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ARTICLE

Spatial effects are determinants of agricultural land prices in Brazil

Os efeitos espaciais são fatores determinantes dos preços das terras agrícolas no Brasil

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Abstract: This study aims to determine whether spatial effects are determinants of agricultural land prices in Brazil. For this purpose, data on the value of the bare land in municipalities in Brazil for 2020, provided by the Federal Revenue Service, were used. Although this database has national coverage, the contiguous data necessary for the application of spatial econometric models allowed us to cover the central-south region of the country. An exploratory spatial data analysis was performed, and the spatial Durbin econometric model was applied. Based on our results, there is a strong spatial dependence on land price, manifested both in the dependent variable, spatially lagged, and through the spillover effects of the independent variables. In addition, it was found that the degree of urbanization of a municipality, the municipal gross domestic product per capita, the average size of properties, the agricultural productivity, and the area dedicated to soybean planting in a rural property are also important determining factors in the pricing of agricultural land. Accordingly, it is possible to conclude that spatial effects influence the determination of agricultural land prices in Brazil.

Keywords: land market, land value, spatial econometrics, price dynamics, land use planning.

Resumo: Este estudo tem como objetivo verificar se os efeitos espaciais são fatores determinantes dos preços das terras agrícolas no Brasil. Para isso, foram utilizados dados do valor da terra nua de municípios do Brasil, para o ano de 2020, disponibilizados pela Receita Federal. Embora a base de dados tenha cobertura nacional, os dados contíguos, necessários na aplicação dos modelos econométricos espaciais, permitiram abranger a região Centro-Sul do país. Foi realizada a análise exploratória de dados espaciais e aplicado o modelo econométrico Durbin espacial. Pelos resultados obtidos verifica-se a existência de forte dependência espacial no preço da terra, manifestada tanto na variável dependente, espacialmente defasada, quanto por meio de efeitos de transbordamento das variáveis independentes. Além disso, verificou-se que o grau de urbanização do município, o produto interno bruto per capita municipal, o tamanho médio das propriedades, a produtividade agrícola e a área dedicada ao plantio da soja, na propriedade rural, também são importantes fatores determinantes do preço das terras agrícolas. Conclui-se que efeitos espaciais têm influência na determinação dos preços das terras agrícolas no Brasil.

Palavras-chave: mercado de terras, valor da terra, econometria espacial, dinâmica de preços, planejamento do uso da terra.

1. Introduction

The agricultural land market has increasingly aroused the interest of investors who focus on the acquisition, management and leasing of land with potential for profit generation through agricultural production, land valuation and revenue generated by leasing them. In general, for an economic agent to be able to engage in agricultural activities, it is necessary to have access to land, which may occur through the acquisition or rental of rural property. As agricultural land prices are spatially heterogeneous, information on their values and their determinants is of great relevance to land use planning and decision-making by economic agents.

Due to its relevance, studies on the value of agricultural land and the determinants of its prices have been conducted throughout the history of economic theory (Telles et al., 2018). The specific interest in the subject has followed the historical dynamics of economic development and events. The main schools of economic theory devoted to the subject are based on the premise that the value of land is intrinsically associated with its productive capacity (Reydon & Romeiro, 1994), that is, the price of land is determined by the rent obtained via agricultural production or leasing. However, in Keynesian theory, agricultural land is understood as an economic asset, and the determinants of its prices are thus linked to the expectations of agents in relation to future earnings and liquidity (Telles et al., 2016).

In the 1950s, when researchers from the United States found that agricultural land prices increased more than their productive gains—a phenomenon classified as land price paradox (Scofield, 1957)— studies on the determinants of agricultural land prices began to incorporate variables that take into account the characteristics of the land as an economic asset.

In Brazil, one of the main actors in global agricultural production, information on agricultural land prices is an important tool for economic agents. Hence, there is an extensive literature on the determinants of agricultural land prices in the country. Starting in the 1970s, the era of the modernization of Brazilian agriculture and access to subsidized rural credit, the issue became the subject of several studies, i.e., Sayad (1977), Camargo & Ferreira (1989), Oliveira & Costa (1977), Pinheiro & Reydon (1981), Rezende (1982), Egler (1985), Bacha (1989), Ferro & Castro (2013), Reydon et al. (2014), Oliveira & Ferreira (2015), Malassise et al. (2015) and Telles et al. (2016). On the one hand, some authors argue that the price of land derives from the income obtained from its productive use; on the other hand, some consider the general macroeconomic movement, public policies and, particularly, speculation in the land market more important. Accordingly, there is no consensus in the Brazilian literature on the determinants of agricultural land prices in the country. There are many hypotheses and countless factors. However, in most of the studies conducted, a wide set of variables is not used, which does not allow us corroborating or refuting one hypothesis to the detriment of another. Hence, although a growing set of methodological and analytical instruments for the treatment of spatial data have emerged in the specialized literature on the determinants of agricultural land prices (Yang et al., 2019; Lehn & Bahrs, 2018a, 2018b; Wang, 2018), there is still a lack of studies applying this focus to Brazil. Among the few studies that have used the analytical instruments of spatial econometrics are Malassise et al. (2015), which covers only the state of Paraná, and those of Uberti et al. (2018) and Santos et al. (2016), which evaluates only local rural markets.

Taking into account the almost unanimous findings in the vast international empirical research based on spatial econometrics (Nickerson & Zhang, 2014; Brady & Irwin, 2011), the hypothesis in this study is that space exerts a strong influence on determining the prices of agricultural land. Thus, the objective of this study is to determine whether spatial elements in fact influence the determination of agricultural land prices in Brazil.

In addition to this introduction, the article is divided as follows: the second section contains the theoretical foundation that underlies the research; the third section describes the materials and methodological procedures used in the study; the fourth section analyses the results; the fifth section discusses the results; and the sixth section provides our conclusions.

2. Theoretical parameters: The spatial dimension of land prices

The incorporation of spatial influence as a factor to be captured in land price models first became possible in the 1990s due to advances in spatial econometrics and increased availability and quality of spatial data (Brady & Irwin, 2011). Benirschka & Binkley (1994) are among the pioneering authors who used spatial models to evaluate the land market. Although their main focus was evaluating the influence of distance to the consumer market on the variation in agricultural land prices in the Corn Belt region of the United States, they recognized the possibility that the error terms in two neighbouring counties could be correlated and, therefore, adopted a spatial error model (SEM).

