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Nogueira, Lauro and Rodrigues, Fábio Lúcio and Santos de Farias Souza, Wallace Patrick and de Araújo, Jevuks Matheus

Universidade Federal Rural do Semi-Árido, Universidade do Estado do Rio Grande do Norte, Universidade Federal da Paraíba

15 June 2025

Drought in the sertão versus violence in the city: A study on the Brazilian semi-arid region[1]

Lauro Nogueira
Postgraduate Program in Economics PPE/UERN - CCSAH/UFERSA
E-mail: lauro.nogueira@ufersa.edu.br

Fábio Lúcio Rodrigues
Postgraduate Program in Economics PPE/UERN.
E-Mail: fabiolucio@uern.br

Wallace Patrick Santos de Farias Souza
Postgraduate Program in Economics PPGE-UFPB
E-mail: wpsfarias@gmail.com

Jevuks Matheus de Araújo
Postgraduate Program in Economics PPGE-UFPB
E-mail: jevuks@gmail.com

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This paper is the original work of the authors and has not been published elsewhere in a peer-reviewed journal.

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ABSTRACT

This study aimed to investigate how water scarcity and periods of drought can affect firearm homicide rates in the Brazilian semi-arid region between 2002 and 2020. To this end, the methodology of inference in counterfactual distributions proposed by Chernozhukov, Fernández-Val and Melly (2013) was employed. The main findings indicate that periods of severe drought have a significant impact on homicide rates in the semi-arid region. These effects are more pronounced when associated with factors such as the presence of rural municipalities and the migration process. In other words, there is strong evidence that drought in the hinterlands/countryside contributes to the increase in crime rates in both urban and rural municipalities. Additionally, the decomposition of the results revealed that periods of extreme drought, coupled with other unfavorable factors, act as triggers for the increase in homicide rates in the Brazilian semi-arid region, significantly exacerbating conditions of vulnerability during these adverse climatic shocks.

Keywords: Water Scarcity; Drought; Homicide Rate; Brazilian Semiarid.

RESUMO

Este estudo teve como principal objetivo investigar como a escassez de água e os períodos de seca podem afetar as taxas de homicídios por armas de fogo na região semiárida brasileira entre 2002 e 2020. Para isso, foi utilizada a metodologia de inferência em distribuições contrafactuais proposta por Chernozhukov, Fernández-Val e Melly (2013). Os principais resultados indicam que períodos de seca severa têm um impacto significativo nas taxas de homicídio na região semiárida. Esses efeitos são mais pronunciados quando associados a fatores como a presença de municípios rurais e o processo de migração. Em outras palavras, há fortes evidências de que a seca no sertão/campo contribui para o aumento das taxas de criminalidade tanto em municípios urbanos quanto rurais. Além disso, a decomposição dos resultados revelou que períodos de seca extrema, juntamente com outros fatores desfavoráveis, atuam como gatilhos para o aumento das taxas de homicídio na região semiárida brasileira, agravando significativamente as condições de vulnerabilidade durante esses choques climáticos adversos.

Palavras-chave: Escassez de Água; Seca; Taxa de Homicídios; Semiárido Brasileiro.

JEL Classification: I3, J1, R1.

1 Introduction

Water insecurity can have devastating effects on economies and jeopardize the well-being of entire populations, especially the poorest and most vulnerable. In other words, water scarcity and/or prolonged droughts remain among the greatest challenges of our time. These natural phenomena, often exacerbated by human activities, have profound implications not only for the availability of water resources but also for social, economic, and political dimensions. One of the most critical and least discussed impacts is the relationship between water scarcity and/or extreme drought and the rise in violence and/or crime, particularly reflected in the significant increase in firearm-related homicide rates in economically vulnerable regions, especially in rural areas (Hsiang; Burke; Miguel, 2013; Koubi et al., 2014; Nairizi, 2017).

Although Durkheim (2005) incorporated climatological factors into his discussions on human behavior and deviance, most contemporary studies tend to overlook these variables as potential contributors to changes in violence and/or crime rates. This is particularly notable given the ease with which meteorological variables can be integrated into both routine activities and the dynamics of criminal behavior. It is crucial to highlight that some studies identify multiple causal channels linking adverse climatic shocks – such as water scarcity and/or extreme drought – to increases in violence and/or crime. For instance, the literature emphasizes that severe droughts have a direct impact on agricultural output by reducing food production, and consequently, household income. In other words, they affect livelihoods, thereby altering the cost-benefit calculus associated with engaging in criminal activities. Furthermore, such climatic shocks influence both individual and collective behaviors, often leading to the emergence of conflicts (Becker, 1968; Goin; Rudolph; Ahern, 2017; Sommer; Lee; Bind, 2018; Nordqvist; Krampe, 2018; Wright; Stewart, 2024).

Despite advances in understanding the socioeconomic impacts of climate shocks, the international literature has faced significant challenges in precisely identifying the causal effects of water scarcity on violence over time, primarily due to potential endogeneity issues. As highlighted by Miguel, Satyanath, and Sergenti (2004) and, more recently, by Burke, Hsiang, and Miguel (2015), climate shocks do not occur in isolation; they are often correlated with other socioeconomic and institutional variables that also influence levels of violence. For instance, regions that are more prone to drought tend to share structural characteristics – such as weak institutions, low economic diversification, and limited access to public services – that simultaneously exacerbate both vulnerability to climate impacts and crime rates. Moreover, the dynamic effects of these shocks can generate feedback loops, in which rising violence further undermines economic and social resilience, thereby intensifying the impacts of future droughts. This raises important methodological concerns about the difficulty of isolating the exogenous effects of climate variables, given the possibilities of simultaneity, omitted variable bias, and spatial and temporal heterogeneity.

