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ESSAYS ON THE ECONOMICS OF NATURAL DISASTERS: EVIDENCE OF THE IMPACTS OF DROUGHT ON SOCIOECONOMIC ASPECTS IN THE NORTHEAST REGION OF BRAZIL

FORTALEZA
2024

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Orientador: Prof. Dr. João Mário Santos de França.
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RESUMO

A presente tese busca fornecer evidências dos impactos da seca em diferentes aspectos socioeconômicos, sendo estruturada em três capítulos, com foco na Região Nordeste do Brasil, uma área com elevado nível de vulnerabilidade social e econômica face às pressões das alterações climáticas. No primeiro capítulo, estudamos como um evento de seca de longa duração afetou o acúmulo de habilidades socioemocionais dos adolescentes. As habilidades socioemocionais são determinantes-chave dos resultados da vida adulta. Mudanças significativas nas condições económicas podem afetar a formação de tais competências, especialmente em idades mais vulneráveis. Entre 2012 e 2017, a região semiárida brasileira foi exposta a uma seca exógena de longa duração. Comparando alunos expostos e não expostos à seca, encontramos evidências de que o episódio da seca reduziu significativamente as habilidades de conscienciosidade dos alunos, uma habilidade relacionada à persistência, organização e foco. Confirmamos esses resultados investigando as facetas associadas aos traços socioemocionais de conscienciosidade e outros resultados relacionados, como as aspirações dos alunos. Encontramos também efeito heterogêneo de acordo com a escolaridade materna, moderando o impacto do choque da seca nas competências socioemocionais. O segundo capítulo lança luz sobre a importância da condição fiscal local para mitigar os efeitos de choques de seca durante o período gestacional sobre resultados de saúde infantil, sobretudo na mortalidade infantil. Comparamos municípios que foram expostos a choques de seca durante o período in útero com aqueles que não experimentaram tal exposição, incorporando a condição fiscal local como um fator moderador desta análise. Os resultados encontrados sugerem que a capacidade fiscal dos municípios é um fator significante para mitigar os efeitos de choques de seca sobre a mortalidade infantil, quando consideramos os indicadores de autonomia fiscal e rigidez orçamentária. Também verificamos que municípios com situação fiscal mais favorável tendem a reduzir os impactos adversos da exposição in útero à seca sobre a mortalidade infantil, particularmente em casos de afecções perinatais. Além disso, encontramos que a ocorrência de seca no primeiro trimestre da gestação aumenta a mortalidade infantil e este efeito é mitigado em municípios com maior capacidade fiscal, sendo mais acentuado em municípios de médio porte populacional. Por fim, o terceiro capítulo fornece evidências empíricas do impacto da seca de 2012 a 2017 sobre as finanças dos municípios do semiárido nordestino. Utilizamos uma estratégia de estudos de eventos em painel para analisar o efeito causal e dinâmico da prolongada seca nas finanças dos governos municipais, comparando (antes e depois) os municípios mais e menos expostos. Os resultados observados mostram que o prolongado choque de seca leva a diminuição das despesas correntes, que é acentuada nos anos iniciais da seca e estabilizado nos anos finais. É verificado uma diminuição nas despesas relacionadas às áreas de administração pública, legislativo, cultura, esporte/lazer e educação. Esses resultados indicam uma resposta estratégica dos gestores públicos locais ao longo da seca, levando a medidas de ajuste orçamental nos municípios mais afetados. Também documentamos que municípios com maior proporção de pobreza são significativamente mais afetados pela seca em termos de redução das despesas correntes do que municípios com menor taxa de pobreza, sugerindo que os eventos climáticos extremos podem contribuir para a desigualdade socioeconômica, ressaltando as considerações de justiça ambiental na compreensão de quem suporta os custos dos desastres naturais.

Palavras-Chave: Choque de Seca; Habilidades Socioemocionais; Condição Fiscal Local; Saúde Infantil; Finanças Públicas.

