Effects of crime in Rio de Janeiro: a spatial analysis for the period between 2014 and 2016

Efeitos da criminalidade no Rio de Janeiro: uma análise espacial para o período entre os anos 2014 e 2016

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Abstract
High population growth and the accelerated urbanization process, in addition to an uncontrolled expansion of the suburbs, all put pressure on the infrastructure and budgets of municipalities mainly in metropolises such as Rio de Janeiro. This article aimed to investigate the socioeconomic and urban factors that affected crime in the State of Rio de Janeiro between the years 2014 and 2016. The methodology included the exploratory analysis of spatial data (AEDE) that showed spatial patterns (spatial clusters) not randomly distributed in the state of Rio de Janeiro and an econometric model using panel data with variables related to population density, the labor market and education. The results show that public action in areas of education and job creation is an important channel through which crime in the state could be reduced.
Keywords: urban economics, panel data, ESDA, Rio de Janeiro.

Resumo
O elevado crescimento demográfico e o acelerado processo de urbanização causam pressão sobre as infraestruturas e orçamentos dos municípios, além de expansão descontrolada das periferias, principalmente em metrópoles como o Rio de Janeiro. Dessa forma, o artigo teve como objetivo investigar os fatores socioeconômicos e urbanos que afetaram a criminalidade no estado do Rio de Janeiro entre os anos de 2014 e 2016. A metodologia contou com a análise exploratória de dados espaciais (AEDE), que exibiu padrões espaciais (*clusters* espaciais) não aleatoriamente distribuídos no estado do Rio de Janeiro, e o modelo econométrico de dados em painel com variáveis relacionadas à densidade populacional, ao mercado de trabalho e à educação. Os resultados revelaram que a atuação pública na área de educação e na geração de emprego é importante canal que contribui para a redução da criminalidade no estado.
Palavras-chave: economia urbana, dados em painel, AEDE, Rio de Janeiro.

1 Introduction

The accelerated process of urbanization, mainly in the second half of the 20th century, caused a change in the spatial configuration of Brazilian cities generating an increase in the urban population from 18.8 million in 1940 to 138 million in 2000. The country underwent a marked development in the area of construction of urban residences, in addition to attempts to meet the other needs of the population, such as employment, transport, health, energy and water (Gomes, 2006).

The economic analysis of criminality is relatively recent and gained prominence with the publication of the seminal work by Becker (1968) in the late 1960s. This author was the first to develop a formal theoretical model in which the decision to commit a crime is based on a rational evaluation around the expected benefits and costs of the act of committing a crime compared to the results of the allocation in the labor market (Cerqueira & Lobão, 2004).

Although urbanization has occurred all over Brazil, its consequences have been felt in different ways in different regions. In addition, the demographic rearrangement happened in large urban centers in a concentrated manner and faster than the reallocation of basic resources to guarantee a dignified life for the entire population. Moura (2004) reports that the most urbanized regions have the worst indicators of social inequality, although they present the best indicators of economic activity (Ramão & Wadi, 2010).

Another important factor for spatial change were the urban reforms carried out in some Brazilian cities, such as Porto Alegre, São Paulo, Recife and, mainly, Rio de Janeiro. In these cities, a process of modern urbanization began excluding the periphery, with basic sanitation works and beautification of the landscapes with the creation of a legal basis for the real estate market. Parallel to this phenomenon, there was the expulsion of a portion of the population excluded from this process, who headed to the hills (Maricato, 2000).

Urban changes have fragmented the urban space into numerous territories with their own characteristics, favoring the installation of criminal activities and weakening society. In other words, the physical space of cities, which is formed by the concentration of population and economic activities, presents a physical and social structure that generates forms of production and reproduction of segregations (Gomes, 2006).

The Institute for Applied Economic Research (IPEA) reported that in 2017 Brazil reached the highest historical level of intentional violent deaths in the country, with 65,602 homicides. These numbers correspond to 31.6 deaths per 100,000 inhabitants (Fórum Brasileiro de Segurança Pública , 2018; Instituto de Pesquisa Econômica Aplicada, 2019). In Rio de Janeiro, the number of violent deaths grows annually and shows the naturalness of the phenomenon of criminality, in addition to the need for effective action by the authorities at the three levels of government: federal, state and municipal. Crime is a major challenge in Brazil, as it is a complex public security agenda that involves intersectoral and integrated actions by the Executive Powers, Parliament, Justice, the Public Prosecutor's Office, the Defender's Office and civil society (IPEA, 2019).

The present work attempts to contribute to the literature on the economics of crime for the formulation of more efficient policies in the state of Rio de Janeiro. Furthermore, the contribution of the article is confirmed by its contemporary analysis and the methodology applied using a database that covers the period between 2014 and 2016, for all municipalities in the state. The analysis, therefore, allows for a spatial and temporal investigation of criminality in Rio de Janeiro. The work aims to analyze how the socioeconomic factors present in the municipalities affected crime in the state of Rio de Janeiro, in the period 2014 and 2016.

In addition, through the Exploratory Analysis of Spatial Data (ESDA) and the panel data methodology, it was possible to verify where criminal incidences occur in the geographic space and to analyze the results of the explanatory variables (population density, employed labor and basic education) against the dependent variable (crime rate), respectively.

The motivation for the research is centered on the need for greater depth of knowledge on the relationship between crime and its determinants related to the urban economy, in the specific case of Rio de Janeiro. Another aspect that reinforces the importance of the study is the use of a database for the period between 2014 and 2016 for municipalities in Rio de Janeiro.

The paper is organized as follows. In addition to the introduction, the second section presents a literature review with authors who address the theory of criminality and empirical studies in Rio de Janeiro. The third section describes the adopted methodology, namely, the exploratory analysis of spatial data and the estimation of the panel data model. The fourth section addresses the data used and the fifth section reports the results. Finally, the final considerations of the research are described at the end of the paper.

2 Empirical analysis

Many theoretical models (Halicioglu, 2012; Mendonça, 2002; Salviato & Mourão, 2014; Tavares, 2017) have been developed based on the model of Becker (1968) and Ehrlich (1973), still with a rational choice approach, but with innovations in empirical research, with the purpose of verifying and analyzing the socioeconomic determinants of crime, as well as the impacts of criminality on economic development (Teixeira, 2011).

In turn, these works explore the relationships between criminality and various economic variables, such as unemployment, gross domestic product (GDP), income inequality, interest rate, inflation and income level, although unemployment and income are the two most common variables in econometric studies. It is worth noting that economic variables do not equally influence the crime rate, since economies have different characteristics (Halicioglu, 2012). Below are some works in the literature of the area in some countries and in Brazil.