Within this context, an aspect that remains underexplored in the literature concerns the intertemporal dynamics of these effects and their persistence over the medium and long term, particularly in developing countries. For example, it is relevant to question whether an episode of water scarcity and/or periods of extreme drought at time t produces immediate effects on violence indicators within the same period t, or whether these impacts occur with a lag, persisting and accumulating over time. Most of the existing evidence focuses on short-term analyses, frequently associated with isolated climate shocks such as heatwaves or single drought events (Hsiang; Burke; Miguel, 2013). However, there is a notable gap in studies investigating whether the effects of water scarcity on violence are inherently transitory, adaptive, or, conversely, whether they represent persistent and structural impacts. Furthermore, the literature lacks methodological approaches that explicitly incorporate spatial and temporal dynamics, capable of capturing lagged effects, regional spillovers, and long-term cumulative trajectories. This gap is particularly relevant for semi-arid regions such as the Brazilian Northeast, where climate shocks are not isolated events but rather recurring structural components that permanently shape the region’s economic, social, and institutional dynamics.

In light of this, the primary objective of this study is to explore how water scarcity and/or periods of extreme drought affect violence, specifically firearm-related homicide rates, in the Brazilian semi-arid region. This is one of the regions most severely affected by water resource scarcity and by the expansion of violence and crime rates. Additionally, the Brazilian semi-arid region presents a range of socioeconomic indicators that reflect a high degree of economic vulnerability, creating an environment highly conducive to the proliferation of violence, particularly during periods of adverse climate shocks. To this end, the study employs the counterfactual distribution inference method proposed by Chernozhukov, Fernández-Val, and Melly (2013), which is distinguished by its use of quantile regression to estimate treatment effects across the entire outcome distribution. Moreover, it allows for a decomposition of the results into three components, similar to the approach adopted by DiNardo, Fortin, and Lemieux (1996). The climate variables of interest – specifically water scarcity, total rainfall volume, and extreme drought periods – were constructed based on the standards proposed by Camarillo Naranjo et al. (2019) and following the methodologies of Rocha and Soares (2015).

It is important to emphasize that water scarcity occurs when the demand for water exceeds the available supply or when water quality is insufficient for its intended use. The United Nations (UN) estimates that approximately 2.2 billion people worldwide currently lack access to safe drinking water. Scarcity can be classified as either physical – when there is simply not enough water – or economic, when inadequate supply infrastructure limits access. Droughts, in turn, characterized by prolonged periods of low rainfall, further exacerbate water scarcity. Factors such as rising global temperatures and increasing climate variability intensify the frequency and severity of droughts, which directly impact agriculture by reducing food production and affecting the livelihoods of millions of people. On the other hand, violence indicators encompass a wide range of metrics, including homicide rates, armed conflicts, domestic violence, and civil unrest. A growing body of research has extensively documented that resource scarcity, particularly water scarcity, can exacerbate social and political tensions, ultimately leading to increased levels of violence. For instance, Hsiang, Burke and Miguel (2013) report a strong correlation between climate variability and the escalation of both inter-state and intra-state conflicts.

This paper concludes the introduction by anticipating the main empirical contributions of the study. The results provide robust evidence that episodes of severe drought significantly increase firearm-related homicide rates in the Brazilian semi-arid region. These effects are far from homogeneous; they become substantially more pronounced when compounded by structural vulnerabilities such as the predominance of rural municipalities and migration flows. Specifically, the findings suggest that extreme water scarcity acts as a catalyst for forced migration from rural areas to urban centers, which subsequently contributes to the escalation of urban violence. The counterfactual distribution analysis further reveals that this impact is disproportionately concentrated in municipalities already characterized by high baseline homicide rates, with upper quantiles displaying effects up to 16 times greater than those in the lower quantiles. Moreover, the decomposition analysis indicates that both observable socioeconomic characteristics and unobservable factors jointly exacerbate the amplification of violence during adverse climatic shocks. In sum, this study demonstrates that drought-induced vulnerabilities – when interacting with rurality and migration – serve as critical triggers for the proliferation of lethal violence, underscoring the urgent need for integrated public policies that address both climate adaptation and violence prevention in socioeconomically fragile regions.

2 Literature Review

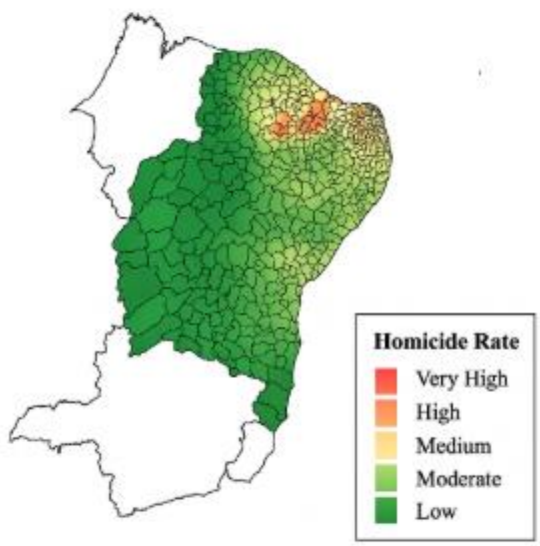
This section is intended to briefly explore some essential concepts associated with the Economic Theory of Crime; however, it first provides an overview of the Brazilian semi-arid region. Additionally, it presents some important findings from the literature addressing the issue.

2.1 Brazilian Semi-Arid Region – Area of Study

According to the Superintendency for the Development of the Northeast (SUDENE), through Resolution No. 176 dated January 3, 2024, the Brazilian semi-arid region, primarily located in the Northeast of the country, comprises 1,477 municipalities. This region is mainly characterized by irregular rainfall and high evapotranspiration rates, factors which, when combined, contribute to a constant risk of water scarcity and prolonged drought periods. The current total area of the region is 1,335,298 km², corresponding to approximately 15% of the Brazilian territory, including parts of the states of Maranhão, Piauí, Ceará, Rio Grande do Norte, Paraíba, Pernambuco, Alagoas, Sergipe, Bahia, Minas Gerais, and Espírito Santo.

