Modifications in land use for agriculture in Brazil: an analysis of microregions in 1990 and 2016

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Acknowledegment:

JEL Codes: Q15, R14

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Keywords: Substitution effect. Production Growth. *Shift-Share* Analysis.

JEL Classification**:** Q11. Q15. R14.

1 Introduction

Agriculture is associated with Brazil's economic growth of Brazil and this is due to the country's importance in the international agricultural scenario, where it stands out as a relevant producer and exporter of various agricultural products, including: soy, sugar and ethanol, paper and cellulose, coffee, maize, among others. Corroborating this idea, the Gross Domestic Product (GDP) of Brazilian agribusiness, calculated by the Center for Advanced Studies in Applied Economics - CEPEA (2018), was R$ 1.28 trillion, representing 20.00% of the total GDP in 2016, being 13.94% related to the agricultural sector. In addition, agribusiness exports were US$ 84.94 billion or 45.9% of all national exports in 2016, of which 32.16% were related to the agricultural sector (FIESP, 2018).

Therefore, it is observed that there is a significant importance of agriculture, not only for Brazilian economic growth in terms of jobs creations and income, but also for the country's insertion in the global market, for the attraction of foreign exchange and for the balance of trade balance. Thus, the agriculture behavior can significantly impact the national economy, deserving a lot of attention from the formulators of the public and private policies.

In this sense, the current performance of the agricultural sector is due, among other factors, to the creation of government programs aimed at the development of agriculture in the country during the 1960s. Until the 1980s the Brazilian government financed several public policies aimed at the development and strengthening of agriculture. However, such programs became less important in the beginning of the 1990s, when the State began a process of deregulation and opening up of the Brazilian economy, causing the agricultural sector to act more according to the rules of supply and demand, dictated mainly by the international market (SANTOS; SILVA, 2001).

However, despite the reduction of government participation in the sector, agricultural production continued to grow considerably (SANTOS; SILVA, 2001; ALMEIDA; SANTOS; CHAVES, 2006; SANTOS; ARAÚJO, 2014; VERÃO; COSTA; FOREST, 2016). Based on these affirmations, the present study sought to analyze the changes in land use in the 558 Brazilian microregions between 1990 and 2016, in order to verify the agricultural activities that gained and lost the biggest amount of area in the period, and to identify the main factors that have boosted the country's agricultural production growth.

Therefore, in addition to this introduction, four other sections make up the paper. The second section presents a brief theoretical review of the changes in the development strategy of Brazilian agriculture in the second half of the 20th century and presents results from recent studies that used the *shift-share* methodology in the Brazilian agriculture analysis. The third section describes the data used and their sources, as well as the methodology applied in the study. In the fourth section are the analysis and discussions. The fifth section ends the paper with the conclusions.

2 Changes in the Brazilian agriculture development strategy in the second half of the twentieth century

The agricultural sector is dynamic, in relation to the diversity of cultivated products as well as in relation to the technology used in production, and it is this capacity of adaptation to the changes in the economic environment that makes it a strategic sector for the promotion of the growth and development of the economies (LEWIS, 1969; FEI; RANIS, 1983; JORGENSON, 1983; SANTOS; SILVA, 2001; BASTOS; GOMES, 2010).

Agriculture is an important sector, mainly because it has several functions that are fundamental to the growth and economic development of countries. According to Johnston and Mellor (1961), in the early stages of development, agriculture has five fundamental roles: (i) food production for the population; (ii) generation of surplus capital for investment in the non-agricultural sectors; (iii) supply of labor to the urban sector, enabling the growth and diversification of economic activity; (iv) provision of foreign currency (surplus in the trade balance) to finance the importation of inputs and capital goods; and, (v) consumer market, to absorb the domestic industrial production. Bacha (2004) also adds a sixth role: (vi) supply of raw material to the national industry.

However, in order for agriculture to be able to fulfill these roles, in the late 1960s, there was a change in Brazil's development strategy, seeking to increase productivity and reduce production costs through modernization of agriculture. This new strategy was based on four main points (BARROS, 1979): (i) greater openness to international trade; (ii) expansion of subsidized rural credit programs; (iii) increased expenditures with rural extension; and, (iv) special treatment to the input sector.

From these points, the most prominent in the literature is the importance given to new sources of financing created by the expansion of credit programs directed at rural producers, which, according to Santos and Silva (2001), was the main factor responsible for the transformations that occurred in the sector in the following decades.

Among these transformations is the discovery of new cultivation techniques that have increased food production. From this, Bastos and Gomes (2010) affirm that, from an industrial fundamentalism, productivity became the main objective, and in Brazil, the technology capable of increasing productivity was developed by private and governmental entities, such as universities and the Brazilian Agricultural Research Corporation (EMBRAPA).

From 1988 onwards, especially in the 1990s, after more than a decade of growth crisis, domestic and foreign public debt became unsustainable and the state was forced to reduce its intervention by submitting the economy to the deregulation model and economic openness (BASTOS; GOMES, 2010). Thus, the agricultural sector was gradually submitted to the market rules (ALMEIDA, 2003).

Despite this change in the agriculture's growth dynamics, the sector continued to increase its production and productivity, being the only sector with a surplus in the trade balance after the implementation of the Plano Real in 1994 (SANTOS; SILVA, 2001). According to Dias and Amaral (2001), this happened due to the emergence of a new set of incentives, the market incentives. The significant reduction in the creditworthiness of rural credit programs has led farmers to invest in reducing the average costs of agricultural holdings. The result was "vigorous productivity growth at the level of the productive unit, with a moderate reduction of cultivated area but a strong reduction in the use of labor" (DIAS; AMARAL, 2001, p. 15).

This productivity growth occurred due to several factors, including the weak development in transport infrastructure, which required intensive use of the land factor, and the use of technologies developed by EMBRAPA, especially related to the new varieties of seeds adapted to the regions of agricultural frontier, in particular for the cerrado regions (DIAS; AMARAL, 2001).

A second prominent factor was named by Dias and Amaral (2001) of "professionalization of agriculture", occurring mainly in the North and Central-West regions of the country. In these regions, between the 1960s and 1970s, there was a strong movement of farmers from the southern region of the country to expand the agricultural frontier. This shift in search of new productive areas took away capital goods and human capital, which were important for the agriculture development in these regions. A factor complementary to the professionalization of agriculture was the substantial reduction in the prices of agricultural inputs, due to changes in relative prices that was generated by the post-1990 trade liberalization (DIAS; AMARAL, 2001).

However, the rise in productivity did not occur in a similar way in all cultures. Agricultural activities focused on domestic markets stood out more in terms of productivity growth than those benefited by the country's insertion in international markets. This heterogeneous behavior of productivity shows that the agricultural sector turned to meet the needs of the Brazilian domestic market and not of the external market, as was expected to occur due to the commercial opening (DIAS; AMARAL, 2001).

Confirming these ideas, Vieira Filho (2014) found for Brazil a significant increase in productivity and production of the agricultural sector in the period of 1961-2012, as well as an expansion in the area planted in the same period, as can be seen in Table 1. Looking at the increase in productivity, it is possible to note the it presented its highest growth between 1990 and 2012, with an average growth rate of 4.46% p.a., mainly due to the advent of the production of genetically modified organisms.

