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Market Access and Agricultural Diversification: An Analysis of Brazilian Municipalities

Bruno Benzaquen Perosa [1], Ramon Felipe Bicudo da Silva [2] and Mateus Batistella [2,3,*]

[1] Institute of Economics and International Relations, Federal University of Uberlandia, Uberlandia 38405-314, Brazil; brperosa@ufu.br
[2] Núcleo de Estudos e Pesquisas Ambientais, Universidade Estadual de Campinas, Campinas 13083-867, Brazil; rbicudo@unicamp.br
[3] Brazilian Agricultural Research Corporation (Embrapa Digital Agriculture), Campinas 13083-886, Brazil
* Correspondence: mateus.batistella@embrapa.br

Abstract: Market access has a deep impact on farmers' decisions, influencing their choice of crops and technology adoption. Crop diversification depends on the availability of markets to trade the agricultural portfolio. This study explored how market access impacted the level of diversification in 5565 Brazilian municipalities from 2013 to 2021. We developed a regression model considering how variables related to market access and commercialization (storage, roads, distribution centers, commercialization credit, among others) affected a local (municipality level) diversification index. After environmental variables were controlled, the results indicated that most of the market access variables have a significant impact on diversification. We also used map analysis to analyze the regional patterns of specialization in Brazilian agriculture, concluding that logistics and commercialization infrastructure have strong influence on the level of diversification in Brazil, a major agricultural powerhouse in the world. The results indicate that market access variables affect diversification and should be considered by policy makers aiming to increase sustainability in agriculture and livestock.

Keywords: spatial econometrics; public farm credit; agribusiness; specialization patterns; logistics

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1. Introduction

A deep transformation has taken place in agricultural production during the last century. The so-called Green Revolution launched after World War II was characterized by the adoption of new technologies allowing yield growth and better use of inputs in agriculture [1]. Along with the advances in agricultural efficiency and productivity, the technologies adopted during the last few decades have also increased emissions of greenhouse gases (GHGs) due to mechanization and intensification in the use of fertilizers [2,3].

Technological innovations, particularly those adapted to tropical conditions, were crucial for Brazil to become a leader as a global supplier of agricultural commodities [4]. The advances in agriculture in the Brazilian savannah (Cerrado) were only possible due to the development of adapted crop varieties, in addition to the intensive use of technological packages, including correction of soil acidity and non-tillage practices [5,6]. The use of these technological packages deeply influenced this sector's organization, generating a specialization pattern in many regions, with grains and cattle prevailing in large areas. Despite the relatively low levels of diversification, this organization allowed Brazilian agribusiness to occupy an important position in the country's economy (in 2022, the agribusiness activities were responsible for 24% of Brazilian GDP and 47% of the country's exports) [7]. Currently, Brazil is one of the largest food exporters, occupying the first position in meat, soybean, maize, and coffee.

This specialization pattern can be noticed in the distribution of agriculture production among Brazilian municipalities. According to data from the Ministry of Agriculture [8], in 2022, the 100 largest producer municipalities (out of 5568 municipalities) were responsible for 34.2% of the cultivated area and 34.7% of the value produced in Brazil. Considering the location of this production, the prevalence of the center-west region, where 67 of the largest producers are located, is clear.

Since the 1970s, the environmental impacts of agricultural activities have gained attention, especially due to the effects of agricultural frontier expansion on forests and other sensitive biomes. The climate change debate urged the necessity of adopting more sustainable agriculture techniques [9]. Conservative or low-carbon agriculture techniques emerged under this demand to increase food production without compromising the environment. The effort to reduce carbon emissions has impacted the development of new technologies under the innovations led by Agriculture 4.0. Even with many technologies available, the adoption by the agricultural sector is still slow, depending on farmers' decisions [10,11]. These decisions consider market access and policy incentives such as subsidized credit.

Among the many techniques for reducing GHG emissions, integrated systems (ISs) that alternate different agricultural productions, such as crops, livestock, and forest, demonstrate the potential for making food production more sustainable without compromising yield and profits [12]. Despite this great potential, IS adoption poses challenges for farmers, (i) first for managing land use through non-conventional management techniques and (ii) second for trading a more diverse portfolio of products.