The Brazilian semi-arid region is home to slightly more than 30 million inhabitants, divided between urban areas (62%) and rural areas (38%). It is a region rich in several aspects: social, cultural, environmental, and economic. According to the Brazilian Institute of Geography and Statistics (IBGE), between 2002 and 2016, the combined contribution of the municipalities in the semi-arid region to the national GDP increased from 4.5% to 5.1%. In 2022, there were 11.4 million people aged 15 or older in the country who were unable to read or write a simple note. The illiteracy rate among this population group was 7.0%. In the Northeast region, this rate doubles compared to the national average and, in many areas – especially rural zones of the semi-arid region – the rate can exceed 20%.

Figure 1: Brazilian Semi-Arid Region – Homicide Rate – 2022



Source: Data compiled and processed by the authors.

In this context, and as shown in the graphical representation in Figure 1, the highest homicide rates in municipalities within the semi-arid region are observed in Ceará and Rio Grande do Norte. Meanwhile, the states of Paraíba, Pernambuco, and Bahia exhibit high rates as well, but these are more concentrated in specific areas. Specifically, in 2022, the state of Bahia had the highest firearm-related homicide rate among the states within the Brazilian semi-arid region and the second highest in the country among federative units (37.22). The ranking of federative units in the region is as follows: Pernambuco (28.3), Sergipe (27.4), Rio Grande do Norte (26.93), Ceará (26.80), Alagoas (25.25), Paraíba (22.62), Maranhão (18.89), and Piauí (18.48). In summary, all present homicide rates well above the national average in 2022, which was 15.68.

It is noteworthy that the Northeast Region (which encompasses virtually the entire Brazilian semi-arid area) had, according to IBGE data for 2022, more than half (51%) of its total population living in poverty. This scenario of high socioeconomic vulnerability, combined with potential catalysts arising from water scarcity (such as low income, hunger, social exclusion, among others), may help explain the surge in firearm-related homicide cases in the Brazilian semi-arid region.

2.2 The Economic Theory of Crime – Classical Version

The Economic Theory of Crime (ETC), developed by Becker (1968), uses economic principles to analyze and explain criminal behavior. This theory assumes that individuals act rationally, weighing the costs and benefits of their actions. The five fundamental pillars of the ETC are:

1. Benefits of crime: encompass financial, emotional, social advantages, among others;
2. Costs of crime: include the risk of being caught, the fear of facing legal and social punishments, and the psychological burden;
3. Deterrence: the perception that a higher likelihood of being apprehended increases the probability of abandoning criminal behavior;
4. Deterrents: measures adopted to prevent or discourage criminal behavior, such as preventive actions, security policies, surveillance, harsh penalties, and other factors that may reduce the attractiveness of crime;
5. Crime rate: may vary according to changes in social, economic, cultural, and political circumstances that influence the incentives and disincentives for committing crimes.

According to the ETC, violence and/or crime rates are not only influenced by the actions of offenders but also by the socioeconomic impacts generated by public policies. These include expenditures on public security, income losses due to penalties, employment opportunities, education, among other factors. Thus, law, order, punishment, and the availability of legal employment are fundamental elements in the composition of the economics of crime. Offenders assess the costs associated with crime, such as the expenses involved in committing the act, loss of income from legitimate work during incarceration, and the likelihood of punishment. Therefore, the decision to commit a crime depends on its profitability, which can be reduced by the increased certainty and severity of penalties (Becker; Becker, 2009).

It is important to emphasize that violence and crime are broad and complex phenomena. Although the ETC offers an interesting perspective, it does not encompass all aspects of criminal behavior. Despite these limitations, this theory introduced an innovative approach to analyzing crime by incorporating economic principles and rational decision-making. The theory has proven useful for understanding and gaining significant insights, enabling the development of more effective and efficient public policies aimed at reducing violence and crime rates.

Recently, due to the considerable increase in crime and violence, especially in Latin American countries with an emphasis on Brazil, there has been a significant rise in research on various forms of violence and crime, both in urban and rural areas. These studies encompass multiple disciplines, including criminology, psychology, sociology, economics, among others (Becker; Becker, 2009; Lochner; Moretti, 2004; Hjal-Marsson; Lochner, 2012).

2.3 Water Scarcity and Drought versus Violence and Crime

Several studies indicate that severe climate changes are associated with an increased likelihood of armed conflicts. Evidence shows that extreme weather events, such as prolonged droughts, can trigger or exacerbate social and political tensions, resulting in violent conflicts. This analysis can be conducted on a global or regional scale, providing insights into the contexts where climate change has the greatest impact on security and stability. Drought is one of the main natural hazards faced by society, with significant consequences for the environment, society, agriculture, and the economy. Current debates on the relationship between severe climatic anomalies, such as water scarcity and extreme drought periods, and violence or crime face limitations due to the lack of concise information and the complexity of the pathways linking these phenomena (Buhaug; Gleditsch; Theisen, 2008; Scheffran et al., 2012; Couttenier; Soubeyran, 2014).

On the other hand, Goin, Rudolph and Ahern (2017) investigate the relationship between climatic conditions and crime in California, focusing on the severe drought period between 2011 and 2015. The results highlight that drought increased economic stress and altered routine activities, potentially raising crime rates. Specifically, the study found a significant increase in property crimes, although it did not show a significant effect on violent crimes during the drought. In another study, Sommer, Lee and Bind (2018) examine whether changes in the heat index and rainfall occurrence influence violent crimes in Boston between 2012 and 2017. Using Rubin's Causal Model and daily crime data, they found that more crimes are reported on temperate days compared to extremely cold days, and on dry days compared to rainy days. Finally, the study suggests integrating weather forecasts into crime prevention programs and considering causal inference approaches to analyze data on the climate-crime relationship.