2.1 Urban economy and crime: a literature review

The relationship between the size of cities and the crime rate has been a common finding in empirical studies, such as that of Glaeser & Sacerdote (1999). The authors showed that the larger the city, the higher the crime rate. Bettencourt et al. (2007) suggested that urban scale theory influences various social and environmental measures, such as crime, pollution, and disease, and may increase more than proportionally as the population size of a city grows.

While larger cities have historically had higher crime rates, this may have changed in recent years. The theory of urban scale advantage converges with this hypothesis and argues that the larger the city, the smaller the negative impact of measures associated with large cities, such as disease, pollution, congestion and crime. Another point addressed is that large cities have undergone some new development, become greener, less congested and safer than small towns and rural areas (Chang, Kim & Jeon, 2019).

In accordance with the theory of the advantage of urban scale, the work of James (2018) on crimes in the United States shows that from 2003 onwards, violent crime rates in the group of cities with a population of more than 1 million inhabitants became smaller than those of groups with 250 to 500 thousand inhabitants. Between the years 2006 and 2016, annual violent crime rates were highest among the group of cities with a population of 500,000 to 1 million,

followed by the group with 250,000 to 500,000, and then the group with a population of more than 1 million. In summary, cities with more than 1 million people in the United States have become safer in recent years compared to cities with less than 1 million.

Litman (2013) also compared the crime rate by population group for all cities in the United States for the year 2012. The author highlighted that crime rates reach the highest numbers in medium-sized cities (250 to 500 thousand inhabitants) and they are lowest in larger cities (over 1 million), with a 23% decrease in violent crime and a 32% decrease in property crime. Litman (2013) highlights that the result is a relatively recent phenomenon resulting from factors such as the aging of the population, lower levels of lead in the blood, better passive and defensive surveillance, as well as better policing methods.

With the accelerated urbanization process, Brazil now has a large population, with approximately 54 million in 1950, rising to 161.6 million in 1995, that is, the population tripled in less than half a century. This growth meant that a large proportion of the population sought survival by leaving the countryside and going to the big cities. In addition, positive socioeconomic indicators contributed to the population increase, such as life expectancy, which increased from 50 to 65 years in 1995, due partly to a reduction in infant mortality which fell from 135% to 55% per thousand births between 1950 and 1995, in parallel with the fall in the risk of death among young women due to childbirth (Chesnais, 1999).

The union of these two factors (demographic growth and improvements in indicators) put pressure on the infrastructure and budgets of municipalities, in addition to uncontrolled growth in the peripheries, mainly in metropolises such as Rio de Janeiro and São Paulo (Chesnais, 1999).

Although Brazil experienced accelerated economic growth between the 1940s and 1980s, there was no significant change in the structure of its social inequality. Rather, this was deepened with the economic decline in the 1980s and 1990s, the increase in unemployment, informal work relationships, income concentration, poverty and the worsening of urban living conditions with the acceleration of crime (Maricato, 2000).

Thus, at the end of the 1990s, the national homicide rate in Brazil was 24.1% while in São Paulo and Rio de Janeiro it reached 59% and 56%, respectively. The increase in violence related to the growth of the urban population in the metropolises during this period explains one of the main causes of death among men aged 10 to 38 year which also affects the life expectancy at birth of the male population. Soon, the violence that was characteristic of rural areas considered less developed when compared to urban areas became an urban phenomenon, one of the results of the recession of the "lost decades" (Maricato, 2000).

In Brazil, Barcellos & Perez (2009) analyzed social exclusion as one of the causes of increasing in crime rates. Their results showed that exclusion stimulated by high socioeconomic inequality is relevant to explain criminality. According to Araújo Júnior & Shikida (2011), there is a relationship between demographic factors and the increase in the homicide rate in Brazil, and their results show that demography is important to explain the behavior of the homicide rate. However, the change in age structure is not the main factor that explains the variation in homicide rates.

Regarding crime in Brazilian states, Cano & Santos (2001) showed a relationship between the rate of urbanization, income inequality and education and the homicide rate. The results showed a positive correlation between the urbanization rate and homicide rate, but they did not find a significant relationship between income inequality and education (Cano & Santos, 2001 apud Cerqueira & Lobão, 2004). The author used panel data for the period between 1985 and 1995 and reinforced that social inequality (measured by the Gini index) had a positive impact on crime in the period under study.

Also for Brazilian states, Andrade & Lisboa (2000) investigated the behavior of the male population homicide rate and its relationship with economic variables, specifically in the states of Minas Gerais, Rio de Janeiro and São Paulo. The results, for the years 1979 and 1997, showed that an increase in real wages and a decrease in inequality reduced the homicide rate.

Additionally, the authors identified the existence of inertia in homicide rates, that is, there is a tendency for a generation that has a high homicide rate when young to continue to show a high homicide rate throughout its life cycle. Still at the state level, Kume (2004) estimated the determinants of criminality from panel data, in the period between 1984 and 1998. The results revealed that the degree of income inequality and the crime rate in the previous period generated a positive effect on the crime rate in this period. On the other hand, GDP per capita, level of education, degree of urbanization and GDP growth have negative effects on the crime rate.

Kahn (2013) investigated the reasons for the drop in crime in the Southeast and its increase in the North and Northeast regions of Brazil. The author found that Brazilian regions experienced rapid and disorderly economic growth causing an increase in income and the availability of goods, but without a corresponding increase in quality of life. Specifically for the metropolitan region of São Paulo, Pezzin (1986) carried out one of the first empirical quantitative studies with cross-section analysis for the year 1983 and time series analysis for the years 1970 to 1984. He found a positive correlation between urbanization, poverty and unemployment in relation to crimes against property in that region.

For the microregions of the state of Minas Gerais, Araújo Júnior & Fajnzylber (2000) conducted an econometric study of the determinants of crime rates in the years between 1980 and 1995. Their results suggest that the higher the average education of the population, the lower the crime rate against the person and higher will be the rates of crime against property. The explanation for this phenomenon is that higher educational levels are related to higher wages and, therefore, to higher opportunity costs for criminal activity. However, there may also be an increase in the number of economically attractive potential victims, so more urbanized micro-regions tend to have higher rates of violence and crime.

In an analysis of Brazilian municipalities, Oliveira (2005) investigated the causes of crime and their relationship with the size of cities. The author used a model with panel data for all municipalities for the years 1991 and 2000. The results were that crime increases with the size of cities and also with a greater economic return from crime and less likelihood of punishment, the greater the size of the city. According to Oliveira (2005), other factors can also influence the increase in crime, for example income inequality, poverty, problems in the family structure and the inefficiency of basic education.