The concept of agricultural diversification varies across agricultural literature. Most of the literature refers to diversified farming systems (DFSs), considering a broad range of practices that increase biodiversity and sustainability in crop and livestock activities [13]. Instead, this paper refers to crop diversification as the introduction of different crops on the same territory. This can include the use of integrated systems (e.g., integrated crop–livestock–forestry) or even the introduction of a different crop or livestock animal in a regular production area. At a regional level, we present a proxy to measure diversification considering the distribution of all agricultural production among different activities at the municipality level.

Farmers' decisions about crop diversification are affected by technological, environmental, economic, and social aspects [11,12]. Recent literature focusing on the drivers of diversification mostly considers the profile of farmers (e.g., age, education, income), access to technology, and environmental concerns as key aspects for diversification. However, market incentives and access also play a key role in farmers' decisions since the economic feasibility of production change depends on the availability of markets valuing the products from the diversification [10].

Local infrastructure, logistics, and other facilities for market access may affect the level of diversification among agricultural chains [14,15]. This paper explores the impact of market access on the diversification of agricultural production. Hence, our hypothesis is that better market access increases the incentives to adopt a more diversified agricultural portfolio. Considering municipal data related to market access infrastructure (access to roads, storage units, population, rural loans, among others), we analyzed how these proxies of market access affect the diversification of rural production.

To explore these relations, this paper is organized into six sections. Section 2 presents a short literature review about agriculture modernization in Brazil, considering drivers affecting diversification. Section 3 presents the methodology. Section 4 presents the data analysis and results. Section 5 presents the discussion, and the last section shares the conclusions.

2. Agriculture Modernization in Brazil—Diversification Drivers

Following the technological advances from the Green Revolution, Brazilian agriculture expansion after the 1950s resulted in the occupation of new lands with export crops such as soybeans and maize [4]. Cattle ranching also played a central role in this expansion, both as an important economic activity and as a means for land occupation and conversion [16,17].

The technological innovation of agriculture in Brazil aimed at increasing productivity. However, the modernization process was mainly applied to monocultures. The mechanical, physical–chemical, biological, and agronomical innovations were key to increasing the yield and land-use area of these crops [18]. The use of machinery, chemical fertilizers, selected varieties, and non-tillage techniques allowed the increase in food production by area and yield [19].

The introduction of these technologies in Brazil was strongly supported by public policies on credit, rural extension, and research from public institutions [20]. The National System of Rural Credit (SNCR) was funded in 1965, seeking to financially support agricultural investments (e.g., machinery, lands, storage structure), crop production (e.g., seeds, fertilizers), and trading costs (storage, minimum price policy). The SNCR played a key role in the adoption of new technologies from the Green Revolution, allowing farmers to access international innovations.

Along with the availability of credit, the Brazilian Agricultural Research Corporation (EMBRAPA) also played a central role in developing technologies for soil correction and management, together with varieties adapted to different biophysical conditions in Brazil [6]. These technologies were applied to many crops such as coffee, orange, cotton, and sugarcane. Still, the most relevant innovations were applied to grains, such as maize and soybeans, adapting these crops to Cerrado conditions, with longer droughts and acid soils [21].

The innovations generated by public and private players were crucial to induce a modernization of agricultural practices in Brazil. The availability of these technologies to farmers combined with the availability of credit and infrastructure investments induced an innovation process that transformed the Brazilian agricultural sector [6,21].

The impact of this modernization process on the diversification pattern of Brazilian agriculture relates to the technological profile of these innovations. Most of these technological packages were customized to larger areas of monoculture crops, reinforcing a more specialized pattern of agricultural development [22,23].

In the 1990s, new techniques proposing the intra-annual rotation of crops (i.e., non-tillage system) started to be adopted by farmers [24]. The soy–maize systems introduced the possibility of more than one crop per year, besides additional advantages for soil fertility due to no-tillage agriculture and nitrogen biological fixation, for example. These technologies expanded on the Brazilian Cerrado [4], allowing a double harvest in the same year and, therefore, reducing the costs of grain production. The use of this double-crop system represented an important diversification process in Brazilian agriculture and showed some challenges faced by farmers in trading a diversified portfolio of products. Still, since maize and soybean use the same marketing channels, farmers have not faced big challenges in terms of trading their production [24].

