Determinants of Agricultural Diversification in Brazil: A Spatial Econometric Analysis

by José Luiz Parré and André Luis Squarize Chagas

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Abstract:

This research has as main objective to analyze the behavior and the importance of agricultural diversification for Brazil, considering its States, for the period from 2002 to 2018. We will propose an analytical model to make it possible to identify the determinants of agricultural diversification in Brazil. Empirically, the study will proceed by estimating an SLX model using panel data and considering the spillover effects, highlighting the importance of location and neighborhood. The study's findings indicate a continued decline in crop diversity with a strong tendency to productive specialization in Brazilian agriculture, mainly in the states located in the Midwest and South regions of the country. The average rates of growth of the indexes presented negative values for the period of analysis: -0.41 % per year for the Simpson index, -0.58% per year for the Shannon index and -0.91% per year for the effective number of crops. It is important to note that some states are allocating practically the entire agricultural area to three or four dominant crops. As for the determinants of agricultural diversification, the results for Brazil are in line with the specialized literature.

Keywords: Agricultural diversity; agricultural diversification indexes; model SLX; data panel; public research.

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1. Introduction

In recent decades, agricultural development has been driven by a modernization paradigm based on specialization (of production), intensification (technological) and gains in scale. The economic logic of this model is based on the search for economies of scale and highly efficient technical production. The increase in specialization, despite improving the technical capabilities of farmers, may weaken their economic resilience as farmers become dependent on the price stability of commodity markets. As input and product prices become more volatile, production risk may increase and compromise the sector's economic sustainability.

According to de Roest et. al. (2017), agriculture’s weakened economic resilience has been exacerbated by the gradual dismantling of the producer price support system, causing an increase in price volatility, which is an almost universal phenomenon. Highly specialized agriculture is only viable when markets are stable and this requires effective market agencies and a good contract environment. In addition, society’s growing demand for more sustainable agriculture and the climate problems affecting the sector, have led many farmers to rethink their agricultural development strategies. They are rediscovering agricultural diversification as a way to reduce market risks, in addition to improving the efficiency of the organization and the use of sector resources.

In this scenario, the diversification of agricultural production emerges as a rational production strategy that can play a role of significant importance to reduce the risks inherent in agricultural activity and positively impact nutritional and environmental aspects in a world with nutritional problems and major environmental changes. Several international studies have already verified the positive impact of diversification of agricultural production, such as Di Falco and Chavas (2008), Di Falco, Bezabih and Yesuf (2010), Chavas and Di Falco (2012), Gurr et al. (2016), Donfouet et al. (2017), Waha et al. (2018). In Brazil, research on agricultural diversification is in its initial phase, with emphasis on Sambuichi et al. (2016), Caldeira (2019) and Piedra-Bonilla et al. (2020a). However, there is no study for Brazil explaining the behavior of diversity and its determinants, as proposed in this article.

Considering the importance of the theme of diversification of agricultural production for the competitiveness of the sector, it is necessary to investigate the level of diversification of the production of Brazilian agriculture, as well as the distribution pattern of agricultural diversification in the Brazilian territory and its spatio-temporal behavior. In addition, we intend to answer two important questions: (i) what are the determinants of agricultural diversification in Brazil?; (ii) Is the adoption of diversification as a strategy for farmers in a region influenced by the characteristics of neighboring regions (spillover effect)?

In addition to filling gaps in the knowledge of the regional growth dynamics of this important sector of the Brazilian economy, the study also contributes by incorporating spatial analysis techniques in the proposed analytical model to identify the determinants of agricultural diversification in Brazil, making it possible to verify the existence of spillover effects between the regions.

In this sense, the general objective of the article is to study the behavior of agricultural diversification for the States of Brazil, for the period from 2002 to 2018. Specifically, we intend to calculate and analyze different agricultural diversification indexes for all States and to estimate an empirical model that allows the identification of the main indicators that affect the behavior of this index, as well as if there was a difference in the growth dynamics of this index over the study period.

The hypothesis tested in the article is that, for the structural and socioeconomic conditions typical of Brazilian agriculture, characterized by a concentration of incentives in certain crops, high structural costs, low investment and poor qualification of the labor force, there was a decrease in agricultural diversification in the states of the country influenced by factors associated with demand, technology and available infrastructure.

To meet these objectives, the article is divided into four parts, in addition to this introduction. The second section deals with the main international and national studies on agricultural diversification; the third section presents the methodological procedures adopted in the research; the fourth section presents the results; final considerations are in the fifth section.

2. Literature Review

2.1. Concepts of agricultural diversity and diversification.

Diversity means a characteristic or state of what is diverse, different, diversified. While diversification means the action of diversifying, altering, transforming. Therefore, unlike what is found in some articles in the literature, the terms are not synonymous. They deal with the same situation, but the term diversity serves to define a characteristic of the study population, being, therefore, more suitable to name an index. In turn, the term diversification is more appropriate to refer to possible changes in the behavior pattern of a population in relation to its composition.

Generally speaking, a region or agricultural property can be considered diversified if it grows multiple agricultural crops instead of focusing on a single crop (monocrop). However, the concept of agricultural diversity can encompass different aspects and meanings, including diversity of cultivated crop species, varietal diversity within crop species and genetic diversity within crop varieties and species (Aguilar et al., 2015). In addition, there may be diversity in the sense of using productive resources together in varied agricultural activities (crop activities) and activities that incorporate other forms of income generation (non-crop activities), such as livestock, agritourism, sales and processing of products on the farm, nature conservation activities, land leasing (Vroege et al., 2020; Monteleone et al., 2018). In this study, we will adopt the concept of agricultural diversity that considers only agricultural production activities within the property, in the same line of action by Aguilar et al (2015); Monteleone et al. (2018); Di-Falco et al. (2017); Donfouet et al. (2017) and Bellon et al. (2020).