Table 1 – Indicators of agricultural production of cereals, fruits, vegetable oils and vegetables from Brazil, from 1961 to 2012

Variable	**Measurement range**	**Item**	**Year**			
			1961	**1975**	**1990**	**2012**
Productivity	Kg/ha	Cereals	1.346,3	1.358,8	1.755,1	4.584,5
		Fruits	12.396,2	12.655,7	12.974,1	16.499,9
		Vegetable oils	178,2	225,9	293,3	492,6
		Vegetables	3.779,2	7.636,0	14.002,1	23.163,6
Production	tons (in millions)	Cereals	15,0	26,2	32,5	89,9
		Fruits	6,9	13,6	29,8	38,4
		Vegetable oils	0,6	2,4	4,1	13,3
		Vegetables	2,1	3,1	5,6	11,1
Area	ha (in millions)	Cereals	11,17	19,31	18,51	19,61
		Fruits	0,56	1,08	2,30	2,33
		Vegetable oils	3,18	10,63	14,09	27,06
		Vegetables	0,54	0,41	0,40	0,48

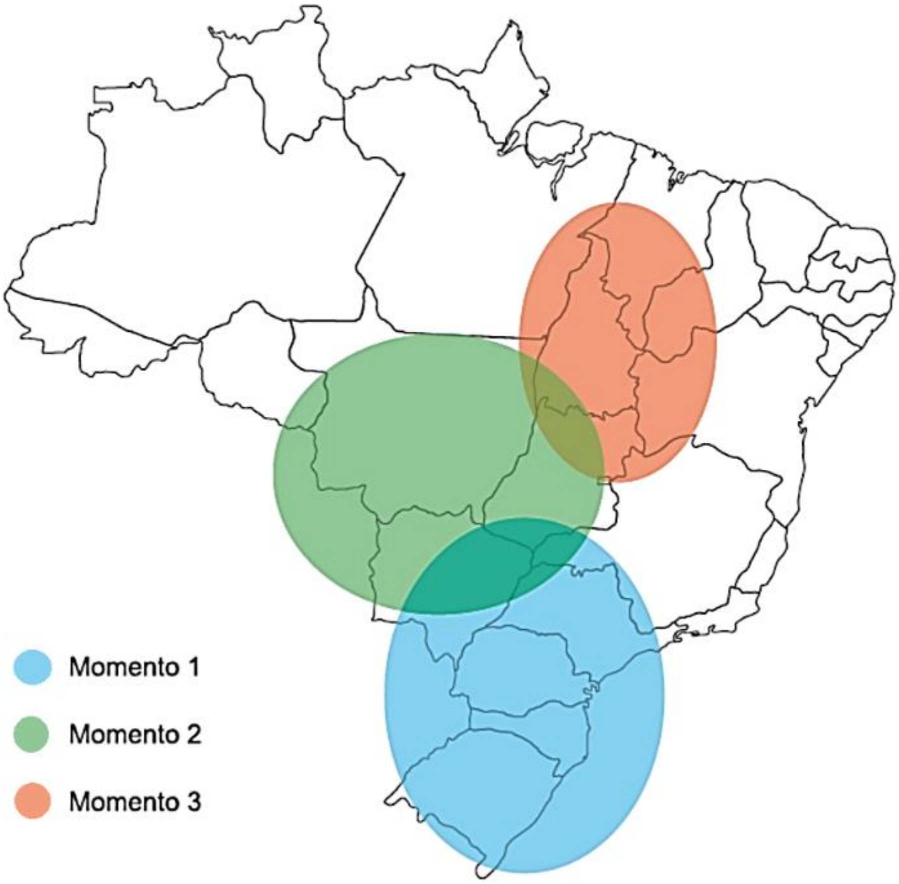
Source: Vieira Filho (2014, p. 402).

In this regard, although the legalization of transgenic soybeans occurred only in 2003, it was already illegally cultivated in the south part of the country since 1997, after the start of the commercialization of the product by Argentina, and corresponded to approximately 10% of Brazilian soybean production. The production of transgenic cotton and maize was only legalized in Brazil in 2005 and 2008, respectively. The genetic modifications made in these crops simplified management, reduced costs, and increased productivity of agricultural establishments (VIEIRA FILHO, 2014).

The impact of the introduction of genetically modified products was so significant that, for the 2016/2017 harvest, Céleres (2018), a specialist consultancy in agribusiness, estimated that 96.5% of the total planted soybean, 82.4% of the maize crops and 78.3% of the cotton plantations in Brazil were from areas planted with genetically modified cultivars.

Regarding the cultivated area, it is evident from the data in Table 1 that it had a strong expansion between the years 1961 and 1975, with an average growth rate of 3.99% p.a.. About the area expansion, Vieira Filho (2014) states that for the period 1960-2012, the expansion of the agricultural frontier in Brazil had three important moments with two prominent movements, as shown in Figure 1.

Figure 1 – Expansion of the agricultural frontier in Brazil: moment (1) 1960-1975; moment (2) 1975-1990; and moment (3) 1990-2014



Source: Vieira Filho (2014, p. 407).

In the first movement, it starts from the legend moment 1, corresponding to the period 1960-1975, when the national agricultural production was concentrated mainly in the states of the south and the state of São Paulo, towards the moment 2. This second moment, from 1975 to 1990, is the result of large investments made in the 1960s and 1970s that made the Midwest in the 1980s the largest grain producer in Brazil. (VIEIRA FILHO, 2014). The second movement, according to Vieira Filho (2014), from movement 2 to movement 3, occurred in the direction of the junction region of the states of Maranhão, Tocantins, Piauí and Bahia, named Matopiba, from the 1990s.

In this way, it can be observed that the technological transformations that allowed these movements of expansion of the agricultural frontier did more than increase the Brazilian production and productivity. They were fundamental to inflationary control and helped to achieve and ensure economic stability in the country in times of crisis, enabling and fostering growth and economic development in Brazil (VIEIRA FILHO, 2014).

In addition, it is verified that the expansion of the agricultural frontier is related to the increase of the technological capacity to produce in several areas, changing the dynamics of the growth of agricultural production in Brazil. Thus, the next subsection addresses some recent studies on the national agriculture production and changes in land use using the *shift-share* method.

2.1 The growth dynamics of Brazilian agricultural production: analysis of study results with the *shift-share* methodology

The *shift-share* methodology has been used by researchers over the years to analyze, among other things, changes in land use in various regions of the country. Yokoyama, Igreja and Neves (1990) identified important changes in the composition of agricultural production in the state of Goiás from 1975 to 1984. The authors pointed to a considerable reduction in the area planted to basic crops of the region, such as cassava, rice and beans, in favor of products exportable or related to the agro-energy sector.

Almeida, Santos and Chaves (2006) found that in Bahia, in the period 1985-2002, there was a growth of bean, maize and soybean crops. In this case, all crops had significant scale and substitution effects and there was still a reduction in the cultivated area of cotton, sugar cane, castor bean and cassava to give space mainly to soybean plantation.

For the Paraná State, Santos and Araújo (2014) pointed out that sugarcane and tobacco crops presented high growth rates from 1980 to 2010, mainly due to the expansion of the cultivated area, through the absorption of areas of other crops, such as cotton, rice and coffee.

For the Mato Grosso do Sul state, Verão, Costa e Forest (2017) evidenced that between the years 1990 and 2011 the expansion of sugarcane production occurred mainly due to the effect area and the substitution effect. It was observed that the sugarcane plantations took areas of other cultures and gained space in the economic/agricultural scenario of Mato Grosso do Sul.

In summary, the main effect highlighted by these researchers was the substitution effect, that is, the producers stopped producing a certain crop to use the land in the cultivation of other products. This, however, occurs for several factors, but the most cited is the search for more profitable crops per unit area (BUNGENSTAB, 2015; YOKOYAMA; IGREJA; NEVES, 1990). Thus, briefly reviewing some of the results of analysis using the *shift-share* method, the next section presents the methodology used in the present paper.

3 Methodology

To analyze the changes in land use for agriculture in Brazil, to verify the agricultural activities that the most won or most lost area in the period 1990-2016 and to identify the most relevant factors for the growth of the production of these activities was the structural-differential or *shift-share*. This method makes it possible to measure the growth of economic aggregates at a regional analytical level and to identify the components of this growth by dividing it into distinct effects.

