NICOLAUS COPERNICUS UNIVERSITY IN TORUŃ

Bulletin of Geography. Socio-economic Series, No. 61 (2023): 103-120
http://doi.org/10.12775/bgss-2023-0028

BULLETIN OF GEOGRAPHY. SOCIO–ECONOMIC SERIES

journal homepages:
https://apcz.umk.pl/BGSS/index
https://www.bulletinofgeography.umk.pl/

Factors associated with rural aging in Brazilian municipalities: an analysis using quantile regressions

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How to cite:
Vogt, C.M. & Fochezatto A. (2023). Factors associated with rural aging in Brazilian municipalities: an analysis using quantile regressions. *Bulletin of Geography. Socio-economic Series*, 61(61): 103-120. DOI: http://doi.org/10.12775/bgss-2023-0028

Abstract. In rural Brazil, aging is an important phenomenon for the future of the country's agricultural production. This process is associated with both increased life expectancy and rural–urban migration. According to studies on migration, young people are more likely to change their place of residence than are older residents, being attracted by the existence of work opportunities and, as a corollary, repulsed by their scarcity. This study assumes that the rate of rural aging tends to be higher in places where the urban-to-rural ratio of work opportunities is high. Thus, using quantile analysis of data from the *2017 Agricultural Census*, the effects that factors associated with income, agrarian structure and location had on rural aging in Brazilian municipalities were assessed. The results suggest that rural areas with low attractiveness situated far from urban centers are the most susceptible to population aging and, consequently, rural depopulation.

Article details:
Received: 07 February 2023
Revised: 06 July 2023
Accepted: 22 September 2023

Key words:
geography, planning & development, demography, population aging, Brazil

Contents:

1. Introduction

The structure of Brazil's rural population has experienced a continuous process of aging since the 1970s (Maia & Buaianain, 2015; Dirven, 2016; Sili et al., 2017; Camarano & Abramovay, 1999). Allied to this, the country is also facing a declining birth rate in rural areas, which further accelerates the aging process compared to urban areas (Schneider, 1994). Population aging is a demographic process that results from a reduction in the birth rate and an increase in life expectancy. It occurs when the elderly population grows at a higher rate than the young population (Almeida, 2002). According to Moreira and Carvalho (2016), the phenomenon affects social classes and countries in different ways, occurring with greater intensity in the wealthier classes, and currently being in more advanced stages in developed countries. Regarding the population aging in subnational geographic areas, migration must be considered a relevant factor. For example, a region may experience a significant increase in its aging rate solely because of the departure of young people from the region. The opposite may also occur, regions that receive young migrants tend to have lower aging rates.

For rural environments, population aging can have negative impacts, such as population depletion and increased social vulnerability. In Brazil, the income disparity between the rural and urban populations is large, with the former experiencing a consequent reduction in social indicators (PNAD, 2015). Regional studies also show the elderly in rural areas are more vulnerable and have less productive potential (Morais et al., 2008). The continuity of family farming is also greatly affected due to the lack of opportunities for younger populations, which intensifies the growing rural exodus and the depletion of labor (Filho et al., 2011). Thus, keeping younger populations in rural areas in order to ensure the future development of Brazilian agrarian production is a challenge for the agricultural economy.

Given the significance of agribusiness for Brazil's economic development, this study aims to examine the defining characteristics of municipalities with high migration potential, characterized by a high proportion of elderly individuals, as well as municipalities with low migration potential, characterized by rural areas with a high proportion of young people. Drawing upon existing literature on the factors contributing to rural aging, this research analyzes the effects of various variables on age distribution within municipalities, while also considering spatial dependence. The primary objectives are twofold: first, to assess how these variables behave in different age distribution patterns, and second, to investigate the influence of location on the proportion of elderly individuals. The study incorporates multiple factors including production structure, long-term investment prospects, potential agricultural and service value added, farm size, rural area size, and geographical location. These selected variables encompass the characteristics identified in the literature as significant influencers of rural aging.

The data utilized in this study are derived from the *2017 Rural Census* survey and municipal accounting values, which were provided by the Brazilian Institute of Geography and Statistics (IBGE). In order to analyze the age distribution patterns within rural areas of Brazilian municipalities, a combination of conditional and unconditional quantile regressions, drawing from the works of Koenker and Bassett (1978) and Firpo et al. (2009), as well as spatially filtered unconditional quantile regression as proposed by Murakami (2019), are employed. These methodologies allow for a comprehensive examination of the relationships between variables and the distribution of age groups in rural settings, offering insights into the complex dynamics at play. This paper is divided into four parts, following this introduction, part 2 consists of a review of the literature on rural aging in Brazil. Part 3 presents the quantile analysis methodology. Finally, part 4 describes the data used and the results and includes the conclusions that can be drawn from the study.

2. Literature review

This literature review section delves into studies on the topic, particularly in Latin America. Subsequently, we also examine published empirical studies and identify the key characteristics mapped that correlate with the subject in the Brazilian context.

2.1. Rural aging

Rural aging is a complex and evolving field of study with demographic, health, social and economic implications. For the phenomenon to be understood, patterns and trends, healthcare challenges, social and economic consequences, quality of life, and policy considerations must be explored. In much of East Asia, Southeast Asia, and Latin America, rural populations are decreasing, while elsewhere, growth is slowing. Fewer children are born in rural areas today than in the recent past, and both fertility and mortality have fallen in rural areas.

The association between rural poverty and population aging is mentioned in China. The increasing aging of the population has become the key factor influencing poverty incidence in most rural areas (Chen et al., 2016). However, it is a heterogeneous phenomenon, Brown et al. (2016) showed, in a study with several aging rural communities, that they can be resilient and that cooperative, multi-scalar relationships can be key to maintaining quality of life among older residents of communities with aging populations.

A study on the long-term effect of aging on the labor stock and investment in human capital in Canada demonstrated that population aging creates more opportunities for human capital investment for young people and, consequently, provides a more specialized workforce in the future (Fougère et al., 2009). The reduction in the number of young workers, however, reduces productive capacity and increases the costs of population aging. This transition may represent increased productivity in the future due to greater investment and greater productivity. Keats and Wiggins (2016), in their study on rural aging in different regions of the world, report that increasing education among the rural population will likely encourage these changes rather than prevent them. Additionally, there are labor shortages in some rural areas, leading to increased rural wages and encouraging mechanization.

An aging population is generally considered an advance in terms of economic development and is seen as a social achievement. However, in relation to rural populations in Brazil and Latin America, it is linked to changes in rural productivity and greater socio-economic precarity (Carone et al., 2005). Empirical evidence suggests the demographic structure affects developed and developing countries differently (Onofri, 2004; Wongboonsin & Phiromswad, 2017). For developed countries, the increase in middle-aged workers has a positive effect, considering the institutional factors of education and investment, whereas the effect of the increase in the elderly is negative. For developing countries, the effects are less clear. According to Dirven (2016), between 2003 and 2012 there was a reduction in the participation of young people in Latin American agriculture and an increase in the participation of the rural population in rural non-agricultural employment (RNAE). Thus, young populations migrated to salaried employment, especially those engaged in RNAE activities. On the other hand, regarding unpaid family farm work, there is a trend towards a decrease in young women and men and an increase in the presence of elderly men.