Other authors in this initial phase who applied spatial models to evaluate the land market are Hardie et al. (2001) and Lynch & Lovell (2003). However, Patton & McErlean (2003) were the first to present a study with a greater interest in evaluating the possible existence of spatial dependence in the agricultural land market in Northern Ireland. Adopting a spatial autoregressive model (SAR), these authors concluded that spatial dependence is significant and that, therefore, its incorporation into models that seek to evaluate the determinants of agricultural land prices is necessary; otherwise, the results will be biased (Patton & McErlean, 2003). Although this study initially received criticism regarding the methodology it adopted (Maddison, 2004; Kostov, 2009b), subsequent work on land markets in the North American state of Illinois obtained similar results (Huang et al., 2006).

Although the literature on the determinants of agricultural land prices is vast, the incorporation of spatial econometrics in this field of research did not occur quickly. In the research on this subject, besides the above-mentioned, the seminal works are those of Maddison (2009) and Abelairas-Etxebarria & Astorkiza (2012). From this theoretical framework, a significant number of studies have emerged emphasizing the need to incorporate spatial dependence in models that deal with the land market (Huettel et al., 2013; Wang, 2018; Lehn & Bahrs, 2018a); thus, spatial econometrics models have become the current standard procedures in the area.

In addition to the usual determinants of land price, spatial econometrics have been used to analyse various phenomena related to the agricultural land market, e.g., how ecosystem services, rural amenities and historical and cultural landmarks are used, valued and capitalized in markets (Ma & Swinton, 2011; Polyakov et al., 2015; Sardaro et al., 2020), to verify the role of real estate speculation and the conversion of land for urban use (Plantinga et al., 2002; Geniaux et al., 2011; Cavailhès & Thomas, 2013; Zhang & Nickerson, 2015) and to analyse the effects of environmental policies (Letort & Temesgen, 2014; Myrna et al., 2019), agricultural subsidies (Karlsson & Nilsson, 2014; Feichtinger & Salhofer, 2016) and tax exemptions on land prices (Dillard et al., 2013). Studies have also evaluated how different databases are able to capture the influences of different determinants (Lynch & Lovell, 2003; Ma & Swinton, 2012).

In addition, spatial econometrics has recently been successfully combined with other econometric tools, resulting in models with a high degree of sophistication and complexity. Two main trends stand out in this process: (*i*) the incorporation of quantile methods that allow analysing the detailed contributions of different determinants via the conditional distribution of land prices (Kostov, 2009a; Lehn & Bahrs, 2018b; Sardaro et al., 2021), with the possibility of incorporating even machine learning elements into such models (Córdoba et al., 2021); and (*ii*) the combination of spatial econometrics with time series econometrics in studies that have focused on the evaluation of the spatiotemporal integration of land markets (Carmona & Rosés, 2012; Yang et al., 2017, 2019; Grau et al., 2020).

In contrast to the international literature, recent Brazilian research on land markets has still largely maintained a traditional econometric approach—e.g., Ferro & Castro (2013), Reydon et al. (2014), Oliveira & Ferreira (2015), Queiroz et al. (2018) and Palludeto et al. (2018)—and therefore disregards the aspects of spatiality and its possible consequences.

In Brazil, a study by Malassise et al. (2015) is one of the few to use a spatial panel model to analyse the behaviour of agricultural land prices, but it is applied only for the state of Paraná. As in international studies, the authors find strong evidence of spatial dependence in the land market of Paraná. Marcato (2016) is another author who has evaluated spatial dependence on the land market and whose study investigates the state of Santa Catarina. However, Marcato (2016) limits his research to an exploratory spatial data analysis, identifying the existence of a significant spatial correlation without any further econometric deepening. Finally, Santos et al. (2016) and Uberti et al. (2018) simultaneously use traditional econometrics and spatial econometrics to test the adequacy of these methods as tools for the development of a property value map in the context of agricultural land. Santos et al. (2016), evaluating the land market in Petrolina, Pernambuco, concludes that both methods can be used for this purpose. Conversely, Uberti et al. (2018), evaluating the agricultural land market in the North Fluminense region in the state of Rio de Janeiro, show that only the spatial model is able to control for spatial autocorrelation and that its performance is therefore superior to the traditional econometric model.

3. Methodology

3.1 Database

The dependent variable used in the study is the value of bare land (VTN) per hectare in 2020 in the municipalities in the South, Southeast and Central-West regions of Brazil, which, collectively, are referred to throughout this study as the central-south region. The data used are those of the Brazilian Federal Revenue Service (Brasil, 2020). In 2019, the Internal Revenue Service began to disclose data on the VTN in the municipalities of the country. These values are reported by local government or state public administration agencies and must follow the standardization provided by Normative Instruction RFB no. 1,877 of 2019.

The availability of data, however, is not yet homogeneous, and such information does not cover the entire Brazilian territory. Thus, due to insufficient information, the North and Northeast regions were not included in the study. In the North region, there are VTN data for 50% of the municipalities, while in the Northeast region, the data are available for only 12% of the municipalities. For the same reason, the states of Rio Grande do Sul (with VTN information for 37% of the municipalities), Espírito Santo (with VTN information for 4% of the municipalities), Goiás (with VTN information for 63% of the municipalities) and Distrito Federal (without data) were also excluded from the analysis. Thus, only the states with VTN information for at least 88% of their municipalities were maintained.

The state of Rio de Janeiro is the only one with information available for all of its municipalities, followed by the states of São Paulo (with 01 excluded municipality), Paraná (02 excluded municipalities), Mato Grosso do Sul (02 excluded municipalities), Minas Gerais (04 excluded municipalities), Mato Grosso (13 excluded municipalities) and Santa Catarina (34 excluded municipalities). Figure 1 shows a map of the municipalities in these states, highlighting the municipalities excluded due to a lack of data, with the exception of the São Paulo municipality of Ilhabela, which was excluded because it is an archipelago municipality—this prevents its use in the construction of neighbourhood matrices necessary for spatial econometric models. In general, the absence of data seems to occur randomly within the states, except in Santa Catarina, whose municipalities that were excluded from the research are concentrated in the mesoregions of Western Santa Catarina, Vale do Itajaí and Grande Florianópolis.