The methodology, shift-share, has been used by several authors to study agriculture in Brazil. Among the pioneering studies of Brazilian agricultural activities using this method, we highlight the work of Patrick (1975), Zockun (1978), Cunha and Daguer (1982), Igreja (1987) and Yokoyama, Igreja and Neves (1990). More recent works have also been used of the *shift-share* method, such as Shikida and Alves (2001), Santos, Faria and Teixeira (2008), Santos and Araújo (2014), Cuenca, Dompieri and Sá (2015), Verão, Costa and Forest (2016), among others.

The quantitative mathematics analysis allows us to measure the growth of agricultural production by dividing it into three effects: area, yield and geographical location. The effect area can be divided into two other effects, scale and substitution, the latter allowing to verify the substitution of one culture for another within the system.

The territorial division of Brazil is established as follows: Major Regions, Units of the Federation (UF), Geographical Meso-regions, Geographical Microregions and Municipalities. There are five major regions in Brazil: North, Northeast, Southeast, South and Midwest. The UF are autonomous entities with their own government and constitution, with 26 states and one Federal District. The Meso-regions are groups of contiguous municipalities belonging to the same UF and total a total of 137. Geographic Microregions are groups of contiguous municipalities belonging to the same Meso-region and totaling 558. The municipalities are the autonomous federal entities of lower hierarchical level, being in all 5570.

Data disaggregated by microregion in 1990 and 2016 were analyzed in order to identify changes in land use in the period at a micro analytical level. All cultures with data available in the database of the IBGE Automatic Recovery System (IBGE, 2017) were considered, with 35 permanent and 33 temporary. The data used were: harvested area (in hectares), quantity produced (in tons) and average yield of production (in tons per hectare). No pasture and livestock productivity data were included due to their unavailability in the micro-regional level of disaggregation for the period considered, making it impossible to study this activity.

Moving forward, as described by Yokoyama, Igreja and Neves (1990), the methodology of analysis is presented. In this sense, the total production of the j-th agricultural activity in the reference region (Brazil) in the initial period (0 = 1990) is given by:

$$Q_{j0} = \sum_{i=1}^{m} A_{ij0}R_{ij0} = \sum_{i=1}^{m} \lambda_{ij0}A_{j0}R_{ij0} \quad (1)$$

In the final period (t = 2016):

$$Q_{jt} = \sum_{i=1}^{m} A_{ijt}R_{ijt} = \sum_{i=1}^{m} \lambda_{ijt}A_{jt}R_{ijt} \quad (2)$$

In which, in (1) and (2),

i is the microregion, which varies from 1 to m, being m = 558 (number of Brazilian geographic microregions);

j is the agricultural activity, which varies from 1 to n, where n = 68 (number of agricultural activities considered);

A_{ij} is the total area used by the j-th activity in the i-th micro-region (in hectares);

R_{ij} is the yield of the j-th activity in the i-th micro-region (in tons per hectare);

λ_{ij} is the relative participation of the i-th micro-region in the total area of the j-th activity in Brazil;

A_j is the total cultivated area of the j-th activity in Brazil (in hectares).

Considering a variation only in the total area of activity j in Brazil, the total production of this activity is given by:

$$Q_{jt}^{A} = \sum_{i=1}^{m} \lambda_{\ ijo}\, A_{jt}\, R_{ijo} \quad (3)$$

Considering a variation in the total area of activity j in Brazil and income in each microregion, the final production is:

$$Q_{jt}^{AR} = \sum_{i=1}^{m} \lambda_{ijo}\, A_{jt} R_{ijt} \quad (4)$$

If the total area, income, and the relative participation of the i-th micro-region in the total area of the j-th activity in Brazil are changed:

$$Q_{jt}^{AR\lambda} = \sum_{i=1}^{m} \lambda_{ijt}\, A_{jt}\, R_{ijt} = Q_{jt} \quad (5)$$

The total variation in the production of the j-th activity from period 0 to period t is given by:

$$Q_{jt} - Q_{j0} = \sum_{i=1}^{m} \lambda_{ijt} A_{jt} R_{ijt} - \sum_{i=1}^{m} \lambda_{ij0} A_{j0} R_{ij0} \quad (6)$$

Or,

$$Q_{jt} - Q_{j0} = \left(Q_{jt}^{A} - Q_{j0}\right) + \left(Q_{jt}^{AR} - \ Q_{jt}^{A}\right) + \left(Q_{jt} - Q_{jt}^{AR}\right) \quad (7)$$

On what,

$Q_{jt}^{A} - Q_{j0}$ is the area effect (EA);

$Q_{jt}^{AR} - \ Q_{jt}^{A}$ is the yield effect (ER);

$Q_{jt} - Q_{jt}^{AR}$ is the geographical location effect (ELG).

Returning to equations (4) and (5), it can be seen that the geographical location effect can be expressed by:

$$ELG = \sum_{i=1}^{m} \lambda_{ijt} A_{jt} R_{ijt} - \sum_{i=1}^{m} \lambda_{ij0} A_{jt} R_{ijt} = A_{jt}\left(\sum_{i=1}^{m} \lambda_{ijt} R_{ijt} - \sum_{i=1}^{m} \lambda_{ij0} R_{ijt}\right) \quad (8)$$

The area effect makes it possible to analyze the variation in production given by changes in the harvested area, demonstrating the effects of expansion or reduction in the area of certain activities. The yield effect shows the changes in production resulting from the productivity of the activities, being linked to the technology employed. The geographic location effect demonstrates the variations in production due to changes in the location of activities and will be positive if the participation of microregions with higher productive incomes in the final period increases, as shown in equation (8).

In order to make the analysis more intuitive and the effects comparable to each other, the three above-mentioned effects are presented in the form of annual average rates of growth, and the sum of them is equal to the average annual rate of growth of production. According to Igreja (1987), multiplying both sides of equation (7) by

$$\frac{1}{Q_{jt} - Q_{j0}}$$

it has been:

$$1 = \frac{\left(Q_{jt}^{A} - Q_{j0}\right)}{\left(Q_{jt} - Q_{j0}\right)} + \frac{\left(Q_{jt}^{AR} - Q_{jt}^{A}\right)}{\left(Q_{jt} - Q_{j0}\right)} + \frac{\left(Q_{jt} - Q_{jt}^{AR}\right)}{\left(Q_{jt} - Q_{j0}\right)} \quad (9)$$

Then multiplying both sides of equation (9) by

$$r = \left(\sqrt[t]{\frac{Q_{jt}}{Q_{jo}}} - 1\right) 100$$

Let r be the average annual rate of growth in the production of the j-th activity. In this way:

$$r = r\frac{\left(Q_{jt}^{A} - Q_{j0}\right)}{\left(Q_{jt} - Q_{j0}\right)} + r\frac{\left(Q_{jt}^{AR} - Q_{jt}^{A}\right)}{\left(Q_{jt} - Q_{j0}\right)} + r\frac{\left(Q_{jt} - Q_{jt}^{AR}\right)}{\left(Q_{jt} - Q_{j0}\right)} \quad (10)$$

On what,

$r\frac{\left(Q_{jt}^{A} - Q_{j0}\right)}{\left(Q_{jt} - Q_{j0}\right)}$ is the area effect (EA);

$r\frac{\left(Q_{jt}^{AR} - Q_{jt}^{A}\right)}{\left(Q_{jt} - Q_{j0}\right)}$ is the yield effect (ER);

$r\frac{\left(Q_{jt} - Q_{jt}^{AR}\right)}{\left(Q_{jt} - Q_{j0}\right)}$ is the geographical location effect (ELG).

Since, in this way, the effects are expressed in annual percentage rates of growth of the production of the j-th agricultural activity.

In addition, the variation in the area used by a particular activity, expressed by

$$A_{jt} - A_{jo} \quad (11)$$

can be decomposed into two other effects: scale effect (EE) and substitution effect (ES), according to equations (12) and (13).

$$EE = (\gamma A_{j0} - A_{j0}) \quad (12)$$

$$ES = (A_{jt} - \gamma A_{j0}) \quad (13)$$

On what $\gamma = \frac{AT_t}{AT_0}$ is the coefficient that measures the variation in the total area (AT) used by all agricultural activities, between the initial and final periods.