In summary, it can be noted that the factors causing the exodus of young people from rural areas are mainly associated with the potential opportunities that the areas themselves and their urban surroundings have to offer. Regions with high potential opportunities will, hypothetically, concentrate the greatest number of young people, whereas those with a low potential will have a higher percentage of elderly people. Thus, regions will react differently to conditions associated with the rural population aging, or high and low rural–urban migration.

The table below summarizes the hypotheses about the potential opportunities and the relationship with rural–urban migration. The characteristics associated with the growth potential of services, the need for labor, the location, and the characteristics of family- or employer-based farming define whether migration will be high or low (Table 1). Based on the literature and hypotheses regarding the migratory potential of young people, the extent to which features related to opportunities explain the proportion of the elderly population in the municipalities will then be investigated. To this end, according to the studies found on the migration of young people from rural areas, characteristics that

Table 1. Hypotheses in relation to rural–urban migration among young people

Low rural–urban migration (low urban opportunities, high rural opportunities)	**High rural–urban migration (high urban opportunities, low rural opportunities)**
Locations with modern/mechanized farming	Locations with dynamic urban centers
Locations with high rural incomes	Central locations, with large urban agglomerations (not remote locations)
Remote and peripheral locations (absence of urban opportunities)	Locations with traditional farming, little mechanization.

Source: authors

can be used as proxies for potential agricultural and urban development, location, and age structure have been highlighted.

2.2. Empirical findings in Brazil

Brazil's agrarian population has changed since the 1970s, when the rural population reached its highest level, representing 44% of the country's total population. In the following years, a process of decline began, which occurred as a result of migration and, later, a fall in fertility, with an increasing predominance of older males as waves of migration largely saw young people (aged 15–35) and women moving away (Camarano & Abramovay, 1999). Today, approximately 29 million people live in the rural areas of Brazil, representing about 15% of the population (IBGE, 2011). Emigrants from rural areas leave in search of better education and work conditions, as the countryside is characterized by cyclical employment, since most crops are temporary. The low demographic density of agrarian regions also creates difficulties in accessing services and labor rights. This negatively influences the quality of jobs on offer, making decent employment scarce and the regions less attractive to young people.

These migratory movements in the Brazilian rural environment reflect transformations in the organization of production and the spatial reallocation of economic resources. The features of the rural exodus show that the mechanization and modernization of agriculture in the 1970s led to the exclusion of part of the population that, consequently, migrated to urban areas (Dirven, 2016; Sili et al., 2017). This contingent of migrants consisted mainly of the productive age groups (i.e., young adults with high fertility rates), while those that remained in the rural areas tended to be older (Schneider, 1994).

It is also known that the vulnerability of elderly populations is greater in rural areas (Morais et al., 2008). Lower incomes and a more limited availability of health services also impact the quality of life of elderly populations. There are differences between the elderly people living in urban areas and those living in rural areas, mainly in terms of income and health. In Brazil, the average income of people living in rural areas is much lower than that of the urban population. In 2015, the residents of urban areas received BRL 1,319 on average, whereas in rural areas this amount was BRL 648.00 (PNAD,

Between 1991 and 2010, the Brazilian rural population aging index rise from 9.7% to 21.4% (Maia & Buaianain, 2015). That is, there was a significant increase in the ratio of elderly people to young people. In their analysis of the Brazilian rural population, Maia and Buainain (2015) point out that, despite there being a general trend towards population aging, the pace is less intense in urban areas. It can be seen, therefore, that over the years the proportion of rural elderly in the municipalities has grown above that observed in non-agrarian populations. The phenomenon is not exclusive to rural areas in Brazil; Chen et al. (2018) also conclude that, in China, the population is more aged and aging more rapidly in rural areas than in urban areas.

From 2006 to 2017, when rural censuses were conducted, there was an increase in age range of farmers above 55 years old. In Figure 1 A-B, the lighter areas represent the municipalities with a lower proportion of producers over 55 years old, while the darker areas indicate those with a higher proportion. Figure 1A shows fewer dark areas than Figure 1B. In 2006, in most municipalities, around 25 to 50% of the population was over 55 years old. In 2017, we can see this proportion rises to 50 to 75% in most Brazilian municipalities.

Thus, we can see the increasing importance of older populations in rural areas of the municipalities, especially in the south and south-east regions of Brazil. According to Maia and Buainain (2015), the south, south-east and north-east regions underwent a more rapid increase in the rate of aging. Figures 1A and 1B also reveal the difference in the age distribution of rural populations in the regions of Brazil. The north, north-east and south-west regions have lower percentages of elderly people in the municipalities and, even though the number increased between 2006 and 2017, the same distribution pattern remains. By contrast, the south and south-east regions stand out for having a higher proportion of elderly people in both periods.

The maps also show that the municipalities located in the Amazon region are the only ones in which the percentage of elderly people in the population does not exceed 25% between the two periods of the census. Similarly, localities in the semi-arid and *serrado* regions also present a lower percentage of elderly people, and that percentage does not increase at the same rate as in the south and south-east regions, as can be seen on the map. By contrast, the states of Rio Grande do Sul and Santa Catarina in the south region saw an increase in the proportion of elderly people in practically all the municipalities. In the 2017 census data map, it can be seen that in virtually all the municipalities

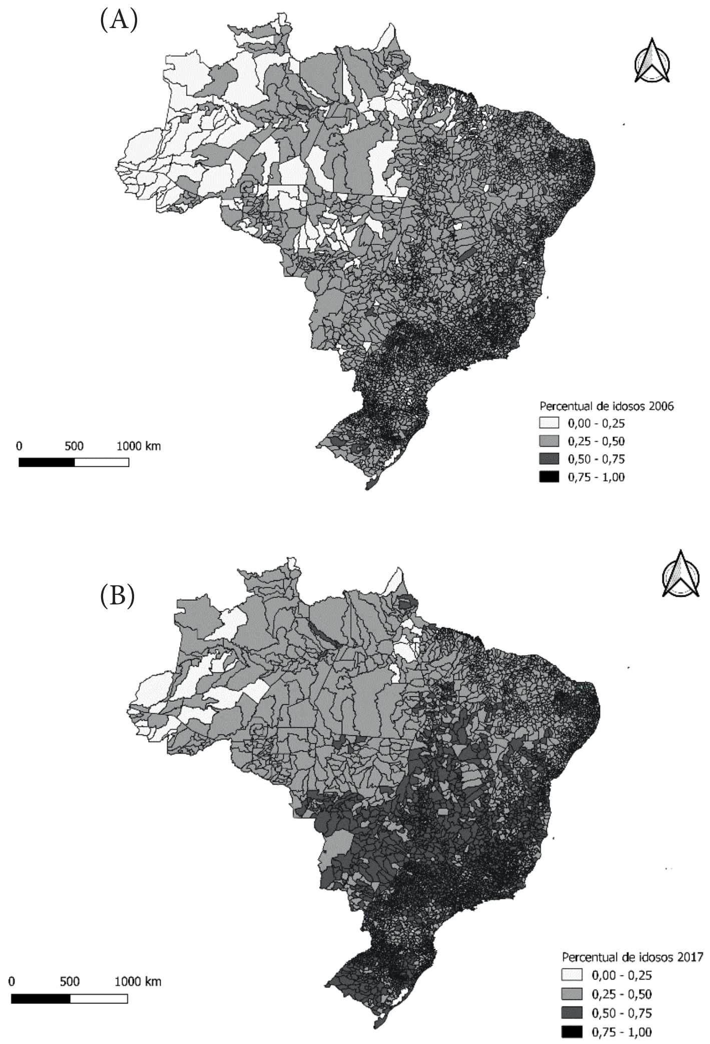

Fig. 1. Proportion of farmers over 55 years old in Brazilian municipalities: (A) in 2006, (B) in 2017
Source: Prepared by the authors from the Agricultural Census (IBGE, 2006 and 2017)

more than 50% of the population in rural areas is aged over 55 years.