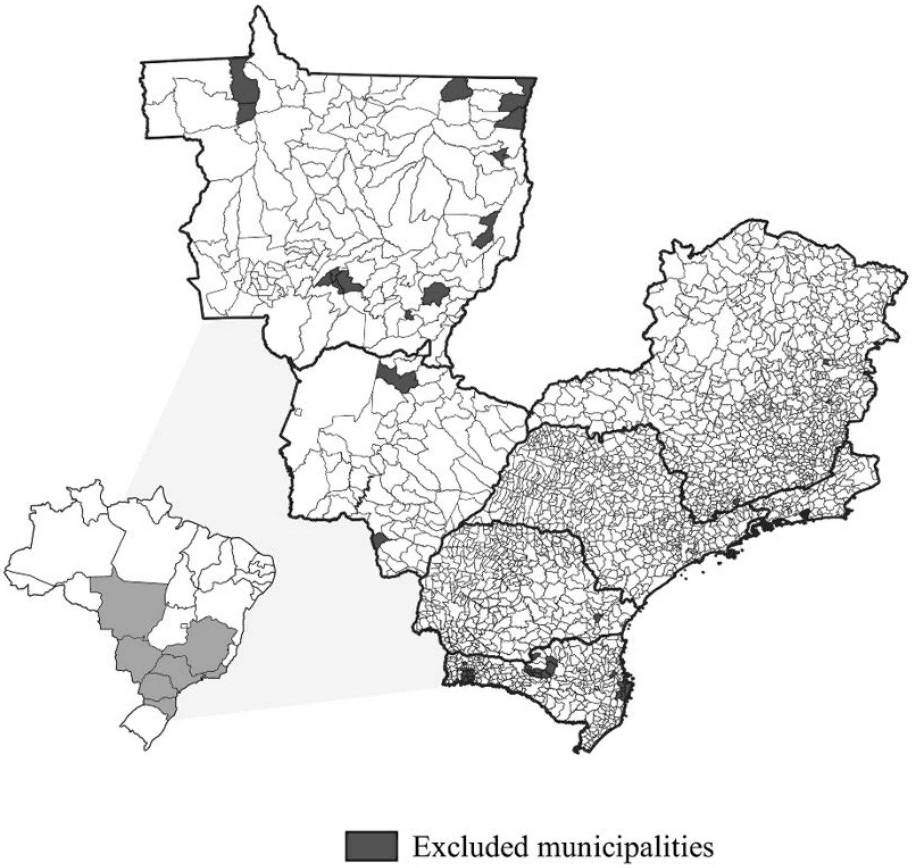

Figure 1 – Municipalities in the central-south region of Brazil included in the study. Source: Prepared by the authors with data from the Brazilian Federal Revenue Service.

Following the exclusion of the municipalities with no data, the final sample consisted of 2,448 municipalities, which correspond to 98% of the municipalities in the seven states considered in the study and 44% of all Brazilian municipalities. The study sample stands out for its relative importance in Brazilian agriculture, considering that the municipalities analyzed were responsible, in 2020, for 63% of the total gross production value of Brazilian agriculture (Instituto Brasileiro de Geografia e Estatística, 2020).

Mostly, the focal VTN data refer to good-fit crop land, whose information is available for 99% of the sample. It is expected to make the land prices in different regions and, therefore, with different edaphoclimatic characteristics, more compatible and comparable. As an exception, for 19 municipalities, data referring to land of regular suitability were used; for four municipalities, land of restricted suitability; and for six municipalities, land for planted pasture. Alternatively, a secondary model was also tested, focused on VTN data relative to land of regular suitability. These results, however, were quantitatively and qualitatively similar to the initial results and, therefore, are not presented in this study.

In addition, the data used demonstrate an important change compared to the original data from the Federal Revenue Service. The information for the municipalities of Santa Catarina, when informed by the state government, corresponds to the minimum value of agricultural land prices provided by the Agricultural Research and Agricultural Extension Company of Santa Catarina (EPAGRI). However, for 2019, the data provided by the Revenue Service are not equivalent to the minimum value but to the most common value of the data provided by EPAGRI, which makes more sense in terms of standardization and information use when consolidated with those from other states. For this reason, in cases where the data source of the Federal Revenue is the EPAGRI, we worked with the most common value of the agricultural land price.

The average value of agricultural land in the municipalities that compose the sample is R$24,455.56, and the values have a high standard deviation (R$21,614.90). The distribution of land values among the municipalities in the central-south region of Brazil is shown in Figure 2.