For Belo Horizonte in particular, Peixoto (2003) portrayed the profile of victims of theft, robbery and physical aggression for the year 2002. Using a Logit model, the results of the research found that economically motivated crimes are not related to personal attributes, except for schooling and economic status. Likewise, the probability of victimization is linked more to the habits and characteristics of the neighborhood, in addition to the crimes of aggression having an influence on age (younger individuals are more likely victims).

For the Northeast, more specially for the municipality of Aracaju, Lemos, Santos Filho & Jorge (2005) evaluated the socioeconomic reasons for crime. The results, based on the Demographic Census of the year 2000 and on the field research with 3240 individuals, indicated that the concentration of income, the characteristics of the infrastructure of the neighborhoods, the low demographic density and the smaller proportion of young people in the total population are determinants of crimes against property.

In the analysis of crime in the metropolitan region of Salvador (RMS), Fernandez & Lobo (2005) used panel data estimation for the years 1993 to 1999. Data were extracted from the Police Documentation and Statistics Center (CEDEP), from the Research of Municipal Information and Statistical Yearbook of Bahia. They found that the increase in demographic density, police efficiency, education, income of municipalities and municipal governments, a reduction in income concentration and the degree of urbanization contribute to a reduction in crime in the 10 municipalities of the metropolitan region.

Faria, Ogura & Sachsida (2013) investigated criminal factors in Brasilia using a regression estimated by ordinary least squares (OLS). According to data from the Civil Police of the Federal District for the years 2006 and 2007 and the District Survey by Household Sample, the overall crime rate was higher in the central area of Brasília. However, despite the higher income concentration of residents in the region, the rate of theft was lower. Based on the results, the authors believe that the high crime rate may be associated with commercial activities, the predominance of vertical housing and larger population size.

Finally, based on the empirical analysis carried out here on crime in Brazil and its relationship with the urban economy, research more directed to the scope of the article will be presented below, namely, works that deal with crime and its determinants for the state of Rio de Janeiro.

2.2 The evolution of crime in Rio de Janeiro

Since the 1970s, the state of Rio de Janeiro has been going through a vicious cycle that combines a decline in participation in the national economy, low levels of social indicators, in addition to the worrying situation of violence and territorial inequality (Osorio, Versiani, & Veiga, 2018). Until the 1980s, homicide rates in the state were close to the national average. However, from 1983 this rate began to increase and accelerate until 1995. Between 1995 and 2006, the number of deaths decreased, although the state still had high homicide rates, between 50 and 40% per 100,000 inhabitants. As of 2007, the rates began to decrease and in 2012, for the first time in 32 years, the number of homicides fell below the national average (Ramos, 2016).

In the period between 2015 and 2018, the state was also one of the hardest hit by the political and economic crisis of recent years. This crisis was influenced by several factors, including the drop in price of a barrel of oil, which consequently affected the state's income; a crisis at Petrobras and their contractors that had a strong presence in Rio; and a loss of almost 1 million formal jobs in the state between January 2015 and January 2018 (Osorio, Versiani, & Veiga, 2018).

On the inequality of existing statistics among the municipalities of Rio de Janeiro, Cardoso et al. (2016) analyzed the rates of intentional homicide, robbery, bodily injury followed by death, homicide by resistance act, police officer killed on duty, missing person and corpse found in the state, municipality and Integrated Area of Public Security (AISP 16) between the years 2002 and 2013. The results showed that the intentional homicide rate showed a significant downward trend in three locations (rates decreased by 17.6% in the state, 38.6% in the city and 31% in AISP 16). This reduction may have been influenced by the result of some specific measures to combat crime, such as the Integrated Target System and the UPPs installed in certain locations in the city of Rio de Janeiro.

Despite advances in public security, with the fiscal and financial crisis of the state and municipal governments, Rio de Janeiro recorded a setback in public security in 2016 with a worsening of crime. More specifically, from the decrease in the presence of the police on the streets, in addition to salary arrears, the absence of the state forces was felt and space for an increase in criminality with parallel power (the militias) was widened through violence (Sistema FIRJAN, 2017).

In 2016, the three main crime groups - crime against property, against life and police activity – all recorded an increase in occurrences. Crimes against life, represented by the violent death indicator (intentional homicide, homicide resulting from opposition to police intervention, robbery and bodily injury followed by death) grew 25% compared to 2015. Intentional homicide accounted for 81% of victims of violent death; and homicide resulting from opposition to police intervention represented 15%. Cases of robbery and bodily injury followed by death accounted for 4%. Cases of police victimization (deaths of police officers) increased by 38% compared to 2015 (Sistema FIRJAN, 2017).

Meanwhile, crimes against property represented by street robbery (theft of mobile phones from pedestrians, in addition to theft from commercial establishments, collectives, banks and ATMs); vehicle theft, home burglary; and cargo theft also increased. Compared to 2015, street burglaries increased by 46.4% and residential burglaries by 11%. In addition, Rio de Janeiro became the most dangerous state for cargo transport, accounting for 43.7% of cargo theft occurrences in the country (Sistema FIRJAN, 2017).

The observed security crisis was reproduced in society, that is, there was the degradation of previously dynamic areas, closing of establishments, withdrawal of investment and the creation of areas where the state had lost control of crime. In peripheral areas, criminality itself organizes itself and controls the closing of schools, commercial establishments, healthcare, streets and access for residents (Sistema FIRJAN, 2017), establishing what can be called parallel power.

As for the characteristics of the composition of intentional deaths, the statistics are similar to the national reality, that is, with more deaths of young men, mainly between 15 and 29 years old, among them black and brown. With regard to geography, considering the AISPs, the areas of the south zone of the city have rates close to those of North America and Europe, while those of the west zone are close to those of Venezuela (Ramos, 2016). This demonstrates the disparities and regional heterogeneity of crime present in the ERJ.

Spatial differences in the incidence of violence are confirmed in the study by Imanishi & Rivero (2012), who carried out a georeferencing work on death records due to homicides in the municipality of Rio de Janeiro, in the period between 2002 and 2006. To test the hypothesis that there is a spatial correlation between violence and the city's favelas, the authors used data from the Municipal Health Secretariat (SMS), from the Demographic Census and maps of favelas and aspects of the territory of the municipality of Rio de Janeiro. The results showed a strong relationship between the spatial layout of the favelas and other types of precarious settlements and the areas with the most victims of homicide, according to their residence.