Due to the heterogeneity of the Brazilian rural environment, regional differences in the proportion of elderly people and in the socio-economic conditions of the elderly are constant. The aging of the rural population in the south region, for example, is much more intense than in other regions of the countries and is attributed to the increase in life expectancy and reduction in fertility (Anjos & Caldas, 2005).

Likewise, features of the production structure may influence the reduction in the need for young labor, due to the use of technology, for example. In livestock farming and family farming, there is relatively little use of technology, whereas in employer-based farming, technology is more widely used (Filho et al., 2011). The increase in the average age of rural populations also impacts the reduction in the amount of available labor, which can lead to a drop in productivity. Additionally, older farmers, despite their greater management experience, may have a shorter planning horizon, which may affect the decision to adopt farming technology (Filho et al., 2011).

Inequality in the distribution of land in Brazil is also present and heterogeneous in the rural reality and has been shown to be constant according to the latest agricultural censuses. The north-east region is the most affected by this problem. As a result, inequality indicators such as Atkinson's and the Gini tend to be worse than average in this region (Hoffmann, 2010). The size of the farm plots, and of intensive or extensive crops, can also influence whether young people decide to remain on the land, based on hereditary rights. The decrease in the size of farming plots due to inheritance results in such small units (below the minimum-sized rural unit [Rural Module]) that their division between the heirs is practically impossible. Because the purchase value of land is beyond the accumulation capacity of many families, the intergenerational tradition of agrarian production is compromised (Brumer, 2004). The exodus of young people from family farming, therefore, also involves problems related to the succession structure and hereditary transfer, and the gender- and generational-based succession patterns are determining factors in the depletion of rural regions (Abramovay et al., 2000).

Regional studies on the causes of aging in rural areas emphasize the lack of continuity associated with family farming and the exodus of young people in search of better employment and income conditions. Increasing numbers of young people born into farming communities search for opportunities outside the rural environment. In the Jequitinhonha region in Minas Gerais, low-income smallholders are those that most encourage the migration of young people to the urban environment, in order to seek better conditions, even if it means the property is not passed on within the family (Mendonça et al., 2013). An investigation of the region of Santa Rosa, in Rio Grande do Sul, found population aging to be driven by the lack of continuity of family farming (Godoy et al., 2010). The non-permanence of young people in rural areas is driven by the low value of the associated activities and the poor quality of life in agricultural occupations. Besides aging, the masculinization of rural areas has also influenced the new agrarian structure in the central region of the state of Rio Grande do Sul, which can have negative impacts on development (Froehlich et al., 2011).

Therefore, based on the understanding of the dynamics of rural aging and the key variables associated with it in Brazil, the following section introduces the empirical strategy to investigate the diverse behaviors of these variables across different distributions of rural aging. Additionally, it explores the influence of spatial dependence on these configurations. This approach aims to provide a comprehensive analysis of the complex relationships between variables and the varying patterns of rural aging, taking into account the spatial aspect to enhance our understanding of the phenomenon.

3. Materials and method

In this section, we present the models employed for the empirical analysis of factors associated with rural aging in Brazilian municipalities. We also present data, their respective sources and utilization strategies.

3.1. Methodology

Quantile regression estimation was used because it provides a differential understanding of the impacts across the age distribution. The most common way of using quantile regression is based on conditional regression (Koenker & Bassett, 1978), which provides a more robust alternative to least squares estimators. With it, we can more accurately identify the effect of certain variables on outliers, – that is, the effect on the distribution tails.

In most cases, however, the results obtained with conditional quantile regression are not generalizable or interpretable in a policy or population context. For this reason, for our estimates, we used unconditional quantile regression, as it provides more interpretable results, since it marginalizes the effect on the distribution of other covariates in the model. Thus, we can analyze the marginal impact considering certain distribution quantiles of the presence of elderly people. In other words, it is possible to verify whether certain variables have similar impacts in municipalities with a greater or lesser proportion of elderly people in the population.

Conditional quantile regression (CQR) can be explained considering the random variable Y with distribution F, as an extension of the linear regression (Koenker & Bassett, 1978). According to Borah and Basu (2013), the regression conditional to the vector of observed covariates $Z=\{X,W\}$ with the conditional quantile operator $Q_\tau(Z)=Z'\beta_\tau^{RQC}$ such that $Q_\tau(Z)= inf_q\{q:F_{(Y|Z)}(q|Z)\geq\tau\}$, which represents the lowest limit of all the values of q in the set defined by $F_{(Y|Z)}$ $(q|Z)\geq\tau$. The conditional quantile operator can be expressed as any function of $Z:Q_\tau(Z)=\xi(Z\wedge'\beta_\tau)$. Analogous to the OLS function, the β are estimated as the absolute residual minimization problem (Eq. 1).

$$\sum_{i=1}^{n} \rho_\tau(y_i - z_i'\beta_\tau) \tag{1}$$

where $\rho_\tau a$ is the value function defined as $\rho_\tau(u)=u(\tau-I(u<0))$ for any $\tau\epsilon(0.1)$. The β_τ coefficients can be interpreted as a partial or conditional effect (depending on whether the variable is continuous or binary) of the quantiles of interest.

For the analysis of the unconditioned quantile regression (UQR), we followed the method presented by Firpo et al. (2009), in which, according to the analysis of Borah and Basu (2013), a model based on the concepts of the influence function (IF) and recentered influence function (RIF) is suggested. This is an analytical tool that can be used to assess the effect of removing or adding an observation on the value of a statistic, $v(F)$, being defined as (Eq. 2):

$$IF\big(y; v(F)\big) = \frac{\left[v\big((1-\varepsilon)F + \varepsilon\delta_y\big) - v(F)\right]}{\varepsilon}, 0 \leq \varepsilon \leq 1 \quad (2)$$

where F represents the cumulative distribution for y; thus, the RIF is obtained by adding this statistic to the IF (Eq. 3):

$$RIF(y; v) = v(F) + IF\ (y, v) \quad (3)$$

The RIF of the mean for the X covariates will have the same coefficients as the standard ordinary least squares regression. For the quantile specified by τ the distribution results will be (Eq. 4):

$$IF(y; q_\tau) = q_\tau - I\{Y < q_\tau\}/f_Y(q_\tau) \quad (4)$$

where q_τ refers to the τth quantile of an unconditional distribution of Y, $f_y(q_\tau)$ is the Y probability function evaluated in q_τ, and $I\{Y<q_\tau\}$ is an indicator variable to show whether an outcome value is less than q_τ or not. By definition (Eq. 5):

$$RIF(y; q_\tau) = q_\tau + IF\ (y, q_\tau) \quad (5)$$

Based on quantile regression methods, the impacts of selected variables on the proportion of elderly people are then estimated. However, when observations are not spatially independent – that is, if there is a relationship between the behavior of a variable associated with the same behavior of a nearby location (neighbor) – then there will be spatial dependence or autocorrelation. This implies the use of methods that consider the territorial effect.