In Nordqvist and Krampe (2018), for example, it is asserted that there are multiple causal channels between climate change and the dynamics of violent conflicts. The study highlights that climatic anomalies such as droughts and water scarcity can: i) lead to the deterioration of people's livelihoods; ii) influence the tactical considerations of armed groups; iii) allow elites to exploit social vulnerabilities and resources; and iv) displace people and increase migration levels. According to the study, these mechanisms are often interconnected and are more noticeable in certain socioeconomic contexts than in others. Meanwhile, Filho et al. (2022) aim to explore how water scarcity driven by climate change can lead to social tensions and conflicts in various regions of Africa. The study reports that water shortages can exacerbate poverty and inequality, thereby increasing the likelihood of violence and homicide.

Various theoretical approaches have sought to understand the relationship between climatic variables and crime rates. Most studies indicate a significant association between climatic anomalies, such as high temperatures, water scarcity, and drought periods, and increases in crime rates. This relationship appears to be particularly severe in developing economies, where it is exacerbated by high social vulnerability and distributive conflicts over resources (Lab; Hirschel, 1988; Ranson, 2014; Bruederle; Peters; Roberts, 2017; Wright; Stewart, 2024).

3 Methodology

3.1 Data Description

The data used in this analysis were obtained from various sources and reflect the discussions present in the literature on the economics of crime. The database information is distributed at the municipal level and has an annual frequency, covering the period from 2002 to 2020, as described in Table 1. The variables of interest refer to the firearm-related homicide rate, adjusted per 100,000 inhabitants, collected by IPEA (2023).

Box 1: Description of Information – Variables

Variable	Description	Source
Outcome Variable		
Homicide Rate	Homicides per 100,000 inhabitants	IPEA
Individual Socioeconomic Control Variables - Victims		
Age	Dummy: young (up to 29 years old)	DATASUS
Education	Dummies: low and high educational level	DATASUS
Marital Status	Dummy: single=0; married=1	DATASUS
Race	Dummy: non-white=0; white=1	DATASUS
Occupation	Dummy: low skilled=0; high skilled=1	DATASUS
Sex	Dummy: female=0; male=1	DATASUS
Native Status	Dummy: migrant=0; native=1	DATASUS
Local/Regional Socioeconomic Variables		
Rainfall	Annual rainfall volume	INPE
Water Scarcity	Deviation of rainfall relative to historical average	INPE
Drought	Dummy: No Drought=0; Drought=1	INPE
Municipality Type	Dummy: urban=0; rural=1	IBGE
Population	Estimated resident population	IBGE
Population Density	Demographic density (population per Km²)	IBGE
GDP	GDP per capita (1,000 R$)	IBGE
Inequality	Income inequality	IBGE
Traffic Mortality Rate	Traffic deaths per 100,000 inhabitants	IPEA
Drug-related Mortality Rate	Drug-related deaths per 100,000 inhabitants	IPEA
Unemployment	Proportion of total population without formal employment	MT
Number of Agents	Formal employment links in the security area	MT
Agent Remuneration	Average formal remuneration in the security area	MT

Source: Data compiled and processed by the authors.

These data were combined with municipal characteristics (covariates – control variables) that reflect climatic, population, and demographic aspects of the municipalities (water scarcity and/or drought periods, total population, and population density), aspects of municipal wealth (GDP per capita), features of the municipal security system (number of security agents per inhabitant and their average remuneration), labor market profile (unemployment rate), local crime aspects (traffic mortality rate and drug-related mortality rate), and municipal income inequality. Additionally, individual variables were integrated, including educational levels, race, age, marital status, sex, migration status, among other relevant factors. Table 1 summarizes the information, variables, and sources used in the analysis.

3.2 Counterfactual Distribution Inference

To investigate the extent to which water scarcity and/or periods of extreme drought may influence homicide rates in the Brazilian semi-arid region, the Counterfactual Distribution Inference (CDI) methodology developed by Chernozhukov, Fernández-Val & Melly (2013) is employed. The adoption of the CDI methodology is justified by its ability to rely on several principal approaches to estimate conditional quantile functions and conditional distribution functions. A significant advantage of using CDI is its capacity to analyze both the effects of simple interventions or anomalies – changes in a single determinant characteristic – and complex alterations involving general changes in the distribution of multiple characteristics.

CDI is particularly applied in cases where an intervention or anomaly causes a modification altering part of the distribution of the set of explanatory variables X – covariates – that determine the response in the outcome variable Y . In other words, CDI consists of estimating the effect on the distribution of Y given a modification in the distribution of X. The observed outcomes are extracted from the sample before the change/alteration and are thus observable, whereas the counterfactual outcomes arise from the sample after the change/alteration and are therefore unobservable. It is then assumed that the covariates are observable both before and after the change/alteration. That is, the observed outcomes are used to establish the relationship between the outcome variable and the covariates, which, together with the observed counterfactual distribution of the covariates, determine the distribution of the outcome after the change/alteration under certain imposed conditions.