Zaluar & Barcellos (2013) also investigated why some locations have high homicide rates in Rio de Janeiro, using spatial analysis. The results revealed that the homicides are concentrated in the areas of conflicts for strategic locations of the geopolitics of drugs and weapons in the city. It was concluded that homicide mortality rates within the favelas were the same or lower than in the rest of the city, but the areas surrounding the favelas have higher rates, especially in areas of conflict between rival armed militias.

Finally, based on a recent survey of crime in Rio de Janeiro, this article aims to investigate how socioeconomic factors can affect crime in the state. In addition, criminal

occurrences over time were evaluated through exploratory analysis of spatial data and through the panel data methodology, also analyzing the influence of explanatory variables, namely: GDP per capita, number of admissions in formal employment, demographic density, number of enrollments and the FIRJAN index of municipal development on the dependent variable (crime rate). The work is motivated by the need for greater depth in understanding of the relationship between crime and variables related to the role of the state as a promoter of public policies for the well-being of the population. Therefore, the importance of this study for the state of Rio de Janeiro is reinforced as a database is built that covers all years of the period between 2014 and 2016, for all municipalities in the state. The analysis therefore enables a spatial and temporal investigation of criminality in Rio de Janeiro, detailed below.

3 Methodology and database

3.1 Exploratory Spatial Data Analysis (ESDA)

The Exploratory Spatial Data Analysis is used to characterize the spatial arrangement of events using georeferenced data. It is a set of techniques that seeks to evaluate not only the absolute position of events, but also to identify their relative distribution, in order to verify the existence of spatial patterns (spatial clusters), spatial regimes or other forms of spatial instability (non-stationarity) (Anselin, 1998). The spatial lag operator of a variable y, formally Wy, can be interpreted as being the average of the value of this variable in the neighboring regions. Moran's I statistic is formally given by:

$$I = \frac{n}{\sum\sum w_{ij}} \frac{\sum\sum w_{ij}(y_i-\bar{y})(y_j-\bar{y})}{\sum(y_i-\bar{y})^2} \tag{1}$$

Where n is the number of spatial units, y_i is the variable of interest, w_{ij} is the spatial weight for the pair of spatial units i abd j, measuring the degree of interaction between them. Moran's I statistic has an expected value of $-[1/(n-1)]$. Thus, values of I that exceed $-[1/(n-1)]$ indicate positive spatial autocorrelation. Conversely, values of I below the expected value indicate a negative autocorrelation (Almeida, 2012). If the angular coefficient is positive, there are indications that the spatial autocorrelation is positive. If the coefficient is negative, there is evidence of negative autocorrelation (Almeida, 2012).

In addition to the global measure of spatial linear association, the diagram represents four types of spatial linear association: High-High (AA) indicates that a spatial unit that belongs to this cluster has a high value of the variable of interest and is surrounded by spatial units that also have high values, represented by the first quadrant of the diagram; Low-High (BA) refers to a cluster in which a spatial unit with a low value of the variable of interest is surrounded by spatial units with a high value, represented in the second quadrant; in the third quadrant is the Low-Low (BB) association, in which the spatial units have low values with adjacent spatial units that also have low values; and High-Low (AB) refers to a cluster in which a spatial unit with a high value of the variable of interest is surrounded by spatial units with a low value, represented by the fourth quadrant (Almeida, 2012).

In this way, ESDA was used to explore the spatial dimension for violent crimes. The variables used in the ESDA and in the econometric regression will be detailed below.

3.2 Panel data

This section describes the panel data model used in econometric regression. Information from the 92 municipalities in the state of Rio de Janeiro (observation units) were used in order to analyze the effects of socioeconomic and demographic variables (number of admissions to formal employment, population density and basic education) on the variable of criminality in the state, between the years 2014 and 2016.

The panel data regression model can be represented by:

$$y_{it} = X_{it}^{j}\beta + \varepsilon_{it} \tag{2}$$

Where y_{it} is the dependent variable i at moment t of time; X_{it}^{j} is the value of the j explanatory variable for municipality i at time t; e ε_{it} it is the error term for unit i at time t. The model has n observations, and the cross-section units have $n>1$ for (i=1, 2, 3, ..., n), in t time periods (t=1, 2, 3, ..., t) e k variables, represented by the unknown j (j=1, 2, 3, ..., k).

In order to identify which are the most adequate procedures to estimate the model, preliminary estimations and some specific tests are necessary. Thus, there is more reliability in the estimation method used to estimate the economic model of crime. Model selection can be done using the Hausman test. This test has an asymptotic X^2 distribution. Accordingly, if the null hypothesis (H_0: random effects are consistent) is rejected, it is more appropriate to use a fixed effects estimator. In the case of this article, the fixed effects model was considered the most appropriate. In the presence of correlation between the error term and one or more regressions, the parameters of the fixed effects model are unbiased.

3.3 Empirical panel data model

Based on the panel data model, the econometric model estimated in this work aims to verify the effects of socioeconomic, demographic and educational variables on the crime indicator in the state. For this purpose, equation 3 presents the empirical model to be estimated:

$$\text{crime}_{it} = \alpha + \beta_1 dens_{it} + \beta_2 merc_{it} + \beta_3 educ_{it} + \varepsilon_{it} \tag{3}$$

where α is the intercept, ε is the error term and β is the coefficients to be estimated. Some problems may arise in estimates that have crime as a dependent variable. In this case, the explanatory variables used in the literature are strongly correlated and, therefore, suffer from the problem of multicollinearity. Although this implication does not affect the quality of the estimators, it can make it difficult to obtain significant estimates for explanatory variables, indicated by the theory (Becker, 1968; Ehrlich, 1973).

Another problem be faced is that of endogeneity, in which the fundamental assumption is that there is no correlation between X and the error term ε. When this occurs, that is, when ε and X are correlated, the traditional estimators for the parameters of the equation become inconsistent. The cause of endogeneity stems from factors such as omitted variables and measurement or simultaneity errors.

In the initial model (2), endogeneity makes it difficult to estimate the parameter of interest β, unless there is another additional variable z called instrument for X that is correlated with X and uncorrelated with ε. Therefore, in order to minimize the problems resulting from the estimation, the empirical model (3) was estimated in two stages. In the first, the parameters of the model (3) that relates X and z were calculated:

$$X_i = \delta_1 + \delta_2 z_i + v_i \qquad (4)$$

The error term of equation (4), v_i, is not correlated with instrument z. Then, the estimated parameters are used to construct a variable resulting from the projection of X into z. In the second step, the original variable X was replaced by $\hat{X}$ and equation (5) was estimated.

$$y_i = \alpha + \beta \hat{X}_i + \varepsilon_i \qquad (5)$$

Since there is no correlation between z and ε, there will also be no correlation between $\hat{X}$ and ε. This procedure allows the consistent estimation of the original parameter of interest β, as will be verified in the estimation results section.