The presence of spatial dependence makes ordinary least squares (OLS) estimation unsuitable because the estimates will be biased, inconsistent or inefficient. Therefore, spatial association models allow us to visualize patterns and describe regions and potential spillovers between regions through specific estimates for this type of situation. The use of spatial analysis is also widely applied in studies examining demographic data, as location plays a significant role in the correlation between variables and space (Marakani, 2019; Wu et al., 2019; Zhang et al., 2023). This ensures greater robustness for the analyses.

Spatially filtered unconditional quantile regression (SF-UQR) extends the traditional unconditional quantile regression framework by incorporating spatial dependencies in the analysis. This technique allows for the examination of how different quantiles of the response variable are influenced by explanatory variables, while also accounting for spatial autocorrelation. Before applying spatially filtered unconditional quantile regression, it is crucial to assess the presence and strength of spatial autocorrelation in the data.

Spatial filtering plays a crucial role in spatially filtered unconditional quantile regression, as it entails the inclusion of spatial weights matrices that capture the spatial associations among observations. This technique is highly valuable for analyzing data with spatial dependence and gaining insights into the varied effects of explanatory variables on different quantiles of the response variable. The methodology employed combines Murakami and Seya's (2019) approach with the methodology developed by Firpo et al. (2009), incorporating Moran's eigenvectors (Griffith, 2003) to account for spatial autocorrelation and implement spatial filtering.

The model can be formulated according to equations (6) and (7). Where r_τ is a vector $N\times 1$ with elements of $RIF(y;q_\tau)$ and $E\gamma$ captures the residual spatial dependence in quantile τ, E is a $N\times L$ matrix compose of a subset of L eigenvector.

$$r_\tau = X\beta_\tau + E\gamma_\tau + \varepsilon_\tau \quad (6)$$

Considering,

$$\gamma_\tau \sim N(0_L, \sigma_\gamma^2 \Lambda(\alpha_\tau))\varepsilon_\tau \sim N(0, \sigma_\tau^2 I) \quad (7)$$

where, 0_L is an $L\times 1$ vector of zeros; the parameter $\sigma^2_{(\gamma,\tau)}$ represents the variance of latent dependent process in quantile τ, and Λ is an $L\times L$ diagonal matrix composed of their corresponding eigenvalue (Murakami & Seya, 2019).

Thus, the UQR (Unconditional Quantile Regression) and SF-UQR (Spatially Filtered Unconditional Quantile Regression) models enable a robust assessment of the relationship between variables and the percentage of elderly individuals in municipalities. The variables used are described below.

Table 2. Study variables: description and effects on the age distribution

Variable	Dimension	Description and source	Expected sign and effect of the variables on youth migration – Sign	Expected sign and effect of the variables on youth migration – Effect
n_mach	Production and socioeconomic characteristics	Number of agricultural machines per municipality by agricultural establishment (tractors, seed drills/planters, harvesters, fertilizer and/or lime spreaders) (IBGE, 2017).	Positive/ Negative	Greater crop mechanization in high-opportunity locations negatively affects youth migration. This effect, however, is expected to differ between age structures, given that in places of low opportunity, greater mechanization reflects less need for labor in employer-based farming and greater migration. Thus, the effect of this variable may differ according to the proportion of elderly in a location.
p_coop	Production and socioeconomic characteristics	Farmers (%) in the municipality belonging to cooperatives or class entities (IBGE, 2017).	Negative	Membership of cooperatives and class entities reflects dynamism in agricultural production. Therefore, this variable is expected to negatively affect youth migration, having a greater effect in places that present less opportunity for young people.
p_tech	Production and socioeconomic characteristics	Farmers (%) in the municipality receiving technical assistance (IBGE, 2017).	Negative	The use of technical assistance can also reflect dynamism in the farming sector. As with membership of cooperatives, this effect is expected to negatively affect youth, with greater effect in places that offer fewer opportunities.
p_finan	Long-term planning and economic development	Farmers (%) in the municipality who obtained financing or loans in 2017 (IBGE, 2017).	Positive/ Negative	Percentage of borrowing represents the long-term investment potential, but also the need for external financing. Thus, the effect of this variable may differ across the age range or between the age groups/distributions.
ln_AV_agri	Long-term planning and economic development	Natural logarithm of the average for the years 2014, 2015 and 2016 of the gross added value of agriculture by municipality, at current prices (R$1,000) (IBGE, 2019).	Negative	The municipality's agricultural income has a negative effect on migration to places with low and high opportunity. This effect is certainly smaller in municipalities with less opportunity due to their lower agricultural income.
ln_AV_serv	Long-term planning and economic development	Natural logarithm of the average for the years 2014, 2015 and 2016 of the gross value added of Services, at current prices - excluding administration, defense, education and public health and social security (BRL 1,000) per municipality, at current prices (IBGE, 2019).	Positive	Income from services shows a positive effect in both quantiles, since the greater the opportunities in an urban environment with a higher share of services, the greater the chance of youth migration. The variable aims to capture the attractiveness of urban areas and explain rural–urban migration. This effect should be greater in places with less rural opportunity.
rural_urb	Location and urban structures	Dummy for the rural–urban typology: 1) Rural: Adjacent Rural and Remote Rural; 2) Urban: Adjacent Intermediate and Remote Intermediate (IBGE, 2019).	Negative Urban =1	Urban regions are likely to affect migration negatively, as these locations present greater opportunities for young people.
Remote	Location and urban structures	Dummy for the remote rural–urban typology:1) Remote: Remote Rural and Remote Intermediate; 2) Non-Remote: Urban, Adjacent Intermediate and Adjacent Rural (IBGE, 2019).	Positive Remote =1	Remote regions are expected to positively affect migrations compared to non-remote regions, since non-remote regions present greater opportunities for young people. This effect should also be greater in locations with less opportunity.
cod_urb	Location and urban structures	Dummy for the urban hierarchy: 1) Central: Regional Capital and Metropolis; 2) Peripheral: Zone Center, Local Center, Subregional Center (IBGE, 2019).	Positive Peripheral =1	Peripheral regions are also expected to positively affect migration compared to central regions. Likewise, this effect should also be greater in locations with less opportunity.
ln_area	Structure of the rural space	Natural logarithm of the area of agricultural establishments [hectares] (IBGE, 2017).	Negative	As smallholder agriculture is related to more migration (due to the lack of land to continue family farming), land area is expected to negatively affect migration. This effect is also expected to be greater for locations with less opportunity.
ln_area_aver	Structure of the rural space	Natural logarithm of the average area of territorial units [hectares] (IBGE, 2017).	Negative	The average area has an effect similar to the total area. Here, the larger the area, the lower the expected youth migration.

