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FACTORS OF PRODUCTION AND AGRICULTURE IN BRAZIL

Factores de produção e agricultura no Brazil

Isabela Romanha de Alcantara[1]
Lucir Reinaldo Alves[2]

ABSTRACT
Agricultural production is closely related to Brazilian economic history. Deep transformations in the use of production factors, such as land, labor, and technology, have marked this trajectory over time. This article aims to analyze and estimate the use of production factors in agriculture in Brazilian municipalities in 2006 and 2017. A spatial econometric analysis was used as a methodology. The results indicated the technology and labor as important factors for agricultural production. The variable related to land extension was not significant. It can be also seen that spatiality also influences the value of agricultural production, given the spillover effect.

Keywords: Agriculture. Land. Labor. Technology. Spatial Effects.

RESUMO
A produção agrícola está intimamente relacionada à história econômica brasileira. Profundas transformações no uso de fatores de produção, como terra, trabalho e tecnologia, marcaram essa trajetória ao longo do tempo. Este artigo tem como objetivo analisar e estimar o uso de fatores de produção na agricultura em municípios brasileiros nos anos de 2006 e 2017. Utilizou-se como metodologia a análise econométrica espacial. Os resultados indicaram a tecnologia e a mão de obra como fatores importantes para a produção agrícola. A variável relacionada à extensão de área não foi significativa. Observa-se também que a espacialidade também influencia o valor da produção agrícola, dado o efeito de transbordamento.

Palavras-chave: Agricultura. Terra. Trabalho. Tecnologia. Efeitos espaciais.

JEL: O13, O33, O54, Q16, R11.

1 INTRODUCTION

The agricultural sector is related to the economic development. Brazilian agriculture is of global importance. Brazil is the main producer and exporter of

[1] Administradora. Mestre em Desenvolvimento Regional e Agronegócio pela Universidade Estadual do Oeste do Paraná (Unioeste). Doutoranda em Economia Aplicada pela Universidade de São Paulo (USP). Analista econômico do Pecege Projetos e Consultoria. Piracicaba. São Paulo. Brasil. E-mail: isabelaralcantara@gmail.com

[2] Economista. Doutor em Geografia pela Universidade de Lisboa (ULisboa). Professor adjunto do Curso de Ciências Econômicas e do Programa de Pós-Graduação em Desenvolvimento Regional e Agronegócio (PGDRA) da Universidade Estadual do Oeste do Paraná (UNIOESTE).. E-mail: lucir.alves@unioeste.br

several products and commodities. However, this panorama was not always like this. Until the 1980s, Brazil was a net importer of food. Brazilian history is linked to the performance of agricultural activities in the country. The development of Brazilian agriculture is based mainly on productivity gains (Gasques et al., 2012).

In governing massive structural change in the richest countries, the growth in agricultural productivity plays a more important role than growth in non-agricultural productivity, because the agricultural sector is an instrumental of economic development of a nation (Chen; Liao, 2015; Nguyen, 2000). Moreover, in short run of developing countries, the economic growth is positively and significantly when aid is directed to the agricultural sector (Kaya; Kaya; Gunter, 2012). The aid policy that most effectively reduces poverty is the one which is supportive of agricultural development, based on education and infrastructure (Mosley; Suleiman, 2007). The increasing of agricultural productivity to poverty reduction since food cost represents a considerable share of the family income. That is, when the food production (agriculture and livestock) expands, prices fall, poverty reduces, and economic development advances (De Janvry; Sadoulet, 2010; Alves; Souza; Brandão, 2010).

Until the 1970s, the growth of agriculture was proportional to the increase of the land factor, whose yield was low in relation to the hectare/production. Productivity in the Brazilian livestock sector was one of the lowest in the world between the 1950s and 1960s. Production was not increasing at the same pace as demand. Relative meat prices rose in a country where protein deficiency in food was predominant in the population (Schuh; Alves, 1970).

The period between the late 1970s and the 1980s was a time of transition marked by paradigm breaks. According to Ferrera de Lima, Piacenti and Alves (2005), the paradigm that describes the process of modernization of Brazilian agriculture can be defined by technological renewals (replacement of traditional techniques by techniques based on scientific knowledge); by the process of agricultural commercialization (a transition from subsistence agriculture without commercial focus and the emergence of paid employment); and by the process of agricultural product industrialization and urbanization of previously predominantly rural areas.

It was the beginning of the modernization process that the sector would experiment in the following decades. Technologies created in developed countries could not be easily adapted in Brazil. Therefore, institutional changes were essential to promote Research and Development (R&D) processes focused at tropical agriculture, since it acts as a catalyst for innovation, increasing the knowledge absorption capacity of farmers (Vieira Filho; Fishlow, 2017). The government instituted specific policies to increase agricultural production and productivity, as well as public investments in R&D, rural extension, and full credit, which were intended to ensure food security and reduce food price (Chaddad, 2016). In 1979 and 1980, the rural credit subsidy reached ¼ of the agriculture and cattle raising Gross Domestic Product (GDP) (Bacha, 2004).