3.4 Database

For the composition of the database on criminality in the state of Rio de Janeiro, information from the Public Security Institute of the state (ISP-RJ) was used. The ISP-RJ is an autarchy directly linked to the State Security Secretariat, whose mission is to produce information and disseminate research and analysis in order to support the implementation of public security policies. Table 1 presents all the variables for violent crimes and victims of traffic crimes that constitute the violent crime rate. These variables were used in the AEDE methodology as a way of identifying the spatial patterns associated with the behavior of municipalities in the state of Rio de Janeiro.

In the empirical panel data model to be estimated (Equation 3), for a better identification of criminality in the state of RJ, the indicator of violent crimes was used as the dependent variable (which will be called crime). The indicator was constructed using the average of the variables presented in Table 1. The objective of the variable was to capture how crime can be influenced by variables that measure the labor market (merc), demographic density (dens) and education (educ) (Becker, 1968; Cerqueira Lobão, 2004; Osorio, Versiani & Veiga, 2018; O'sullivan, 2011; Ramos, 2016). In addition, the aspects presented in the explanatory variables made it possible to verify how the characteristics presented affect the crime rate, since Rio de Janeiro has municipalities with heterogeneous crime indicators.

Table 1 – Variables of violent crime rate

Indicators	Description
hom_doloso	Intentional homicide
lesao_corp_morte	Bodily injury followed by death
Latrocínio	Robbery (robbery followed by death)
hom_por_interv_policial	Death by intervention of state agent
tentat_hom	Attempted murder
lesao_corp_dolosa	Intentional bodily harm
Estupro	Rape
hom_culposo	Negligent homicide
lesao_corp_culposa	Culpable bodily injury

Source: Informations from the Public Security Institute of the state (ISP-RJ).

As for the explanatory variables, demographic density aims to capture the influence of the size of cities that can also determine the evolution of crimes. According to Glaeser & Sacerdote (1999), crime rates are higher in large cities than in small towns and rural areas. Thus,

the population density variable will be calculated by dividing population and area of municipalities, according to the years 2014 to 2016. The aim here is to test the hypothesis that larger cities may have higher crime rates. Data on the population and area of the municipalities were obtained from the website of the Brazilian Institute of Geography and Statistics (IBGE).

Considering the variable that relates the labor market to crime, the number of admissions to formal employment was computed, extracted from the Annual Relation of Social Information (RAIS) database and divided by the population for the years under study. Thus, the proxy intended to test Becker's theory (1968), which states that individuals opt for the legal market when there is an option for attractive jobs. It is expected, therefore, that the relationship between crime and the variable that reflects he labor market has a negative sign, inferring that the greater the opportunities for formal work, the lower the inclination of individuals towards criminality and, consequently, the lower incidence of crime in the municipalities of Rio de Janeiro.

Finally, the division between students enrolled in high school and the total population of the municipality was used as a schooling proxy. The data source was obtained from the Ministry of Education (MEC). The purpose of the variable was to assess the relationship between the education and crime. It is clear that a population with better qualifications is better prepared to enter the labor market and is less predisposed to crime (Becker, 1968). Thus, people with a high level of schooling have higher wages, thus opting for the best market conditions. As a result, a negative relationship between crime and the education variable was expected.

Next, in Table 2, a summary of the variables considered for the analysis of crime in Rio de Janeiro can be seen.

Table 2 – Summary of the variables used in the estimation

Variables	Expected sign	Theoretical and empirical references	Source
Crime (dependent variable)		Osorio, Versiani & Veiga, 2018; Ramos, 2016; O'Sullivan, 2011; Becker, 1968; Cerqueira Lobão, 2004	ISP - RJ
Population density	+	Oliveira (2005)	IBGE
Job market	-	Becker (1968)	RAIS
Education	-	Araújo Júnior & Fajnzylber, 2000; Ehrlich, 1975; Kume, 2004; Fernandez & Lobo, 2005	MEC

Source: Own elaboration.

4 Results

4.1 Univariate global spatial autocorrelation

When starting a study on the exploratory analysis of spatial data, it is necessary to define the matrix of spatial weights (W). The choice of matrix should aim to reflect a certain spatial arrangement of interactions resulting from the phenomenon to be evaluated. The process for choosing the best matrix, based on the dependent variables to be used, was performed by replacing several matrices, such as Queen (queen), Rook (tower), k nearest neighbors for k= 5, k =10, k=15 and k=20.

Table 3 shows the values of the Moran I statistics for the dependent variable[1], in which the use of the geographic contiguity matrix by queen convention (Queen) stands out as

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[1] The means of the dependent variables between 2014 and 2017 were calculated.

contiguous in addition to border, in a map view. The queen spatial weight matrix showed the highest value of Moran's I statistic, which was also significant.

Table 3 – Spatial weight matrices

Moran's Violent Crime Rate	Moran´s I	Mean	Standard deviation	Probability
Queen	0.0846	-0.0110	0.0239	0.004940
Tower	0.0844	-0.0110	0.0242	0.005110
5 nearest neighbors	0.0492	-0.0109	0.0208	0.012540
10 nearest neighbors	0.0542	-0.0109	0.0145	0.000330
15 nearest neighbors	0.0614	-0.0109	0.0116	0.000010
20 nearest neighbors	0.0496	-0.0110	0.0099	0.000010

Source: Own elaboration using the *software Geoda*.

Parallel to the results of the Moran I indicator, Figure 1 shows the Moran scatterplot for the average crime victim rate. The value of Moran's I statistic for the variable rate of violent crimes in the municipalities of Rio de Janeiro was positive, equal to 0.085, and statistically significant at the 1% level. As the value of Moran's I statistic was significant, the null hypothesis of spatial randomness was rejected. In other words, municipalities in Rio de Janeiro with a high rate of violent crimes tend to be neighbors with municipalities with the same characteristic. Similarly, municipalities with low violent crime rates tend to have similarly situated neighbors.