During the early 2000s, new techniques considering the rotation of different agriculture ISs, including crops, animal production, and forestry, gained attention considering both economic and environmental benefits. ISs have shown good potential for market risk reduction and better environmental management. For instance, integrated crop–livestock–forest (ICLF) systems are one of the main bets of Brazilian authorities for reducing GHG emissions in agriculture and land use change (in 2020, these emissions represented over 70% of total emissions in the country, according to SEEG [25]).

Despite environmental and income diversification advantages, the adoption of ISs faces a variety of barriers, from technology access and capital availability to trading challenges. Bowman et al. [26] and Gil et al. [11] explored these barriers, considering physical (e.g., climate, soil), economic (e.g., markets, prices, infrastructure), social/personal (i.e., age, education), and informational (access to information about technology) factors. Perosa et al. [10] showed a central role played by information access in explaining the adoption of ISs in Brazil. However, although market access is usually mentioned in these studies, these factors are not central to their analysis.

Market access depends on several infrastructure variables, such as access to roads, availability of storage houses, and distance from consumer markets. As an example, farmers near cities may introduce fruits, vegetables, and other perishable products to their portfolios [27]. This is not possible for farmers more distant or with difficult access to roads and other means to make their production available for consumers. Therefore, this "local specificity" of the lands affects the capacity of farmers to diversify their production [27].

The concept of local specificity is widely explored under the transaction cost theory as an important attribute that explains governance strategies for ruling transactions [28,29]. This concept considers the impact of proximity between a buyer and a seller on the costs of a transaction [30]. One example would be the transaction of perishable goods such as fruits and vegetables, which depends on the time and costs of transportation. Local specificity explains why perishable goods are usually produced closer to the consumption centers [27]. Access to roads and storage also influences the transaction cost and, therefore, the economic viability of commercializing some products [31].

This relation between location and market access is a key aspect in understanding the willingness to adopt a more diversified agricultural production system. Lancaster and Torres [27] explored the motivation for diversification of fruit and vegetable farmers in the US, considering distance from consumers and other local drivers. The authors found a strong relationship between the distance from the market and the willingness to diversify production. Therefore, "short millage" chains present higher diversification levels than "long millage" chains. In environmental terms, the short chains can be considered more sustainable due to the lower level of transportation emissions [32]. This factor adds to the environmental benefits of diversified crops.

The rationale behind this behavior is related to the influence of market access on farmers' decisions about their crop portfolio. In some regions, the existence of a logistic infrastructure for grains may generate incentives to only cultivate this category of crops. On the other hand, the existence of local distribution centers for fruits and vegetables may increase local production of highly diversified portfolios instead of large-scale monocultural systems. Therefore, the local infrastructure and market access affect production specialization or reduce diversification [33].

This paper investigates if market access affects agricultural diversification, using Brazilian municipalities as the unit of analysis. To achieve this goal, we use a spatial econometric regression model and map visualization of regional patterns of Brazilian agriculture and livestock production. As a surrogate for market access, we consider farm credit, logistics, and distribution infrastructure.

3. Methodology

In this study, a spatial econometric regression model was applied to investigate how agricultural production diversification at the municipality level is driven by different factors. The analysis was conducted on a dataset on Brazilian agricultural economics for the period of 2013–2021. The municipality level represents the lower aggregation level form of publicly available data in Brazil. Thus, the decision to utilize municipalities as the unit of analysis in this study was founded on this data availability, but also on the fact that many policies and incentives for agricultural production in Brazil are designed and implemented at the municipality level.

Additionally, we used map visualization techniques to identify regional patterns of specialization in Brazilian agriculture. The maps were built using secondary data from public databases.