Under the support of EMBRAPA (*Empresa Brasileira de Pesquisa Agropecuária)* - created in 1973, whose mission, vision and values are guided towards the sustainability of agriculture for the benefit of Brazilian society - agriculture has become a sector based on knowledge and science. In the 1990s, the development of agricultural knowledge and its use by local producers were responsible for a significant productivity gain, in which, among the reasons for such success, are cited the improvement of degraded tropical soils; genetic improvement of plants; and integrated management system (Vieira Filho; Fishlow, 2017). Thus, as a result of efforts undertaken by rural producers, government, science and technology institutions, and other public and private agents, significant productivity gains were observed in the agricultural sector. Grain production grew more than six-fold between 1975 and 2017, while the area planted only doubled (EMBRAPA, 2018).

Contini *et al*. (2010) highlight three agricultural policy instruments that have contributed to the evolution of this sector over the past few years, such as: subsidized credit, science and technology, and rural extension. Between 1975 and 2010, Brazilian agriculture was marked by a substantial increase in productivity (2.95% per year), with soybean cultivation being the flagship. The productivity of the five main grains (rice, corn, beans, soybeans, and wheat) increased production at rates of 3.66% per year. Brazil's prominence in the international context has grown in recent years. Agribusiness exports generated a trade balance of US$ 403 billion from 1997 to 2009, contributing to the balance of the country's external accounts. Projections indicate that Brazilian agriculture and agribusiness exhibit excellent growth potential (Contini *et al*., 2010).

Brazilian agribusiness products are present in several countries around the world. In 2018, the main destinations for agribusiness exports were China, whose share was more than 35% of the total exported value, followed by the European Union economic bloc formed by 28 countries (17.6%) and the United States (6.7%) (AGROSTAT, 2019).

Given the importance of agriculture in Brazil, its role as a driving force for innovation and regional development, and the different ways in which the factors of production in each region are used, this work addresses agriculture in all Brazilian municipalities, focusing on answering the following problem: How do Brazilian municipalities use each factor of production in agriculture? It is in this context that this paper aims to analyze and estimate the use of production factors in agriculture in Brazilian municipalities in 2006 and 2017.

The contribution of this study is its focus on examining spatial relationships in the use of agricultural production factors across Brazilian municipalities. Unlike prior research, which primarily analyzed productivity gains at a national or regional level, this work offers a detailed assessment of how spatial dependence and spillover effects influence agricultural productivity on a municipality-by-municipality basis. This perspective not only sheds light on the heterogeneous impacts of land, labor, and technological factors but also emphasizes the significance of localized spatial dynamics in shaping agricultural outcomes. Thus, the study aims to fill a critical gap in understanding the geographic interdependencies in Brazilian agriculture.

In order to respond to the problem and reach this objective, the next session presents the theoretical foundation focused on the function of agricultural production. The third session describes the methodology used and the procedures performed. The results and discussions are in the fourth session. Furthermore, in the fifth session, there are the conclusions.

2 THE SCOPE OF AGRICULTURAL PRODUCTION FUNCTION

This topic focuses on contextualizing some studies about the main factors of the production function. Among the factors that influence agricultural production, there are labor, land and technology.

Production is the process of transforming inputs into products through the use of production factors. The combination of these factors can occur in different ways, with different results. Their optimal use generates a competitive and/or comparative advantage for the enterprise with a spillover effect in a region.

The right combination of production factors and the introduction of innovations results in optimal production and economic progress. Economic analysis is concerned with evaluating the basic conditions to achieve the maximum use of resources, in order to obtain the greatest possible amount of production (Hayami; Ruttan, 1988).

In order to verify the causes of agricultural productivity differences between developed and less developed countries, Hayami (1969) identified the determinants in 38 nations in the 1957-1962 period, classifying them into conventional inputs (labor, land, fertilizers, and machinery) and unconventional inputs (education and research). Through the estimated aggregate production function, Hayami (1969) concluded that: i) the difference in inputs of modern manufactured factors is explained more by the difference in productivity than by differences in original factor endowments; ii) that education and research are crucial to determine the difference in productivity. Hayami (1969) also relates these results to the Schultziana hypothesis, in which the strategic factors for the transformation of low production from traditional agriculture to highly productive modern agriculture are the new profitable inputs, such as chemical fertilizer and improved seed varieties. Thus, less developed countries cannot close the productivity gap without investing in education and research to improve the quality of labor and create better techniques suitable for their local environments. However, this investment may not be fruitful unless it is complemented by efforts that have improved the supply conditions of modern conventional inputs, such as fertilizers and machinery (Hayami, 1969).