Figure 1 – Violent Crime Rate Scatter Diagram
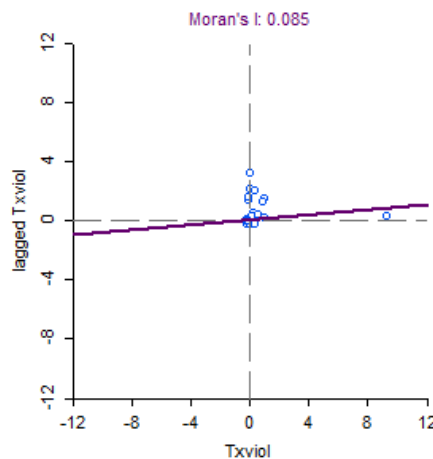
Source: Own elaboration using the *software Geoda*.

The result in Figure 1 also indicates that the prevalence of violent deaths is greater the larger the size of the cities, due to the greater economic return and the lower probability of punishment, as highlighted by Glaeser & Sacerdote (1999) and Oliveira (2005). The authors investigated the causes of crime and the relationship with the size of cities and concluded that the size of the city is a relevant factor to explain crime. This also confirms an important characteristic, which is that the high crime rates in the state of Rio de Janeiro are leveraged by the capital and the metropolitan region, and the municipalities in the interior have lower rates (Ramos, 2016).

Furthermore, the justification is due to the existence of determining factors in large urban centers that contribute to crime, such as greater income concentration/inequality, lack of

family planning; a higher proportion of slums and lack of urban planning, higher proportion of unemployed people, higher incidence of organized crime, inconsistent public security, slowness of justice, impunity, among other factors (Confederação Nacional de Municipios - CNM, 2009).

To corroborate the results and visualize the indicator's spatial approach, Figure 2 shows the regions with positive spatial autocorrelation, according to violent crimes. The regions are highlighted as follows: the region in dark blue (Low-Low) indicates municipalities with a low concentration of violent crime rate, surrounded by municipalities with the same characteristic. The municipalities under this configuration in the interior of Rio de Janeiro are: Santo Antônio de Pádua, Itaocara, Cambuci, Carmo, Macuco, Cantagalo, São Sebastião do Alto, Cordeiro and Vassouras. In the regions highlighted in dark red (High-High) are the municipalities whose locations are concentrated in the Baixada Fluminense, capital and metropolitan region: Nova Iguaçu, Belford Roxo, Duque de Caxias, São João de Meriti, Magé, Rio de Janeiro (capital) and Niterói (Greater Niterói).

Figure 2 – Cluster map of the violent crime rate
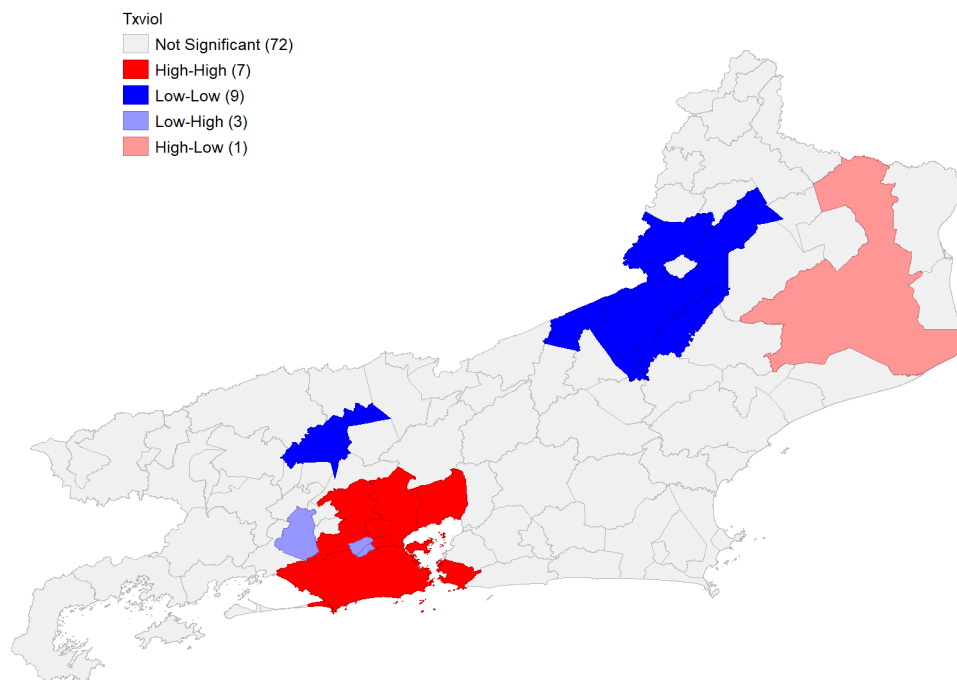
Source: Own elaboration using the *software Geoda*.

Thus, the municipalities with a high concentration of violent crime rates are surrounded by municipalities with the same profile. There are, however, regions where the autocorrelation is negative, such as the municipality in light red (High-Low), Campos dos Goytacazes (interior). This municipality has a high concentration of violent crimes but is surrounded by municipalities with low concentrations of violent crimes. This indicates that, for the High-Low configuration, smaller municipalities with a low demographic density, which did not have a sharp increase in violent crimes and continue to present almost zero crime rates, have heterogeneous characteristics among municipalities in the metropolitan region and other cities in the interior. of the State. The municipalities in light blue (Low-High), represented by Seropédica, Mesquita and Nilópolis (Baixada Fluminense), reflect those with a low concentration of crime, with

neighbors where the concentration of crime remains high. In addition, for part of the municipalities, the statistics were not significant, as indicated by the gray part of the map.

Likewise, the high incidence of violent crimes in the capital and in some municipalities in the metropolitan region may be related, among other factors, to the presence and dispute over territory between the militia and drug trafficking in the region, in addition to the historical problems of violence in the region. The war between militia groups and drug traffickers has collaborated to increase the number of deaths not only in the metropolitan region, but throughout the state. In addition, the state government has contributed to the increase in fatality rates, with its security policy being based on brutality and lethal confrontations in recent years (2016 to 2019) (IPEA, 2019).

It is noteworthy that the municipalities in the Alto-Alto (High-High) group belong to the metropolitan region and have a high demographic density and high occurrence of violent crimes too. In addition, the state of Rio de Janeiro stood out as the most dangerous in the country in terms of cargo theft in 2016, showing the fragility of the ports, which do not have an adequate security and customs control system, and the weakened structure of the Federal Highway Police. These weaknesses are used by criminal factions that manage to smuggle goods that are financed by cargo theft (Sistema FIRJAN, 2017).

In summary, the results presented reinforce the pattern of policing, especially in metropolitan areas and on the outskirts of large cities. Their work prioritizes the fight against drug trafficking and the fight in the favelas under the justification that criminals are in these places and that drug trafficking is the main crime the state faces (Rio de Janeiro, 2019) . It should be noted that Rio de Janeiro has the highest death rate in the country as a result of police intervention (Fórum Brasileiro de Segurança Pública, 2018).

