analysis presented in section 3.1, the use of the random effects model proves to be more appropriate.

The results obtained by the random effects model show that the variables considered explain 67.32% of the variations in the value of agricultural production and that the model as a whole is statistically significant, given that the p-value of the F-test was lower than the significance level of 1%. However, they show that all the variables considered, except the dummy for the South region, exert a positive and statistically significant influence on the value of agricultural production in the country, which is in line with expectations, since it is assumed that increases in the levels of inputs used increase the value of production. Thought, as expected, there are production differences due to the geographic location of the municipalities.

Table 02 – Fixed and Random Effects Estimates for Brazilian Municipalities (2006 and 2017)

VARIABLES	POOLED REGRESSION	FIXED EFFECTS (FE)	RANDOM EFFECTS (RA)
Constant	3,0582 (0.0000)	-	3,1771 (0.0000)
Employed personnel	0.2809 (0.0000)	-0.0080 (0.7885)	0.2566 (0.0000)
Area of the establishment	0.1583 (0.0000)	0.2852 (0.0000)	0.1549 (0.0000)
Number of tractors	0.6288 (0.0000)	1,0549 (0.0000)	0.6603 (0.0000)
DNE	0.4048 (0.0000)	-	0.4226 (0.0000)
DSE	0.2547 (0.0000)	-	0.2202 (0.0000)
DS	0.0451 (0.2284)	-	-0.0114 (0.7827)
DCO	0.2536 (0.0000)	-	0.2096 (0.0000)
DNSA	0.5298 (0.0000)	-	0.5098 (0.0000)
R^2	0.7078	0.4053	0.6732
Adjusted R2	0.7076	-0.1899	0.6730
F-test	3,049.16 (0.0000)	1,144.42 (0.0000)	20,750.00 (0.0000)
Chow's F-test	-	1,7064 (0.0000)	-
Breusch-Pagan LM-test	153.54 (0.0000)	-	-

[5] Practical significance is given by the sign and magnitude of the estimated coefficients, while statistical significance is based on the T-test values, that is, the ratio between β and its standard error (Wooldridge, 2015).

Hausman test	-	640.80 (0.0000)	-
Akaike criterion	22,353.16	22,389.13	22,369.52
Schwartz criterion	22,418.13	58,791.06	22,434.49

Source: Prepared by the author, based on research results (2024).

There is evidence that, on average, as the number of workers increases by 1%, the value of national agricultural production increases by 0.26%. Similarly, when the area of the establishment is expanded by 1%, production increases by 0.15%. These relationships were also identified by Pintor and Piacenti (2016), when they found that increases in the workforce employed and in the area harvested may be a reflection, among other reasons, of the fact that increases in the area of establishments increase agricultural GVA and, consequently, the value of production. However, the main determinant of production value is the number of tractors on the establishment, so that, on average, each 1% increase in this parameter increases production value by 0.66%. Benevides *et al*. (2018) also observed a positive influence of this variable on the value of production, when studying agriculture in Germany, Brazil, China, the United States, France, India, Japan, Mexico, Russia and Turkey.

When observing regional differences, it was found that, on average, the Northeast is the region that contributes most to the increase in the value of Brazilian production, while the opposite can be said about the Center-West. This result for the Northeast is consistent with that obtained by Pintor and Piacenti (2016), who found high representation for the states of Bahia, Maranhão and Piauí, which are part of the Brazilian Northeast, explaining the importance of this region in the production of cotton, corn and soybeans. Similarly, the fact that the municipality is located in a region with a non-Semi-arid climate contributes, on average, to the value of agricultural production increasing to a greater extent than those located in Semi-arid regions. This inference may be associated with the fact evidenced by Silva *et al.* (2019) that municipalities that are not part of the Semi-arid region have greater technical efficiency, indicating that municipalities belonging to the Semi-arid and non-Semi-arid regions face different opportunities for agricultural production. Therefore, according to these authors, practices of coexistence with the Semi-arid region are essential to overcome the climatic and productive challenges of this region.

5 FINAL CONSIDERATIONS

Considering the arguments presented, it can be concluded that the agricultural sector is of great importance to Brazilian development, contributing to the formation of income in the country, obtaining foreign exchange from exports that, in a certain way, facilitated the industrialization process, in addition to promoting internal supply. It is important to highlight that, throughout Brazilian history, its cycles were related to the expansion of some agricultural product, which proves the relevance of this segment for the country. Furthermore, agriculture has shown some progress over the years, which has enabled the transition, in certain areas, from rudimentary production to production that relies on a modern and sophisticated technical apparatus, allowing for greater productivity. This fact was only possible due to the modernization of agriculture, which occurred from the 1950s onwards, which allowed the introduction of technological innovations and changes in production relations.

Despite the importance of agricultural modernization for the country, especially in terms of increasing productivity and, consequently, the value of production, it is possible to see that this process has occurred slowly. Thus, it can be inferred that, even in contemporary times, the diffusion of access to new technologies in Brazil does not occur at the same speed at which they are created. As a result, certain municipalities develop more than others, accentuating regional disparities.

As the results of this study show, investment in production inputs, especially in the number of tractors, can significantly increase the value of agricultural production. In this context, the government needs to intervene in the sector by creating new policies and improving existing ones, so that as many Brazilian farmers as possible can invest in their production and thus increase the value of national production, which tends to generate benefits not only from an economic but also social point of view. These public policies could be directed towards investments in technology and innovation; provision of training and refresher courses for rural workers; and improvements in rural infrastructure, with the aim of facilitating the flow of production.

Finally, the results found in this research were in line with the literature on the determinants of agriculture, which corroborates the importance of discussing this topic. Thus, it is encouraged other researchers conduct studies in this area, bringing new contributions that fill the existing gaps, such as the use of other analytical tools, such as quantile regression for Panel Data, and the inclusion of new variables that explain agricultural production in Brazil.

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