Alves, Souza and Marra (2017) estimated an econometric model for Brazilian agricultural production through the factors of land, labor and technology for the five macroregions. The macroregions of traditional technology, mainly the North, correspond to the dominance of land and labor in the value of production explaining. This phenomenon can be justified by the availability of cheap land in the region, which causes a discouragement in the investment in land saving technologies. In contrast, in the South, given its historical context of colonization, the use of technology was the factor that stood out the most. Alves, Souza and Marra (2017) conclude that alliances between rural leaders, mayors and governors in order to create favorable public policies, in the face of market imperfections, may have been decisive for the South to achieve such a result, instrumented through cooperatives, associations and involvement of the political class.

In the State of Paraná (Brazil), Strassburg *et al.* (2014) estimated the production function of agriculture in 2006 using the factors of technology (tractor), capital (financing/investment), area, and labor. The first three factors proved to be determining factors in agricultural production in this state. The 1% increase in technology, capital, area and labor tends to cause an increase of 0.59, 0.27, 0.13, and 0.03 in the value of production, respectively.

The production factors are related to each other but are studied according to different approaches. Land, labor, and technology factors are elements that determine the use of knowledge in different forms, whether physical or not.

Land is an indispensable natural resource in the agricultural production process. For Marshall (2013, p. 115), "by Land is meant the material and the forces which nature gives freely for man's aid, in land and water, in air and light and heat." Here, the land factor will be treated in the sense of soil - area of agricultural establishments. Its value and use depend on local characteristics and spatial arrangement.

The challenge of land productivity is to make farming produce more and also reduce the cost of production per unit of product. The selection of cultivars and the use of modern inputs, in the face of adversity caused by pests and diseases, can contribute to land productivity (Alves, 2018). When the cost of land is not considered, the use of this factor tends to be extensive, and not intensive, in order to achieve greater returns on capital and labor (Marshall, 2013).

A product emerges from the application of labor to the resources provided by nature, whose use is directed to meet the needs and human desires. Labor is a human activity that has an economic utility. In the words of Marshall (2013, p. 115), "by Labor is meant the economic work of man, whether with the hand or head". Here, the labor factor is interpreted as workers.

For Marshall (2013), the first condition for an organization to be efficient is the allocation of employees according to their skills and training that allow them to perform well in the activity, and can be assisted by machines and other equipment. Labor productivity is measured by the area each worker cultivates, influenced by mechanical technology. The scarcity of labor, legal insecurity in the labor sphere, and other complications concerning human resources management influence the demand for this factor (Alves, 2018).

Smith (1983) studies the factors that make up the price of goods, among them, labor. Labor compensation corresponds to the amount of work employed, complexity, dexterity, cleverness and talents of the individual (natural and acquired by experience). When the capital factor accumulated in the hands of the entrepreneur, he tends to employ it in the hiring of hardworking people (labor), providing them with raw materials and subsistence in order to earn a profit from the sale of the product. In other words, the value that workers add to an input is divided into two parts: i) the amount received in the form of wages, and ii) the profit of the entrepreneur, for all capital and wages that he had previously financed, plus the business risk.

Capital, according to Marshall (2013, p. 115), can be defined as "the main stock of wealth regarded as an agent of production rather than as a direct source of gratification". It consists mainly of knowledge and organization, some of which may be privately owned, and some may not. Knowledge is the most potent mechanism of production and allows us to subjugate nature and shape it in order to satisfy our desires. The organization supports knowledge (Marshall, 2013).

The optimal use of resources depends on accumulated knowledge and the capacity to absorb new knowledge (Vieira Filho; Silveira, 2011). In general, Alves, Souza and Marra (2017) summarize that the knowledge generated through research institutions encompasses many branches of basic and applied analysis. Farmers accumulate knowledge available in production systems, assess their profitability, buy inputs and carry out production. Knowledge is transformed into technologies and inputs that reflect such knowledge (Vieira Filho; Silveira, 2011), being decisive in guiding production and whether or not it is physical (Duarte; Alves, 2016). The general objective is to reduce the cost relative to the total produced (Alves; Souza; Marra, 2017). Here, the capital factor approach will focus on the use of technology, considered a factor of production.

Duarte and Alves (2016) classify the technology in two typologies: i) physical, which refers to any attribute with material characteristics, with innovation being incorporated (for example, agricultural machinery, fertilizers and pesticides, adapted seeds, improved breeds); and ii) non-physical (for example, such as land care, production management and planting and harvesting seasons). Therefore, the effects of technology outweigh the simple increase in productivity. Its implications also generate effects on financial and technical viability, ecological and social effects by reducing the social cost. Alves (2018) lists technology as a factor that saves land and labor.

Therefore, the study of the production function seeks to analyze how different factors are employed productively. The optimal combination of these factors determines the productivity and the competitive / comparative advantage of the sector in the market. In agriculture, the appropriate articulation of production factors can generate a spillover effect on regional economic development and in the generation and consolidation of production chains.

3 METHODOLOGY

In order to meet the proposed objective, which is to analyze and estimate the use of production factors in agriculture in Brazilian municipalities in 2006 and 2017, the methodology presents the tools that were used in this work. The object of this study is Brazilian agriculture.