2.2. Importance of agricultural diversification.

Although modern market-based agriculture has been extremely successful in meeting the needs of food and energy for an expanding global population, the techniques used and productive specialization may have reduced biodiversity in rural areas and made producers dependent on the sector's price stability. An alternative to this development model, called market-based agricultural diversification, predicts a shift from monoculture to a variety of crops to meet market demand at different times of the year, eventually leading to a transfer of resources from a crop to a wider mix of crops with the aim of increasing the sector's income and profit (Bellon et al., 2020).

The relevance of agricultural diversification is widely documented in the literature. Studies show that diversification plays an essential role in ensuring food/nutrition security and stabilizing food production (Bellon et al., 2016; Waha et al., 2018), in addition to mitigating the uncertainty and economic risk faced by farmers, particularly if the risks associated with different crops are not related (de Roest et. al., 2017; Di Falco & Chavas, 2008; Di Falco & Perrings, 2005). Several studies also show that agricultural diversification brings technical and environmental advantages to agriculture, preserving biodiversity and establishing a better functioning of the agro-ecosystem, increasing the resistance of agriculture to climate change (Davis et al., 2012;

Monteleone et al., 2018; Liebman & Schulte, 2015; Lin, 2011; Donfouet et al., 2017). The diversification of the production can also bring market advantages, making it possible to migrate from the commodities market to the sale of differentiated goods, with higher market value, such as organic products, local products, sustainable products (Bowman & Zilberman, 2013; de Roest et. al., 2017).

In Brazil, research on agricultural diversification is in its initial phase, with emphasis on Sambuichi et al. (2016), Caldeira (2019) and Piedra-Bonilla et al. (2020b). However, national surveys present the format of case studies, evaluating family farming or specific regions, It is important to study the topic more broadly, due to its complexity and the heterogeneity of Brazilian agriculture. There are no studies for Brazil that bring the contribution proposed in this article, treating diversity as a dependent variable and trying to explain its behavior over time through a spatial econometric model of determinants.

3. Methodology

For this research, given the objective of building indicators for agricultural diversification in Brazil and verifying the determining factors of diversification, it will be necessary to divide the methodology into sub-items. Initially, we present the methodological proposal to calculate and analyze the diversification, following we present an item dealing with the research database. Finally, we present the methodological proposal to estimate the effects of the determinants of agricultural diversification in Brazil.

3.1. Agricultural Diversification Index

To check the evolution and behavior of agricultural diversity in the states of Brazil, the following indicators are calculated: Simpson index (D), Shannon index (H) and the Effective Number (EN) (Shannon, 1948; Simpson, 1949; Magurran, 1988). These indexes show similar behavior and share the same basic input (proportion of individuals in relation to the total), with EN derived from H.

The Shannon diversity index is constantly used in agricultural diversity studies (Donfouet et al., 2017; Monteleone et al., 2018) being expressed by:

$$H' = -\sum_{i=1}^{n} p_i \ln p_i \qquad H' \geq 0 \qquad (1)$$

Where p_i is the proportional area of the i-th crop in the total area planted in a specific geographic location (State); n is the total number of crops grown in the area. According to Magurran (1988), the Shannon index normally presents values between 1.5 and 3.5.

The Effective Number is an indicator of diversity derived from the Shannon index:

$$EN = exp^{H'} \qquad EN \geq 0 \qquad (2)$$

According to Aguilar et al. (2017) EN is an easily interpretable index, the value of which represents an estimate of the number of crops that dominate production in a given region. The authors present an illustrative example, if a region is producing 10 crops with each one accounting for 10% of the planted area, it would have an EN = 10, while a region producing 10 crops with only one crop occupying 91% of the cultivated area and the other nine occupying 1% of the total area would have an EN = 1.65.

The Simpson diversity index was adopted by several authors to analyze agricultural diversity (Sambuichi et al., 2016; Sen et al., 2017; Piedra-Bonilla et al., 2020a; Bellon et al., 2020). According to Magurran (1988), the Simpson index indicates the probability that any two individuals drawn at random from an infinitely large community belong to different species. Still according to the author, the Simpson index is strongly weighted in relation to the most abundant species in the sample, although it is less sensitive to species richness; assuming the maximum value of 1, when there is only 1 species (complete dominance), and values close to zero when there is a high number of species; thus, as the value of the index increases, diversity decreases[1]. For this reason, Simpson index is generally expressed as its value subtracted from 1, making interpretation more intuitive, the higher the index, the greater the diversity:

$$D = 1 - \sum_{i=1}^{n} p_i^2 \qquad 0 \leq D \leq 1 \qquad (3)$$

Where p_i is the proportional area of the i-th crop in the total area planted in a specific geographic location (State); n is the total number of crops grown in the area.

In the econometric analyzes of this study, we adopted the Simpson index for the following factors: a) shows a similarity with the Herfindahl index, which is widely used in economic literature to measure the concentration of a specific sector; b) the index scale ranges from 0 to 1, its interpretation being simpler and comparable between regions.

3.2. Database Specification

In the agricultural environment, diversification may be related to different activities, including the production of different types of crops, such as permanent, temporary crops, forestry, fish farming, livestock, besides being able to present several genetic varieties in the same crop (SAMBUICHI et al., 2014).