ABSTRACT

The present thesis seeks to provide evidence of the impacts of drought on different socioeconomic aspects, being structured in three chapters, focusing on the Northeast Region of Brazil, an area with a high level of social and economic vulnerability to the pressures of climate change. In the first chapter, we studied how a long-lasting drought event affected the accumulation of socio-emotional skills in adolescents. Socio-emotional skills are key determinants of adult life outcomes. Significant changes in economic conditions can affect the formation of such skills, especially at more vulnerable ages. From 2012 and 2017, the Brazilian semiarid region was exposed to a long-lasting exogenous drought. Comparing students exposed and not exposed to drought, we found evidence that the drought episode significantly reduced students' conscientiousness skills, a skill related to persistence, organization and focus. We confirm these results by investigating facets associated with the socioemotional traits of conscientiousness and other related outcomes such as student aspirations. We also found a heterogeneous effect according to maternal education, moderating the impact of the drought shock on socio-emotional skills. The second chapter sheds light on the importance of local fiscal conditions to mitigate the effects of drought shocks during the gestational period on infant health outcomes, especially infant mortality. We compare municipalities exposed to drought shocks during the in utero period with those that did not experience such exposure, incorporating local fiscal conditions as a moderating factor in this analysis. The results found suggest that the fiscal capacity of municipalities is a significant factor in mitigating the effects of drought shocks on infant mortality, when we consider the indicators of fiscal autonomy and budget rigidity. We also found that municipalities with a more favorable fiscal situation tend to reduce the adverse impacts of in utero exposure to drought on infant mortality, particularly in cases of perinatal conditions. Furthermore, we found that the occurrence of drought in the first trimester of pregnancy increases infant mortality and this effect is mitigated in municipalities with greater fiscal capacity, being more pronounced in municipalities with a medium population size. Finally, the third chapter provides empirical evidence of the impact of the drought from 2012 to 2017 on the finances of municipalities in the northeastern semiarid region. We used a panel event study strategy to analyze the causal and dynamic effect of the prolonged drought on municipal government finances, comparing (before and after) the most and least exposed municipalities. The observed results show that the prolonged drought shock leads to a decrease in current expenditures, which is accentuated in the initial years of the drought and stabilized in the final years. There is a decrease in expenditures related to the areas of public administration, legislative, culture, sport/leisure and education. These results indicate a strategic response from local public managers throughout the drought, leading to budget adjustment measures in the most affected municipalities. We also document that municipalities with a higher poverty rate are significantly more affected by drought in terms of reduced current expenditure than municipalities with a lower poverty rate, suggesting that extreme weather events can contribute to socioeconomic inequality, highlighting environmental justice considerations in understanding who bears the costs of natural disasters.

Key words: Drought Shock; Socioemotional Skills; Local Fiscal Condition; Infant Health; Public Finances.

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THESIS OVERVIEW

Over the past decades, climate change has been recognized as a global challenge impacting various sectors of society. The occurrence of extreme weather events is expected to become even more frequent and intense in the coming years (IPCC, 2014). In Brazil, according to the Digital Atlas of Disasters, between 2000 and 2019, there were more than 43 thousand records of disaster occurrences, affecting approximately 189 million people and resulting in an estimated loss of around 344 billion Brazilian Reais. Nearly half of these occurrences were attributed to drought, the most frequent type of natural disaster in the country, affecting approximately 105 million people with an estimated cost of around 250 billion Brazilian Reais during the mentioned period.

Particularly, drought is a special type of natural hazard that, in economic terms, exhibits specific spatial and temporal characteristics and is strongly influenced by short and long-term policy choices (Freire-González et al., 2017). Unlike other natural disasters such as floods, earthquakes, and hurricanes, drought manifests gradually and silently, and its impacts are not immediately visible. The precise onset or termination moment is not easily defined. This lack of visibility, temporality, and risk characterization can lead to significant human suffering and substantial economic losses at the local level, particularly affecting small-scale agriculture or subsistence farming (Sena et al., 2014; Guha-Sapir et al., 2012).

Climate projections have suggested that droughts will become more frequent, severe, and prolonged in many parts of the world, driven by population and economic growth, and primarily, changes in climatic conditions (IPCC, 2014). In the last decade, numerous regions globally, such as California, Africa, and Southern Europe, have faced intense and persistent droughts. In Brazil, from 2012 to 2017, the semiarid region, especially in the Northeast, experienced the worst drought in history, according to data from the National Institute of Meteorology (Inmet). In light of this, assessing the economic and social effects of drought aids in developing future strategies to mitigate the impacts of these extreme climatic events, enhancing the planning, management, and implementation of such strategies (Fernandez et al., 2023).

In this perspective, this thesis aims to provide empirical evidence of the impacts of drought on various socio-economic aspects, being structured in three chapters that address different issues on this topic, with a focus on the Northeast Region of Brazil, an area characterized by a high level of social and economic vulnerability in the face of the pressures of climate change.

In the first chapter, we aim to investigate the impact of the prolonged drought that occurred between 2012 and 2017 on the socio-emotional characteristics of students. For this purpose, we employed an applied research approach to high school students in Ceará, in 2015, using the SENNA instrument, which measures the five socio-emotional traits related to the Big Five inventory: Conscientiousness, Openness, Extroversion, Agreeableness, and Emotional Stability. We then compared the differences in socio-emotional abilities among students residing in municipalities highly exposed to drought in comparison to students in municipalities not exposed to drought. Our measure of exposure to the drought shock is related to the proportion of months during which a municipality records a low precipitation level according to the Standardized Precipitation Index (SPI). We defined treated municipalities as those above the 75th percentile of the distribution of months during the dry period.

Therefore, by demonstrating that climate change affects socio-emotional accumulation, this first chapter contributes to the literature on the impact of natural disasters on the economy. It provides insights into the non-agricultural impact of climate change, offering evidence that the impact of drought can affect other characteristics that constitute human capital, extending beyond cognitive skills.