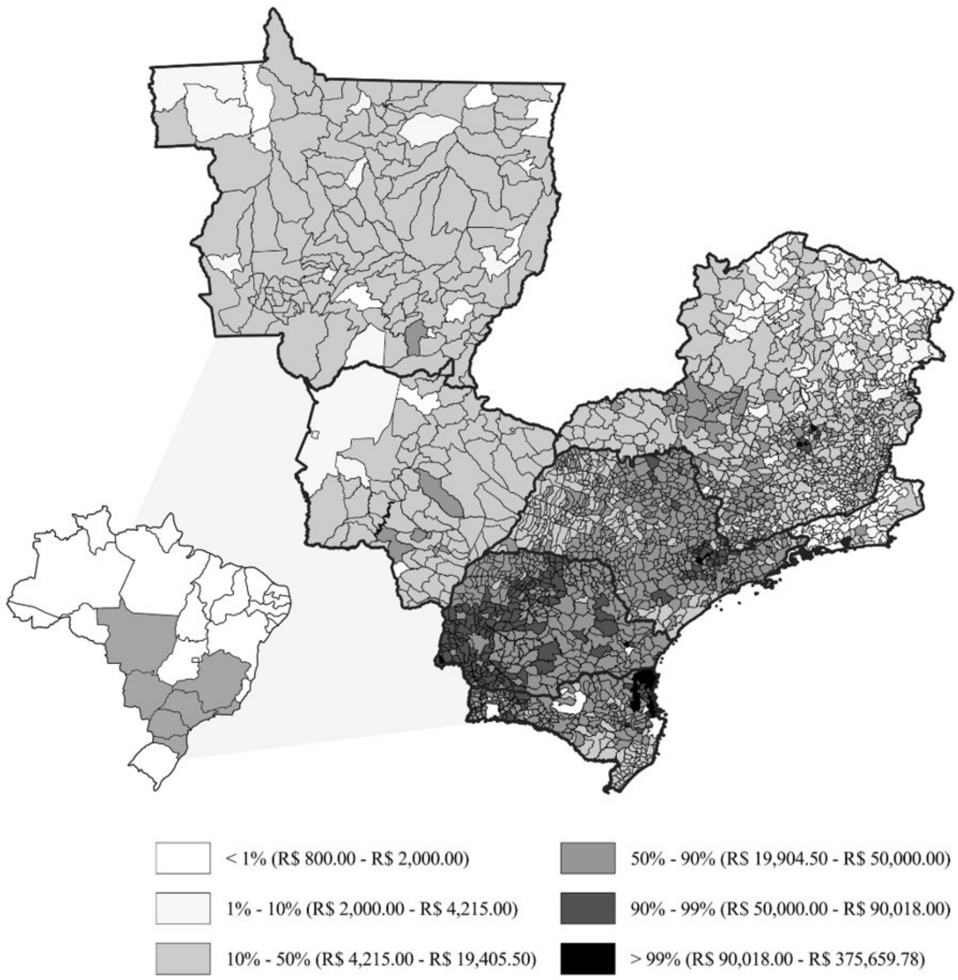

Figure 2 – Percentile distribution of agricultural land prices in central-south Brazil in 2020. Source: Prepared by the authors with data from the Brazilian Federal Revenue Service.

The state with the lowest mean VTN is Mato Grosso (R$7,808.09), while the state with the highest mean VTN is Paraná (R$46,884.73). The municipality with the lowest VTN value is São Francisco, Minas Gerais (R$800), while the municipality with the highest VTN is Sarzedo (R$375,659.78), also in Minas Gerais. Although this value may, in principle, include a measurement error, given its 17 standard deviations above the mean value of the sample, we decided to maintain it throughout the study, as this is the same VTN in the municipality informed by the Technical Assistance and Rural Extension of the State of Minas Gerais (Empresa de Assistência

Técnica e Extensão Rural do Estado de Minas Gerais) for 2019 and 2021; therefore, there is consistency in the disclosure of this information.

3.2 Econometric model

The spatial Durbin model (SDM) was used in the study, where, in addition to the spatially lagged dependent variable, the spatial lag of the explanatory variables is also incorporated. The choice of this model over other spatial econometric models was initially due to the results we obtained with the Moran's I test and the Lagrange multipliers in their robust versions, which suggested the existence of spatial dependence in the model, manifested through the dependent variable. The additional inclusion of spatially lagged explanatory variables occurred because the SDM produces more flexible direct and indirect effect parameters than the traditional spatial autoregressive model, and it is also an estimator capable of generating nonbiased parameters, even in the presence of eventual specification errors (LeSage & Pace, 2009; Elhorst, 2010; Halleck Vega & Elhorst, 2015).

Regarding the spatial weight matrix, it is assumed that ideally, its choice should be guided by economic theory or duly justified by econometric modelling (Corrado & Fingleton, 2012; McMillen, 2012; Halleck Vega & Elhorst, 2015). However, to date, a definitive answer to this question has not been provided in the literature on land markets, although some studies have attempted, in an incipient way, to determine the matrix of spatial weights with innovative methods (Cotteleer et al., 2011; Wang, 2018). Thus, a more pragmatic strategy was adopted in the present study; we opted for the matrix configuration that best fits the research data according to the value of Moran's I test, applied to the residuals of the ordinary least squares model.

The following matrices most frequently identified in the literature in the area were tested: queen contiguity matrix (as in Lehn & Bahrs, 2018b; Myrna et al., 2019, Yang et al., 2019), inverse distance matrix (as in Lehn & Bahrs, 2018a; Sardaro et al., 2020; 2021) and inverse square distance matrix (as in Abelairas-Etxebarria & Astorkiza, 2012; Cavailhès & Thomas, 2013; Letort & Temesgen, 2014). According to this criterion, the weight matrix we adopted was the queen contiguity one.

A series of socioeconomic characteristics and agricultural production of the municipalities that according to the literature can explain the behaviour of agricultural land prices were included as independent variables. All monetary variables were corrected by the Extended National Consumer Price Index (IPCA) for June 2020[1], the last month available for states and municipalities to send their VTN data to the IRS. The details of these selected variables are shown in Chart 1.

The inclusion of variables that have been little explored in the national research is noteworthy, but some of them have already been consolidated in the international literature, e.g., the degree of urbanization of municipalities, the distance to urban centres and the size of agricultural properties. On the other hand, the value of the Rural Property Tax Rural Property Tax (Imposto sobre a Propriedade Territorial Rural - ITR) is often included in national studies on land markets as a proxy variable that represents the land maintenance cost (Malassise et al., 2015). However, considering that the calculation of such tax is based on the value of the bare land disclosed, its use here would have resulted in a bias of reverse causality. Therefore, it was discarded from the study. In addition to the variables described in Chart 1, the estimated model includes fixed effects for mesoregions, to capture, at least partially, the influence of edaphoclimatic and specific regional land markets characteristics on land prices.

[1] 1 USD = 5.4754 BRL.

Chart 1 – Description of the variables used.