Thus, the area effect is:

$$(A_{jt} - A_{j0}) = (\gamma A_{j0} - A_{j0}) + (A_{jt} - \gamma A_{j0}) \quad (14)$$

The substitution effect shows the change in the participation of each activity in the total area available, that is, if the participation of one activity has decreased, the substitution effect will be negative, indicating that this activity has been replaced by another activity, and if the participation the substitution effect will be positive, indicating that the activity replaced other(s), taking such areas within the system. Once the relative participation of each activity in the total constant area is considered, the scale effect shows the changes in the activity area due to only the change in the amplitude of the system, so the effect demonstrates how the behavior of each activity would be if the variation in the total area was evenly distributed among all activities (SANTOS; FARIA; TEIXEIRA, 2008).

Still following the Igreja (1987), similarly to the mathematical manipulations applied to equation (7), the scale and substitution effects can also be presented as annual average growth rates. In this sense, multiplying both sides of equation (14) by

$$\frac{1}{A_{jt} - A_{j0}}$$

one obtains:

$$1 = \frac{(\gamma A_{j0} - A_{jo})}{(A_{jt} - A_{j0})} + \frac{(A_{jt} - \gamma A_{j0})}{(A_{jt} - A_{j0})} \quad (15)$$

Then both sides of equation (15) are multiplied by the area effect, as defined in equation (10). Thus, one obtains:

$$EA = EA\frac{(\gamma A_{j0} - A_{jo})}{(A_{jt} - A_{j0})} + EA\frac{(A_{jt} - \gamma A_{j0})}{(A_{jt} - A_{j0})} \quad (16)$$

Em que,

$EA\frac{(\gamma A_{j0} - A_{jo})}{(A_{jt} - A_{j0})}$ it is the scale effect;

$EA\frac{(A_{jt} - \gamma A_{j0})}{(A_{jt} - A_{j0})}$ is the substitution effect.

Likewise, here scale and substitution effects are expressed in annual percentage rates of average growth of production of the j-th agricultural activity.

This study analyzed the changes in land use for agriculture in the Brazilian microregions, verifying the agricultural activities that most gained and most lost area in the period 1990-2016, identifying the advance of crops in the geographical units considered and the most relevant effects for the production of these activities. From this methodology, the results are presented in the next section.

4 Results and discussions

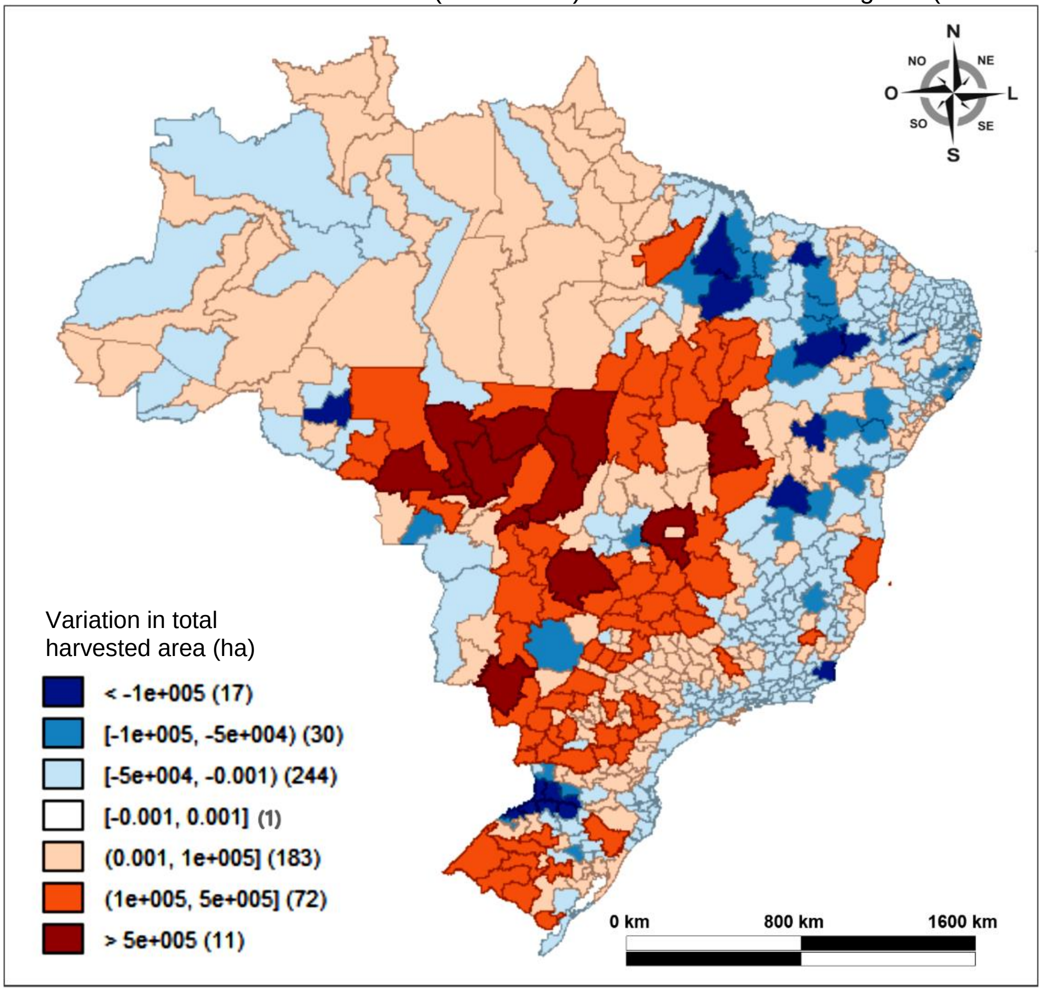
In order to analyze the changes in land use in the 558 Brazilian microregions between 1990 and 2016, this section initially makes an analysis of the harvested area from permanent and temporary crops, as well as the analysis of the variation in the total harvested area. Next, the effect of substitution and other effects on selected agricultural activities is verified and the main factors that drove the growth of the production of these activities in the mentioned period.

Firstly, considering the data on the 35 permanent crops and the 33 temporary crops available in SIDRA, it is observed that the total harvested area of agricultural activities increased from approximately 50.5 million hectares (ha) in 1990 to 75.3 million in 2016, with a positive variation of 49.05%, or an average annual growth of 1.55% p.a.. However, when the permanent and temporary crops are analyzed separately, there are quite different behaviors. The permanent activities showed a fall of 18.90% in the harvested area, which represents an average rate of -0.80% p.a., while the temporary activities increased by 60.01%, which indicates an average growth rate of the harvested area of 1.82% p.a. Thus, the growth of the area of temporary crops was due both to the expansion of the agricultural frontier and to the incorporation of areas formerly occupied by permanent crops.

In the Figure 2 shows the variation in the total harvested area (in hectares) in the Brazilian microregions from 1990 to 2016. In general, 266 microregions showed an increase in the total harvested area, with highlight to 72 that had elevation between 100,000 and 500,000 ha and 11 with gain of area above 500 thousand ha. Of the regions that had growth above 100 thousand ha, a concentration is observed in the states of Mato Grosso, Goiás, Paraná, southwest of Rio Grande do Sul, west of Minas Gerais, central region of Mato Grosso do Sul, west of São Paulo and at the junction between Maranhão, Tocantins, Piauí and Bahia (Matopiba).

Also in Figure 2, 291 microregions presented a drop in the total harvested area, mainly concentrated along the entire Brazilian east coast. Among the regions with losses of more than 50 thousand ha, there is a concentration in large parts of the states of Maranhão and Piauí, some regions in Bahia, west of Santa Catarina and extreme north of Rio Grande do Sul.