The second chapter sheds light on the importance of local fiscal conditions in addressing aggregate exogenous shocks, such as the occurrence of natural disasters. Specifically, the central objective of this chapter is to investigate whether the fiscal situation of municipalities in the Northeast region of Brazil contributes to mitigating the effects of idiosyncratic drought shocks during the gestational period on infant health outcomes, including infant mortality (and its main causes), birth weight, gestation time, among others. To achieve this, we compare municipalities that were exposed to drought shocks during the in utero period with those that did not experience such exposure, incorporating the local fiscal condition as a moderating factor in this analysis. The interaction between the drought shock and the local fiscal situation is a distinctive feature of our analysis, allowing us to assess whether resilience to adverse climatic conditions varies significantly according to the fiscal capacity of municipalities. Thus, we aim to explore how variations in the fiscal capacity of municipalities may modulate the impact of drought shocks on infant health outcomes.

The municipality's capacity to provide resources and essential services during and after extreme weather events, particularly those related to maternal and child health, plays a crucial role in mitigating adverse impacts. Therefore, understanding the interaction between extreme weather conditions, neonatal health, and the local fiscal situation is essential for a comprehensive and effective approach to address these interconnected challenges.

The third and final chapter of this thesis, although having a distinct analysis, is indirectly connected to the issues addressed in Chapter Two. Specifically, the primary objective of this chapter is to explore the fiscal and budgetary consequences of natural disasters at the local level, by providing empirical evidence of the impact of the drought from 2012 to 2017 on the finances of municipalities in the Northeast semiarid region. It is worth noting that municipal governments are the main providers of essential public goods and services that directly and indirectly impact the lives of citizens. They are the government level closest to the citizens and the primary entity responsible for addressing crises, such as the occurrence of natural disasters. Thus, we employ a panel event study strategy to analyze the causal and dynamic effect of the drought on the finances of municipal governments. We compare the fiscal and budgetary implications (before and after) for municipalities with varying intensities of drought shocks but with similar socioeconomic and geographic characteristics. Our measure of drought shock takes into account the chronic nature of this climatic phenomenon in our study area. We gauge the intensity of this event based on the ratio between the average annual precipitation from 2012 to 2017 and the long-term average annual precipitation before the drought (1950-2011).

The financial dynamics analyzed in the third chapter underscore the importance of understanding budgetary implications in the face of extreme weather events at the local level. Such events not only affect the municipal government's ability to provide essential goods and services but also have distributive consequences, impacting different segments of the population unevenly. This is particularly pronounced in an area with high socioeconomic vulnerability, as is the case in the Brazilian semi-arid region.

Finally, general conclusions of this thesis are drawn, along with contributions to related literature and policy recommendations regarding the specified approaches.

CHAPTER 1 - LONG-LASTING DROUGHT AND ADOLESCENT SOCIOEMOTIONAL SKILLS

1.1 INTRODUCTION

Socioemotional skills influence a wide range of individual and societal outcomes (Heckman et al., 2019; Almlund et al., 2011). Such skills can be defined as the individual capacities that are manifested in consistent patterns of thoughts, feelings, and behaviors, that can be developed through formal and informal learning experiences, and that influence important socio-economic outcomes throughout the individual's life, like educational attainment, wages, job performance, and health outcomes (OECD, 2017). Recent evidence documents rising returns of non-cognitive skills in comparison with cognitive skills (literacy and numeracy) in the 2000s (Edin et al., 2022; Deming, 2017), suggesting the growing importance of these skills for the labor market. A key factor in socioemotional skill formation is economic conditions. Changes in economic variables can drastically affect the accumulation of non-cognitive skills, and the magnitude of this effect depends on the individual's stage of socioemotional development (Kankaraš and Suarez-Alvarez, 2019). Particularly, one vulnerable group is adolescents[1]. Exposure to larger changes in economic conditions during this critical period of development can lead to socioemotional deficits that have consequences for their future well-being.

Despite a large number of evidence about the impact of natural disasters on cognitive skills or schooling, few studies have addressed the effect of such events on non-cognitive skills; exceptions are Adhvaryu et al. (2019); Akee et al. (2018); Mehra et al. (2019); Nordstrom and Cotton (2020). This paper attempts to contribute by investigating the impact of a long-lasting drought shock on Brazilian students' socioemotional traits[2].

We follow a widely used approach that exploits variation in local rainfall as a proxy for local exposure to drought (Shah and Steinberg, 2017; Burke et al., 2015; Corno et al., 2020). However, differently from the standard approach that considers short-run shocks (one year or season), our drought event corresponds to a persistent period of below-normal precipitation. From 2012 to 2017, the Northeast region of Brazil was affected by an unprecedented and long-

[1] Adolescents have several behavioral biases that affect investments in human capital and can be intensified with greater and unexpected changes in the economic conditions, see (Steinberg, 2014; Bursztyn et al., 2019; Lavecchia et al., 2016).

[2] We will consider the following terms interchangeable: socioemotional skills, socioemotional traits, personality traits, and non-cognitive skills.

lasting dry episode caused mainly by three exogenous factors: an abnormally high sea surface temperature (SST), the successive events of La Niña (2010-2011) and El Niño (2015-2016). The combination of these factors produced a period of six consecutive years of drought in the region[3]. We exploit this unique and exogenous episode to estimate its impact on adolescents' socioemotional traits.