To obtain a model that allows verification with a counterfactual outcome generated, it is convenient to examine the relationship between the observed outcome and covariates using a conditional quantile representation. For example, let Y^0 represent the observed outcome, and X^0 be the $(p \times 1)$ vector of covariates with distribution function F_X^0 prior to the intervention/anomaly. Here, $Q_Y(U|X)$ denotes the conditional u-quantile of Y^0 given X^0. Thus, the outcome Y^0 can be linked to the conditional quantile function through the following Skorohod representation:

$$Y^0 = Q_Y(U^0|X^0), U^0 \sim U(1,0) \perp X^0 \sim F_X^0, \tag{1}$$

In turn, Equation 2 emphasizes that the counterfactual inference process involves constructing the covariate vector for a different distribution, that is, $X^C \sim F_X^C$, here F_X^C It is a known distribution function of the covariates after the intervention/anomaly. Thus, under the assumption that the conditional quantile function is not modified by the intervention/anomaly, the counterfactual outcome Y^C is generated by:

$$Y^C = Q_Y(U^C|X^C), \tag{2}$$

Where $U^C \sim U(1,0)$ is independent of $X^C \sim F_X^C$. Additionally, the IDC assumes that the quantile function $Q_Y(u|x)$ can be evaluated at each point x within the support of the covariate distribution F_X^C. This assumption requires that the support of F_X^C is a subset of the support of F_X^0, or alternatively, that the quantile function can be adequately extrapolated. Such assumptions are formalized below.

- The conditional distribution of the outcome given the covariates is the same before and after the intervention policy;
- The conditional model is valid for all $x \in X$, where X is a compact subset of R^P that contains the supports of F_X^0 and F_X^C.

To infer the total effect of an intervention on the outcome, it is necessary to identify the distribution and quantile functions of the outcome before and after the policy. The conditional distribution function associated with the quantile function $Q_Y(u|x)$ is represented by:

$$F_Y(y|x) = \int_0^1 1\{Q_Y(u|x) \leq y\} du, \tag{3}$$

Based on the assumptions about how the counterfactual outcome is generated, the marginal distribution is represented by:

$$F_{Y^j}(y) = Pr\{Y^j \leq y\} = \int_x F_Y(y|X) dF_X^j(x), \quad (4)$$

Where the index $j \in \{0, C\}$ corresponds to the status before or after the intervention/anomaly. The u-quantile treatment effect of the water issue can be obtained by:

$$QTE_Y = Q_{Y^C}(u) - Q_{Y^0}(u), \quad (5)$$

Similarly, the effect on the u-distribution of the intervention/anomaly is expressed by:

$$DE_Y(u) = F_{Y^C}(Y) - F_{Y^0}(Y), \quad (6)$$

It is important to highlight that several distinct estimation scenarios were conducted to explore how water scarcity and/or periods of extreme drought may have affected homicide rates over the analyzed period. Additionally, the study seeks to decompose the likely effects of water resource scarcity on firearm homicide rates as proposed by DiNardo, Fortin and Lemieux (1996). In summary, the total difference between the control and treatment groups is calculated and divided into three parts: The first part reflects the impact of the observable individual characteristics of homicide victims, that is, all covariates – individual, environmental, and socioeconomic factors – considered in the analysis. The second part represents the average effect of the coefficients across the entire distribution, i.e., the average coefficients associated with each covariate. Finally, the last part relates to unobserved characteristics, representing the residual effect of unobserved factors influencing homicide rates in the region.

4 Results

Table 1 presents descriptive data on the main characteristics of homicide victims in the Brazilian semi-arid region. Between 2002 and 2020, the semi-arid region recorded 113,769 victims of firearm homicides. These data provide a detailed overview of the individual characteristics of these victims over the period.

Table 1: Descriptive Statistics – Dummy Groups

Socioeconomic Information	Dummies: I/II	Proportion I	Proportion II
Municipality	Rural/Urban	54.19	45.81
Educational Level	Low/Medium	90.50	9.50
Occupational Status	Low/Medium	87.52	12.48
Age	Young/Adults	56.10	43.90
Race/Ethnicity	Non-White/White	89.33	10.67
Gender	Men/Women	94.55	5.45
Marital Status	Single/Married	75.90	24.10
Nativity	Natives/Migrants	69.62	30.38

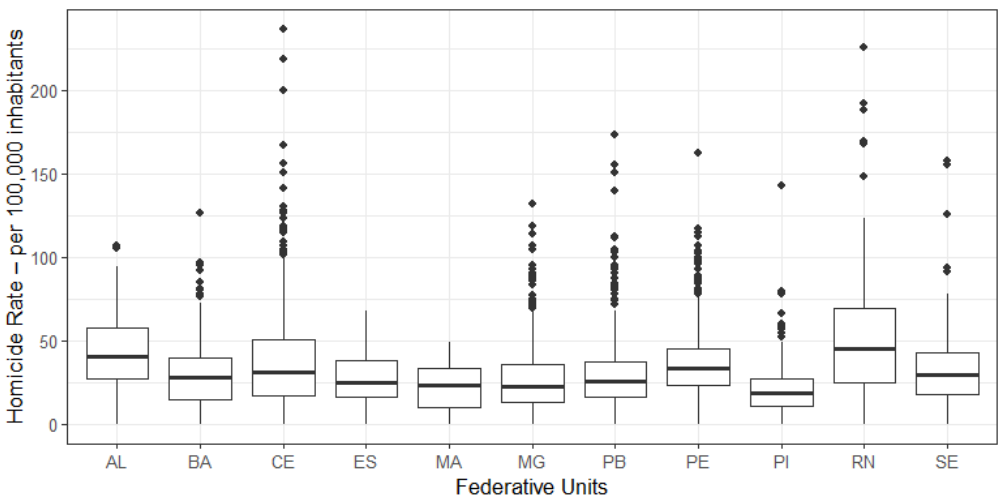
Source: Data compiled and processed by the authors.

Of the total, 54.19% of the murders occurred in predominantly rural municipalities, and about 70% of the victims had not completed the first cycle of elementary education, while less than 10% had 12 or more years of schooling. Nearly 90% of the victims were declared non-white (Black, Brown, and Yellow), and 94.55% were male. Additionally, 56.10% were at most 29 years old, and 75.9% were single or not in a stable union. Slightly more than 30% of the victims were migrants, and 87.52% held low occupational quality positions.