In this research, we will choose to work with the diversification of agricultural production considering temporary and permanent crops in the analysis – according to the classification by IBGE(2010), determining the level of agricultural diversification in the regions analyzed. It is noteworthy that in this analysis only agriculture is verified, disregarding the other productive activities (forestry, livestock, etc); Aguilar et al (2015) and Donfouet et al. (2017) also adopted this procedure. We can consider two justifications for this procedure, firstly, we seek to investigate the process of increasing monocrops in agriculture in the region and secondly, in the available data the harvested area is not a

[1] According to Magurran (1988) this initial version of the index is given by $\sum_{i=1}^{n} p_i^2$

common measurement unit among other activities, for example, in forestry, many products are accounted for in tons, which would make the construction of the index impossible. For the calculation of the agricultural diversification index in Brazil, by Federation Units, data were used on the area planted in hectares (ha) of 64 agricultural crops obtained from the Municipal Agricultural Production database (PAM), research carried out by the Brazilian Institute of Geography and Statistics (IBGE, 2019).

As the present article will use a spatial panel of data for the States (Units of the Federation) of Brazil to analyze the determinants of agricultural diversification in the period from 2002 to 2018, other sources of secondary data will also be considered to obtain the other research variables, all for the period from 2002 to 2018. The series that present monetary values used in this article were deflated based on the General Price Index - internal availability (IGP-DI) -, prepared by Fundação Getúlio Vargas (FGV), based in December 2010.

Table 1 presents a list of variables that were used in the research, with their description and the respective basic sources.

Table 1: Variables used in the research.

Var.	Description	Source
ID	Agricultural diversity indices (Simpson, Shannon and Effective Number)	PAM – IBGE
POP	Population	IBGE
GDPpc	GDP per capita (corrected values - base 2010)	IBGE
VAAgrop	Gross value added of agriculture/Total gross value added	IBGE
PROD	Productivity – Gross Value of Agricultural Production (GVP)/Planted Area	PAM – IBGE
USO	Planted area/KM2 State	IBGE
STOR	Static capacity warehouses/total agricultural production	CONAB, IBGE
CRED	Agricultural credit/ Gross Value of Agricultural Production (GVP)	BACEN

The choice of explanatory variables followed the literature related to the study of agricultural diversity (Benin et al., 2004; Anwer et al., 2019; Di Falco & Zoupanidou, 2017; Donfouet et al., 2017; Sambuichi et al., 2016). The POP and GDPpc variables represent the effects of demand from regions on the adoption of diversity by farmers. The

VAAgrop variable characterizes the economic profile of the states, indicating the importance of the agricultural sector in relation to the total sectors of the economy. The technological characteristics of the states' agriculture are captured by the variables PROD and USO, representing productivity (average yield) and intensity of use of agricultural land. Finally, the variables STOR and CRED can be considered as proxies of available infrastructure for the agricultural sector in the states.

3.3. Empirical Strategy

According to Di Falco & Zoupanidou (2017) agricultural production is a dynamic process that involves the choice of inputs to obtain a certain level of production. Another important decision by farmers is about which crops they will produce in a given period of time (safra). The decision on which products will be produced and in what quantity involves an analysis of the socio-economic and physical environment, considering the characteristics of farmers and agricultural properties, the resources and technologies available, the demand and prices of different products, the incentives received, the natural characteristics of the production region (Anwer et al., 2019; Benin et al., 2004; Sen et al., 2017; Culas & mahendrarajah, 2005; Donfouet et al., 2017; Waha et al., 2018; Davis et al., 2012; Bellon et al., 2020).

Some of the factors that explain the adoption of diversification by farmers in a given property or region may be influenced by the neighborhood, in technical terms, there may be an indirect overflow effect of an explanatory variable that is in one region influencing the dependent variable of another region (spatial spillover). In this sense, the SLX model (Spatial Lag of X) will be adopted in this study, which incorporates the spatial effects in the explanatory variables. The adoption of the SLX model is also justified by observing the specific characteristics of Brazilian agriculture in which the physical and cultural aspects are more similar between close regions than between distant regions, for example, the rainfall regime of a region is generally similar to that of the neighboring region, or the use of agricultural technology occurs in certain regions.

According to Vega & Elhorst (2015), the SLX model has the advantage that the spillover effects are more direct, both in terms of estimation and interpretation, they are also more flexible than the normally used SEM models (spatial error model), SAR (spatial autoregressive model), SAC (spatial autoregressive combined) and SDM (spatial Durbin model).

The SLX model is defined as:

$$Y = X\beta + WX\theta + \varepsilon \tag{4}$$

Direct effects and spillover effects do not require additional calculations on the SLX model. The direct effects are the estimates of the coefficients of the basic variables (non-spatial, β_k) and the spillover effects are those associated with the spatially outdated explanatory variables (θ_k). According to Vega & Elhorst (2015), in the SLX model there are no prior restrictions imposed on the relationship between direct effects and spillover effects, which is a limitation of the SAR and SAC models.

Some econometric problems can arise when estimating the equation (4). In Brazil, within the process of agriculture modernization and the specificity of each region, some characteristics of the sector are unevenly distributed across regions and may imply regional heterogeneity. The use of a data panel model helps in adjusting parameter estimates as it controls cross-sectional heterogeneity and unobserved values. In this sense, the layout of the data in a panel has some advantages in relation to the use of cross section data: one of the first advantages is that the panel data increases the number of observations, increasing the degrees of freedom and thus reducing the collinearity between the variables; another advantage is the possibility of observing phenomena linked to the behavior of variables over time; in addition, the analysis with panel data reduces the effects caused by omission or poor specification of variables correlated with the explanatory variables, thus being able to control the heterogeneity between the observations, isolating the effects of these unmeasured variables. These unobserved effects that cause spatial heterogeneity can be measured by fixed and random effects models. In the first, heterogeneity manifests itself in the intercepts and in the second in the error component.