To measure the socioemotional traits, we used a survey applied to secondary students in Ceará, a Northeast state of Brazil, in 2015. This instrument called the SENNA instrument, measures the five socioemotional traits of the Big Five inventory: Conscientiousness, Openness, Extroversion, Agreeableness, and Emotional Stability. It is important to highlight the scarcity of data sources that evaluate the socioemotional competencies of the Brazilian population, which creates difficulties in formulating adequate public policies. In this context, SENNA stands out as a unique and valuable dataset to assist subnational governments in improving educational outcomes. The instrument was developed by a group of specialists, and its statistical properties were extensively tested (Primi et al., 2016b,a, 2021). The SENNA instrument addresses key issues related to self-reported surveys, such as acquiescence bias, reference bias, and student attention during the survey application. These issues are particularly important in developing countries like Brazil (Laajaj et al., 2019; Laajaj and Macours, 2021).

We compare differences in the socioemotional skills of students that lived in municipalities highly exposed to droughts relative to students who lived in municipalities not exposed to droughts. Our measure of exposure to drought shock is related to the proportion of months that a municipality records a low precipitation level according to the Standard Precipitation Index (SPI). We define the treated municipalities as those above the 75º percentile of the distribution of months of the dry period. We set the treatment this way to avoid problems related to temporal variations in dry periods over the years[4]. Although our estimates do not represent a causal relationship, we adopted several empirical strategies, such as sample selection and the addition of controls that may suggest a causal effect of drought shock on socioemotional skills.

Our results suggest that long-term drought episodes are adversely correlated with conscientiousness skills, which is related to the ability that helps to focus attention and behavior on the relevant things when we need to meet standards. The conscientiousness skill potentially

[3] The last time a similar phenomenon occurred was over eighty years ago Marengo et al. (2018).
[4] In the robustness section, we test variations of the definition of occurrence of drought events.

affects long-term individual outcomes, like college attendance, high school or university graduation, and others associated with persistence and focus on long-run objectives (Heckman and Mosso, 2014; Almlund et al., 2011; Heckman et al., 2019). Other socioemotional skills are negatively affected; however, they are not statistically significant.

Besides the main results, a special feature of the SENNA instrument is the possibility to decompose the socioemotional traits in their facets, allowing us to understand the effect of the long-lasting drought shock in more detail. For instance, the construct of conscientiousness can be decomposed into four facets: Focus, Determination, Organization, and Persistence. We estimate the effect of drought exposure on these facets using a similar empirical strategy. We find that students' focus, organization and persistence are negatively associated with drought shock. Student determination is also negatively and statistically significantly affected; however, the effect size is smaller than other Conscientiousness facets.

We attempt to explain the larger association between drought shock and conscientiousness by the student's aspiration. Dalton et al. (2016); La Ferrara (2019) argue, theoretically, that economic shocks, such as droughts, can reduce the marginal benefit of students making an effort, consequently affecting their aspirations about the future. As the drought persists over at least four years (2012–2015), these two effects, the reduction in the marginal benefit of effort and the decrease of student aspiration may impact the student's effort, potentially modifying their personality traits during the adolescence[5]. Thus, student aspiration is expected to be affected by drought shock as well. We re-estimate the effect of drought on measures of student aspirations. We find evidence that drought shock adversely impacts the student's aspiration to continue studying during and after high school.

The literature has documented a large number of studies investigating the effects of droughts on human capital formation. Most research has explored the impacts of drought on infant mortality and birth health outcomes, showing that negative rainfall shocks are strongly associated with lower birth weights and higher infant mortality (Rocha & Soares, 2015; Lin, Liu, & Xu, 2021). Other studies have demonstrated that exposure to drought shocks during the in utero period leads to reduced child anthropometric growth (Hoddinott & Kinsey, 2001; Abiona, 2017, 2022). These works highlight how in utero conditions affect individual outcomes during adulthood, thereby evidencing the need for interventions during critical periods for

[5] Recently, Dweck (2017) developed a psychological theory that explains these mechanisms. According to it, individual goals (aspirations in economic literature) are the origin of the formation of personality traits. Then, factors that modify the individual goals may affect the personality trait development process.

human development, such as childhood and adolescence (Cunha and Heckman, 2009). In the same vein, a body of studies has explored the effects of drought on the cognitive abilities of children and adolescents (Branco & Féres, 2018; Nordstrom & Cotton, 2020). For instance, Ortiz (2022) demonstrates the existence of a significant negative impact of natural disasters on the acquisition of cognitive skills in students studying in rural areas of Colombia, which more strongly affects economically vulnerable students.

The main contribution of our work is to show evidence of the effect of droughts on human capital formation in a specific age interval (i.e., adolescence) in a poor region of Brazil. Cunha and Heckman (2009) emphasize the importance of non-cognitive skills in the development of human capital and how these skills are fundamental for educational, occupational, and social success. Our paper contributes to this literature by showing that adverse events, such as droughts, can impair these non-cognitive skills. In this literature, drought events are interpreted as an income shock to the agricultural sectors (Shah & Steinberg, 2017; Björkman-Nyqvist, 2013), affecting the ability of families to invest in the development of their children's skills.