Variable	Description	Year	Source
ln_price	Natural logarithm of bare land value - VTN (in Brazilian reais)	2020	Federal Revenue Service
Urb_degree	Degree of urbanization (%) in the municipality	2017	IBGE
Over_100ha	Proportion (%) of properties with more than 100 hectares in relation to the total of properties	2017	IBGE - Agricultural Census
Productivity	Value of agricultural production (in thousands of reais) per hectare of planted area	2020	IBGE - Municipal Agricultural Production
Soybean_area	Proportion (%) of soybean planted area in relation to total planted area	2020	IBGE - Municipal Agricultural Production
Credit_ha	Value of agricultural subsidy in the 2019-2020 harvest (in thousands of reais) per hectare of planted area	2019/ 2020	Central Bank and IBGE - Municipal Agricultural Production
Agricultural_ GDP	Proportion (%) of the gross domestic product (GDP) in the agricultural sector in relation to total municipal GDP	2018	IBGE
Per_capita_GDP	Municipal GDP per capita (in thousands of reais)	2018	IBGE
Owner	Proportion (%) of landowners in relation to total agricultural producers	2017	IBGE - Agricultural Census
Distance	Distance (in 100 km) to the nearest municipality with more than 500 thousand inhabitants	2020	IBGE and DATASUS

To estimate the model, the dependent variable was transformed into a logarithmic scale. Conversely, the independent variables were used in their original forms, as several of them were already expressed as a percentage and others, expressed in monetary terms, had some zero values, preventing their logarithmic transformation. Therefore, the estimated model is of the log-linear type, considered the most common model for this kind of analysis (Zhang & Nickerson, 2015). Thus, the following equation summarizes the model used in the study:

$$\ln(P) = \alpha + \rho W \ln(P) + X\beta + WX\theta + \mu + \varepsilon \tag{1}$$

where $\ln(P)$ represents the natural logarithm of the VTN of the municipalities we analysed; X represents the set of explanatory variables that determine the land price; μ represents the fixed effects of the mesoregions; W represents the matrix of spatial weights, defined according to the queen contiguity matrix; α, ρ, β and θ are the parameters to be estimated; and ε represents the random error term of the model. The model is estimated by maximum likelihood, with robust standard errors regarding violations of the error normality assumption.

Due to the existence of feedback and spillover effects, the parameters estimated using the SDM model cannot be directly interpreted as the marginal effects of the independent variables on the dependent variable, as in traditional econometric models (Elhorst, 2010; Golgher & Voss, 2016). Accordingly, along with the parameters obtained using Equation 1, the direct, indirect and total effects of the parameters are presented, as suggested by LeSage & Pace (2009).

4. Results

4.1 Exploratory spatial data analysis

Our analysis of the prices of municipal agricultural land in the central-south region begins with an exploratory spatial data analysis. Initially, we found a high and statistically significant value for Moran's I of the logarithm of land prices (I = 0.8279, p-value <0.01), whose result is further reinforced by the Moran's dispersion diagram shown in Figure 3, where the data appear, in general, quite concentrated around the line of the slope.

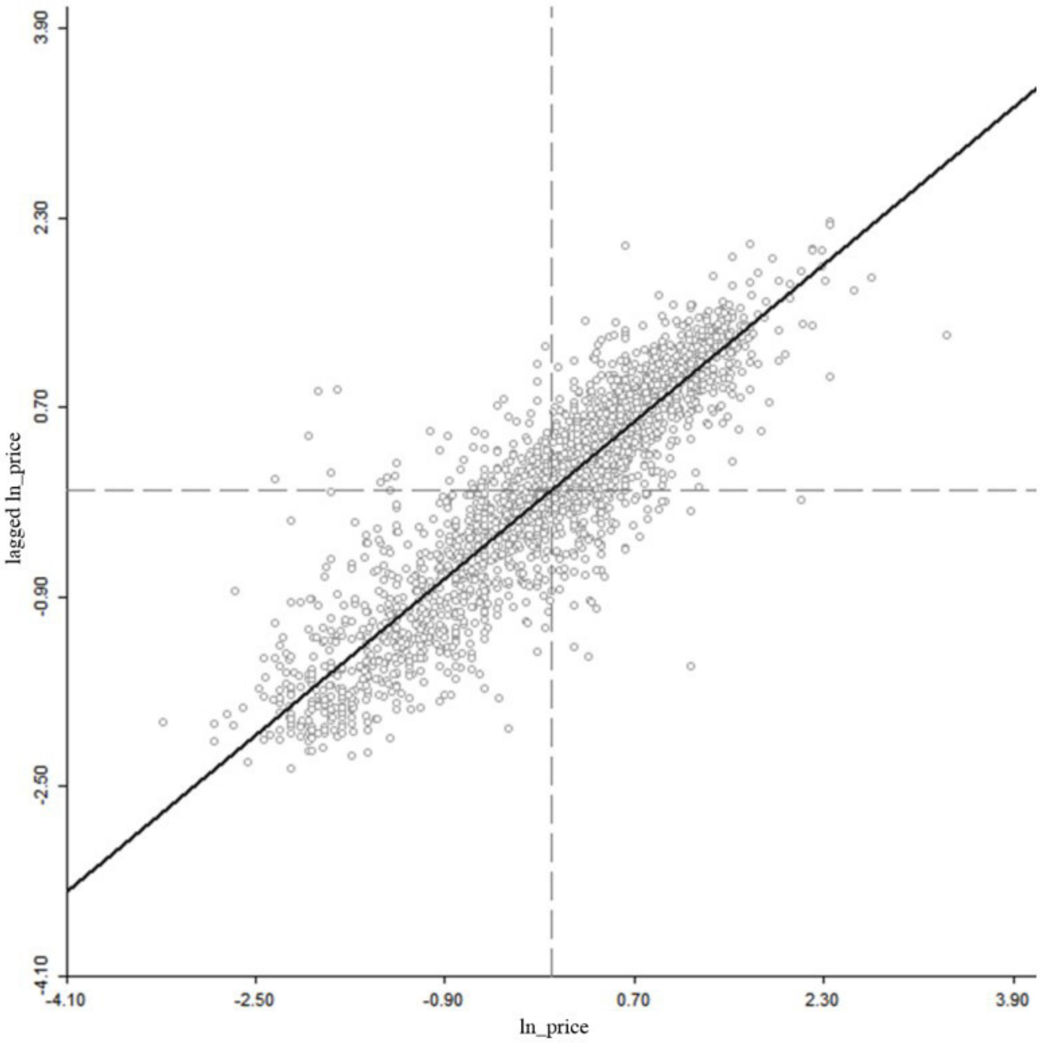

Figure 3 – Moran's dispersion diagram of agricultural land prices in central-south Brazil in 2020. Source: Prepared by the authors with data from the Brazilian Federal Revenue Service.

Next, Figure 4 shows a cluster map of the region considered in the study. Of the total number of municipalities included, only 18 were found to be part of the High-Low and Low-High clusters. Thus, to facilitate a visualization of the remaining results, only those municipalities that form clusters of the High-High or Low-Low types are highlighted in Figure 4.