This work is an applied research, of quantitative and explanatory nature. Silva and Menezes (2005) define applied research as a practical application and directed to specific problems. The quantitative approach requires the use of statistical techniques because it considers that everything can be quantifiable in order to classify and analyze the data. The point of view of explanatory research seeks to identify the factors that contribute to the occurrence of a particular phenomenon, that is, deepens the knowledge of reality by seeking for the reason of things. As for technical procedures, this work is bibliographic and documentary, in which, according to Silva and Menezes (2005), is prepared from materials already published, such as the theoretical and literary basis, and elaborated from materials that have not received analytical treatment, such as secondary data that were needed to analyze the factors of agricultural production (land, labor and technology).

Based on the model proposed by Alves, Souza, and Marra (2017)[3] on the function of agricultural production, proxies were selected to describe the factors of

[3] For the variable land, Alves, Souza, and Marra (2017) used the value of the area exploited in terms of rent. For labor, they used the expenditure in this production factor. Moreover, for technology, the value of inputs that sometimes save the land and sometimes save labor. The authors used

land, labor, and technology, whose observations are for all municipalities in Brazil for 2006 and 2017. The technology, according to Duarte and Alves (2016), can be physical and not physical. Therefore, here, the technology of physical character is portrayed through the proxy number of tractors, implements, and machines existing in agricultural establishments, and the non-physical character, through the proxy percentage of establishments whose producer has higher education. Agricultural policy variables at the municipal level were not included in this study due to the unavailability and lack of granularity in municipal-level policy data across the timeframe analyzed.These variables can be better understood with the support of Table 1. Secondary data from all municipalities in Brazil for the years 2006 and 2017 were used, whose data source was the Agricultural Census (IBGE, 2006a, 2017a) and Municipal Agricultural Production (IBGE, 2006b, 2017b).

Table 1 – Variables

Variable	Variable type	Description	Data source
PROD	Dependent (y)	Value of agricultural production (thousand reais)	Municipal Agricultural Production (IBGE, 2006b, 2017b)
LAN	Independent (x_1)	Area of agricultural establishments (hectares)	Agricultural Census (IBGE, 2006a, 2017a)
LAB	Independent (x_2)	Number of persons employed in agricultural establishments (persons)	Agricultural Census (IBGE, 2006a, 2017a)
TECnp	Independent (x_3)	Percentage of establishments whose producers have higher education (establishments)	Agricultural Census (IBGE, 2006a, 2017a)
TECp	Independent (x_4)	Number of tractors in agricultural establishments (units)	Agricultural Census (IBGE, 2006a, 2017a)

Source: prepared by the author.

The first step was to apply the model proposed by Alves, Souza, and Marra (2017), i.e., production value as dependent variable and land, labor, and technology as independent variables. The estimated econometric model starts in an a-spatial way, by the classical linear regression model, according to Equation 1.

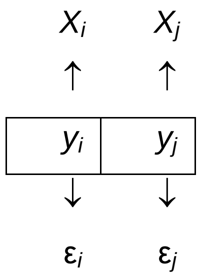
conventional econometrics, whose model was logarithmized, and the results presented for the macro-regions and Brazilian states.

$$y = \alpha + \beta_1 LAN + \beta_2 LAB + \beta_3 TEC_{np} + \beta_4 TEC_p + \varepsilon \qquad (1)$$

Being $\varepsilon \sim N(0, \sigma^2 I_n)$; *y* is a vector *n* by *1* of observations on agricultural production; α is the constant; land, labor, and technology are matrices *n* by *k* of observations with an associated vector *k* by *1* of coefficients β; ε is a vector *n* by *1* of random error terms.

Graphically, this model can be represented according to Figure 1, in which regions *i* and *j* are neighboring, whose polygons are represented by contiguous rectangles; the arrows indicate the interaction between the variables and the random error of their respective regions, with no interaction between the spatial units, nor spatial lag.

Figure 1 - A-spatial process



Source: Baller *et al.* (2001), Almeida (2012), adapted.

It is noteworthy, as Almeida (2012) states, that there is a differentiation between conventional and spatial econometrics in which some assumptions of the Gauss-Markov model and the Classical Linear Regression Models (CLRM) are violated, namely: i) linearity of parameters; ii) perfect collinearity; iii) zero conditional mean; iv) homoscedasticity; v) independence from errors; vi) normality from error.

To verify the presence of spatial association patterns in the model, we used Moran I Statistics. The Lagrange Multiplier (LM) and robust LM tests were used to identify the best model to estimate, and the Akaike and Schwarz Information Criteria were used to verify model quality.