In this sense, our results suggest that public policies should consider both the economic and psychosocial impacts of droughts to mitigate their negative effects on human capital formation. Furthermore, in line with the arguments of Cunha and Heckman (2009), we emphasize the need for interventions that not only focus on cognitive skills but also strengthen non-cognitive skills, which are essential for the holistic development of individuals and for reducing inequalities in opportunities.

Our article is also included in the literature on the malleability of socioemotional traits, particularly during adolescence. Several studies suggest that socioemotional skills are malleable at specific periods in a student's life, such as childhood (Kautz et al., 2014; Alan, Boneva, & Ertac, 2019). Other types of shocks also affect personality traits during adolescence, such as health shocks (Elkins, Kassenboehmer, & Schurer, 2017) or test score rankings (Pagani, Comi, & Origo, 2021). Our paper contributes to this literature by showing that critical changes in economic conditions during adolescence impact the development of socioemotional skills.

Lastly, our paper also contributes to the literature on the economic impacts of natural disasters (Takasaki, 2017; Cavallo & Noy et al., 2011; Oliveira, 2019). Most of the economic literature focuses on the negative effect of extreme climatic shocks on the agricultural sectors (Deschênes & Greenstone, 2012; Burke & Emerick, 2016). Adaptation strategies, such as

changing crop mixes, investing in irrigation, and reallocating labor (Colmer, 2018; Aragón, Oteiza, & Rud, 2021), can mitigate the effect of natural shocks. Our research highlights that, in addition to the direct economic impacts, natural disasters also affect socioemotional accumulation. Thus, our findings provide insights into the non-agricultural impacts of natural disasters.

Besides this introduction, section two discusses the drought that occurred in Northeast Brazil between 2012 and 2017. Section three presents the data and the empirical strategy adopted. In turn, section four presents the main results, the heterogeneous effect analysis, and the effect of the drought on student expectations. Section five discusses the main conclusions.

1.2 BACKGROUNDS

In this section, we discuss the determinants of the persistent drought that affected the Brazilian semi-arid region between 2012 and 2017 and the main socioeconomic characteristics of the study area.

1.2.1 Study area and the long-lasting drought in Brazilian semiarid: 2012–2017

The semiarid region located in the Brazilian Northeast is characterized by low socioeconomic factors such as high rates of illiteracy, low income levels, and social exclusion, among others. In climatic terms, this region is exposed to the observed extremes of climate variability, mainly droughts, that produce land degradation and desertification. The combination of these characteristics makes this region one of the world's most vulnerable territories to climate change (IPCC, 2014).

Drought is a natural and recurrent phenomenon in this Brazilian region, resulting in significant material and human damage and socioeconomic loss. Dry episodes in semiarid areas are often associated with large-scale phenomena such as El Ninõ and La Ninã events or related to an intense meridional sea surface temperature (SST) gradient over the tropical Atlantic (Marengo et al., 2018). Although droughts are frequent in the region, persistent periods of low rainfall (more than three consecutive years) are very rare.

From 2012 to 2017, the Brazilian semi-arid region was impacted by a long-lasting period of low precipitation that caused damage throughout the region. This prolonged drought period was caused by a combination of three main factors that happened in sequence during this period. First, the La Nina, which began in 2012, was responsible for the below-average

rainfall reduction during the years 2012 through 2014. Earlier, between 2009 and 2010, the Atlantic Inter-Tropical Convergence Zone (ITCZ) migrated to an abnormal position, indirectly contributing to a drop in rainfall in the semi-arid region (Rodrigues and McPhaden, 2014; Marengo and Bernasconi, 2015)[6]. Both events were followed by El Nino, 2015-2016, which extended the dry period until 2017. The combination of these three factors is extremely rare, and the last time a similar drought occurred in the region was more than eighty years ago (Marengo et al., 2018; Santana and Santos, 2020).

The state of Ceará, the study area, is located in the Northeast region of Brazil, with approximately 87% of its total area situated in the semiarid region. On average, the population size of the municipalities is 46,000 inhabitants, with approximately 44% of the population residing in rural areas. The average poverty rate is approximately 68% of the municipalities' population, the average per capita income is around R$ 262.50, and the average unemployment rate is 7.12%, according to the 2010 Demographic Census.

According to the Digital Atlas of Disasters in Brazil, between 2012 and 2017, there were 966 records of disaster occurrences (emergency situation decrees) due to drought in the state of Ceará, affecting about 9.72 million people and causing an estimated loss of approximately 15.9 billion reais. During this period, 90% of the municipalities' revenues in Ceará came from government transfers, which also requested federal public assistance to mitigate the impacts of the prolonged period of low precipitation, including special lines of credit for small farmers and distribution of water by trucks (carros pipa) in rural and urban areas.