On the one hand, there is a cluster of high prices for agricultural land along practically the entire length of Paraná. In Santa Catarina, high-price clusters are formed in certain regions, especially in the mesoregions of the Itajaí Valley, Greater Florianópolis, Northern Santa Catarina and Western Santa Catarina. Conversely, in the state of São Paulo, high-price clusters are formed, concentrated mainly in the mesoregions of Ribeirão Preto, Campinas, Metropolitan São Paulo and Macro Metropolitan Paulista.

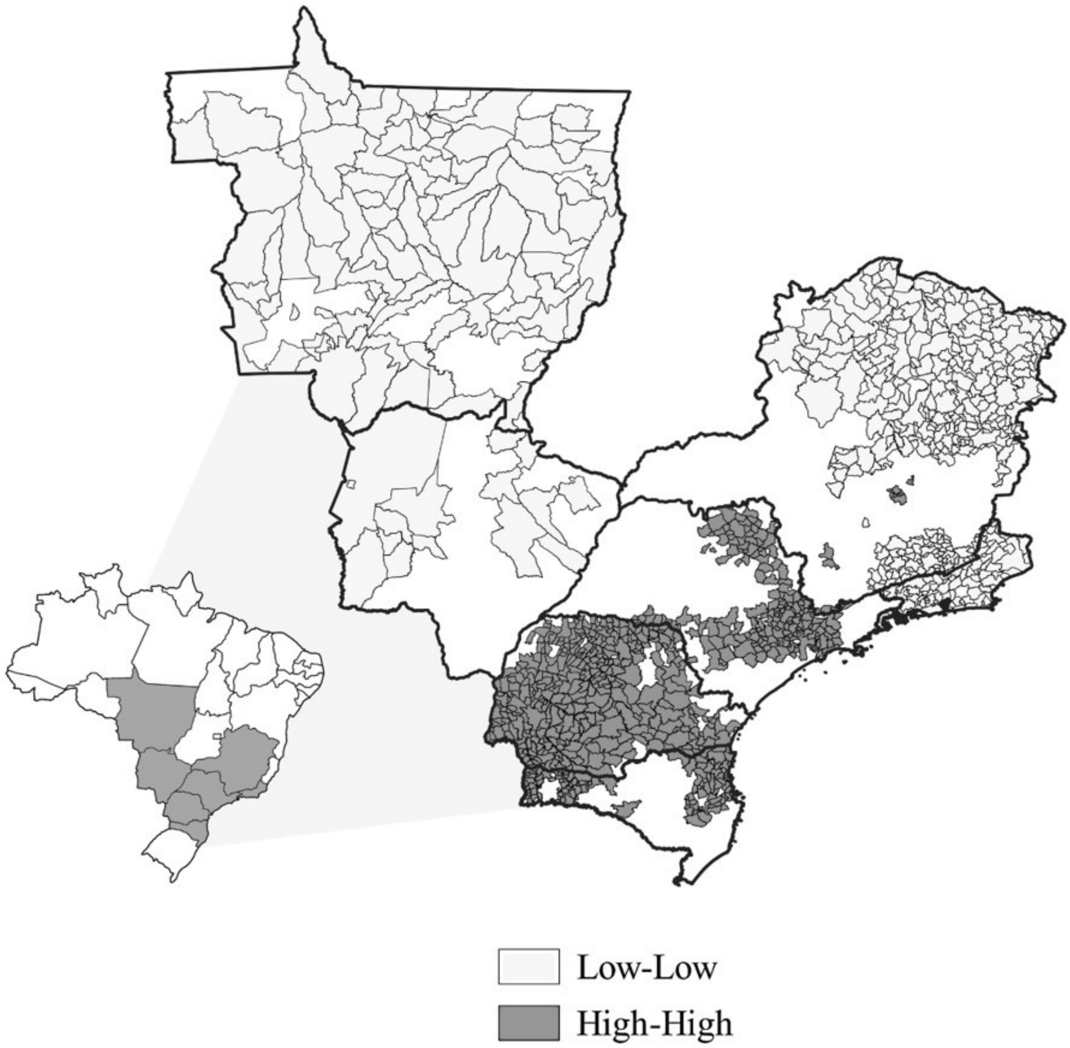

Figure 4 – Formation of agricultural land price clusters in central-south Brazil in 2020. Source: Prepared by the authors with data from the Brazilian Federal Revenue Service.

On the other hand, a cluster of low prices for agricultural land throughout much of the state of Mato Grosso is formed, especially in the North, Northeast and Central-South mesoregions of Mato Grosso, extending to the state of Mato Grosso do Sul in the mesoregion of the Pantanais. A low-price cluster is also formed in nearly the entire state of Rio de Janeiro, together with the Minas Gerais municipalities near the Rio de Janeiro border. The northern portion of the state of Minas Gerais, especially its Northern, Jequitinhonha and Mucuri Valley mesoregions, is also predominantly composed of a large cluster of low prices.

Thus, it can be inferred from this analysis that the spatial dimension seems to be strongly linked to the price of agricultural land in the municipalities in the South, Southeast and Central-West regions of Brazil. However, other important determinants of land prices, which may simultaneously have strong spatial dependence, such as soil productivity, have not been considered. Therefore, it is necessary to use more advanced tools that are capable of taking these characteristics into account to adequately isolate and measure the effects of spatiality on the variable of interest in this research.

4.2 Econometric results

The results of the traditional econometric model, estimated by ordinary least squares, where the potential determinants of land prices are controlled for, are shown in Table 1. At first glance, the model seems to have a good fit ($R^2 = 0.79$), in addition to most of the statistically significant variables, with a significance level of 1%.

Additionally, the spatial diagnosis of the model is shown at the bottom of Table 1. Thus, even after controlling for the included covariates, the regression error term has a significant Moran's I statistic at the 1% level (I = 0.2645), confirming the existence of spatial dependence on the land price and thereby indicating the need to estimate the spatial econometric model.

Our choice of the model to be estimated is based on the test results of the Lagrange multipliers, also shown in Table 1. As observed, while the test value is statistically significant at the 1% level, even in its robust version, regarding the presence of spatial lag in the dependent variable, the same does not occur in the robust version of the test for the presence of spatial dependence in the error term. Thus, the SDM is chosen instead of the spatial Durbin error (SDE) model.