All the results presented by ESDA are consistent with the literature and reflect the current scenario of crime, the determining variables and the outcome according to the process of urban growth (planning) in the state over the years. As verified in the literature review, the combination of sociodemographic factors indicated in the univariate and bivariate spatial analysis reflects the pressure on the infrastructure and budgets of municipalities, in addition to urban spillovers, which affect not only peripheral areas (favelas), but the metropolitan regions of Rio de Janeiro (Chesnais, 1999).

The next item aims to find out, through the panel data model, whether the determining factors of the urban structure in Rio de Janeiro, such as demographic density, formal employment of labor and education, can influence crime rates in the state.

4.2 Result of the panel data model

This item presents the results of the estimation of the panel data model, whose regression involves the dependent variable, the indicator of violent crimes and victims of traffic crimes, of violent crimes, with the explanatory variables that measure the labor market, population density and education, according to the empirical model (Equation 4). Estimates were performed from a balanced panel for the 92 municipalities in the state of Rio de Janeiro, in the period from 2014 to 2016. Descriptive statistics were calculated for all variables, as well as the correlation matrix (Appendix A). The results can be found in Table 4.

Table 4 – Descriptive statistics

Variables	Average	Standard deviation	Minimum	Maximum	Observations
Crime	0.1663092	0.6457291	0	6.979445	N=276
Population density	704.6778	1881.549	12.51652	13082.43	N=276

Job market	0.1369234	0.7401746	0.00103	8.30862	N=276
Education	0.2560875	1.043729	0.0000374	11.6391	N=276

Source: Own elaboration.

From the results in Table 4, it can be observed that the average of the education variable was higher compared to the crime and labor market variables, and the average of the population density variable in the municipalities drew attention due to its very high value. It is noteworthy that the correlation matrix helped to verify whether there was any case of autocorrelation between the explanatory variables, which was not confirmed (values below 80%).

For the econometric estimation, the variables used were the rates of violent crimes (variable dependent on the econometric model) against demographic density, the number of admissions to formal employment per capita and the number of enrollments in secondary education per capita, as they configure the explanatory variables and are the most representative in the literature of the area (Araújo Júnior & Fajnzylber, 2000; Becker, 1968; Ehrlich, 1973; Halicioglu, 2012; Mendonça, 2002; Salviato & Mourão, 2014; Tavares, 2017).

In order to use the most adequate model to obtain a consistent result, the ordinary least squares, fixed effect and random effect models were estimated (Table 5). According to the results in the MQO model, the variables of demographic density, labor market and qualified population were positive and highly significant. The explanatory power of the model (R^2) was 98%.

To verify the existence of multicollinearity between the set of returns, the variance inflation factor (VIF) test was performed. In the respective test, the VIF mean must be in the range between one and 10. According to the VIF result, its value was below three, which did not provide evidence of multicollinearity. Based on the Breusch-Pagan test, the hypothesis of homoscedasticity was rejected, in which the error terms (ε) must have constant variance, that is, the model presented evidence of heteroscedasticity. According to Gujarati & Porter (2011), heteroscedasticity does not invalidate the consistency and non-bias of the estimators, but they did not have minimum variance and were not efficient.

Table 5 - Estimation results

Variable Crime (dependente)	MQO	Fixed Effect	Random Effect
Population density	0.0000217***	0.0002423	0.0000248***
Job market	0.8169311***	0.7650049***	0.8329604***
Education	0.0286987***	-0.0087312***	0.0000963
Constant	0.0317944***	-0.1069588	0.0347603***
R^2	0.98	0.79	0.98
Observations.	276	276	276

(1) Significance levels: *** Significant at 1%; ** Significant at 5%; * Significant at 10%; the others were not significant.
Source: own elaboration using Stata software.

In the absence of unobserved effects, retention by the stacked OLS method is adequate. However, in view of the unobserved heterogeneity, the application of this method is not the most appropriate, since it produces biased estimates and serious specification errors, according to the problems shown in item 3.2. The unobserved effects can be modeled using fixed or random effects and, to decide between these effects, the Hausman test[2] is performed. The Hausman test was significant, thus rejecting the null hypothesis. Thus, retention with fixed

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[2] Hausman Test: 43.89 (p-valor: 0.0000).

effects is preferable to random effects. This result confirms that the phenomenon under study was influenced by specific effects not observed. It is known that the consistent security of the model is based on the hypothesis of strict exogeneity. Therefore, it is assumed that this hypothesis is valid so the results are also valid. Given the possibility of endogeneity, the resistance of the robust model for fixed effects was performed again using an instrumental variable (Table 6).

The individual decision to commit a crime or not in a city depends on some endogenous and exogenous factors. There are individual characteristics, such as the moral cost, which are considered exogenous, and endogenous characteristics (locations in each municipality), such as size, organization and way of dealing with criminals. The endogenous variable in the model is demographic density, as urban density facilitates crime and decreases the probability of punishment. Furthermore, the density variable must be correlated with the crime that is likely to be found in the error term. Furthermore, it is not directly observable. The instrumental variable used was the Firjan index of municipal development, due to its exogeneity with the variable of interest.

The motivation for using an instrumental variable comes from the problem caused by the bias of omitted variables in the panel data regression model. When faced with the prospect of omitted variable bias (or unobserved heterogeneity), it is possible to ignore the problem and suffer the consequences of biased and inconsistent estimators. It is also possible to try to find and use a suitable proxy variable for the unobserved variable; or assume that the omitted variable does not change over time and use fixed effects or first differentiation methods. The idea of using the instrumental variable method is to leave the unobserved variable in the error term, but instead of estimating the model by OLS, an estimation method that recognizes the existence of the omitted variable was preferred. The Wald chi-square test, with three degrees of freedom (the number of restrictions tested) indicates that the estimates of the regression coefficients are efficient in satisfying the restrictions of the null hypothesis. In other words, it is assumed that all coefficients can be simultaneously equal to zero and, thus, at least one model coefficient is not equal to zero.

Based on the model shown in Table 6, the determinants of crime in the municipalities of Rio de Janeiro were evaluated, namely demographic density, labor employment and level of education of the population.

Table 6 – Regression of the data model on panel data with fixed effect by instrumental variables

Dependent variable:	Crime
Population density	0.0002423
Job market	0.7650049***
Education	-0.0087312***
Constant	-0.1069588
R^2	0.76
Wald Test	16729.68***
Observations	276

(1) Significance levels: *** Significant at 1%; ** Significant at 5%; * Significant at 10%; the others were not significant.
Source: own elaboration using Stata software.