Source: prepared by the authors

Table 3. Statistics of chosen variables

Indicators	p_over55 (%)	n_mach (%)	p_coop (%)	p_tech (%)	p_finan (%)	AV_agri (R$ 1.000)	AV_serv (R$ 1.000)	Area (ha)	Areaavr_ (ha)
Mean	0.49	0.65	0.37	0.27	0.16	48,943.94	503,539.9	63,062.86	95.32
Standard Deviation	0.09	1.01	0.21	0.23	0.12	81,367.58	6,684,993	135,559.7	196.52
Minimum	0.18	0	0	0	0	23,956	1,989,577	1	0.06
Maximum	1	19.94	0.97	0.99	0.75	1,423,956	434,402,359	4,232,478	5,639.73

Source: *Agricultural Census* (IBGE, 2016) and Municipal Registers (IBGE)

3.2. Description of the data

To test the hypotheses regarding rural–urban youth migration, the marginal impacts of the factors described in Table 2 were analyzed, in the distribution of the percentage of people over 55 years of age in rural municipal areas, for the research, all 5,570 Brazilian municipalities were taken into consideration (*p_over/mais55*, IBGE, 2016). Data from the Brazilian Institute of Statistics and Geography (IBGE) relating to the added value of agricultural and services were used, as well as the census of the rural population, in addition to the maps provided by the institution. The *2017 Rural Census* conducted by IBGE is carried out in all Brazilian municipalities. Information was gathered from 5,073,324 rural establishments, covering a total area of 351,289,816 hectares classified as rural areas by the institute (IBGE, 2016).

To investigate the effect of productive changes in the countryside (Carone et al., 2005; Filho et al., 2011), data were used on the number of agricultural machines, membership of cooperatives (percentages) and the farmers' use of technical assistance (percentages). The long-term planning scenario (Fougère, 2009; Filho et al., 2011) and economic development was examined based on farmers' borrowing (percentages) throughout 2017 and the added value of the agriculture and services sectors. It is also expected to identify the rural-to-urban migration potential from the values of agricultural production and services, since services are more linked to urban potential and agricultural production to rural potential. Issues related to location (Godoy et al., 2010; Mendonça et al., 2013) were examined by identifying the locations as central or peripheral, urban or rural, and remote or non-remote. Issues related to the size of the properties and the available rural area (Abramovay et al., 2000; Brumer, 2004) were also analyzed. The selected variables are similar to those used in other studies on the rural population, such as those by Chi and Ventura (2011), which use demographic characteristics, socio-economic conditions, accessibility to transport, natural amenities and land development. Table 2 shows the selected variables, as well as the expected sign and effect given the hypothesis based on migration in areas of high and low opportunities.

Table 3 shows the mean, standard deviation, minimum and maximum statistics of the variables used.

Thus, based on the selected data and methods, we expect to be able to identify whether there is a difference in the effect of each of the characteristics associated with the elderly population in the municipalities.

4. Results and discussion

The results of the unconditional and spatially filtered unconditional quantile regressions (Tables 4 and 5) show there is a difference in the effect the variables have in the different distributions of the percentage of elderly people. The estimate of the mean effects, in the ordinary least squares regression (OLS) (Table 4), shows the mean results are different from those represented by the quantiles q10, q20, q30 and q40 and q60, q70, q80 and q90. This reinforces the importance of quantile analysis, where the effect on the proportion of elderly people is different in municipalities with few elderly people (in the lowest quantiles) or with many elderly people (in the highest quantiles).

Regarding the spatially filtered unconditional quantile regressions, the I Moran refers to a measure of spatial autocorrelation called the normalized Moran's I index. This measure is used to assess the presence of spatial patterns in a dataset. The normalized Moran's I index ranges from -1 to 1, where values close to -1 indicate negative spatial autocorrelation (dispersed clusters), values close to 1 indicate positive spatial autocorrelation (close clusters), and values close to 0 indicate the absence of spatial autocorrelation (random distribution). For the analyses, the indicator exhibited a variation from 0.4936 at the q40 quantile to 0.2349 at the q90 quantile (Table 5). Furthermore, the relationships were decreasing across different quantiles, indicating that as the number of elderly individuals increased, the estimated spatial correlation decreased.

About the variables related to factors associated with production characteristics, the results showed a different pattern in municipalities with younger or older rural populations in the unconditional regression. The number of machines (*N_mach*) has a negative effect on the proportion of elderly people in municipalities, with more youth in rural areas. This effect, however, is positive in locations with older people. The results of the RIF show that the marginal effect in the quantile with the significantly younger population (q20) has a marginal effect of -0.0085 machines per percentage of elderly people, and in the quantile with a more elderly population (q90) the marginal effect is 0.007 (Table 4). Considering the spatial effect in the quantiles, the estimative do not show a difference in the signal (Table 5). Thus, the number of machines contributes negatively to the percentage of elderly people. Also, the younger the population, the smaller the effect of the number of machines.

The finding supports the hypothesis that there is a difference in production due to age change. In places with more opportunities and less youth, more mechanization may have a negative effect on the percentage of elderly people, whereas in places with fewer opportunities the result is positive or smaller. Thus, the use of technology can lead to increased profitability and dynamism of production, ensuring the permanence of young populations, but it can also reduce the need for labor by increasing aging in locations that already retain a smaller percentage of young people. As mentioned in previous studies, there is a change in the production structure in places with higher numbers of elderly people (Carone et al., 2005; Fougère, 2009; Filho et al., 2011). Additionally, locations with better working conditions may have less potential for rural–urban migration (Keats & Wiggins, 2016).

The percentage of properties belonging to cooperatives or class entities (*p_coop*) has a negative effect on the proportion of elderly people. The marginal effect indicates that, in locations with a higher number of elderly people, the percentage of properties participating in cooperatives has a greater effect on population aging. The result seems to suggest that more dynamic cultures involving more intense interaction between properties negatively contribute to youth migration. The belonging to cooperatives or class entities, however, is not significant for the spatially filtered unconditional quantile regression estimation, except for the q10. When a variable is significant in an unconditional quantile regression estimation but not significant in a spatially filtered unconditional quantile regression estimation, it may indicate that the inclusion of the spatial component has altered the relationship between the variable and the response variable.

In the unconditional quantile regression, the variable may have a significant effect on the estimation of the response variable's quantile, regardless of the spatial structure of the data. However, by adding the spatial component in the spatially filtered unconditional quantile regression, the variable's effect may become diluted or even statistically insignificant. This can occur because the inclusion of the spatial component takes into account the influence of spatial neighbors, which can explain part of the variability in the response variable that was previously attributed to the variable in question. Additionally, spatial correlation between observations can modify the relationships between the independent and dependent variables. The inclusion of the spatial component can alter the significance and ffectt of the variable in question, highlighting the importance of considering spatial autocorrelation when interpreting the results.

Regarding the role of technical assistance, however, the CQRs show an inverted U-shaped (Figure 2), with an overall positive effect on the percentage of elderly, but that is smaller in the extreme quantiles. For the spatially filtered unconditional quantile regression, the effect is negative and higher in quantiles q60 and q90, with more elderly people,

The effect the percentage of properties that received financing (p_fin) diminishes across the quantiles (Fig. 2). The marginal effect of the percentage of properties with bank financing throughout 2017 is positive in municipalities with a younger rural population and negative in municipalities with an elderly rural population. In municipalities with fewer elderly people (q10), the percentage of producers receiving financing has a positive effect of 0.09 on the percentage of elderly people (Table 4). In municipalities with more elderly people, the effect is negative, at -0.61 (Table 4). For the spatial estimation, only the results in areas with a higher proportion of elderly individuals were significant and positive.