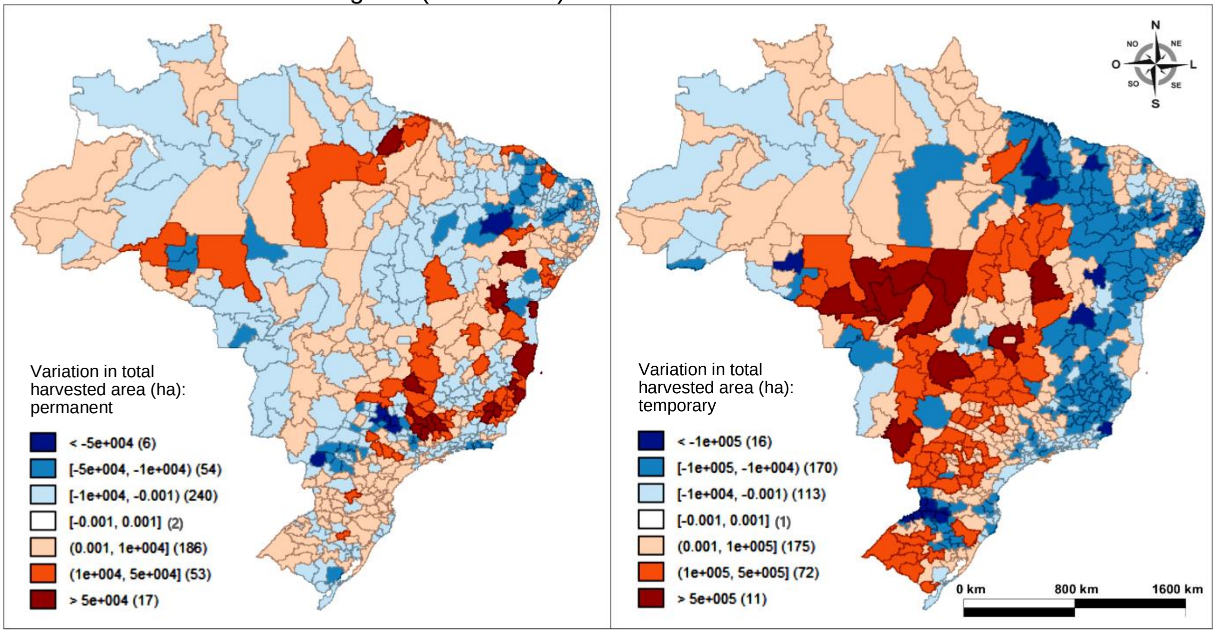
Figure 2 – Variation in total harvested area (in hectares) in the Brazilian microregions (1990-2016)



Source: authors, based on IBGE (2017) data, using GeoDa software.

Analyzed separately, as already mentioned and can be seen in Figure 3, while the permanent crops presented a reduction in the harvested area, the temporary crops had a very significant increase. Area gains in permanent agricultural activities are concentrated in the west and south of Minas Gerais, by the expansion of coffee and fruit growing, Espírito Santo, by the increase in the area for the production of rubber, coconut (coconut from Bahia) and other fruits, and southeastern Bahia, with the expansion of coffee, coconut, palmito (palm heart), guarana, dendê (oil palm), cacao, rubber and sisal. On the other hand, the evolution of the temporary crops shows a growth in the harvested area mainly in the Matopiba region, by the growth of soybean, maize and herbaceous cotton areas, and in the states of the Midwest region, by the growth of soybeans, maize and sugarcane, besides Paraná, also by soybean, maize and sugarcane elevation, and southwest of Rio Grande do Sul, by the expansion of soybean and rice.

Figure 3 - Variation in the harvested area (in hectares) in permanent and temporary crops in the Brazilian microregions (1990-2016)



Source: authors, based on survey data, using GeoDa *software*.

This increase in the harvested area from temporary crops set the tone for the significant growth in the total harvested area, as shown in Figure 2. In relation to the microregions of the Midwest and the Matopiba region, this increase is mainly due to the expansion of the agricultural frontier which was only possible due to the advent of new technologies that enabled agricultural production in the country's extensive savannah region (VIEIRA FILHO, 2014). The net gain of harvested area in the states with agriculture already fully developed, as in the case of São Paulo, Paraná and Rio Grande do Sul, may have occurred for several reasons, among them the replacement of livestock by agricultural crops. However, the hypothesis cannot be easily verified, or ruled out, by the scarcity of data exposed in the methodology.

In the Figure 2, shows that the micro-regions of the states of Maranhão, Ceará, Rio Grande do Norte, Paraiba, Pernambuco, Alagoas, Sergipe and Bahia had a considerable net loss of harvested area in the period under analysis, that this loss was more pronounced in temporary crops. The caatinga, which is the biome present in most of this region, is strongly affected by climatic phenomena such as *El Niño* that causes long periods of drought in the Brazilian northeast, which leads to significant falls in the harvested area, in production and, consequently, in the agricultural productivity of the region (MARENGO, 2008). This scenario has a double effect on the reduction of the area, since it impacts directly through losses and indirectly by discouraging farmers.

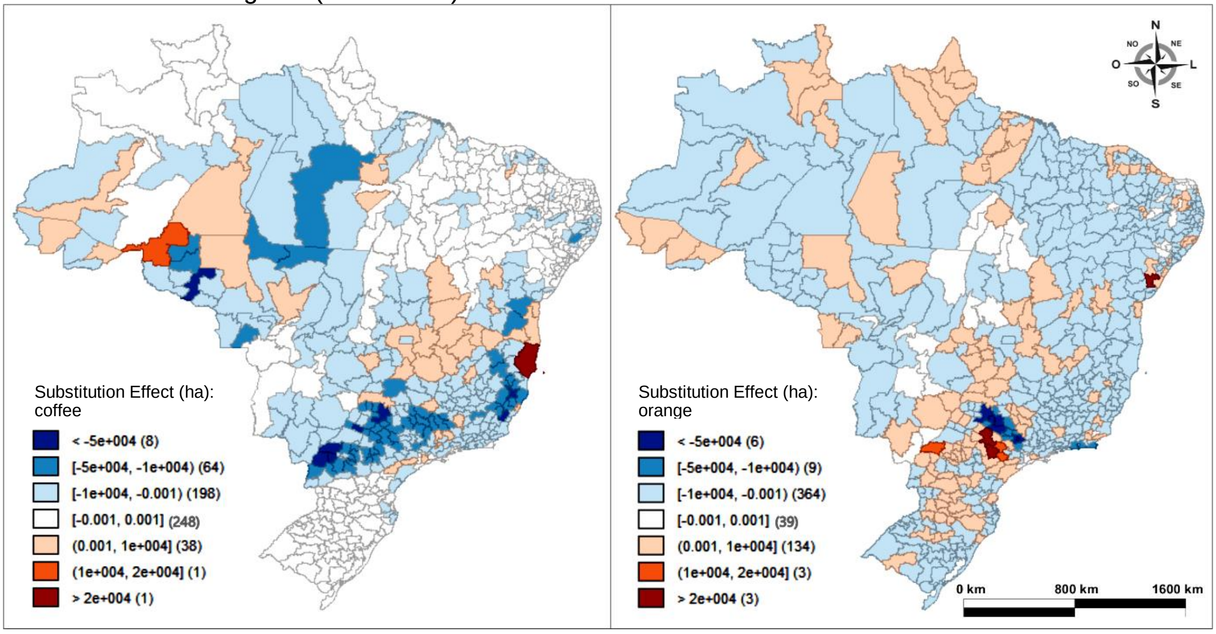
The fall in the harvested area from permanent crops was more spatially distributed, being relatively more concentrated only in the northwest of Paraná, mainly due to the fall in the coffee area, northeast of São Paulo, by the reduction in coffee and orange, and in some regions of Piauí, due to the decrease in cashew nut and arboreal cotton area. On the other hand, the negative variation in temporary crops was more evident throughout the Northeast of Brazil, with a decrease in cassava, sugarcane and herbaceous cotton crops in the east of Minas Gerais, with a reduction in herbaceous cotton in Espírito Santo and west of Santa Catarina, with soybean and wheat fall, and northern Rio Grande do Sul, with soybean reduction. In addition to the above-mentioned crops, all regions cited showed significant declines in areas harvested from rice, beans and maize.