The spatial autocorrelation coefficient, Moran's I, was first proposed by Moran (1948), in which the measurement of autocovariance in the form of a cross-product was used. That is, this indicator measures the spatial autocorrelation from the product of the deviations from the mean. Algebraically, this statistic is presented according to Equation 2.

$$I = \frac{n}{\sum\sum w_{ij}} \left(\frac{\sum\sum W_{ij}(y_i - \bar{y})(y_j - \bar{y})}{\sum(y_i - \bar{y})^2} \right) \tag{2}$$

Where *n* is the number of regions (spatial units); $\sum\sum \mathrm{w_{ij}}$ is the sum of all the weighting elements of the matrix for the spatial unit pair *i* and *j*; $(\mathrm{y_i} - \bar{\mathrm{y}})(\mathrm{y_j} - \bar{\mathrm{y}})$ are the deviations from the mean, in which $\mathrm{y_i}$ is the variable of interest. This calculation allows estimating the autocorrelation function for each neighborhood order, whose null hypothesis (H_0) is that of spatial independence, being necessary to establish the statistical significance. The result of Moran's I varies from -1 to +1, being 0 (zero) the value that indicates spatial randomness. The values closer to -1 indicate negative (inverse) spatial autocorrelation due to the existence of dissimilarity between the values of the attributes and the spatial location of this attribute. The positive spatial autocorrelation indicates a similarity between the values of the attribute and the spatial location of this attribute, whose values of Moran's I are close to +1.

In short, the Moran I statistic provides three types of information: i) the significance level provides information on the random or standardized distribution of data; ii) the sign (positive or negative) indicates the type of attributes relationship between the spatial units (direct or indirect); iii) the magnitude of the statistic provides the strength of spatial autocorrelation, that is, the closer to +1 the stronger the concentration, and the closer to -1 the data is, the more dispersed the data, and zero indicates spatial randomness (Almeida, 2012).

The Lagrange Multiplier (LM) statistic is a focused[4] test because it has the ability to specify the shape assumed by spatial autocorrelation. The LM tests can be classic or robust, lag or error tests, performed with the residues of the OLS model. Golgher (2015) describes that in the LM test error is assumed $\rho = 0$ and tests the null hypothesis of H_0: $\lambda = 0$. If the null hypothesis is rejected, the choice focuses on the SEM model. Otherwise, there is an indication that such residues do not present significant spatial correlation to justify the use of the SEM model. Similarly, the LM

[4] Tests to detect spatial autocorrelation that can be diffuse or focused, in which the former investigates whether there is a spatial dependence on residues, where it is not based on a specific specification. The second, on the other hand, is a specific econometric-spatial model, in which an indication of the predominant type of spatial autocorrelation is provided.

lag test compares the OLS model with the spatial lag model, whose null hypothesis $H_0: \rho = 0,$ assuming $\lambda = 0.$

The robust error LM test also tests the null hypothesis of $H_0: \lambda = 0$, but does not assume that $\rho = 0.$ This test, in the words of Golgher (2015, p. 140), "examines whether there is still spatial correlation in errors when the specification already contains the spatial lag, but of unknown value." And the robust LM *lag* test tries the null hypothesis of $H_0: \rho = 0$ but does not assume that $\lambda = 0.$ That is, "we test whether we should include a spatial *lag* term if a spatial correlation is already present in errors of unknown value." Thus, it is possible to detect the occurrence of the model's spatial dependence and verify if it is of the lag or error type. After these procedures, it is known that the coefficient of determination, R^2, is not the most appropriate indicator to verify the quality of the regression.

For Almeida (2012), in the estimation by Maximum Likelihood, it is recommended to use the value of the likelihood function (LIK - whose interpretation is the higher the value, the better the model), the Akaike (AIC) and Schwarz (SC) Information Criterion whose equation can be expressed by 3 and 4, respectively.