The results show that, considering younger populations have less accumulated capital, they are expected to have less access to resources. Thus, in places with greater potential for opportunities, the level of borrowing is higher in places with a higher percentage of elderly people. In places with less potential for opportunity, investment prospects are smaller; that is, the greater the number of elderly people, the lower the percentage of borrowing among the population. The long-term planning scenario reinforces the difference in productive agricultural structures considering the age change of producers (Filho et al., 2011).

Regarding the added values of agriculture and services (*ln_AV_agri* and *ln_AV_serv*), the former has a negative effect, and the latter a positive effect on population aging (Tables 4 and 5). The greater the agricultural production, the smaller the proportion of elderly people, and the greater the production of services, the greater the proportion of elderly people. This effect shows that young people tend to stay in places with strong agricultural production and leave the countryside when the availability of jobs outside the sector is higher. These variables can explain the dynamics of rural–urban migration, with added value of services being linked to the attractiveness of urban areas and the added value of agriculture to the rural environment.

The effects of the added values of both agriculture and services diminish between the quantiles. Thus, the greater the number of elderly people, the smaller the marginal impact. Therefore, the factor related to agricultural income and work opportunities outside the rural sector are more relevant for the permanence of young people in places that have a lower percentage of elderly people or greater potential for opportunities.

The rural area (ln_Area) of the municipalities has negative marginal effects in relation to the proportion of elderly people, so the larger the area, the younger the population. This effect decreases over the quantile range, which means that the marginal impact of area size is more negative in municipalities with a larger number of elderly people (Table 4; Fig. 2). When considering the spatial effect, the variable still exhibits a negative variation; however, the difference between the quantiles is not substantial, indicating that, regardless of the size of the elderly population, smaller areas have a higher percentage of rural elderly individuals (Table 5; Fig. 3).

By contrast, the average area (ln_area_aver) has a positive and increasing impact over the quantile range (Table 4). In other words, locations with greater potential for young people have a larger rural area, but the average size of properties is smaller. In the spatial analysis, the correlation leads to a continuous but decreasing positive effect; in other words, areas with more young individuals have larger areas, while areas with more elderly individuals have smaller areas (Table 5; Fig. 3). The results confirm whether the division of agricultural plots according to inheritance has an effect on the youth migration (Abramovay et al., 2000; Brumer, 2004).

Concerning the location of rural areas, peripheral municipalities have a positive and decreasing effect on the proportion of elderly people in relation to central locations. This reinforces the fact that central locations with more options for young people will have a lower proportion of elderly people. The marginal effect decreases in line with the increased number of elderly people in the municipalities (Fig. 2). In the spatial model, the effect is significant and increasing for higher quantiles. In other words,

Table 4. Unconditioned quantile regression (UQR/RIF)

Variable	OLS	q10	q20	q30	q40	q50	q60	q70	q80	q90
Constant	0.5216[1]	0.3586[1]	0.4467[1]	0.4587[1]	0.4809[1]	0.4995[1]	0.5352[1]	0.5754[1]	0.6271[1]	0.7166[1]
n_mach	-0.0026*	-0.0015	-0.0085[1]	-0.0063[1]	-0.0087[1]	-0.0049**	-0.0020	0.0005	0.0029	0.0070[1]
p_coop	-0.0100**	0.0163	-0.0058	-0.0191**	-0.0199**	-0.0202**	-0.0192**	-0.0208[1]	-0.0143*	-0.0082
p_tech	0.0610[1]	0.0067	0.0498[1]	0.0754[1]	0.0931[1]	0.0864[1]	0.0850[1]	0.0996[1]	0.0857[1]	0.0568[1]
p_finan	0.0090	0.2018[1]	0.1243[1]	0.0666[1]	0.0164	-0.0191	-0.0515[1]	-0.1063[1]	-0.1298[1]	-0.1282[1]
ln_AV_agri	-0.0158[1]	-0.0356[1]	-0.0210[1]	-0.0152[1]	-0.0135[1]	-0.0108[1]	-0.0096[1]	-0.0117[1]	-0.0098[1]	-0.0087[1]
ln_AV_serv	0.0112[1]	0.0198[1]	0.0126[1]	0.0110[1]	0.0120[1]	0.0111[1]	0.0102[1]	0.0089[1]	0.0078[1]	0.0039**
ln_area	-0.0174[1]	-0.0082**	-0.0154[1]	-0.0178[1]	-0.0221[1]	-0.0225[1]	-0.0216[1]	-0.0167[1]	-0.0179[1]	-0.0186[1]
ln_area_aver	0.0398[1]	0.0495[1]	0.0450[1]	0.0454[1]	0.0496[1]	0.0476[1]	0.0410[1]	0.0319[1]	0.0282[1]	0.0226[1]
Periphery	0.0302[1]	0.0265**	0.0136	0.0176**	0.0277[1]	0.0308[1]	0.0363[1]	0.0392[1]	0.0386[1]	0.0408[1]
Urban	0.0089[1]	-0.0014	0.0057	0.0075*	0.0050	0.0097**	0.0106[1]	0.0181[1]	0.0154[1]	0.0253[1]
Remote	-0.0716[1]	-0.1620[1]	-0.0943[1]	-0.0757[1]	-0.0628[1]	-0.0516[1]	-0.0431[1]	-0.0323[1]	-0.0321[1]	-0.0233[1]
R2	0.273	0.130	0.154	0.176	0.193	0.191	0.176	0.160	0.130	0.088

Source: Prepared by the authors. Note: 1 Significant at 1%; ** Significant at 5%; * Significant at 10%