In other words, the descriptive data presented in Table 1 reveal that victims of firearm-related homicide violence in the Brazilian semi-arid region commonly come from highly vulnerable socioeconomic backgrounds. For the most part, the victims are individuals with low educational attainment, low-quality employment, young, male, single, and non-white. Another notable characteristic is that approximately one-third of the victims were migrants from other states or regions. These findings suggest forced migration due to the lack of opportunities provided by Brazilian society. This issue is emphasized in the contemporary literature on inequality of opportunity (Roemer, 1998; Lefranc; Pistolesi; Trannoy, 2008).

Figure 2 provides a detailed description of homicide rates by federative unit over the analyzed period, using annual data. It is observed that the median homicide rate in the states of the semi-arid region is quite high throughout the period, generally hovering around or above 30 homicides per 100,000 inhabitants. Furthermore, the historical average (dotted line) shows annual values ranging from about 30 to well over 200 homicides per 100,000 inhabitants. Notably, the semi-arid regions of the states of Ceará and Rio Grande do Norte stand out, exhibiting rates exceeding 200 homicides per 100,000 inhabitants. In other words, the semi-arid areas of both states experience surges/shocks in crime rates, reflecting a greater escalation and loss of control over criminal activity. On the other hand, the semi-arid parts of the states of Espírito Santo and Maranhão show the lowest dispersion in homicide rates. That is, in these areas, homicide rates appear to be more controlled.

Figure 2: Homicide Rate – Brazilian Semi-arid Region – 2002 to 2020



Source: Data compiled and processed by the authors.

Here is a simple exercise analyzing the mean differences in homicide rates according to certain individual and/or municipal characteristics. Examining the partial results presented in Table 2, it appears that there is no difference in the simple mean of homicide rates with respect to drought periods. This result may be related to the fact that, although some municipalities experience water scarcity, this does not necessarily classify them as undergoing drought periods.

Table 2: Mean Test of Homicide Rates by Groups

Variable	Groups	Treated	Control	Difference (%)
Climate Shock	Drought / No Drought	33.75	33.95	-0.19
Municipality	Rural / Urban	38.14	28.66	9.48***

Educational Level	Low / Medium	34.62	32.62	2.00***
Occupation	Low-skilled / High-skilled	33.94	32.61	1.33***
Age	Youth / Adults	35.02	32.23	2.79***
Ethnicity	Non-White / White	33.97	33.20	0.77***
Gender	Male / Female	33.81	33.79	0.02
Marital Status	Single / Married	34.83	31.75	3.07***
Nativity	Migrants / Natives	31.12	34.96	-3.83***

Source: Data compiled and processed by the authors.
Note: * $p < 0.1$;** $p < 0.05$; *** $p < 0.01$

Regarding the type of municipality, the difference-in-means test indicates that rural municipalities, on average, have a homicide rate that is 9.48 points higher than that of urban municipalities. For the other variables (education, occupation, age, race, marital status, and place of birth), all exhibited significant differences in means, as expected, except for sex. This is an intriguing result because, although there is a substantially higher absolute number of male homicide victims, the results do not show a statistically significant difference in homicide rates between men and women. Overall, the findings are consistent with what is reported in the literature (Lima; Bueno, 2022; ABSP, 2023).

It is worth noting that the procedure presented in Table 2 does not constitute a causal analysis. The results represent mere associations, as there may be underlying factors influencing the observed outcomes. Regardless of the method employed thus far, there is strong evidence indicating a significant discrepancy in the impact of violence and crime across different social strata. This disparity highlights not only inequality in outcomes but, more importantly, inequality of opportunity within the Brazilian context, particularly in the semi-arid region. The fact that individuals are more likely to become victims of violence or homicide due to their social background starkly reveals the deep divisions embedded in Brazil's social structure. These findings are often cited in the literature as examples of unfair inequality, as they are largely rooted in initial life conditions. Therefore, it is crucial to implement effective public policies aimed at eliminating these disparities, as advocated by theories of justice (Rawls, 2017).

The following section presents the estimates based on the counterfactual distribution inference method proposed by Chernozhukov, Fernández-Val and Melly (2013). The results reported in Table 3 confirm the hypothesis that climate anomalies, such as periods of extreme drought, can influence crime rates. Specifically, the findings indicate that the impact of drought on firearm homicide rates in the region increases along the homicide distribution. In summary, the effect observed in the most violent municipalities is 33% higher than that observed in the least violent municipalities, according to the distribution quantiles.

In terms of municipality type – that is, homicide rates in urban versus rural areas – the results aligned with expectations. On average, homicide rates are 7.20 times higher in predominantly urban municipalities compared to rural ones. In this context, when drought conditions are combined with rural municipalities, a negative and decreasing effect is observed across the entire distribution. In other words, drought periods appear to reduce homicide rates in rural areas while increasing them in urban municipalities. These findings raise at least one important question: can drought in the countryside lead to increased violence in the cities? The answer, based on the integrated results comparing drought and rural areas, drought and migration, and the combination of drought, migration, and rural areas, suggests that the answer is yes.

Table 3: Quantile Treatment Effect on Homicide Rates in the Brazilian Semi-Arid Region

Treatments – Variables of Interest	Quantile 0.25	Quantile 0.50	Quantile 0.75
Extreme Drought	2.00***	2.38***	2.66***
Rural Municipalities	-7.48***	-6.80***	-7.71***
Interaction: Drought/Rural	-5.84***	-8.41***	-10.28***
Interaction: Drought/Migrant	21.92***	38.89***	54.12***
Interaction: Drought/Migrant/Rural	3.57***	19.82***	56.93***

Source: Data compiled and processed by the authors.
Note: * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$

Specifically, the interaction between drought and rural municipalities shows a negative effect on homicide rates that increases across the distribution. In the most violent rural municipalities, this reduction is approximately half of that observed in the least violent rural municipalities. Regarding drought versus migration, there is a strong and positive effect on homicide rates. In summary, in the least violent municipalities, the effect is 21.92 and increases by nearly 2.46 times in the most violent municipalities. These findings suggest that a possible forced migration from rural areas to cities, driven by extreme water scarcity, may contribute to higher homicide rates in predominantly urban areas.