Therefore, in the present study, we estimate a-spatial and spatial data panels (SLX model) for the states of Brazil (26 states and the federal district) in the period from 2002 to 2018 (17 years), totaling 459 observations.

Specifically, to verify the determinants of agricultural diversification, the following a-spatial function will be estimated:

$$D_{it} = \beta_0 + \sum_{j=1}^{N} \beta_j X_{j,it} + \varepsilon_{it} \quad (5)$$

Where D is the Simpson index, β_0 is the constant term; j are the independent variables (Table 1), t is the time period; i are the space units (States); ε_{it} is the error term.

The functional form of the SLX model is obtained by adding the spatial lags of the explanatory variables:

$$D_{it} = \beta_0 + \sum_{j=1}^{N} \beta_j X_{j,it} + \sum_{j=1}^{N} \theta_j WX_{j,it} + \varepsilon_{it} \quad (6)$$

The models will be compared using spatial dependency tests to see if the SLX model really eliminates the spatial dependence on the estimated residuals. For this purpose, the local Pesaran CD (p) test is applied (2004) and the randomized test R(w) by Millo and Pirras (2018), for a-space panel (5) and SLX panel specifications (6).

The spatial weighting matrix (W) used to obtain the spatial lags was a matrix of k-nearest neighbors with 3 neighbors to capture the local neighborhood. Other specifications of the weight matrix were tested and the results of the estimates generate the same conclusions.

4. Results

4.1. Evolution of agricultural diversity indexes in the States of Brazil

To contextualize the discussion that presented in this article, initially, we present the evolution of the diversity indexes calculated for the states of Brazil (26 states and the Federal District) from 2002 to 2018. Diversity studies generally assume that diversifying is important for the sector, for farmers and the environment, but do not provide information on their behavior over time (Bellon et al., 2020; Di Falco, et al., 2017). An exception is the study by Aguilar et al. (2015) in which they used data from the US Agricultural Census, to quantify agricultural diversity for the United States at the municipal level from 1978 to 2012. The authors' findings indicated that diversification has declined in the US, but that changes in crop diversification have varied between and within agricultural production regions.

Figure 1 clearly demonstrates a trend towards a decrease in the average values of the diversity indexes for the Brazilian states during the analyzed period. This decrease in the diversity of the agricultural production agenda in the country is causing a concentration of production in a few products, as it was also verified by Piedra-Bonilla et al. (2020a), who assessed the evolution of agricultural and agricultural-forest diversity for Brazil using the Simpson and Shannon indexes, considering the value of production. Although the authors use data at the municipal level, their results have been aggregated for five major regions of Brazil. Despite the differences in data treatment, both studies clearly show a concentration on agricultural production in Brazil.

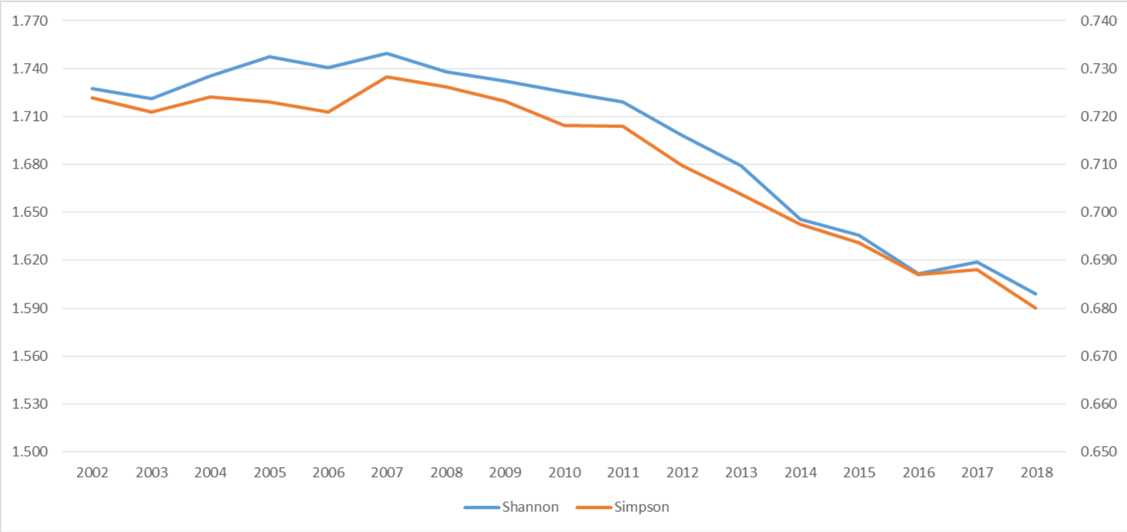

Figure 1: Shannon and Simpson indexes for the States of Brazil – 2002 to 2018. Source: Research results. Obs. - Left axis referring to Shannon and the right referring to Simpson. Medium values.

The values of the Shannon index decreased from 1.72 in 2002 to 1.60 in 2018 and the Simpson index varied from 0.72 to 0.68 in the same period. However, the biggest drops in the indexes can be seen from the 2009-2010 period, mainly influenced by a concentration of production in the states of Rio Grande do Sul (RS), Paraná (PR), Santa Catarina (SC), Mato Grosso (MT), Mato Grosso do Sul (MS) and Goiás (GO), important producing regions of the country. In these states there was an increase in the area of sugar cane, corn and soybeans; on the other hand basic products like rice, beans and potatoes showed a decrease in cultivated area. Aguilar et al. (2015) also observed similar behavior for some regions of the USA, explaining that genetic improvements and technological advances associated with increased demand and rising prices, have made corn and soy a profitable combination for many producers.