Moving forward, some crops were selected for detailed analysis of the substitution effect and other effects of the same in the Brazilian microregions in the reference period. The choice of products was due to their relative importance in relation to the substitution effect in hectares, that is, we opted to analyze those activities that had the highest gains or the highest losses, in hectares, in relation to the total area movement harvested between all the products and in all the national territory.

Losses on harvested area from permanent crops were widely dispersed across crops. Therefore, among the selected agricultural activities, only two are permanent: coffee and orange. Figure 4 shows the substitution effect on the harvested area (in hectares) of the two crops in the Brazilian microregions between 1990 and 2016.

Considering the average substitution effect in Brazil by crop, coffee was the permanent activity that most lost harvested area in the period, with a fall of 2.34 million hectares, accounting for 11.32% of the entire negative substitution effect. Two microregions stood out with the elevation in the area: Porto Velho (RO) and Porto Seguro (BA). The reduction was more pronounced in some microregions of Paraná, São Paulo and Espírito Santo. This significant drop in the area negatively impacted production with a negative area effect of 1.19% p.a., generated by a positive scale effect of 1.86% p.a. (which shows the impact on production if the variation in the total area was evenly distributed among all activities) and a negative substitution effect of 3.05% p.a., 92% p.a.. This shows that, even with the considerable decrease in the area, with coffee giving space to other crops, the change of crop to regions with higher productivity guaranteed yield gains that prevented a decline in output, even if this growth was at a relatively low rate.

Figure 4 – Substitution effect on the harvested area (in hectares) of coffee and orange Brazilian microregions (1990-2016)

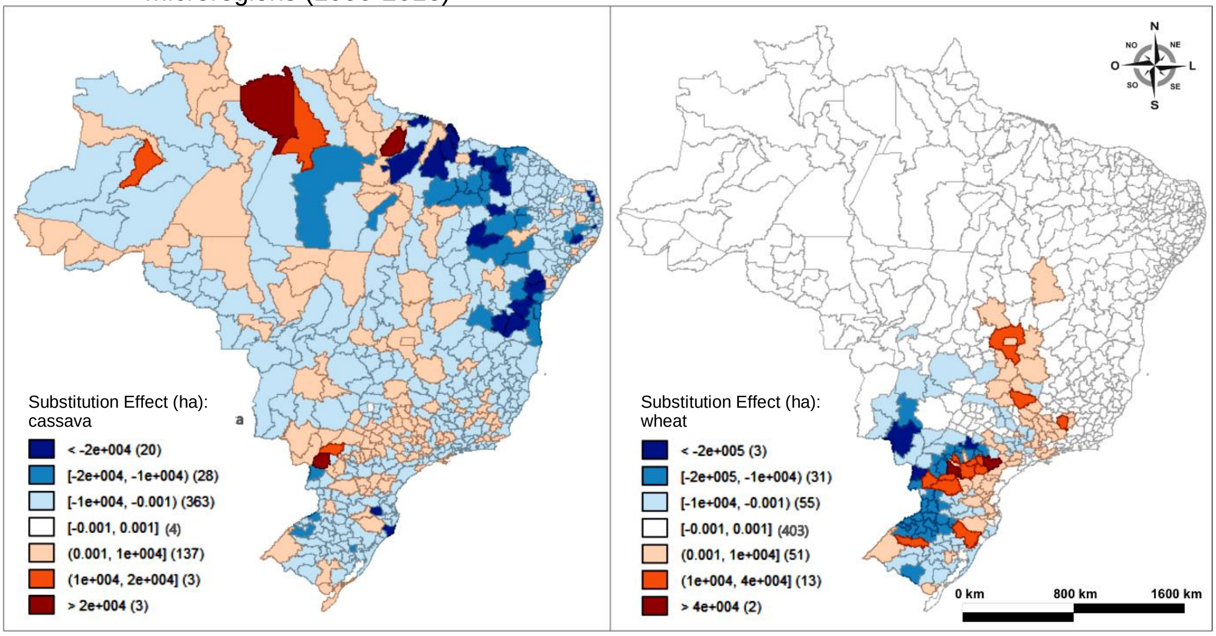


Source: authors, based on survey data, using GeoDa *software*.

In relation to the orange, there was a reduction of 701.9 thousand hectares, representing 3.39% of all the negative substitution effect, being this reduction quite dispersed spatially. In the microregions in which it was most concentrated, Figure 4 shows a migration of this crop from the northeast of São Paulo to regions closer to the center of the state. The orange yield was the one that fell the most among the selected crops, with an average rate of -6.06% p.a. This decrease was a reflection of a negative substitution effect of 5.80% p.a., which generated an area effect of -2.10% p.a. (considering the scale effect of 3.70% p.a.), and a negative yield effect of 4.08% p.a.. Although the effect geographic location indicates that there was migration to more productive areas, it was only 0.12% p.a..

Initiating the analysis of temporary agricultural activities, Figure 5 shows the substitution effect in the harvested area (in ha) of cassava and wheat in the Brazilian microregions during the analysis period. Cassava yielded approximately 1.48 million ha (7.16% of the total yield), with significant declines in much of the Brazilian northeast and gains in the northwest of Paraná and northwest and northeast of Pará. The cassava presented decrease in production at a rate of -0.55% p.a., resulting from a yield effect of -0.04% p.a. and an area effect of -1.13% p.a., the latter being strongly impacted by the substitution effect of -3.15% p.a.; only the geographic location effect was positive at 0.62% p.a.. Thus, although it migrated to regions with higher productivity, there was a reduction in total productivity and the substitution of cassava for other activities in the great majority of microregions showed capital for the fall in its production.

Figure 5 – Substitution effect on harvested area (in hectares) of cassava and wheat in the Brazilian microregions (1990-2016)



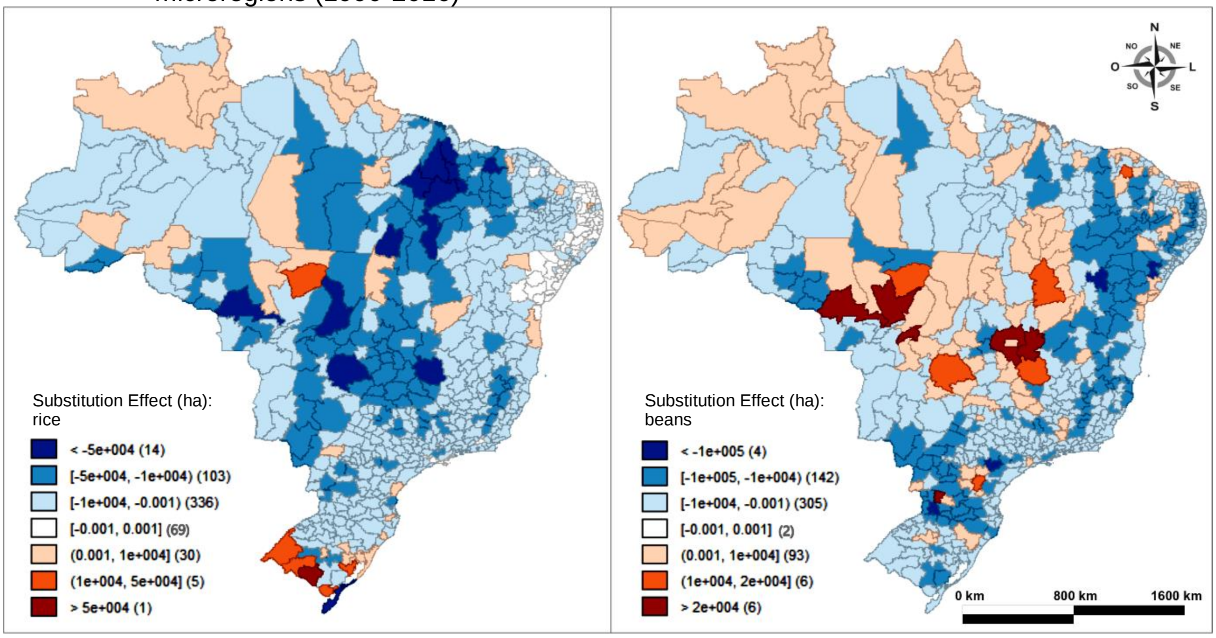
Source: authors, based on survey data, using GeoDa *software*.