3.1. Dataset

The different datasets came from freely available public sources. Agricultural data were retrieved from the Brazilian Institute of Geography and Statistics (IBGE), the Municipal Agricultural Survey (PAM—in Portuguese (https://sidra.ibge.gov.br/tabela/5457, accessed on 9 May 2023)). Livestock data came from the IBGE Municipal Livestock Survey (PPM—in Portuguese (https://sidra.ibge.gov.br/tabela/3939, accessed on 9 May 2023)). Climatic and topography variables were obtained from the WorldClim 2.1 data [34]. Transportation costs for agricultural output were downloaded from the Brazilian Transportation

Costs product [35]. Agricultural financial credit information was obtained from the Central Bank of Brazil, the Matriz de Dados (https://www.bcb.gov.br/estabilidadefinanceira/tabelas-credito-rural-proagro, accessed on 10 June 2023). The information on municipal storage capacity for agricultural products was retrieved from the National Register of Warehousing Units of Agricultural Products, at the National Food Supply Company—Conab (https://sisdep.conab.gov.br/consultaarmazemweb, accessed on 15 September 2023). The information on food distribution facilities (CEASAs) was also obtained from the CONAB database (http://www3.ceasa.gov.br/siscomweb/, accessed on 19 September 2023). Finally, we used data from the Brazilian Institute of Geography and Statistics (IBGE) through the SIDRA database for population census information (https://sidra.ibge.gov.br/Tabela/631, accessed on 5 September 2023) and municipal GDP (https://sidra.ibge.gov.br/tabela/5938, accessed on 5 September 2023).

3.2. Spatial Econometric Model

Our study adopted a spatial model given the spatial structure of the datasets analyzed, which consisted of a total of 5565 Brazilian municipalities and their respective agricultural dynamics between 2013 and 2021. Since agriculture and livestock production is a spatial phenomenon that occurs on the land surface, we considered spatial-dependence patterns in the observed variables [15,17]. Hence, spatial models are more suitable for evaluating statistical relationships among variables while yielding more robust regression coefficients and statistical significance [36]. Although this model presented a very suitable specification for the analysis we proposed, there are some limitations due to the lack of longer data series of credit in Brazil and the data available at the farmer level (rural property level). If these data were available, it would be possible to conduct a deeper analysis of farmers individually, and for specific sectors of the agribusiness, such as beef producers or soybean and maize producers.

The dependent variable in our model represents the diversification in agriculture and livestock activities at the municipality level (i.e., unit of analysis) in the period 2013–2021—which we name "Agri-livestock diversity". As spatial dependence may be present among neighbor municipalities, we adopted the spatial lag model (LAG-model), which is more suitable for this case. Here, we consider the spatial dependence from an empirical but also theoretical (first Tobler's law of geography [37]) perspective which indicates that if one municipality starts a new cycle of agricultural production [17], for example, by diversifying its agriculture and livestock portfolios, the nearest neighbor municipalities will be more likely to diversify as well—i.e., a diffusion process. Hence, the LAG-model is the most suitable as it accounts for the possible effects of the changes in the dependent variable in each municipality on its neighbors' dependent variable [38]. The LAG-model is provided by Equation (1):

$$\begin{array}{c} y - pWY + X\beta + \varepsilon \\ \varepsilon \ \sim \ N\left(0, \sigma_\varepsilon^2 \ I_N\right) \end{array} \tag{1}$$

where Y is the vector of values of the dependent variable, p is the spatial lag coefficient, W is the weighted matrix capturing spatial dependency among the data, β is the direct effect in a given municipality (i.e., effects on diversification given a change in the independent variables), and ε is the error term. The W matrix is designed in the first-order queen contiguity style [39]. To confirm the necessity of spatial regression models instead of ordinary least squares (OLS) regressions, we applied the global Moran's I test on residuals of an OLS regression to evaluate the spatial autocorrelation among observations [40].