This change in the production of the states can be seen in the changes in the diversity indices presented in figures 2 to 4. For the construction of these Figures, all states of Brazil and the Federal District were considered and three years of the study (initial - 2002, final - 2018 and an intermediate year - 2010). There is a peculiar behavior for each state of the federation, however, the majority shows a decrease in the diversity captured by all indexes.

Figure 2 shows the evolution of Simpson's diversity index (which is adopted in the regressions of this study). There is a great variability in the index values, with the lowest value of 0.476 being obtained for the state of Alagoas (AL) in 2010 and the highest value of 0.881 was calculated for the state of Bahia (BA) in 2010 also. Despite the decline in diversification over the period, most states had a Simpson index value above 0.65 in 2018, which can be considered a diversified agriculture.

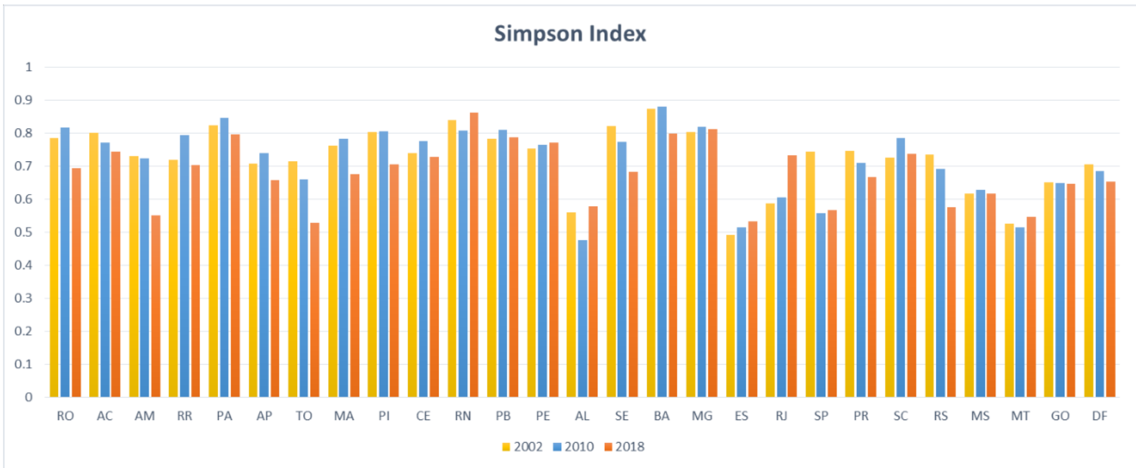

Figure 2: Simpson indexes for the States of Brazil – 2002, 2010, 2018.
Source: Research data.

Figure 3 shows the evolution of the Shannon diversity index for the states of Brazil. Despite the difference in the scale, the behavior is similar to the previous one, with the lowest value of 1.07 being obtained for the state of Mato Grosso (MT) in 2018 and the highest value of 2.51 was estimated for the state of Bahia (BA) in 2010. Highlight for the low values of diversity presented by the states of the Midwest region of the country.

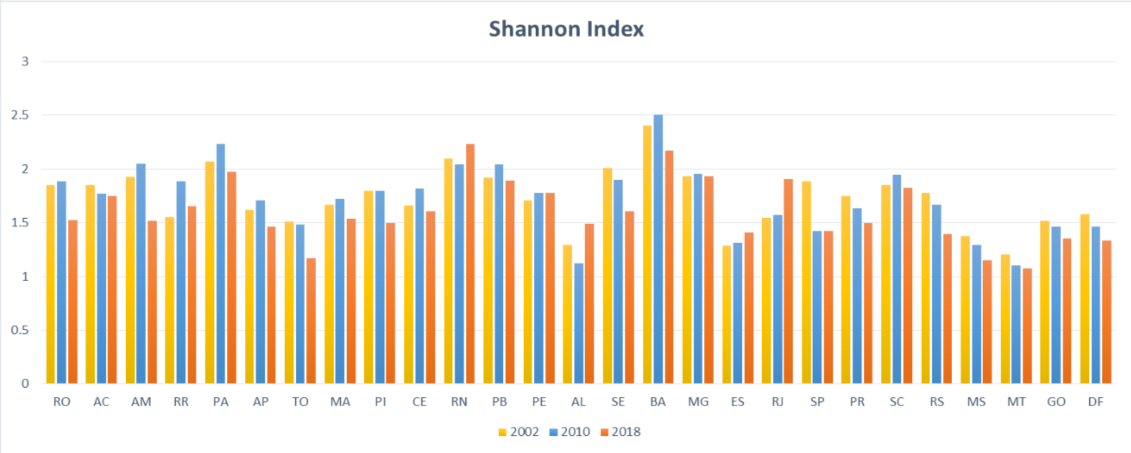

Figure 3: Shannon indexes for the States of Brazil – 2002, 2010, 2018.
Source: Research data.

The previous indexes are commonly used in studies for diversity in Brazil (Sambuichi et al., 2016; Piedra-Bonilla et al., 2020a). However, the index shown in Figure 4 can be considered an innovation presented by this study, because it shows the effective number of crops that dominate the cultivated area in a given region (state). This index was also used by Aguilar et al. (2015). Considering that in the calculation of the indexes, 64 crops were considered, an important result presented by this index is the low value for the main agricultural producing states in Brazil, close to 5 dominant crops, and for some states in the Midwest this number is in 3 crops, a tendency to concentrate the agricultural production agenda in the states.