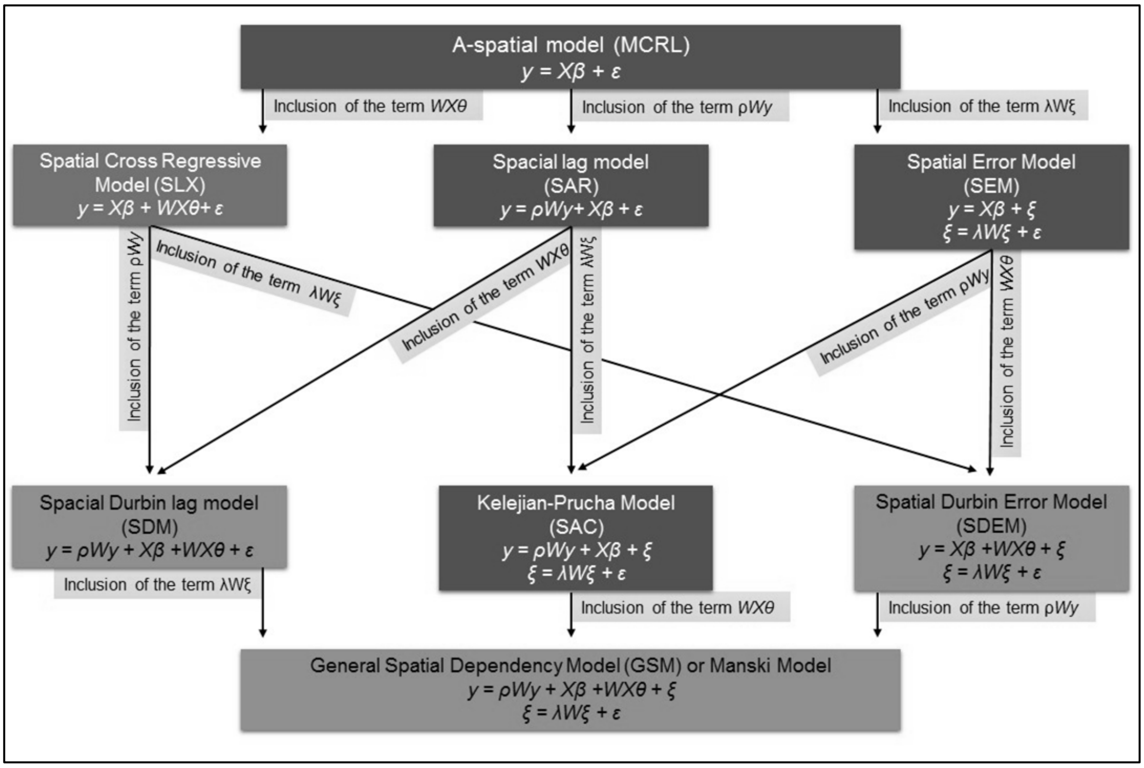
$$AIC = -2 \times LIK + 2k \quad (3)$$

$$SC = -2\ LIK + k, ln(n) \quad (4)$$

Where *LIK* is the maximized likelihood log, and *k* is the number of regression coefficients. The lower the value of the criterion, the better the model.

The spatial econometric model depends on the theoretical and empirical aspects involving the phenomenon. Spatial lags are incorporated into the model in order to capture these underlying aspects. Therefore, the lags (such as the substantive spatial dependence models and the residual spatial dependence models) are able to control the spatial dependence, with X consisting of the exogenous explanatory variables, and ε is the error term and ξ is the spatially lagged error term (Almeida, 2012; Anselin, 1988, 2001). In the words of Baller *et al.* (2001, p. 566) "'spatial dependence' is used as a general term to refer to either a spatial 'lag' model or a spatial 'error' model". Figure 2 presents the spatial models used in the empirical analysis of cross-section data, in which ρWy is the spatially lagged dependent variable, $WX\theta$ is the spatially lagged independent variable, $\lambda W\xi$ is the spatially lagged error.

Figure 21 - Spatial models



Source: Prepared by the author, based on Almeida (2012) and Golgher (2015).

SAR, SEM, and SAC models are considered to be global range spatial dependence models, whose spillover range has a global effect due to the inference of the spatial multiplier reflected in all regions of the study area. On the other hand, the SLX model has a spatial dependence on the local range, i.e., the range of spatial dependence is located, whose impact is observed in only certain regions of the study. The SDM, SDEM, and GSM models have global and local spatial dependence.

The most commonly adopted estimators in spatial econometric applications are based on the principles of Maximum Likelihood (ML), Instrumental Variables (IV), Quasi-Maximum Likelihood (QMV), Generalized Moment Method (GMM), and Two-Stage Least Square (2SLS), according to the chosen model and the normality of the residuals. Table 2 summarizes the estimation methods of the spatial models.

Table 2 - Summary of econometric models estimation methods

Model	Normality	Method
SAR	Yes	ML
	No	IV or QML
SEM	Yes	ML
	No	GMM or QML
SLX	Yes	OLS or ML
	No	2SLS
SDM	Yes	ML
	No	IV or QML
SDEM	Yes	ML
	No	GMM or QML
SAC	Yes	2SLS special or QML
	No	ML

Source: Almeida (2012, p. 211), adapted.

What guides the econometric-spatial specification is the theory and literature related to the subject, such as Alves, Souza, and Marra (2017) and Duarte and Alves (2016). Spatial econometrics considers the geographical disposition of observations, having the ability to capture endogenous and exogenous factors of the region. Spatial lags can be incorporated into the model to capture underlying aspects. However, by using spatial data in a regression, some hypotheses of Gauss-Markov and the Classical Linear Regression Model (CLRM) are violated, making the OLS no longer the Best Linear Estimator Unbiased (BLUE). Thus, in the presence of spatial data, other methods are suggested according to the normality of the residues and the model adopted. Spatial models vary in scope, which can be local and global, and in relation to the use of spatial elements such as ρ, λ, and θ, based on a contiguity matrix W. The use of these elements is essential for the estimation of non-biased coefficients and is determined by the form of interaction between the dependent, independent and error variables.

4 RESULTS AND DISCUSSION

There are several approaches that define the production function. According to the model proposed by Alves, Souza, and Marra (2017), the agricultural production function is formed by the factors of land, labor, and technology, in which, in this paper, the technology is disaggregated into physical and non-physical aspects, as already presented in the methodology.