Table 1 – Determinants of agricultural land prices of the municipalities in the central-south region of Brazil in 2020 (based in Ordinary least squares model – OLS model).

Variable	Parameter		Standard error
Urb_degree	0.002191	***	0.000310
Agricultural_GDP	0.001287		0.000872
*Per_capita*_GDP	0.001071	***	0.000398
Over_100ha	−0.007607	***	0.000988
Owner	0.000070		0.000720
Productivity	0.006085	***	0.001139
Credit_ha	−0.000241	***	0.000052
Distance	−0.092778	***	0.016964
Soybean_area	0.002493	***	0.000683
Constant	9.080633	***	0.131743
Fixed Effects (mesoregions)	**Yes**		
Observations	2,448		
R^2	0.792		
F	137.581	***	
Moran's I (error)	0.265	***	
ML (lag)	561.852	***	
ML robust (lag)	101.288	***	
ML (error)	464.016	***	
ML robust (error)	3.452	*	

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

The results of the SDM model are shown in Table 2, with the parameters of the spatially lagged variables represented by the inclusion of the letter W along with the variable name. Since the parameters of this regression do not accurately reflect the marginal impacts of the variables included in the model, for now it is sufficient to emphasize that the spatially lagged dependent variable has a positive and statistically significant sign (W.ln_Price = 0.4524), confirming all initial prognoses regarding its influence on the determination of agricultural land prices in the central-south region of Brazil.

Table 2 - Determinants of agricultural land prices of the municipalities in the central-south Brazil in 2020 (based on the spatial Durbin model – SDM).

Variable	Parameter		Standard error
Urb_degree	0.001217	***	0.000278
Agricultural_GDP	0.000927		0.000779
Per_capita_GDP	0.000227		0.000353
Over_100ha	−0.003177	***	0.001009
Owner	0.000872		0.000661
Productivity	0.004204	***	0.001079
Credit_ha	−0.000289	***	0.000045
Distance	−0.079555		0.076594
Soybean_area	0.002267	***	0.000735
W.Urb_degree	0.002173	***	0.000627
W.Agricultural_GDP	−0000003		0.001644
W.Per_capita_GDP	0.001601	**	0.000773
W.Over_100ha	−0.005236	***	0.001677
W.Owner	−0.002550	*	0.001337
W. Productivity	0.003076		0.001925
W.Credit_ha	0.000366	***	0.000134
W.Distance	0.057593		0.082199
W.Soybean_area	−0.000654		0.001107
W.ln_price	0.452450	***	0.022425
Constant	4.942867	***	0.263286
Fixed Effects (mesoregions)	**Yes**		
Observations	2,448		
Pseudo R^2	0.812		
Wald χ^2	12568.583	***	
Moran's I (error)	−0.018		

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

Furthermore, the Moran's I test, when applied to the residuals of the new model, has a notable value that is very close to zero and is not statistically significant (I = −0.0176), suggesting that the previously identified spatial dependence was adequately addressed, thereby reducing our concerns of an eventual omitted variable bias in the model.

Finally, Table 3 presents the direct, indirect and total effects, providing a correct interpretation of the marginal impacts of the independent variables on the price of agricultural land in the central-south region.

Table 3 - Direct, indirect and total effects of determinants of agricultural land prices of the municipalities in the central-south region of Brazil in 2020.

Variable	Direct effects		Indirect effects		Total effects	
Urb_degree	0.001486	***	0.004706	***	0.006192	***
	(0.000284)		(0.001047)		(0.001145)	
Agricultural_ GDP	0.000968		0.000719		0.001687	
	(0.0008)		(0.002793)		(0.003078)	
Per_capita_ GDP	0.000395		0.002944	**	0.003339	**
	(0.000366)		(0.001321)		(0.001465)	
Over_100ha	−0.003836	***	−0.011529	***	−0.015365	***
	(0.000981)		(0.002502)		(0.002577)	
Owner	0.000659		−0.003724	*	−0.003065	
	(0.000666)		(0.002226)		(0.002406)	
Productivity	0.004696	***	0.008601	***	0.013297	***
	(0.001068)		(0.003099)		(0.003303)	
Credit_ha	−0.000265	***	0.000407	*	0.000142	
	(0.00005)		(0.000235)		(0.000261)	
Distance	−0.077422		0.037311		−0.040110	
	(0.072082)		(0.084085)		(0.030789)	
Soybean_ area	0.002303	***	0.000642		0.002945	*
	(0.000712)		(0.001659)		(0.001688)	

Note: *** p < 0.0; ** p< 0.05; * p < 0.1.

Given the total of the variables included in the model, only the degree of urbanization, the proportion of properties with more than 100 hectares and productivity of the land have statistically significant total effects at the 1% level as well as a per capita GDP and proportion of area planted with soybeans that are significant at the maximum statistical limit of 10%.

5. Discussion

Considering our correct estimation and presentation of our model and our proper controlling for spatiality, it is possible to perform a detailed analysis of the variables treated as determinants of agricultural land prices in central-south Brazil.

The degree of urbanization proved to be a statistically significant variable, contributing directly and indirectly to the formation of agricultural land prices. This result, although it has not been explored in the recent Brazilian literature, aligns with most of the international literature on the subject, which has established the relevance of population density and related variables for land prices in other markets (Lehn & Bahrs, 2018a; Letort & Temesgen, 2014).

The share of agricultural GDP in municipal GDP—treated here as an indicator of agricultural importance in a local economy—was not statistically significant in the model. This result corroborates the findings of Karlsson & Nilsson (2014), who have also shown that in different regions in Sweden, specialization in agriculture does not contribute to the formation of agricultural land prices.

Municipal per capita GDP is a statistically significant variable at the 5% level, mainly due to its indirect influence on land prices, given that its direct effects are not statistically significant. Lehn & Bahrs (2018a), in a study of the German state of North Rhine-Westphalia, also state that the indirect effects of municipal per capita income outweigh its direct effects. However, its influence on land prices is negative and not significant. In a second study, with a quantile approach, the same authors claim that per capita income, although it has a negative influence on land price, has effects that are significant only on the lower and upper limits of their land price distribution (Lehn & Bahrs, 2018b). On the other hand, Cavailhès & Thomas (2013) and Huang et al. (2006) show that income is positively associated with the price of agricultural land in Belgium and the US state of Illinois, respectively.