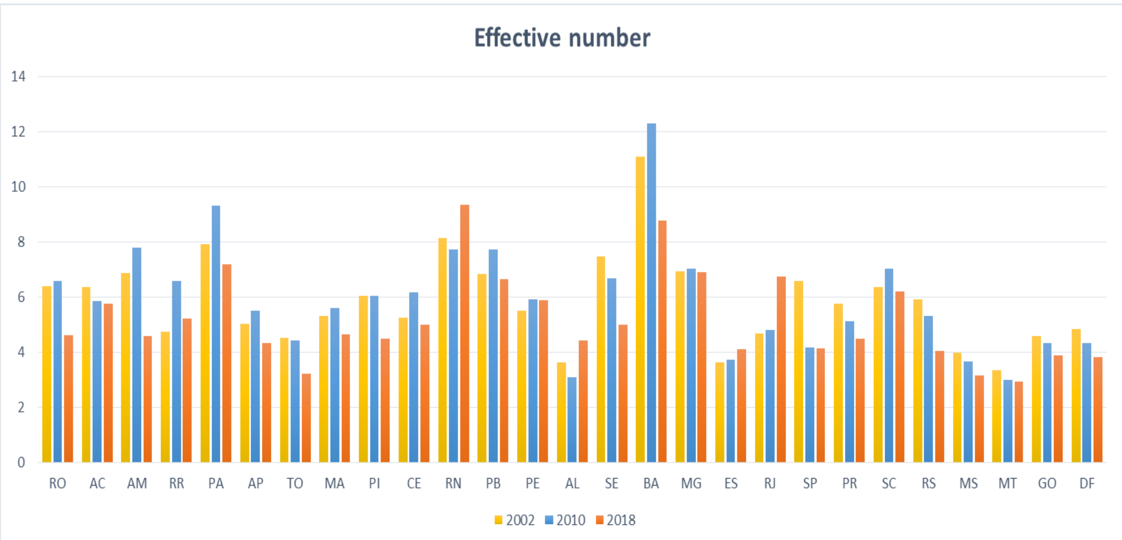

Figure 4: Effective number of crops for the States of Brazil – 2002, 2010, 2018.

Source: Research data.

To give greater confidence in the behavior of the indexes over the analyzed period, the respective growth rates[2] for the period from 2002 to 2018 were calculated (Figure 5). Most states had negative growth rates, although some had positive rates. On average, the values were negative: -0.41% per year for the Simpson index, -0.58 % per year for the Shannon index and -0.91% per year for the effective number of crops. Among the states that had the highest negative rates in the period, we can highlight Amazonas (AM), Tocantins (TO), Bahia (BA), São Paulo (SP), Paraná (PR) and Rio Grande do Sul (RS).

Also according to Figure 5, we have three important producing states that present positive values for the Simpson index and negative values for the Shannon index and effective number. They are the states of Mato Grosso do Sul (MS), Mato Grosso (MT) and Goiás (GO). A possible explanation for the sign inversion of the growth rate of the indices for the states of the Midwest (MS, MT and GO) is the smallest amount of crops grown in these states, which influenced the result of the indexes (richness x homogeneity). In this case, the Shannon index and the effective number showed a greater sensitivity to the quantity (richness) of crops grown in the states.

Some states still showed positive values for all indexes, that is, these states have managed to diversify their agricultural production in recent years. The states of Roraima (RR), Minas Gerais (MG), Espírito Santo (ES) and Rio de Janeiro (RJ). Despite a strong concentration of production presented by the state of São Paulo (SP), the other states of the Southeast region of Brazil (MS, ES and RJ) presented a diversification of their agriculture with areas destined to different crops.

[2] The growth rates were calculated according to the following expression: $\ln Y_t = \beta_0 + \beta_1 t$

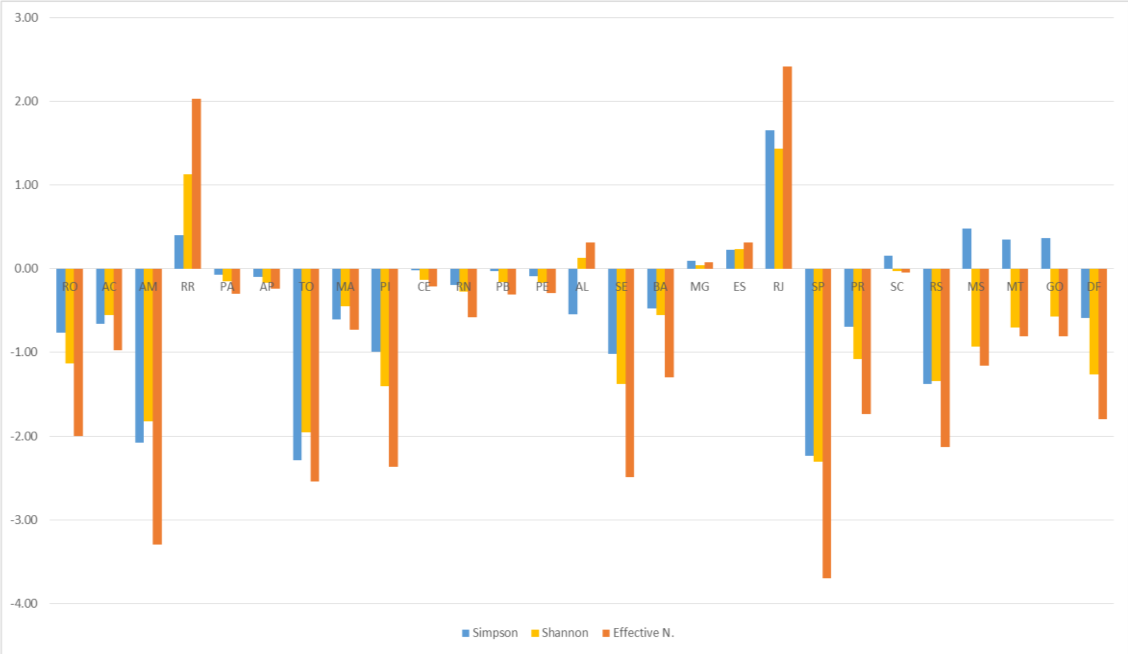

Figure 5: Average annual growth rate of the diversity indexes (in %). 2002-2018.
Source: Research data.