Regarding wheat, although there is a slight elevation of the area in Goiás and Minas Gerais, the great majority of the Brazilian microregions do not have production due to the edaphoclimatic conditions necessary for their cultivation. This crop lost 1.83 million ha, approximately 8.84% of the total loaned, with considerable declines in southern Mato Grosso do Sul, in the west of Paraná, in the south-central of São Paulo and at the western junction of Santa Catarina and Rio Grande do Sul, and elevation mainly in the central region of Paraná and southeast of São Paulo. Even with a negative area effect of 0.49% p.a., generated by a substitution effect of -1.75% p.a. (considering a scale effect of 1.26% p.a.), wheat production was one of the fastest growing in the period, at a rate of 3.10% p.a. This growth in production was due to the effect of geographical location of 0.33 % p.a. and by the considerable increase in productivity, demonstrated by a yield effect of 3.26% p.a..

Two agricultural activities quite present in the Brazilian culture stood out for losing a relevant part of their harvested area: rice and beans. Figure 6 shows the substitution effect on the harvested area of these crops in the microregions. Rice lost 3.94 million ha (19.04% of the total lost by all crops), with a reduction in the great majority of microregions, especially in central Brazil and Maranhão, and in the west and southwest of Rio Grande do Sul and in the Sinop micro-region (MS). Even with the relevant drop in the area, represented by the substitution effect of -3.21% p.a. and an area effect of -1.63% p.a. (1.58% p.a. scale effect), the rice showed a rise in yield at a rate of 1.39% p.a., resulting from a yield effect of 0.91% p.a. and a geographic location effect of 2.11% p.a., indicating that migration to more productive regions was the one that most positively impacted the production.

Bean was the temporary culture that most ceded area to other activities (considering the average substitution effect) with a fall of 4.39 million hectares, or 21.23% of the total, in the states of Santa Catarina, Paraná, Mato Grosso do Sul, Rondônia and northeastern states. The regions that increased the harvested area with the product were the south-west of Paraná, center-west of Mato Grosso, around the Federal District and western Minas Gerais. Substitution of the bean by other crops is evident by the substitution effect of -3.34% p.a. which, considering a scale effect of 1.75% p.a., caused an area effect of -1.59% p.a.. Nevertheless, given the increase in productivity, expressed by a yield effect of 2.03% p.a., and the location effect of 0.18% p.a., there was a growth of bean production in Brazil at an average rate of 0.61% p.a..

Figure 6 – Substitution effect on harvested area (in hectares) of rice and beans in the Brazilian microregions (1990-2016)

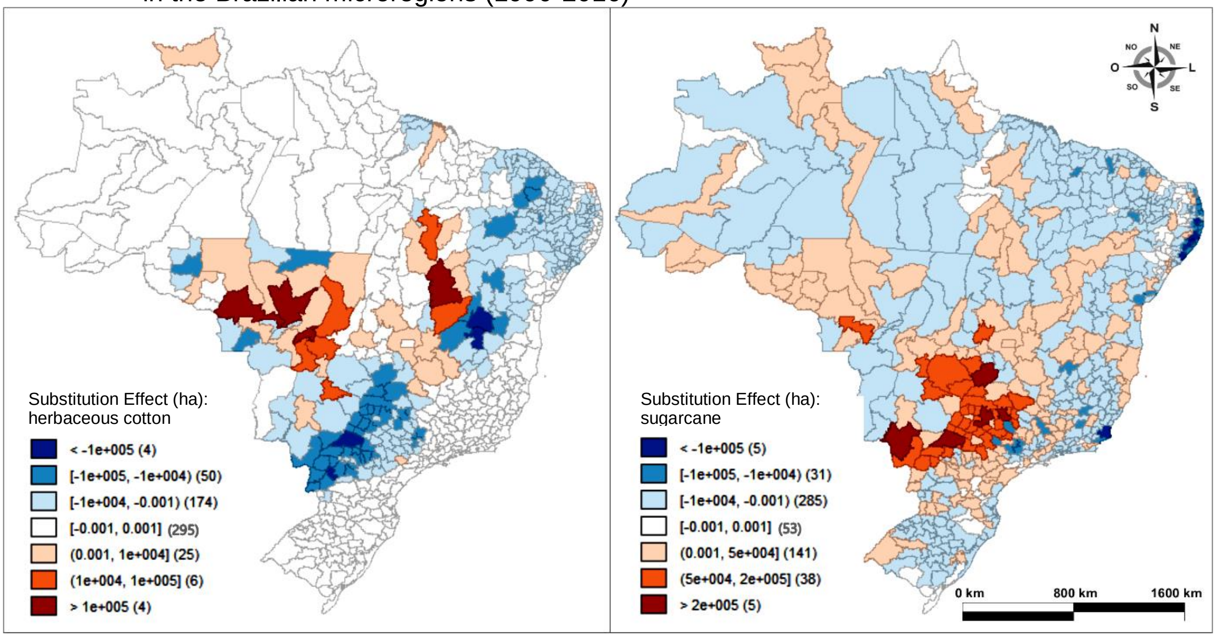


Source: authors, based on survey data, using GeoDa *software*.

The substitution effect in the harvested area from herbaceous cotton and sugarcane in the Brazilian microregions from 1990 to 2016 is shown in Figure 7. The average fall in the harvested area with herbaceous cotton was 1.08 million ha (5.21%

from total), being distributed in the south of Bahia, as well as other regions of northeast of Brazil, in the north of Minas Gerais and along the strip that interconnects the west of Paraná, south and east of Mato Grosso do Sul, west of São Paulo, a mining triangle and south of Goiás. Some regions in Mato Grosso and northwest of Bahia stand out because of the elevation in the cotton area. This fall impacted negatively the production, with a negative area effect of 0.78% p.a., generated by negative substitution effect of 2.13% p.a. (given the scale effect of 1.35% p.a.); However, the effect geographic location was positive enough (4.32% p.a.) to guarantee a significant growth in production of 2.59% p.a., demonstrating that migration to regions with higher productivity guaranteed and expansion of the quantity produced.