The size of agricultural properties has direct and indirect negative and statistically significant effects on determining the prices, per hectare, of agricultural land in the central-south region, despite the limitations of the variable we included in the model, which considers only the percentage of agricultural properties with more than 100 hectares in the municipalities analysed. Although the influence of the size of rural property is frequently addressed in the international literature regarding land prices, its results in these studies are not unanimous. Sardaro et al. (2020), who have found evidence that the size of properties positively influences land prices in Italy, attributes this result to the existence of economies of scale in local agricultural production. This result is supported by the works of Myrna et al. (2019) and Feichtinger & Salhofer (2016). Conversely, Lehn & Bahrs (2018a) and Polyakov et al. (2015) show that the size of properties has an influence in the shape of a parabola—negative in its linear effects but positive in squared terms. The negative result for the variable in the present study also supports the results of Zhang & Nickerson (2015).

Although Reydon et al. (2006) have already addressed the negative relationship between property size and the price of Brazilian agricultural land, this variable has been omitted in much of the Brazilian literature. An exception, however, is the work of Santos et al. (2016), in which the negative relationship between these two variables is identified in the context of the rural land market in the municipality of Petrolina, Pernambuco.

The influence of local land ownership structure on the agricultural land market in this study is captured through the variable Owner, which measures the percentage of landowners in relation to the total number of agricultural producers in a municipality. The effect of this variable, which was not statistically significant, conflicts with findings in the international literature. In Wang (2018), for example, the percentage of agricultural land operated by owners exerts a strong positive influence on the price of agricultural land in the U.S. state of Pennsylvania. Moreover, Feichtinger & Salhofer (2016) show that a higher percentage of leased land reduces the price of agricultural land in the German region of Bayern. According to these authors, this is because a high percentage of leased land suggests the existence of a better developed land rental market, which acts as a substitute good for land purchase and consequently reduces the price of land.

In the Brazilian literature, Souza et al. (2012) have failed to detect the existence of a relationship between land concentration and the land market in the state of São Paulo due to the high Gini index of land tenure throughout the time series analysed in their study.

As expected, land productivity has proven to be an important variable in determining agricultural land prices when taking into account the frequency with which this topic has been addressed in the international literature on the subject (Sardaro et al., 2020; Zhang & Nickerson, 2015) whether measuring productivity in monetary terms or in terms of agricultural production. Similarly, Malassise et al. (2015) show that land productivity, measured in terms of the gross value of production per square kilometre, positively impacts the price of land in the municipalities of Paraná.

Agricultural subsidy, in turn, has statistically significant negative direct effects and positive spillover effects, which we found to be statistically significant at the 90% confidence level. In the sum of these opposite effects, however, their total effects are not significant. This result contrasts with those presented by Wang (2018), Feichtinger & Salhofer (2016) and Dillard et al.

(2013), where both the direct and indirect effects of different government subsidies have positive impacts on the price of agricultural land.

Based on graphical analyses of time series, it is suggested that agricultural subsidy is positively associated with the price of agricultural land in the state of São Paulo (Souza et al., 2012) and Paraná (Volsi et al., 2017). These results are further reinforced by econometric analysis (Malassise et al., 2015). Ferro & Castro (2013), however, show that although rural subsidy positively influences the price of land in agricultural frontier and transition regions, it does not exert influence in developed agricultural regions, which could explain our results, since we focused only on predominantly developed regions.

The distance between rural property and large urban centres and consumer markets and its influence on the determination of agricultural land prices is a matter of great interest in the international literature, as it is also the main issue raised by Benirschka & Binkley (1994)—a precursor of the application of spatial econometrics applied to this theme. In addition, almost unanimously, studies have concluded that the more distant lands are from urban centres, the lower land prices will be (Sardaro et al., 2020, 2021; Wang, 2018; Feichtinger & Salhofer, 2016; Zhang & Nickerson, 2015; Letort & Temesgen, 2014; Dillard et al., 2013). Nevertheless, this subject has been rarely addressed in the Brazilian literature.

In the context of the central-south region in Brazil, the distance from a municipality to the nearest large municipality is not a statistically significant variable. Although the definition of a large municipality we initially used was that of one with more than 500,000 inhabitants, the criteria of 100,000 and 250,000 inhabitants were alternatively tested. However, in general, our conclusions regarding this variable did not change.

A possible explanation for our findings' divergence from the results predominantly found in the literature may be our level of data disaggregation. While the value of bare land used in the study refers to a mean municipal value, much of the recent international literature has used disaggregated data at the farm level, thus making it possible to measure the exact distance between a focal property and the nearest urban centre, not simply the distance between municipalities, which we have measured in the present study. However, Uberti et al. (2018), whose research used data from the North Fluminense region, notably found no evidence that the distance between rural properties and the Campos de Goytacazes centre influences their value.

Finally, the soybean planted area, in relation to the total planted area in a municipality, has a positive impact on the determination of land prices, although there are no spatial spillover effects for this variable. This result is not surprising, given the importance of soybean cultivation for Brazilian agriculture; its influence on land prices has been previously identified in the national literature (Queiroz et al., 2018; Palludeto et al., 2018; Malassise et al., 2015; Ferro & Castro, 2013).

6. Final considerations

In this study, we sought to evaluate the potential determinants of agricultural land prices in central-south Brazil. As expected, we have shown that spatiality exerts a strong influence on the determination of agricultural land prices in the region, due to both the spatial dependence identified in the dependent variable of the model and the spillover effects of the independent variables.

In addition to the spatial issue, the study tested the influence of other variables that have already been consolidated in the international literature but remain little explored in the Brazilian literature on the subject, as well as the variables typically used in analyses of the area. We found that the degree of urbanization of a municipality, the municipal GDP per capita, the average size of properties, the agricultural productivity, and the area dedicated to soybean planting are significant variables in the determination of land prices.

Regarding future related research, it is expected that data from the Federal Revenue Service will continue to be released periodically and, moreover, that its scope will be extended to other regions of the country. Thus, it will be possible to analyse an even greater number of municipalities via the application of these data in a spatial panel, thereby conferring greater reliability to future results.

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