4.2. Determinants of agricultural diversity in Brazil

Table 2 presents the results of the estimations of the model of determinants of diversity for the states of Brazil. The second column (1) shows the polled model, while columns (2) and (3) consider individual heterogeneity not observed through fixed and random effects, respectively. The Hausmann test indicates the rejection of the hypothesis of the absence of correlation between individual effects and explanatory variables. Therefore, for the empirical analysis, we only considered the fixed effects model (column 2).

As for the variables indicative of the effect of demand on agricultural diversity, GDP per capita had a positive (coefficient = 0.214) and significant sign, indicating that an increase in the population's income leads to a more diversified consumption of food and, consequently, stimulates the diversity of crops. Anwer et al. (2019) obtained the same positive effect of per capita income by analyzing agricultural diversity in India. The quantitative effect of demand, captured by the population (POP), showed a negative sign, however, it was significant only at 10%; moreover, in the other models (grouped and random data) the signal was positive and with better levels of significance. The importance of the agricultural sector to the state's economy, measured by the variable *VA Agrop*, showed a positive sign, indicating that states with a more agricultural economic profile have a higher level of diversity.

Table 2 also presents the effects of two technological variables on diversity, with both productivity (PROD) and land use (USO) having negative effects. The productivity variable showed a sign contrary to the expected, perhaps because it was calculated from monetary values, privileging, in this case, the commodities market that have shown high prices in recent years. Anwer et al. (2019) also obtained negative signs for technological variables (intensity in the use of fertilizers, tractors and irrigation), being that the authors justified the signs contrary to the expected to possible diseconomies of scale that resulted in high production costs. Benin et al. (2004) had no significant effects of irrigation and fertility on agricultural diversity. As for the USO variable, which indicates the proportion of area cultivated with crops in relation to the total area of the municipality, it showed a negative and significant sign. The behavior of this variable can indicate that diversity prevails in small properties, but it is not possible to state precisely because the data are aggregated.

Variables considered as infrastructure proxies, such as storage and agricultural credit, were also included in the analysis. As expected, the storage variable showed a negative relationship with diversity, indicating its prevalence in grain production regions. The credit variable in relation to the value of production showed a positive sign, but it was not significant, also indicating a greater targeting of credit for the production of agricultural commodities.

Table 2: Panel data model for the determinants of agricultural diversity, 2002-2018 (without spatial effects)

Variables	**Pooled (1)**		**Fixed effect (2)**		**Random Effect (3)**	
	Coefficient	**p-value**	**Coefficient**	**p-value**	**Coefficient**	**p-value**
Constant	-1.040	0.000			-1.040	0.000
Ln POP	0.063	0.000	-0.106	0.081	0.060	0.019
Ln GDP *per capita*	-0.113	0.000	0.214	0.000	0.023	0.421
Ln VA Agrop	-0.040	0.000	0.180	0.000	0.054	0.000
Ln PROD	-0.009	0.622	-0.178	0.000	-0.073	0.000
Ln USO	-0.034	0.000	-0.193	0.000	-0.089	0.000
Ln STOR	-0.055	0.000	-0.020	0.000	-0.019	0.000
Ln CRED	0.004	0.742	0.001	0.953	0.000	0.988
Number of Observations	459		459		459	
Adj. R-squared	0.424		0.142		0.108	
F Test	F: 49.09		p-value	0.0000		
LM B-P Test	Chisq: 1546.2		p-value	0.0000		
Hausmann Test	Chisq: 48.53		p-value	0.0000		

Source: Research data.

Spatial analysis should only be implemented if tests indicate the existence of spatial effects on the data. In the case of a data panel model, it is necessary to verify the hypothesis of transversal dependence of the data, that is, if the nearest units are more correlated than the most distant units. For that, we adopted the local test CD(p) by Pesaran (2004) and the randomized test R(w) by Millo and Pirras (2018), for a-space panel and space panel specifications (SLX). The difference is that the randomized test R(w) is robust to global dependence induced by common factors and persistence of serial correlation in data. The null hypothesis of both tests is the spatial transversal independence and non-correlated residuals between the units, with no spatial dependence.

The results presented in Table 3 are very illuminating about the need to include spatial effects and also to eliminate the spatial dependence obtained by the SLX model. The Pesaran CD and Millo R (w) tests are statistically significant for the a-spatial panel model, indicating the occurrence of spatial dependence. On the other hand, when considering the SLX space panel specification, the test values are not significant, indicating that the residuals do not have spatial dependence.

Table 3: Tests for spatial dependence on panel data

Specifications	**CD(p) Pesaran Test**		**R(w) Test**
	z	**p-value**	**p-value**
A-space panel	2.4148	0.0157	0.0020
Spatial panel (SLX)	0.1562	0.8759	0.7800

Source: Research results.
Note: Matrix k3 neighbors. Fixed effects considered.

Table 4 presents the results of the estimations of the model of determinants of diversity for the states of Brazil, considering the spillover effects. To achieve this objective, a model of spatial lags of explanatory variables was adopted (Spatial Lag of X – SLX), which was also adopted by Vroege et al. (2020). Table 4 was organized in order to bring the same information as the a-spatial model, the second column (1) presents the information from the polled model, while columns (2) and (3) consider individual heterogeneity not observed through fixed and random effects, respectively. The spatial Hausmann test indicated the rejection of the hypothesis of the absence of correlation between individual effects and explanatory variables. Therefore, for the empirical analysis, only the fixed effects model will be considered (column 2).