According to the results, forced migration appears to generate more violence in both urban and rural areas. When drought, rural municipalities, and migration are combined, there are substantial and increasing effects on homicide rates, especially in the most violent rural municipalities. Notably, the effect on the upper quantiles of homicide rates is significantly larger. The effect at the upper quantile (municipalities with the highest firearm homicide rates) is nearly 16 times greater than that observed at the lower quantile (municipalities with the lowest firearm homicide rates). These findings suggest that drought in rural areas may lead to forced migration (even if temporary) and increase violence both in cities and rural regions. It is important to emphasize that the homicide rates reported by the Atlas da Violência (IPEA) are calculated based on the location of the crime, not the victim's place of residence. This factor may also be influencing the results presented.

Table 4 presents the decomposition of the total differential between the control and treatment groups using the method proposed by DiNardo, Fortin and Lemieux (1996). The first component reflects the impact of observable characteristics of homicide victims, while the second captures the average effect of the covariate coefficients (individual, environmental, and socioeconomic factors) that shape homicide rates in the respective localities. As shown, there is a negative and declining effect up to the median distribution of homicide rates in the Brazilian semi-arid region. However, in municipalities with higher homicide rates, this effect reverses, becoming more than three times greater than that observed in less violent municipalities. In summary, in the most violent cities, the results suggest that periods of extreme drought significantly impact violence. In practical terms, water scarcity appears to generate substantial problems related to violence and crime, particularly in regions already characterized by higher levels of conflict.

It is important to highlight that the likely migration flow from smaller municipalities, driven by periods of extreme drought, toward larger municipalities with greater economic opportunities may be reflected in the heterogeneous effects observed across the distribution. In summary, drought may negatively affect homicide rates in some localities while exerting a positive effect in others. Regarding the decomposition of the treatment effect differential between rural (treated) and urban (control) municipalities, the analysis indicates that simply being classified as a rural municipality has a statistically significant effect on homicide rates across all points of the distribution. The decomposition of these effects reveals that the total gap for predominantly rural municipalities is approximately 13 among the 25% least violent municipalities, increasing to 15.09 among those with the highest homicide rates. Approximately 48% of this gap is explained by the characteristic of being predominantly rural, while the remaining 52% is attributed to the average coefficients of the distinct characteristics observed between rural and urban municipalities. In summary, these results suggest the presence of the phenomenon widely recognized in the literature as the 'ruralization of crime', specifically associated with migration toward typically rural municipalities.

Table 4: Quantile Average Treatment Effect – Decomposition

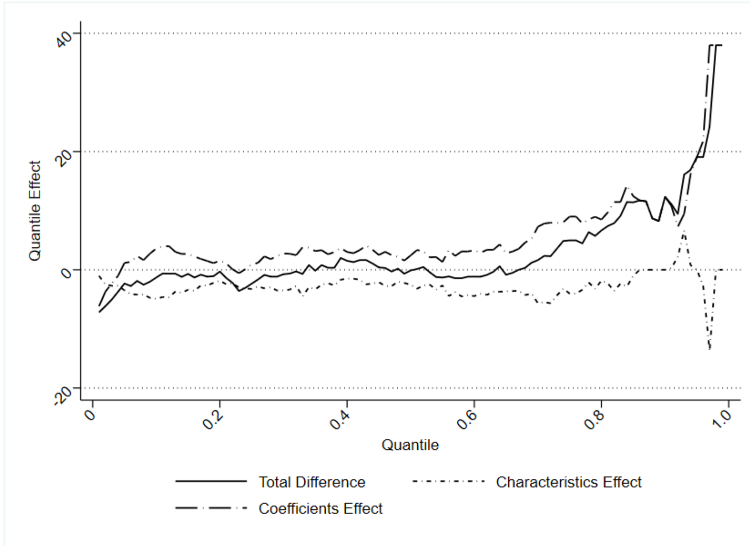
	Homicide Rate versus Treatment								
Quantile	0.25	0.50	0.75	0.25	0.50	0.75	0.25	0.50	0.75
Treatment	**Drought**			**Rural**			**Migrant**		
Characteristics	-1.76	-2.41	-2.89	7.67	7.23	7.67	-0.16	-1.67	−1.94
Coefficients	0.65	1.99	6.41	5.31	7.86	6.02	-2.46	-3.65	-8.86
Total Differential	-1.11	-0.42	3.52	12.98	15.09	13.69	-2.62	-5.32	-10.80
Treatment	**Drought/Rural**			**Drought/Migrant**			**Drought/Migrant/Rural**		
Characteristics	5.76	8.12	9.44	-1.26	-2.58	-1.90	6.00	7.41	10.16
Coefficients	6.95	8.72	2.70	2.29	6.60	12.90	11.27	17.70	12.58
Total Differential	12.71	16.84	12.14	1.03	4.02	11.00	17.27	25.11	22.73

Source: Data compiled and processed by the authors.