Figure 7 – Substitution effect on the harvested area (in hectares) of herbaceous cotton and sugarcane in the Brazilian microregions (1990-2016)

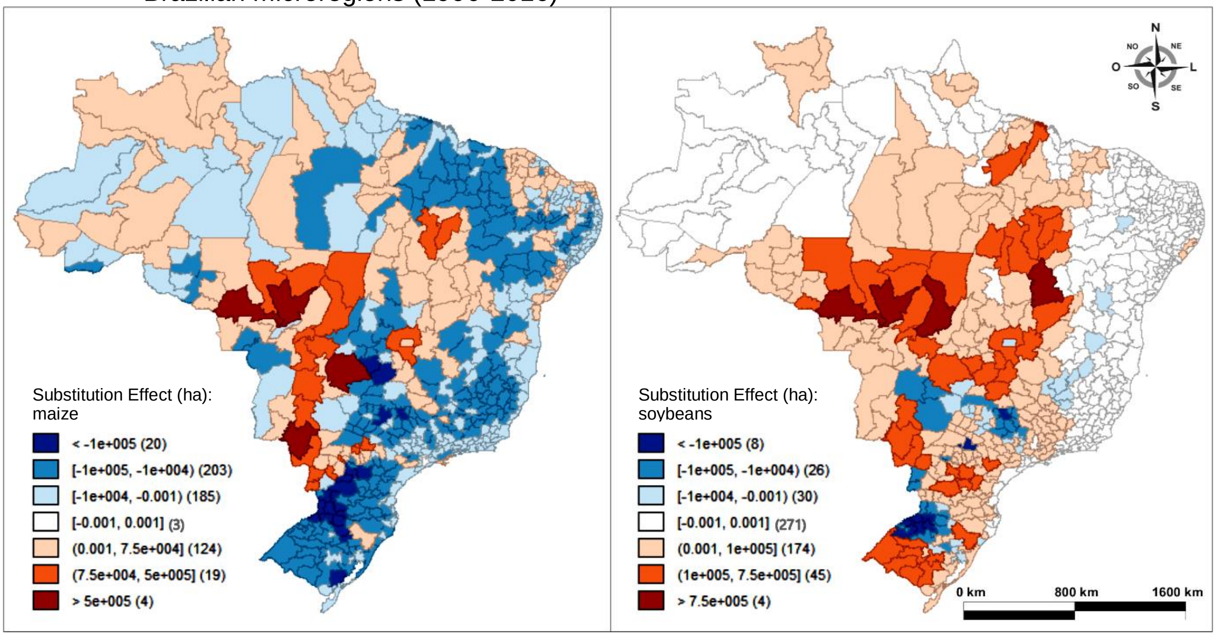


Source: authors, based on survey data, using GeoDa *software*.

About sugarcane, this was the second activity that most incorporated areas of other crops, with a positive substitution effect of 3.86 million hectares, representing 18.65% of all positive substitution effect. There was shift of this activity from the northeastern coast to São Paulo, north-west of Paraná, Mato Grosso do Sul, Minas Gerais, Triângulo Mineiro and Goiás. Sugarcane production was the third highest in the period, at an average rate of 4,22% p.a., and was the only activity with all the positive effects. The effect that most boosted production was the area, with an average rate of 3.05% p.a., summing a 1.07% p.a. and a substitution effect of 1.98% p.a., demonstrating an expansion over areas formerly destined for other crops and also over previously unused areas in agriculture. The migration to more productive regions is evident by the geographic location effect of 0.71% p.a. and by the yield effect of 0.45% p.a..

In order to conclude the disaggregated analysis of selected crops, Figure 8 shows the substitution effect in the harvested area of two main Brazilian agricultural activities: maize and soybean. Despite having lost a large part of its harvested area, 2.02 million ha (9.78% of the total), maize production in Brazil was the second one with the highest growth, with an average rate of 4.32% (0.67% p.a.) and the highest income effect among selected crops: 4.17% p.a.. The fall in the area had a small negative effect on production, evidenced by the substitution effect of - 0.38% p.a., but as the scale effect was 1.06% p.a., the area effect was positive, indicating an expansion to areas that were previously non-agricultural. Maize area losses are observed in most microregions in the South, Southeast and Northeast regions of Brazil, with a higher concentration in north of Rio Grande do Sul, west of Santa Catarina and center-south of Paraná, and the gains area were more concentrated in the northwest of Paraná, central vertical range of Mato Grosso do Sul, southwest of Goiás, several microregions of Mato Grosso and at the junction of Maranhão and Piauí.

Figure 8 - Substitution effect of on the harvested area (in hectares) of maize and soybeans in the Brazilian microregions (1990-2016)



Source: authors, based on survey data, using GeoDa *software*.

On the other hand, soybeans stand out as the crop that most incorporated other activities, expanding its harvested area to 16.03 million hectares, which is equivalent to 77.49% of total area effect (ha). The falls were more concentrated in the western junction of Rio Grande do Sul and Santa Catarina, northeast of São Paulo and southwest of Minas Gerais; and the gains are evident in most of the micro-regions of southern Rio Grande do Sul, central Paraná, Central-West Brazil and Matopiba. Soybean production was the one that grew the most during the period, at an average rate of 6.25% p.a., generated by the greater positive substitution effect (2.27% p.a.) and a scale effect of 0.80% p.a., which culminated in higher area effect (3.07% p.a.), in addition to the second largest income effect of 3.65% p.a..

Maize and soybean were the only activities among those selected for analysis that presented negative geographical effects, with -0.52% p.a. and -0.47% p.a., respectively. Although the amplitude is small, this indicates an expansion in areas of lower productivity, which is evident in Figure 8, which shows positive substitution effects in the Brazilian Midwest and in Matopiba, regions with more recent and still developing agricultural exploitation, in terms of productivity. Even so, the two cultures showed the highest average rates of production growth, 4.32% p.a. for maize and 6.25% p.a. for soybean, driven by the also higher positive yields, of 4.17% p.a. and 3.65% p.a., respectively. Thus, the gain in productivity was the most relevant factor for the increase of the production of said grains.

Of the selected activities, the only two with positive substitution effects were sugarcane and soybeans, which together were responsible for incorporating 96.14% of total area provided by other activities. On the other hand, coffee, orange, cassava, wheat, rice, beans, cotton and maize had negative substitution effects, yielding 85.98% of the area incorporated by other crops. It should be noted that cassava and orange crops were the only ones with a reduction in production in the analyzed period. Not coincidentally, the activities that had the greatest negative substitution effects were also among the activities, and for orange the drop in production was even more pronounced due to the significant fall in productivity.

Thus, when analyzing the results of the study and presenting the notes and the discussions about them, the next section concludes the present research with the conclusions.

4 Conclusions

The article analyzed in general the changes in land use in the 558 Brazilian microregions, between 1990 and 2016, in order to verify the agricultural activities that most gained and most lost area in the period and to identify the main factors that drove the growth of production country in this period.

Through the data analyzed, there was a significant increase of about 49.05% in the total harvested area of agricultural activities, mainly due to the expansion of the Brazilian agricultural frontier, whose evolution to the Midwest and the area called Matopiba caused major changes in the country's agriculture. While permanent activities showed a decrease of 18.90%, temporary activities increased by 60.01%, showing a growth of these last ones also by the incorporation of areas formerly occupied by permanent crops.

Of the ten activities selected for detailed analysis of the effects, the main result was that 96.14% of the area ceded by other crops was incorporated by only two activities, sugarcane and soybean. Maize was the crop with the highest productivity gain in the period. Soybeans, maize and sugarcane showed the highest average growth in production. In spite of this, of the eight selected crops that had fallen in the area, all (excepting cassava and orange) had an increase in production, driven by positive geographical effects and / or yield. This shows a strengthening of activities in which the country already has international prominence in the production and the strong positive influence of the technological gains to the national agricultural productivity.

It should be noted that the Alto Pantanal and Jauru microregions in Mato Grosso together account for 31.71% of the natural area from Pantanal Biome's, and the entire state concentrates 38.79%; and the micro-region Baixo Pantanal, in Mato Grosso do Sul, accounts for 48.37% of this biome, and the state accounts for 61.14% (EMBRAPA, 2007). The three microregions together account for 80.07% of the biome and in the three there was a net fall in the harvested area from both permanent and temporary crops, indicating that there was no advance of agricultural activity on the Pantanal in the period. In the states of Legal Amazon, the elevations in the area are more relevant in Mato Grosso, eastern Pará, southeast of Rondônia and Tocantins. More detailed studies are needed to verify the areas of expansion in these regions, also considering livestock and deforestation.

Therefore, for further research, it is suggested to deepen this study, considering qualitative analyzes that better explain the behavior of each agricultural activity and the effects found here. In addition, there is a need for detailed investigation of regional particularities that may have influenced agricultural development in the same.

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