The dependent variable Agri-livestock diversity was created by accounting for all agricultural products and types of livestock (e.g., cattle) in a municipality. A Shannon diversity index (SDI) value was applied to the agricultural data using the information on planted areas (71 products including annual crops and fruits), and one SDI value was applied to all types of livestock using information on the number of animals (10 different animal species). Then, the indices were summed to generate a single diversity index (Agri-livestock diversity = SDI for agriculture + SDI for livestock). The SDI is more suitable in our case as it is capable of capturing the occurrence of rare species in ecology [41], or in our study, products with lower occurrence (e.g., a specific fruit being produced in a small piece of land in a given municipality) [4,42]. The SDI is given by Equation (2):

$$SDI = -\sum_{i=1}^{S} p_i ln p_i, \tag{2}$$

where p_i is the abundance (i.e., proportion of planted area) of each agricultural product i (or proportion of different livestock animals—e.g., cattle, pigs) and s is the total number of agricultural products or livestock. Then, we have one SDI value for livestock and one for crops. As the next step, we sum both to obtain the Agri-livestock diversity. Finally, with the Agri-livestock diversity for each year (2013 and 2021), we calculate the change in the period (Δ9 = Agri-livestock diversity 2021—Agri-livestock diversity 2013), so the dependent variable in the model will represent changes in diversity along the period.

As independent variables, we selected a set of controls considering infrastructure, socioeconomic, and environmental factors with an influence on land-use dynamics in Brazilian agricultural systems [14,15,43].

The first group of variables relates to infrastructure. In a large country such as Brazil, distances to ports and major consumption centers significantly affect transportation costs for agricultural products [44]. Additionally, most agricultural production is moved using roads, having a significant impact on the final costs. Hence, the development of diversified agricultural systems can be influenced by proximity to infrastructure for transportation, which indicates that lower costs of transportation (better market access) may influence more diversified systems. The transportation variable (Road2017) represents the mean costs of each municipality taking its agriculture/livestock outputs to ports (and large consumption centers), considering the national infrastructure for transportation in 2017 [35].

Another infrastructure variable (distarm) considers the mean distance from agricultural storage units, using Conab's (Brazilian National Agricultural Agency) database. This variable was built considering the total storage capacity (tons) in a municipality, in 2022, including both public and private types of storage systems (e.g., bulks, silos, and other structures for storing the production). Storage plays a key role in farmer's decisions and capacity to access markets [45]. This variable has a dubious effect: on one hand, this storage may facilitate trading agriculture production, which could increase the incentives for diversification; on the other hand, most of the agricultural storage structure in Brazil is used for grains, which is associated with a less diversified production system (exporting monocultures) [4]. The effects of this kind of infrastructure will depend on the profile of farmers and the production in each region.

The third infrastructure variable (DistCeasa) considers the proximity from food supply centers (Central de Abastecimento—CEASA), which are key for vegetable and fruit commercialization, using mean distances. This variable is important for explaining access to markets, especially for perishable products. Therefore, the presence of these distribution centers must affect the incentives for the diversification of agricultural production at local levels. A positive relation is expected to be found between the presence of these centers and the diversification level.

In the socioeconomic group of independent variables, we included financial incentives that have been previously noted to influence the diversification of rural production [27,46,47]. The variables considered here refer to the availability of capital for necessary investments in crop diversification. Since a large part of agricultural expenses in Brazil is funded by a consistent farm credit system [48,49], we included two types of credit available for farmers (investment and commercialization).

For both types of credit, which are variables in our model, commercialization (CredCom) and investment (CredInvest), we applied the total financial credit (Brazilian currency—BRL) received by farmers in the period 2013–2021. As credit has cumulative effects on rural property over the years (e.g., the improvements to a farm, such as improvements in soil fertility and storage, last for a long time) [43], these variables represent the total capital applied in farms in the period to better represent the role of the financial support in diversification. Commercialization credit considers public policies to guarantee farmers' income, such as minimum price guarantees or loans for farmers to hold their harvest and sell in the future at better prices. Therefore, this type of credit is key for farmers to stock their production in local storages or to trade on local markets.

A third socioeconomic variable relates to the municipality per capita income (GdpCapita) of 2010. This variable measures the municipalities' GDP per their total population and captures a wealth measure of each region, which may affect the local consumption potential and the development of local markets [17]. This may increase the incentives for diversification since farmers may access local consumers.

In the last group of variables, we included environmental factors affecting agricultural activities such as precipitation and topography. Although these variables have no effect on market access, they control different factors affecting agricultural and livestock production, ultimately shaping patterns of diversification (instrumental variables). Annual precipitation (Precipitation) data were retrieved from the WorldClim (Bioclimatic variable 12—period 1970–2000), and slope data were derived from the elevation data built from the SRTM elevation data [34]. For both variables, we used mean values for each municipality. These above-mentioned variables may also impact farmers' decisions and need to be controlled to analyze the "market-effect" influence on diversification.