In terms of economic activity, the services/trade sector accounted for about 46% of the total GDP between 2012 and 2017, while the manufacturing industry and agriculture represented approximately 17% and 4.5%, respectively, of the municipalities' total production during the period. Figure A1, in the Appendix, shows the evolution of the average per capita GDP and the participation of the agriculture, services/trade, and industry sectors in the municipalities of Ceará from 2008 to 2019. We observe that during the prolonged drought period (2012-2017), there was a relative decline in the participation of agriculture in the municipalities' GDP, highlighting the effects of the long-term drought on agricultural activity.

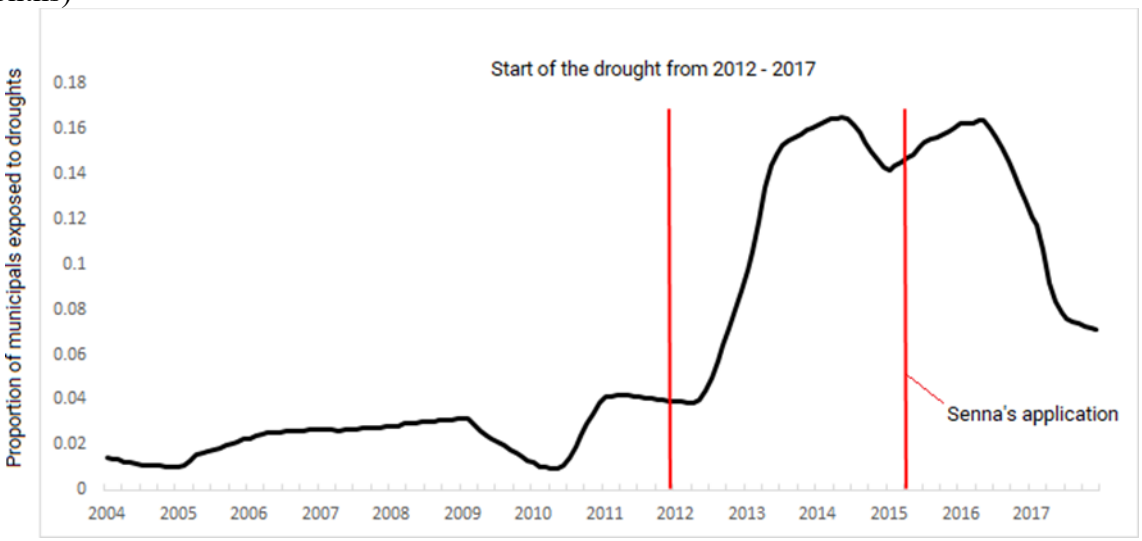
We observed the socioemotional skills of students in 2015, representing four consecutive years of drought exposure (2012 to 2015). The persistence and intensity of this

[6] An anomalously northward/southward position of the ITCZ, determining less/more rainfall in Northeast. These mechanisms induce and intensify the precipitation in the region.

episode were unexpected by students, despite the region being constantly affected by droughts. To understand the long-lasting drought variation in the state of Ceará, we computed the moving average of the last 48 months (four years) of the proportion of municipalities exposed to drought according to our main drought measure, based on precipitation levels. Figure 1 shows that the number of municipalities classified as in drought, considering the average of the last 48 months, increased to 13 perceptual points in 2015. This means that after 2012, the number of municipalities that experienced some degree of drought rose rapidly. Since 2004, students have not been exposed to such a long-lasting period of drought as from 2012 to 2015.

The analysis of this phenomenon is interesting for several reasons. First, it was an exogenous event, potentially caused by global climate anomalies. Climate scientists expect such events to occur more frequently in the coming years as the earth's temperature rises. Then, this paper contributes to explaining the potential effect of long-lasting drought periods on students' socioemotional skills. Second, unlike short-term climate shocks, this drought lasted more than six years (2012–2017) and promoted a large economic loss for the region. This event is useful for exploring how individuals adapted to enduring climate episodes and whether adaptation prevented its impact on students' socioemotional skills.

Figure 1 - Moving average of the proportion of municipalities exposed to drought (48-months)



Source: Elaborated by the authors
Note: Figure 1 presents the proportion of municipalities exposed to drought during the years 2004 through 2017. This proportion is calculated as the moving average of the last 48 months (last four years). Drought is classified according to the Standardized Precipitation Index (SPI). The lines in red denote the official drought period in the region according to the Brazilian Ministry of Integration.

1.3 DATA AND EMPIRICAL STRATEGY

1.3.1 Data

1.3.1.1 Socioemotional traits

To measure socioemotional skills, we used a specific instrument applied to all students in the state of Ceará in 2015. The students were in the 10th grade, corresponding to the first academic year of secondary school. The instrument, called SENNA, was developed by the Instituto Ayrton Senna, a Brazilian civil society organization focused on citizen agency and public service provision.

The SENNA instrument consists of a self-report questionnaire (57 items) that measures socioemotional skills related to the Big Five personality inventory[7]. Socioemotional skills refer to the ability to regulate one's thoughts, emotions, and behavior, and can be divided into five constructs: Openness, Conscientiousness, Extraversion, Agreeableness, and Emotional Stability (also called Neuroticism). Openness is related to creativity, curiosity, and artistic interest. Conscientiousness is associated with persistence, organization, determination, and efficiency. Extraversion is related to being outgoing, having social initiative, and having enthusiasm. Agreeableness, in turn, is correlated with compassion, trust, and respect for the other. Finally, emotional stability is connected with the modulation of stress and frustration.