To test the model's spatiality, the contiguity matrix chosen was that of 4 neighbors (based on Euclidean distance) because it presented greater contiguity (verified by Moran's I statistics). In addition, the choice of the weight matrix also reflect the theoretical nature of the spatial relationships involved in the phenomenon being studied. For instance, the externalities influencing agricultural production are local, such as municipal policies or nearby environmental conditions. Therefore, the decision to use a k-nearest neighbor matrix reflects our hypothesis that the most significant interactions in Brazilian agricultural production occur locally, among geographically proximate municipalities.

In this topic, the econometric analysis is initiated by the a-spatial and spatial regression with the observations of 2006, followed by the a-spatial and spatial regression of 2017. At the end of the topic is presented a comparative analysis of the final spatial results between periods, i.e., regression 2 and 4.

In order to adjust the data of the variables (categorical), the model that had the best adjustment was the log-lin type, based on the Akaike (AIC) and Schwarz (SC) Information Criteria. Therefore, the estimated a-spatial regression can be represented according to Equation 5.

$$logProd = \alpha + \beta_1 LAN + \beta_2 LAB + \beta_3 TEC_{np} + \beta_4 TEC_p + \varepsilon \tag{5}$$

Table 3 presents the results of the regressions performed with the help of *GeoDaTM* and *GeoDaSpace version 1.0 software*.

Table 3 – Regressions

Coefficients	2006		2017	
	(1) OLS	**(2) SAR**	**(3) OLS**	**(4) SAR**
α	3,2445452 [0,000000]***	1,6664979 [0,000000]***	3,3278107 [0,000000]***	1,3450570 [0,000000]***
LAN	-0,0000002 [0,0109484]	-0,0000001 [0,1107773]	0,0000000 [0, 6881069]	-0,0000000 [0,9681291]
LAB	0,0000542 [0,000000]***	0,0000518 [0,000000]***	0,0000522 [0,000000]***	0,0000501 [0,000000]***
TECnp	1,2941637 [0,000000]***	0,6797017 [0,000000]***	1,9525668 [0,000000]***	0,9064637 [0,000000]***
TECp	0,0017158 [0,000000]***	0,0012191 [0,000000]***	0,0014425 [0,000000]***	0,0008660 [0,000000]***
ρW_logPROD		0,4565578 [0,000000]***		0,5594485 [0,000000]***
Regression Diagnosis				
R^2	0,327343		0,339144	
Pseudo R^2		0,6051		0,6689
Spatial Pseudo R^2		0,3661		0,4055
Akaike info criterion	11440,4		13899,7	
Schwarz criterion	11473,5		13932,8	
Jarque-Bera	16492,4337 [0,000000]***		6123,9630 [0,000000]***	
Spatial dependence diagnosis				
I of Moran	0,5389 [0,000000]***		0,5615 [0,000000]***	
LM_{ρ}	3684,6736 [0,000000]***		4257,9692 [0,000000]***	
LM^*_{ρ}	303,8713 [0,000000]***		491,2438 [0,000000]***	
LM_{λ}	3605,9049 [0,000000]***		3915,8506 [0,000000]***	
LM^*_{λ}	225,1026 [0,000000]***		149,1252 [0,000000]***	

Resids Moran's I	0,538862 [0,00100]***	0,18102 [0,00100]***	0,561543 [0,00100]***	0,102035 [0,00100]***

Note: The probability is shown in brackets. *** Indicates that the value is significant at the 1% certainty level. ** Indicates that the value is significant at the 5% certainty level. * Indicates that the value is significant at the 10% confidence level.
Source: Prepared by the author.

The first regression presented (1) was of the a-spatial type with observations for the year 2006, whose method was that of the Ordinary Least Squares (OLS). According to the spatial dependence diagnosis, Moran's I indicates that the model has positive spatial autocorrelation. Moreover, under spatial effects, OLS is no longer the Best Linear Estimator Unbiased (BLUE). The classical Lagrange Multiplier statistic (LM_{ρ} and LM_{λ}) points to the need to include a spatial lag term in the model, and this situation is confirmed by robust LM tests (LM^*_{ρ} and LM^*_{λ}). That is, the Spatial Autoregressive Model (SAR) is the most appropriate. Regarding the normality of the residues, the Jarque-Bera test was significant at 1%, indicating that the null hypothesis of normality of the residues should be rejected.

The second regression, SAR model, was performed using IV in which the instruments were the *TECnp, TECp, LAN, LAB* variables with first-order spatial lag, and the instrument was the dependent variable, l*ogPROD*, also spatially lagged. The spatial estimator was the two-stage least square type. The SAR model is designed to capture the spatial interaction by including a spatially lagged dependent variable. This means that the agricultural production value in one municipality is influenced by the production values in neighboring municipalities. This effect is crucial for agriculture, where spillover effects such as the spread of technology, market interactions, or environmental conditions can occur between neighboring areas.

The concept of spillover effects in agriculture refers to the influence that economic activities or conditions in one municipality can have on the agricultural productivity of neighboring areas. In the context of this study, the significant spatial lag coefficient indicates that agricultural production in one municipality is not isolated but is affected by the performance and characteristics of nearby municipalities.