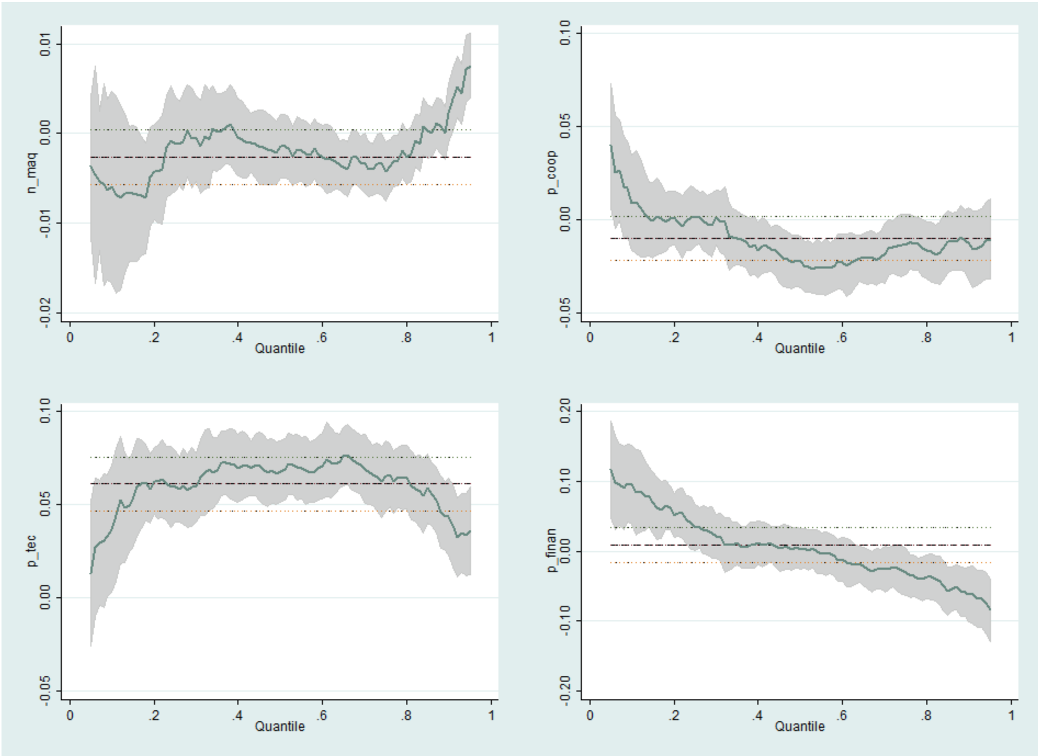

Fig. 2. Graphs of the results of the conditioned quantile regression and ordinary least squares
Source: Prepared by the authors

Table 5. Spatial filtered unconditioned quantile regression

Variable	q10	q20	q30	q40	q50	q60	q70	q80	q90
Constant	0.2989[1]	0.3995[1]	0.4500[1]	0.4834[1]	0.5011[1]	0.5416[1]	0.5717[1]	0.6178[1]	0.7060[1]
n_mach	-0.006*	-0.011[1]	-0.006[1]	-0.010[1]	-0.008[1]	-0.006[1]	-0.006[1]	-0.004**	-0.0006
p_coop	0.0341**	0.0143	0.0062	0.0048	0.0055	0.0001	-0.005	0.0022	-0.0003
p_tech	-0.058[1]	-0.041[1]	-0.037**	-0.031**	-0.031[1]	-0.027**	-0.00004	-0.004	-0.027**
p_finan	0.0119	0.0205	-0.014	-0.027	-0.013	-0.028	-0.052[1]	-0.054**	-0.046*
ln_AV_agri	-0.018[1]	-0.012[1]	-0.009[1]	-0.012[1]	-0.011[1]	-0.011[1]	-0.012[1]	-0.009[1]	-0.009[1]
ln_AV_serv	0.0154[1]	0.0105[1]	0.0090[1]	0.0099[1]	0.0095[1]	0.0080[1]	0.0084[1]	0.0074[1]	0.0029*
ln_area	-0.008**	-0.010[1]	-0.012[1]	-0.011[1]	-0.010[1]	-0.009[1]	-0.008[1]	-0.011[1]	-0.011[1]
ln_area_aver	0.0467[1]	0.0397[1]	0.0365[1]	0.0362[1]	0.0315[1]	0.0263[1]	0.0220[1]	0.0220[1]	0.0184[1]
Periphery	0.0141	0.0002	0.0033	0.0129*	0.0198[1]	0.0242[1]	0.0249[1]	0.0230[1]	0.0261[1]
Urban	0.0041	0.0017	0.0043	0.0015	0.0067**	0.0097[1]	0.0133[1]	0.0106*	0.0194[1]
Remote	-0.042[1]	-0.018**	-0.020**	-0.010	-0.005	-0.001	-0.00002	-0.005	-0.002
I Moran	0.1648	0.2569	0.3616	0.4276	0.4585	0.4774	0.4653	0.4177	0.4625
R2	0.4526	0.4614	0.4620	0.4936	0.4853	0.4528	0.4039	0.3486	0.2349

Source: Prepared by the authors. Note: 1 Significant at 1%; ** Significant at 5%; * Significant at 10%; Estimates done using Rstudio and the package Murakami (2017)

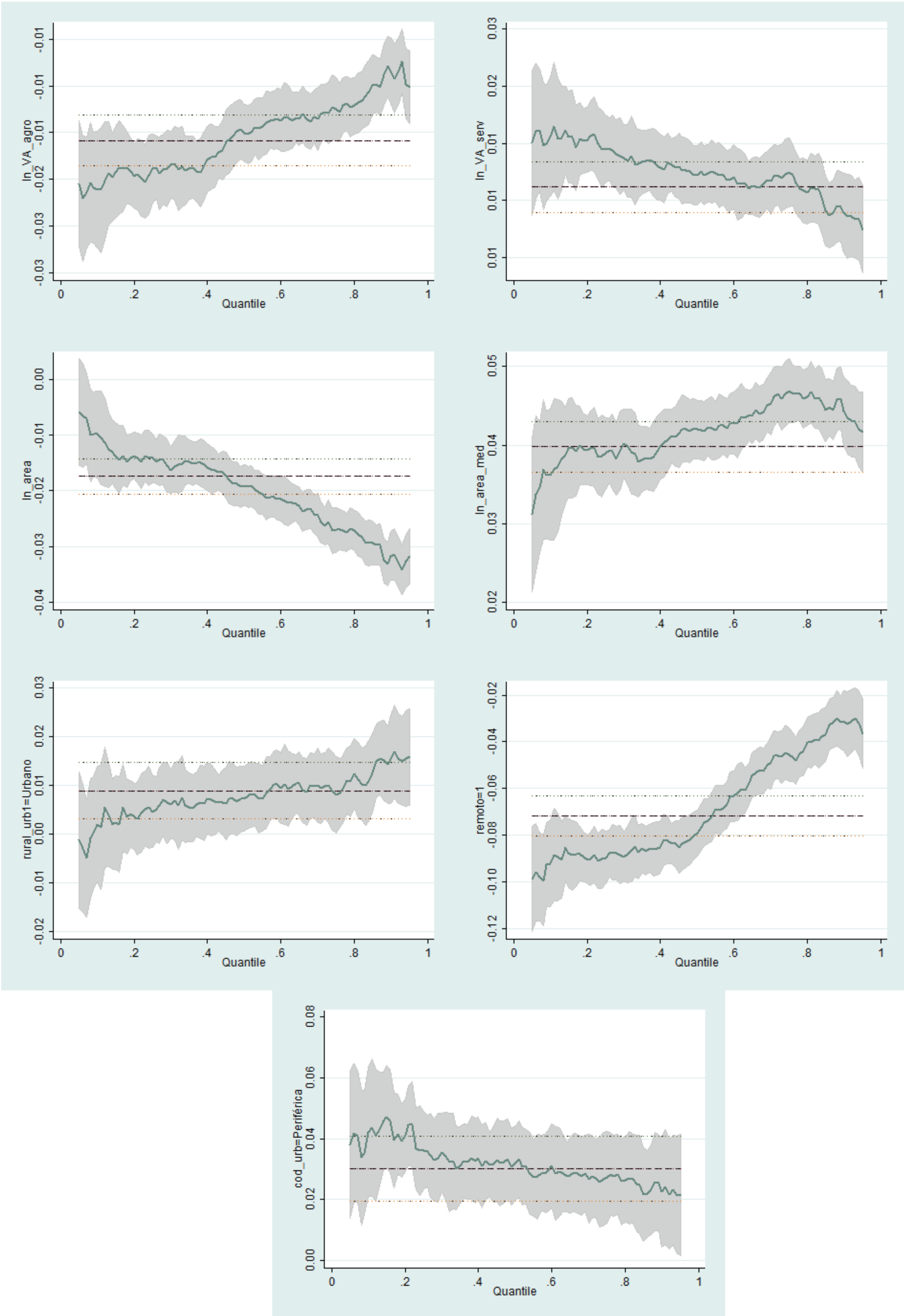

Fig. 3. Graphs of the results of the spatially filtered unconditional quantile regression
Source: Prepared by the authors