The original sample consists of 109,606 (86% of the total secondary students in 10th grade in 2015) students. However, due to sample constraints, we analyze a sample that contains nearly 20,000 students. The instrument also collects demographic and socioeconomic information such as gender, age, race, and mother's education.

Despite widespread use to measure socioemotional traits, self-report instruments are limited in several ways. The main limitation associated with such instruments is the reference bias (Heckman et al., 2019) caused by students' differences about the questions[8]. The SENNA instrument attempts to reduce the reference bias by applying vignettes that improve the performance of surveys. The vignettes anchor the student's perception and reduce the problems related to comparing levels of personality skills across different groups (Primi et al., 2016a).

[7] The nomenclature of constructs in the SENNA Instrument is different from the conventional Big-Five constructs, although the instrument measures the similar socioemotional aspects. We recognize the relevance of SENNA nomenclature, however, we prefer to adopt the conventional names of Big-Five to facilitate the exposition.

[8] For instance, poor students may interpret the concept of persistence differently from non-poor students because they have different notions, promoted from their experiences, about what it means.

The SENNA version used in this paper contains 20 vignettes, four for each socioemotional trait[9].

Another important issue related to self-reported instruments is the desirability bias. Students can answer the questions according to what they expect to be considered socially desirable. The construction of the SENNA instrument considered the possibility of desirability bias. For this reason, several comparisons were made of the instrument's responses with other variables that are associated with socioemotional skills but not with desirability bias, such as performance and school dropout. The results did not indicate the presence of desirability bias (SANTOS and PRIMI, 2014; SANTOS, BERLINGERI, and CASTILHO, 2017).

Particularly, in developing countries the self-reported survey presents high acquiescence bias (Laajaj et al., 2019; Laajaj and Macours, 2021), in which students tend to answer all items with a similar response pattern. The SENNA instrument has 13 items with reverse meaning, that is, where answering "I totally agree" to a certain statement, for instance, can indicate a negative aspect of the behavior. These items allow us to identify the presence of and adjust the estimates for acquiescence bias. In addition, the SENNA survey includes two items that measure student attention while completing the survey. These items ask students to respond to a specific answer to a given question[10]. This item type identifies whether students read the questions before answering them. We excluded from the sample the students who wrongly answered both verification items.

The psychometric characteristics of the SENNA instrument were tested and presented a well-defined factor structure, and high internal consistency[11], and external validity when related to measures of performance in Portuguese and math test scores (Primi et al., 2021). In summary, the SENNA instrument is a reliable tool for measuring the socioemotional skills of students in low-income countries such as Brazil.

1.3.1.2 Weather data

Our measure of drought exposure is derived from the monthly precipitation rate. We exploit ground station data provided by the Department of Agriculture and Water Supply of the

[9] In fact, all students responded to at least one vignette for each socioemotional construct. The remaining vignettes were randomly distributed to the students, and each student answered one additional vignette for each construct. This procedure was done to avoid losing students' attention while answering the survey.
[10] For example: *In this question, mark option 3.*
[11] Cronbach's alpha, respectively: Openness (0.90), Conscientiousness (0.94), Extraversion (0.98), Agreeableness (0.98), and Emotional Stability (0.88).

Government of Ceará. In Ceará, there are 274 meteorological stations representing coverage of almost 1.5 stations per municipality. These stations have been providing highly accurate measurements of the weather at daily frequency since 1970. To avoid bias due to the creation and deactivation of stations over time, we restricted the sampling to start in 1991[12].

To measure the drought intensity, we estimate the Standard Precipitation Index (SPI), which is used for detecting and characterizing meteorological droughts. The SPI indicator, developed by McKee et al. (1993), measures precipitation anomalies at a given location, based on a comparison of observed total precipitation amounts for an accumulation period of interest[13] with the long-term historic rainfall record for that period. The historic record is fitted to a probability distribution (the gamma distribution), which is then transformed into a normal distribution such that the mean SPI value for that location and period is zero.

Our historical records from monthly precipitation correspond to 26 years, from 1991 to 2017. We aggregate the precipitation records at the average municipal level. We complement the weather data with average municipal temperature obtained from Global Climate Monitor, which exploits multiple climate data sources and provides georeferenced data of the global climate (Camarillo-Naranjo et al., 2019).

1.3.1.3 Additional data

We also use additional data from the Department of Agriculture and Water Supply to measure the water coverage, and several economic activity variables from *Instituto Brasileiro de Geografia e Estatística* (IBGE) to assess the economic impact of the long-lasting drought in Ceará. We also used data from the *Instituto de Pesquisa e Estratégia Econômica do Ceará* (IPECE), a local governmental agency of statistics. Lastly, the Secretary of Basic Education of the State of Ceará (SEDUC-CE) shared a unique student ID that allowed us to identify students who migrated to different schools during the drought period. We used this dataset to address potential threats to the empirical strategy. All control variables at municipal level were measured in 2010, before the beginning of drought.