Table 1 presents the variables of the model.

Table 1. Description of the variables.

Acronym	Variable Name	Description
W_SdivChange	Diversification Index	Variation in agricultural diversification in the municipality (2013–2021)
CredCom	Commercialization Credit	Value of commercialization credit in the municipality (2013–2021)
CredInv	Investment Credit	Value of investment credit in the municipality (2013–2021)
DistCeasa	Distance from Ceasa (distribution center)	Distance from food distribution units (2022)
distArm	Distance from Storage	Distance from storage units (2022)
GdpCapita	Per Capita GDP	Per capita income in the municipality (2010)
Precip	Precipitation	Level of precipitation in the municipality (1970–200)
Slope	Slope	Slope variation in the municipality
road2017	Access to Roads Index	Costs of each municipality taking its agriculture/livestock outputs to ports (2017)

4. Results

Table 2 presents the main results found using the regression model.

Table 2. Spatial regression model results.

Independent Variable	Model Coefficient
W_SdivChange	0.456818
Constant	0.00532343
CredCom	8.35404 *
CredInv	9.96232
DistCeasa	−0.00712316 **
distArm	0.0361965 **
GdpCapita	0.000836871 *
Precip	−2.53503
Slope	−0.00516287
road2017	−1.26064
R-squared	0.156933

* Indicates significance at the 95% confidence level, ** = 99%, n = 5565.

From the results of our spatial model, most of the variables were statistically significant at the 95% confidence level. The two categories of public credit indicate that only the commercialization (CredCom) type has a significant relation with diversification. The relation is positive, showing that more commercialization credit in the considered period, is associated with increased diversification.

The variable of distance to food commercialization units (DistCeasa) was significant and negative, indicating that the shorter the distance from a CEASA, the higher the probability of production diversification. This result can be interpreted as a positive effect of better logistical infrastructure on a farmer's decision to diversify production.

Considering the distance to storage facilities, the variable (DistArm) showed statistical significance, with a positive signal indicating that the shorter the distance from a facility, the lower the probability of production diversification. This variable is considered an important aspect of the market access structure: since most of the storage infrastructure is located in grain production regions (Figure 1a), this variable captures the specialization pattern of grain production regions, such as Mato Grosso and Goiás states in Central Brazil and Paraná and Rio Grande do Sul in the south.