Table 6. The mean difference in selected variables between Positive Net Migration and Negative Net Migration

Variable	Average		Probabiliy (P-Value)
	Positive Net Migration	Negative Net Migration	
n_mach	306.32	260.66	0.0070
p_coop	0.36	0.40	0.0000
p_tech	0.28	0.24	0.0000
p_finan	0.16	0.18	0.0002
AV_agri	40,794.02	32,517.34	0.0006
AV_serv	48,610.90	33,335.69	0.0000
area	65,335.46	48,199.59	0.0000
area_aver	120.97	74.77	0.0000

Source: Prepared by the authors

locations with a higher proportion of elderly individuals tend to have more peripheral locations and fewer central locations (Table 5; Fig. 3).

Regarding the proximity of the municipalities to urban areas, the effect is more significant in those with higher proportions of elderly people. In the spatial model, the effect is only significant in q60 to q90 (Table 5). This may be due to the presence of small properties in urban rural areas that are used by people (usually the elderly) for leisure purposes (according to Hoffmann, 2010). It is important to note that the census information also includes small rural and semi-rural properties acquired by the urban population. As such units are not normally permanent residences/used for residential purposes, the owners are expected to be older people. Hoffmann (2010) cites differences in property size when analyzing data from the *Agricultural Census*, which considers the variable "municipal area" compared to data from the *National Household Survey* (PNAD) which considers "agricultural enterprises". Thus, it is expected that agricultural municipalities neighboring metropolitan areas, where the *per capita* income is higher, are expected to concentrate a higher percentage of elderly people due to the existence of such dwellings/ establishments.

For remote locations, the effect is negative and increases with the proportion of elderly people. Thus, more-remote areas will have more young people (Table 5), which is unexpected since remote areas tend to have fewer opportunities. However, issues related to logistics and the scarcity of opportunities in the surrounding areas compared to non-remote regions may explain this finding. Hence, the young population would tend to remain in areas of low opportunity when there are no alternatives in the surroundings. Thus, the search for better socio-economic conditions and location (Godoy et al., 2010; Mendonça et al., 2013) showed that agricultural income and job opportunities outside the rural sector have an impact on the permanence of young people in rural areas. This finding is stronger in regions with less opportunity or that already have a larger contingent of elderly people.

The analysis of mean differences between rural municipalities with positive and negative net migration in 2017 was also carried out based on the selected variables. According to Table 6, the mean difference in the selected variables is significant between the two categories. The results reinforce the correlations found in the quantile analyses concerning aging. Thus, rural municipalities with positive net migration have, on average, a more significant number of machines, technical assistance, agricultural products, and gross value added of services (BRL in millions), area, and average area. On the other hand, they have smaller cooperatives and a lower percentage of financed properties.

In summary, the results confirm those of other regional studies and the relationship of some variables with rural aging. At the same time, they show that farming is transforming due to this demographic effect. Regions with fewer potential opportunities for young people are also more impacted by these factors. The results also highlight the importance of planning concerning the aging process of the Brazilian population (Queiroz & Turra, 2010). The study, however, could be replicated for other agricultural censuses, given that the variables may change over time (Chi & Ventura, 2011).

5. Conclusions

The rural population in Brazil is undergoing an accelerated aging process that is bringing about changes in property profile and transforming the country's agricultural economy. The use of the quantile regression method, associated with the interpretation of the selected variables, enabled us to identify the trends of the variables involved in the age distributions, as well as their marginal impact considering municipalities with higher and lower rates of rural aging. The results of the unconditional and spatially filtered unconditional quantile regressions indicate variations in the impact of variables across different distributions of the percentage of elderly people. The mean effects estimated through ordinary least squares regression (OLS) differ from those represented by the quantiles q10, q20, q30, q40, q60, q70, q80, and q90, highlighting the importance of quantile analysis. This suggests that the effect of variables on the proportion of elderly people differs in municipalities with low or high percentages of elderly individuals.

Spatial analysis using the normalized Moran's I index reveals the presence of spatial autocorrelation in the dataset. The index varies across quantiles, indicating a decreasing spatial correlation as the number of elderly individuals increases. This suggests that, as the population ages, the estimated spatial correlation diminishes. This autocorrelation is corrected using appropriate spatial models, thereby generating unbiased relationships between the percentage of elderly individuals in rural areas and correlated variables.

Regarding the variables related to production characteristics, the number of machines (N_mach) has a negative effect on the proportion of elderly people in municipalities with a younger rural population but a positive effect in areas with older individuals. The percentage of properties belonging to cooperatives or class entities (p_coop) also has a negative effect on population aging, with a greater impact in locations with higher percentages of elderly people.

The percentage of properties receiving financing (p_fin) shows a positive effect on the proportion of elderly people in municipalities with a younger rural population but a negative effect in areas with an older population. These findings suggest that areas with more opportunities and resources tend to have higher levels of borrowing in places with a higher proportion of elderly individuals.

The added values of agriculture and services (ln_AV_agri and ln_AV_serv) have contrasting effects on population aging. Greater agricultural production is associated with a smaller proportion of elderly people, while increased service production is linked to a higher proportion of elderly individuals. This indicates that young people tend to stay in areas with strong agricultural production but migrate away from rural areas when job opportunities in non-agricultural sectors are more abundant.

The size of the rural area (ln_Area) in municipalities shows a negative effect on the proportion of elderly people, meaning that larger areas have a younger population. However, the effect diminishes as the number of elderly individuals increases. In contrast, the average area (ln_area_aver) has a positive and increasing impact, indicating that locations with greater potential for young people have larger rural areas but smaller average property sizes.

Peripheral municipalities and more-remote areas exhibit different effects on population aging. Peripheral locations have a decreasing positive effect on the proportion of elderly people, suggesting that central areas with more opportunities attract a smaller proportion of elderly individuals. Remote areas, unexpectedly, show a negative effect that increases with the percentage of elderly people, possibly due to logistics issues and limited opportunities in the surrounding regions.

Overall, the findings emphasize the influence of various factors on the aging of rural populations in Brazil. The results highlight the importance of considering spatial autocorrelation and quantile analysis in understanding the complex relationships between variables and population aging. Factors such as production characteristics, access to resources, added values of agriculture and services, rural area size, and location play crucial roles in shaping the demographic dynamics of rural areas. Thus, policies designed to strengthen and promote growth are essential for the continuity of rural production in regions in which opportunities are scarce. If there is no appreciation of the rural environment to the detriment of urban areas, the current generations may be the last to remain in the poorest rural areas of Brazil. This trend, in addition to causing depopulation, contributes to the growth of pockets of urban poverty in municipalities.

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