It is current in the specialized literature that some decisions made by farmers are strongly influenced by the behavior of agents located in neighboring regions (Vroege et al., 2020; Lapple et al., 2017). We hope to verify if there are neighborhood effects in the adoption of the diversification of crops. Considering the characteristics of the heterogeneous distribution of diversity among neighboring states verified in figures 2, 3 and 4, it is possible that some states behave as a spatial cluster with their own characteristics.

The insertion of spatially lagged variables may also influence the values of the coefficients of the variables with direct effect (variables originating in the region itself), however, this effect was not verified in the results of the SLX Model with fixed effects presented in Table 4, column (2). All coefficients showed values, signs and levels of significance very similar to those verified in the model of a-spatial data panel (Table 2, column (2)), with the exception of the population variable that shows a positive sign, but not significant.

Table 4: Spatial panel model (SLX) for the determinants of agricultural diversity, 2002-2018 (with spatial effects)

Variables	**Pooled (1)**		**Fixed effect (2)**		**Random Effect (3)**	
	Coefficient	**p-value**	**Coefficient**	**p-value**	**Coefficient**	**p-value**
Constant	-2.305	0.000			1.684	0.178
Ln POP	0.079	0.000	0.154	0.101	0.097	0.039
Ln GDP per capita	-0.108	0.000	0.302	0.000	0.251	0.000
Ln VA Agrop	-0.012	0.167	0.159	0.000	0.138	0.000
Ln PROD	0.001	0.945	-0.166	0.000	-0.145	0.000
Ln USO	-0.032	0.000	-0.200	0.000	-0.170	0.000
Ln STOR	-0.061	0.000	-0.024	0.000	-0.022	0.000
Ln CRED	0.004	0.974	0.004	0.719	0.002	0.845
WLn POP	0.038	0.023	-0.458	0.000	-0.319	0.000
WLn GDP per capita	0.138	0.000	0.032	0.657	0.052	0.423
WLn VA Agrop	0.074	0.000	0.027	0.552	0.042	0.325
WLn PROD	-0.093	0.000	-0.090	0.046	-0.109	0.011
WLn USO	-0.018	0.072	0.033	0.411	0.014	0.695
WLn STOR	-0.050	0.000	-0.016	0.097	-0.019	0.041
WLn CRED	0.070	0.000	0.004	0.813	0.008	0.645
Number of Observations	459 (n=27, T=17)		459		459	
Adj. R-squared	0.547		0.211		0.230	
F Test	F: 40.495		p-value	0.0000		
LM B-P Test	Chisq: 1172.0		p-value	0.0000		
Spatial Hausmann Test	Chisq: 43.57		p-value	0.0000		

Source: Research results.

Regarding the spillover effect of the explanatory variables, significant coefficients were obtained for at least one demand variable, one of technology and one of infrastructure. According to Table 4, the spatially lagged variable referring to the population (POP) had a negative and significant indirect effect, indicating that the adoption of a more diversified production agenda by agriculture in a state can be negatively influenced by the population of neighboring states. This result indicates that, even in a region with a small population, farmers can produce a diverse range of products with the aim of selling to other regions with larger markets.

The technological variable productivity (PROD) had both direct and indirect negative effects on the agricultural diversity of the states. The interpretation of the sign contrary to the expected of the direct effect remains the same already presented for the results of Table 2, that is, scale diseconomies at the farm level and high value of agricultural commodities. However, the negative sign with a 5% significance of the spillover effect may indicate a competition between regions in the adoption of technology, where regions with less technology have greater agricultural diversification as a mechanism of economic resilience. The variable static storage capacity in relation to the total produced by agriculture (STOR) presented a negative direct and indirect effect according to Table 4. The interpretation can be the same for both situations, regions with less storage structure present a more diversified agricultural production and regions with greater structure adopt a concentrated production in grains.

5. Conclusion

This study is the first to estimate a spatial data panel model (SLX model) to verify the determinants of agricultural diversity in Brazil. As far as we know, no other study in Brazil has obtained the information and results of the effects of demand, of technology and infrastructure on the intention of agricultural producers to adopt a more diversified production. Additionally, the study provided evidence that the SLX model has good results in eliminating the effects of spatial dependence on the regression residuals, being a good option in relation to the more sophisticated spatial econometric models.

The analysis of the evolution of the indexes demonstrated a continuous decrease in productive diversity with a strong tendency towards productive specialization in Brazilian agriculture, mainly in the states located in the Midwest and South regions of the country. The average rates of growth of the indexes presented negative values for the period of analysis: -0.41% per year for the Simpson index, -0.58% per year for the Shannon index and -0.91% per year for the effective number of crops. It is important to note that some states are allocating practically the entire agricultural area to three or four dominant crops.

As for the determinants of agricultural diversification, the results for Brazil are in line with the specialized literature. The demand effect was positive, indicating that improvements in the population's income stimulates the adoption of diversification by farmers, reflecting a more diversified consumption of food by consumers. The effect of technology presented negative signals for the two variables used in the research, contrary to what was expected in theory, however, similar results were obtained by other studies indicating that farmers who diversify their production may not adopt the traditional technologies that predominate in agriculture. The variables related to infrastructure presented the lowest values of the estimated coefficients and problems of significance.

The SLX model presented a good fit and adequately incorporated the spatial effects. Spillover effects were obtained for all categories of variables, demand, technology and infrastructure. All negative effects indicate a possible competition between regions in the use of factors of production and their relationship with diversity.

The findings of this study may serve for agricultural policy makers to understand the problems that can occur with productive concentration in the agricultural sector and the factors necessary to encourage a more diversified production. Future research should focus on the disaggregation of the database to achieve a refinement of results at the level of microregions and municipalities.

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