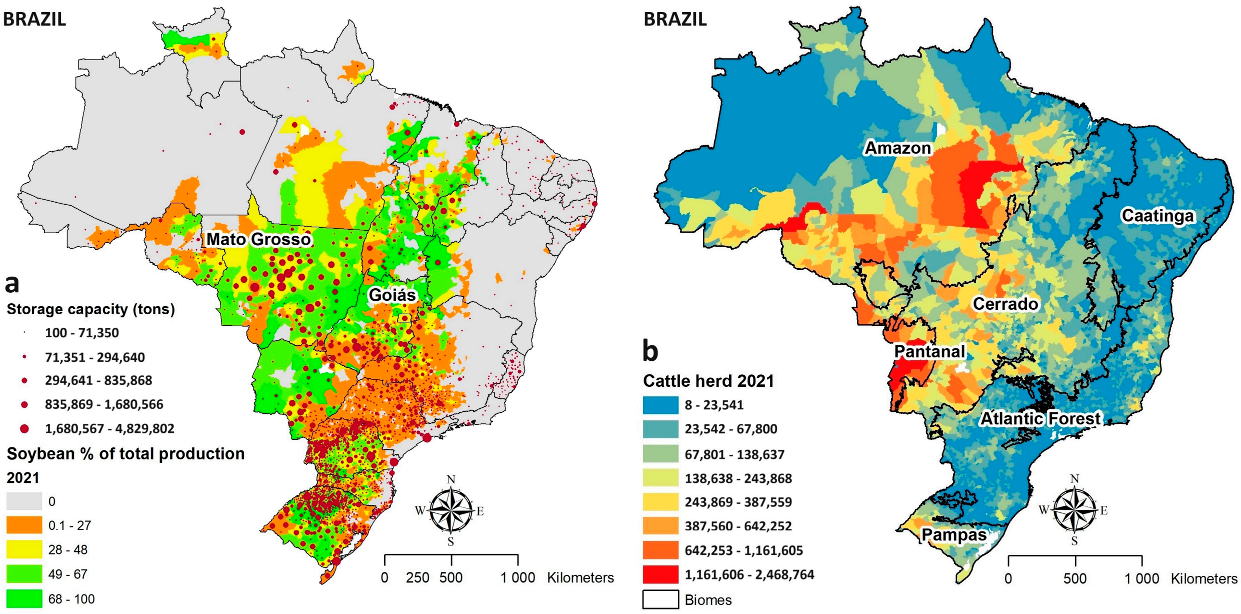

Figure 1. (**a**) Share of the soybean production in relation to all agricultural production and the spatial distribution of storages and total capacity at the municipality level; (**b**) cattle herds (number of animals) (**b**) in Brazilian municipalities. The data for both maps refer to the year of 2021.

The transportation cost variable (road2017) was negative, but not significant. This result indicates the difficulties faced by farmers in transporting their production to consumption centers or export hubs, such as ports.

The local income variable (GdpCapita) was statistically significant and positive. Even though this factor is not directly related to agriculture diversification, it captures the economic profile of each region. The results indicate that wealthier regions have increased potential for diversification during the period of analysis.

The precipitation variable was also significant and showed a negative relation with diversification. This result is counterintuitive (more diversification was expected to be seen in regions with more precipitation) but can be explained because regions with higher precipitation levels in Brazil (such as the Amazon in the north) present low levels of agricultural activities and diversification. This can be seen in Figure 2, which presents the level of diversification (Agri-livestock diversity) in the different regions of the country.

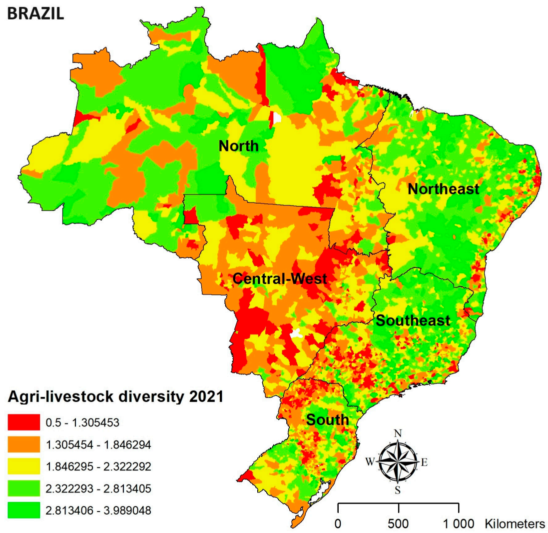

Figure 2. Agri-livestock diversity in Brazil in 2021.

The results indicate a specialization pattern in Brazilian agriculture. Diversification depends especially on credit and transportation costs (Table 1), highlighting the role played by policies and infrastructure related to market access.

5. Discussion

Most of the results reveal regional production clusters in which a specialization pattern emerges due to natural, socioeconomic, and infrastructural drivers. These patterns are strongly related to the historic development of agriculture in Brazil. The challenge of trading grains in regions distant from markets demanded the construction of an efficient infrastructure of roads, ports, and storages [50]. Even though this infrastructure allowed access to markets of different products, there is a clear specialization pattern driven by grain commercialization [35,51]. This can be observed in a map showing soybean crops in Brazil, which are highly concentrated in the central-western and southern regions (Figure 1a).

In grain production regions, cattle seem to be the more suitable diversification choice. This can also be visualized in Figure 1b, which shows that the regions with larger cattle herds are closer to grain production areas or in many cases in the same municipalities. This possible integration of grains and cattle can be used to expand integrated production systems, such as integrated crop–livestock–forest systems. The existence of grain storage facilities and slaughterhouses can facilitate trading this production portfolio. Grains and other export products with advantages for long-mileage transportation tend to dominate the agricultural regions with higher transportation costs and reduce incentives for farmers to adopt a more diversified portfolio.