The variable representing population density was not significant. This must be linked to the heterogeneity observed between municipalities, as specified by the AEDE. Thus, in the specific case of Rio de Janeiro, it is not possible to state that crime increases with the size of cities. The heterogeneity present in the urban structure indicates that even municipalities with

a low population density can have high crime rates. Therefore, the relationship between the size of cities and the crime rate referred to in empirical studies, such as those of Glaeser & Sacerdote (1999) & Oliveira (2005), do not represent the behavior of this determining factor for Rio de Janeiro.

According to Becker's theory (1968), explained in the theoretical framework, the relationship between crime and workers in the market and between crime and education is negative - the greater the job opportunities and the higher the educational level, the lower the incidence of the number of crimes in the region. The effect of these variables, however, can be ambiguous since, according to Araújo Júnior and Fajnzylber (2000), regions with higher levels of education are also regions with a greater number of economically attractive victims, bearing in mind that the education of a population can be used as a measure of income.

When considering the coefficient of the variable that represents the population's education, it was found to be negative and significant. This result shows that the higher the educational level of the population in the municipalities, the lower the individual's willingness to commit crimes. On the other hand, the result of the effect of education on crime is ambiguous, constituting a question that can be answered empirically. In other words, since higher educational levels are associated with higher wages, there are higher opportunity costs for criminal activity. Furthermore, education can have the effect of increasing the "moral" cost associated with participating in illegal activities (Araújo Júnior & Fajnzylber, 2000; Ehrlich, 1975).

In Tables 5 and 6, it can also be seen that the effect of the education variable on crime varied according to the estimation method. The result shows the dissuasive effect of the education variable on violent crimes against people. This is in line with the argument that in the case of crimes against people, which do not always involve economic benefits, the effects of education on the costs of crime can be expected to dominate the effects on the potential benefits, decreasing the incidence of crime and criminal activities (Fernandez & Lobo, 2005; Kume, 2004).

The variable that measures the population involved in the formal labor market showed a positive sign and was significant at 1% significance. It is worth noting that many works highlight two effects of this variable. The first one represents the effects on the benefits of crime, that is, the increase in the number of jobs tends to increase the available wealth. In this way, a greater return on criminal activity increases the level of criminality, as well as the depreciation of human capital due to the time of absence in the labor market (the longer the time that the agent remains unemployed, the greater the probability of participating in the crime). The second effect refers to the opportunity costs, as the increase in the number of jobs reduces the opportunity costs of the criminal agent by providing opportunities for earnings in legal activities in the formal labor market (Oliveira, 2005).

Thus, when analyzing the variable that reflect the population's employment, it was possible to identify a positive relationship between the employed population and crimes in Rio de Janeiro. As intuitive as this negative relationship may be, the empirical literature (Andrade & Lisboa, 2000; Gould, Weinberg & Mustard, 2000) obtained similar results for the coefficient with a positive sign. This lack of consistency in the effect seems to be related to the high level of informality in the labor market that exists not only in Rio de Janeiro but also in all Brazilian states.

5 Conclusions

This article aimed to investigate socioeconomic and urban factors such as education, population density and the labor market and their effects on crime in the state of Rio de Janeiro, between 2014 and 2016. It also attempts to contribute to the literature on the economics of crime so as to aid in the formulation of more efficient policies in the state of Rio de Janeiro.

The exploratory analysis of spatial data allowed us to state that the spatial patterns (spatial clusters) in the state of Rio de Janeiro are not randomly distributed in space. The results also demonstrate that the process of violence in small cities increased. This phenomenon was identified in the AEDE in relation to the variables linked to crimes. Based on the crime statistics in these municipalities, the intensity of the increase in violent crimes between 2014 and 2016 goes in the opposite direction to what has been happening in the capital. While the capital had a moderate or marked decrease in the number of violent crimes, the other municipalities saw an increase in several areas of crime.

As noted, the variable on population density was not significant, indicating the heterogeneity and inequality of socioeconomic factors among the municipalities of Rio de Janeiro. The characteristic of the population density variable showed that it cannot be considered as a single factor that potentiates violence. As for the effect of the education variable, the respective variable obtained a negative sign and was significant at 1%, having an opposite effect on crime.

The result seems to indicate that public investment in the area of education should be considered as a policy to reduce crime in the state of Rio de Janeiro. This confirms what was identified in the literature review, that interventions in the educational area directly affect criminal activity. Therefore, public action in the area of education and the fight against crime must be aligned in areas where the low-income population is more concentrated. According to the results obtained, education can be considered as one of the channels that contributes to reducing crime.

The result on the labor market variable emphasized a positive and significant relationship, at 1%, between the population employed in the formal labor market and crime in Rio de Janeiro. The explanation for this result may be associated with the income effect inherent to areas where there is a greater concentration of companies, as well as the fragmentation of this urban space that enables the creation of markets and informal businesses (street commerce, street vendors, temporary jobs, illegal hiring of workers). This can be an attraction to the expansion of criminality both in these places and in their surroundings (spillovers). Therefore, greater economic dynamism must also be accompanied by public policies that enable the safety of these places and ensure the mitigation of the direct and indirect effects of crime.

Finally, it is worth mentioning that this article represents the first step to empirically indicate the role of public security in the face of the determining factors of crime in Rio de Janeiro. In this regard, it is important to identify which actions taken by the state have caused an increase in violence in isolated and more distant areas. One of these factors could be the implementation of Pacifying Police Units (UPPs). The units are responsible for the migration of crime to the metropolitan region and to the interior of the state. Another worrying factor that has advanced considerably in recent years, especially in metropolitan regions, is to the issue of militias, which have transferred groups of drug dealers to other regions, also contributing to the internalization of crime.

As future contributions to the literature in the area of economics of crime, one can examine the effects of the borders of states neighboring Rio de Janeiro. In addition, a more in-depth study using the panel data methodology on all neighborhoods in the capital over a longer period may allow for a more detailed investigation of the mobility of crime, highlighting its weaknesses and possible solutions for mitigating the effects of crime in the state capital.

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Apêndice A – Matriz de Correlação

	Crime	Densidade populacional	Mercado de trabalho	Educação
Crime	1			
Densidade populacional	0.3647	1		
Mercado de trabalho	0.6905	0.3064	1	
Educação	0.7659	0.3126	0.7473	1

Fonte: elaboração própria com base no *software Stata*.

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