The migration factor (dummy = 1) indicates that non-native individuals are more likely to be victims of firearm-related homicides. On average, being a native of the municipality reduces the likelihood of becoming a firearm homicide victim by 5.32%. This characteristic directly accounts for 31.45% of the total differential effect between migrants and natives. The remaining 68.55% is associated with other characteristics that differentiate the two groups based on place of birth and place of death. It is important to note that the total differential effect among the 25% most violent municipalities is 21.89% higher than the median quantile observed. Being a native of the municipality, on average, reduces the probability of becoming a firearm homicide victim by 5.32%. This factor directly explains 31.45% of the total differential effect between migrants and natives, while the remaining 68.55% is attributed to other distinguishing characteristics between the two groups concerning place of birth and death. It is particularly noteworthy that the total differential effect among the 25% most violent municipalities is 21.89% higher than the median quantile.

When analyzing the intersection of drought and rural characteristics, drought and migration, and finally the combination of drought, rurality, and migration, it is observed that these associated factors have statistically significant effects on homicide rates across all points of the distribution. Specifically, when examining the total differential effect for the combined condition of rural municipalities experiencing drought and migration, the estimated effects increase considerably at all quantiles. Focusing on the upper quantile, the effect more than doubles compared to the combination of drought and migration, and increases by 87.23% relative to the combination of drought and rurality.

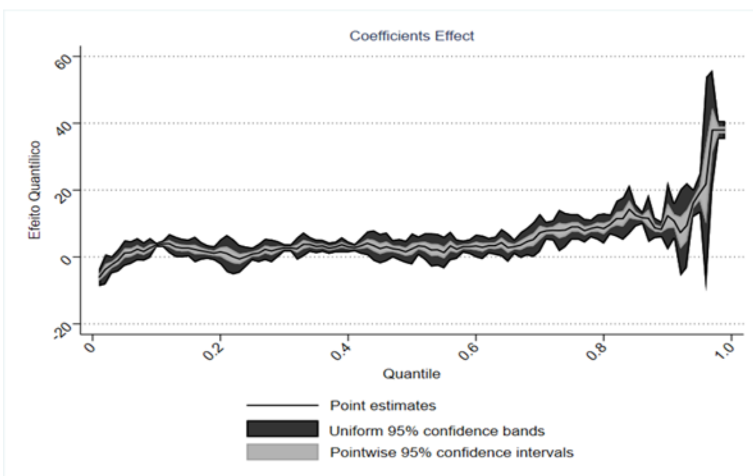
Figura 3: Seca *versus* Taxa de Homicídios – Decomposição



Source: Data compiled and processed by the authors.

Finally, Figure 3 illustrates the proposed quantile decomposition. In summary, the total differential between the control and treatment groups is obtained and decomposed into three components. The first represents the effect of the observable individual and municipal characteristics of homicide victims and municipalities in the Brazilian semi-arid region, that is, it captures the contribution of all covariates, including individual- and municipality-level socioeconomic factors, used in the analysis. The second component reflects the average effect of the coefficients across the entire distribution, meaning the mean coefficients associated with each covariate. Lastly, the third component is associated with unobserved characteristics; in other words, it represents the residual effect of unobserved factors that influence firearm homicide rates in municipalities within the Brazilian semi-arid region.

Figura 4: Seca *versus* Taxa de Homicídios – Decomposição



Source: Data compiled and processed by the authors.

The results illustrated in Figure 3 reveal that the average effect of the coefficients of the control variables across the entire distribution is what sustains the positive effect of extreme drought periods on firearm homicide rates in the region, up to approximately the upper quantile (quantile 0.75). In other words, climate anomalies such as droughts, when combined with socioeconomically vulnerable environments, act as critical triggers for surges in violence and crime. These findings are further corroborated in Figure 4, which shows that the positive effect of extreme drought periods on firearm homicide rates is, in general, driven by differences in the average coefficients between municipalities affected by drought and those not exposed to this type of climate anomaly, conditional on both individual- and municipality-level socioeconomic characteristics.

5 Concluding Remarks

This study aimed primarily to investigate how adverse climatic shocks, such as water scarcity and/or drought periods, may affect firearm homicide rates in the Brazilian semi-arid region from 2002 to 2020. To achieve this objective, the methodology of inference on counterfactual distributions proposed by Chernozhukov, Fernández-Val and Melly (2013) was adopted. Additionally, a decomposition of the effects of drought on firearm homicide rates was conducted following the approach of DiNardo, Fortin and Lemieux (1996).

The main results reveal that periods of severe drought significantly affect homicide rates in the Brazilian semi-arid region. These effects are more pronounced when combined with other factors, such as the predominance of typically rural municipalities and migration. Individual control variables, including education, occupation, race, marital status, and age, were significant and exhibited the expected direction, as corroborated by the literature. One notable exception is the variable related to the sex of homicide victims, as there is no statistically significant difference between men and women in determining homicide rates, although approximately 95% of victims are male in relative terms. On the other hand, the migration factor, when associated with drought periods and typically rural municipalities, emerges as a predominant driver of the evolution of homicide rates in the Brazilian semi-arid region. Specifically, the combination of these three factors nearly doubles the observed homicide rates, particularly in the most violent localities.

In summary, there is strong evidence that drought in rural/backcountry areas contributes to increased crime rates in predominantly urban municipalities, especially when associated with migration processes. The combination of drought periods with characteristics such as the predominance of rural municipalities and migration further intensifies this indicator of violence and criminality. Moreover, the data decomposition identified that periods of extreme drought act as a trigger, significantly exacerbating conditions of high vulnerability during these adverse climatic shocks. When analyzing the combined effects of drought, rurality, and migration, the observed impacts nearly double across all points in the distribution of homicide rates in the region. It is worth emphasizing that these adverse factors, combined with social and individual vulnerabilities, constitute a potentiating mix for homicide rates in the Brazilian semi-arid region. However, it becomes crucial to investigate other scenarios and aspects, particularly to verify whether forced migration due to water scarcity and/or severe drought periods truly plays a central role in the observed outcomes or if such migration is part of the broader process of the ruralization (interiorization) of crime.

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