Another factor that played an important role in the expansion of agriculture in the Cerrado is related to the public credit system [18,50]. The data analyzed here showed an important impact of commercialization credit on the level of diversification. One aspect that can explain this credit effect is related to the use of commercialization credit by farmers of different production scales. Small and medium farmers are more dependent on public credit than larger producers, which have access to private forms of financing for production and commercialization, such as personal funds or "barter operation" (farmers sell their production in advance to trading companies and other input traders). Since larger farms present a more specialized profile adapted to scale economies, the farmers using more public credit are small and medium, which tend to have more diversified production.

The market access structure plays a key role in the agricultural pattern of each region [51]. The results indicated how variables related to market access and commercialization (access to credit, roads, ports, and storage infrastructure) are important in influencing diversification patterns. Previous research analyzing these patterns [27] found that fresh and perishable products demand closer and faster access to consumer markets. The distance factor can be overcome by infrastructure that allows the transportation of perishable products, but this is dependent on high investments, usually from the public sector. On the other hand, grains are usually cultivated far from these markets but have good storage and road infrastructure for accessing export channels like ports [52].

In the case of the Brazilian Cerrado, trade infrastructure facilitating large-scale grain production is already in place, generating incentives for farm specialization in specific crops such as soybean, maize, and cotton [52]. The maps presented in Figures 1 and 2 show that larger cattle- and soybean-producer municipalities present lower diversification levels.

Although infrastructure opens opportunities for diversification, farmers also consider many other issues when deciding on land-use strategies [14]. Firstly, there is a geographical suitability of some agricultural products, such as coffee in higher elevation areas [53]. This may be explained by both natural aspects (climate, soil, etc.) and institutional factors such as the regional identity of some products [54]. The existence of geographic origin and identification labels may reinforce these patterns [55], generating local externalities for farmers producing the same product.

Cultural factors may also affect the choice and permanence of farmers in some activities [46]. It was found that cultural factors may also affect the choice and permanence of farmers in some activities, and personal identity with some activities that predominate in certain regions was emphasized. There is a peer effect, in which farmers follow the choices of neighbors [10,17]. These aspects reinforce these local patterns and reduce the incentives for crop diversification. These factors also affect farmers' incentives to adopt more sustainable practices [10,56].

Therefore, the results found in this study highlighted how regional factors affecting market access play a significant role in explaining the diversification patterns in different production regions.

6. Conclusions

This study analyzed how variables related to market access (farm credit, logistics, and distribution infrastructure) affected the agricultural diversification in Brazilian municipalities in the period from 2013 to 2021. To conduct this analysis, an index of agricultural diversification was built and tested as a dependent variable in a spatial econometric model with a set of independent variables (including infrastructure, logistics, credit, consumer income, and natural conditions). The results from the model indicated that socioeconomic and infrastructure factors have positively influenced the patterns of diversification in Brazilian municipalities. Considering the agrifood production regions in Brazil (Figure 2), it is possible to verify that some activities like grain and livestock occupy the nearest areas, revealing production and distribution relations. These patterns are a consequence of technological and market drivers, which create incentives for farmers to favor some activities over others. Even though production specialization plays a positive role in yield and may reduce production costs, the lack of diversification may cause supply constraints of fresh products in some regions and increase farmers' risks [57,58]. The transportation costs of some fruits and vegetables over long distances may increase prices and reduce the quality in domestic markets.

These regional patterns also make it harder to generate incentives for farmers to adopt more sustainable and integrated production systems, such as integrated livestock–forest systems. Even when technology is available and economic advantages are perceived by potential adopters, farmers may not adopt the system if they do not have a viable distribution and trade infrastructure for the "new" portfolio of products. Our results bring new contributions to the induced innovation theories [59], which focus mainly on technology availability for farmers. Future research should consider other economic and sociological factors affecting a farmer's decision to diversify.

Public policies aiming to improve food access and incentivize the adoption of integrated low-carbon production systems should consider market access as a key variable.

The construction of distribution infrastructure (storages, roads, distribution centers) is crucial to create incentives for farmers to seek a more diversified production, specifically in regions away from consumer markets.

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