A similar situation occurred with regressions 3 and 4, whose observations are from 2017. The diagnosis of spatial dependence and the normality test of regression 3 residuals also indicated that SAR is the most appropriate model, using IV by means of the two-stage least square method. Regression 4 presents the final result of the model for the 2017 observations.

Formally, SAR-type spatial econometric regression, as per regressions 2 and 4, can be expressed according to Equation 6.

$$logProd = \alpha + \beta_1 LAN + \beta_2 LAB + \beta_3 TEC_{np} + \beta_4 TEC_p + \rho W logProd + \varepsilon \quad (6)$$

The labor, physical and non-physical technological factors contributed positively to the value of agricultural production in Brazil in 2006 and in 2017. The land factor presented a negative coefficient, although it was not significant in both periods analyzed.

When analyzing the variables that indicate the physical (*TECp*) and non-physical (*TECnp*) technology, it is noticeable that both variables had expressive relation to the value of agricultural production. The positive coefficient of *TECnp* both in 2006 and in 2017 portrays that knowledge at a higher level is directly related to the value of Brazilian agricultural production. The coefficient of physical typology technology, which corresponds to the number of tractors in agricultural estabilishment, was also positive both in 2006 and in 2017, indicating a direct relationship with the value of agricultural production.

The labor factor positive coefficient (*LAB*) indicates that the number of people employed in agricultural establishments has a direct relationship to the value of agricultural production over the analyzed period.

Although the land factor (*LAN*) had a negative coefficient, this variable was not significant in any of the periods analyzed, which prevents a consistent analysis of this factor. This phenomenon may be related to the coexistence of intensive activities, where less land is used to produce more agricultural products and extensive activities. In other words, modern production techniques can make the amount of area available to agricultural establishments not determine the value of agricultural production.

The lagged dependent variable (*ρW_logPROD*) was significant both in regression 2 of 2006 and in regression 4 of 2017. This spillover effect indicates that the value of agricultural production of neighboring municipalities is also essential to determine the value of agricultural production of a given municipality. That is, the location and spatial arrangement of municipalities influence agricultural production, as well as their neighborhood relationship.

Agricultural production factors are used heterogeneously in Brazil. Non-physical technology, related to the higher education of rural producers, was the most critical factor in both 2006 and 2017. Physical technology, related to the use of tractors, was the second most important element in determining the value of agricultural production. The importance of the labor factor has changed slightly over time, while the land factor has not been significant for agricultural production. Besides that, it is noticed that the spatiality and the contiguity relationship also determine the value of agricultural production in a municipality, given the spillover effect.

5 CONCLUSIONS

The history of agricultural production is very similar to Brazilian economic history. Deep transformations in the use of production factors, such as land, labor, and technology, marked the trajectory of agriculture over time. The competitiveness of this sector has been a catalyst for regional growth and development in several historical periods. Brazil went from being a net importer of food to be one of the world leaders in commodity exports. Research and innovation in the agricultural sector were crucial in this process.

In order to reach the objective of this paper, the effect of land, labor and physical and non-physical technologies factors, as well as the spillover effect, on the value of agricultural production were quantified. The econometric analysis confirmed the importance of technology, for the value of Brazilian agriculture production in both 2006 and 2017. The land factor was not significant in either 2006 or 2017. The labor factor coefficient was also positive in both period analyzed. In view of the results of the spatial dependence diagnosis, the spillover effect related to the location of the municipalities was also included in the econometric model. This indicates that the spatial layout and the contiguity ratio of the municipalities also positively influence the value of agricultural production.

Over the past few decades, environmental protection laws and urban development established a territorial limit for agricultural production in Brazil. Due to the intensification of urbanization, the growth of the service sector and the increasingly intensive use of technologies, the supply of labor has decreased in rural areas. In order to obtain productivity gains and sustainable progress, the incorporation of technological innovations in modern agriculture has become crucial. Technological innovation requires knowledge. Brazilian agriculture has become a science-based sector.

In order to achieve productivity gains and sustainable progress, the incorporation of technology into modern agriculture has become crucial. The optimal use of resources depends on accumulated knowledge and the capacity to absorb new knowledge. In general, the knowledge generated through research institutions covers many branches of fundamental and applied analysis. Farmers accumulate available knowledge in production systems, assess their profitability, purchase inputs, and carry out production. In other words, knowledge is crucial to guide agricultural production.

Innovation and technology have helped Brazil in the process of economic development, and the case of Brazilian agriculture is an example to illustrate this process. In short, agribusiness is a complex and dynamic system. Overcoming the challenge of sustainable development requires a systemic vision and the abandonment of traditional approaches, considering the integration of the different elements of the agri-food chain.

This analysis has the potential to facilitate participatory planning; we suggest bringing farmers to the discussion table with planners since the knowledge economy has become a determinant of the excellent performance of the sector. Based on the proposed discussion, it is clear that from the expansion of the use of technology and dialogue between institutions and producers, it is expected that agricultural productivity will continue to grow more and more.

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