[12] The state of Ceará has historical problems with droughts. The novel O Quinze, wrote by Raquel de Queiroz, a Brazilian writer, describes problems related to a major drought that occurred in 1915. These historic droughts encouraged the government of Ceará to invest in technology to measure and try to anticipate such events. Thus, the ground stations in the state of Ceará have a high coverage rate and are stable over the years, unlike in other regions in developing countries.

[13] We focus on SPI 12 months that is more suitable for long-term droughts.

1.3.2 Sample Restrictions

The original database contains approximately 109,606 first-year high school students from Ceará, representing 86% of the students in this grade. Given the nature of the climate phenomenon we are analyzing, it is necessary to introduce some restrictions in the sample.

We excluded the five largest Ceará municipalities: Fortaleza, Caucaia, Sobral, Maracanaú, and Juazeiro do Norte. These municipalities are generally more urban and have a better quality sewage infrastructure than the other municipalities[14]. This may moderate the impact of drought on students, generating noise in the estimates. The sample was reduced by 36,699 students.

The climate event did not occur linearly over time. That is, municipalities may have been affected differently (higher or lower intensity of drought) in different years between 2012 and 2015. Thus, students who were cumulatively equally exposed to drought, in terms of months of exposure, may have different effects depending on when the municipality was affected. To minimize this problem, we chose to compare students in highly drought-exposed municipalities against students from municipalities that were not exposed to drought. We define the total exposure to drought of a municipality i, $TotalExposure_i$, as the number of months from 2012 to 2015 (48 months) that the municipality presented SPI below -1, which represents the presence of moderately dry month[15], that is:

$$TotalExposure_i = \sum_{m=1}^{48} \mathbb{I}\{SPI_{im} \leq -1\} \quad (1)$$

where $\mathbb{I}\{SPI_{im} \leq -1\}$ is an indicator function that assigns 1 if SPI is below -1 to the municipality i in the month $m = 1, \ldots, 48$. Thus, municipalities are considered as highly exposed to drought (treated) as those that are above the 75th percentile of the $TotalExposure_i$ distribution. The municipalities in the control group are the municipalities that were not exposed to drought between 2012 and 2015, i.e. $TotalExposure_i = 0$. The restriction to high and low drought exposure municipalities reduces an additional 28,050 students from the sample.

Additional sample restriction refers to students who wrongly answer the two attention items. The SENNA survey includes two items that measure the student's attention while filling out the instrument. These items ask students to respond to a specific answer to a given question. This type of item identifies whether students read the questions before answering them and is

[14] In the appendix, we report the main estimation including those municipalities. The results are quite similar. See Table A6.

[15] The SPI classification for drought is: $SPI \in [0; -0.99]$ "near normal"; $SPI \in [-1; -1.499]$ moderately dry; $SPI \in [-1{,}5; -1{,}99]$ severely dry, and $SPI \leq -2.0$ extremely dry.

particularly important in long self-report instruments such as the SENNA[16]. We exclude from the sample the students who wrongly answered these items.

The final sample consists of 23,354 students, 14,156 belonging to the control group and 9,198 to the treaty group, arranged in 110 municipalities (59% of the total number of municipalities in Ceará) and 250 high schools (38% of the total number of schools in 2015).

1.3.3 Empirical Strategy

The empirical analysis consists of comparing students in highly exposed drought municipalities relative to less exposed drought municipalities. Thus, to test the effect of long-lasting drought on students' socioemotional skills, we estimate the following equation:

$$y_{ims} = \alpha_0 + \alpha Treat_m + \theta_1' X_{ism} + \theta_2' X_m + \epsilon_{ims} \quad (2)$$

where y_{ims} is the socioemotional measure of student i, in the school s, in municipal m. We focus our attention on the five socioemotional constructs: Openness, Conscientiousness, Extraversion, Agreeableness, and Emotional Stability.

The variable $Treat_m$ is a dummy variable assigning one to highly exposed municipalities and zero to municipalities not exposed to drought. We measured drought exposure using the proportion of months, from 2012 to 2015, in which a municipality experienced a dry precipitation anomaly. The monthly anomalies are measured using the Standard Precipitation Index (SPI) classification. We chose to consider municipalities that had at least a moderate drought to avoid noise.

The treated municipalities are those that have high exposure to monthly dry episodes (above the 75th percentile), and the students in the control group are those in municipalities that were not exposed to drought in any month from 2012 to 2015. The parameter of interest is α, which captures the standardized deviation of socioemotional skills associated with municipal-specific variation in exposure to drought.

The vector X_{ism} is a set of student's pre-determined characteristics, such as gender, parent's education, racial status, age[17], and a variable indicating if the student attended pre-school. In turn, X_m represents a vector of municipal pre-determinant controls, measured before the drought, such as the proportion of elderly, local inequality (Gini Index), average temperature

[16] In the appendix, see Table A1, we compare the characteristics of students that answered and not answered correctly the attention items using normalized difference (ND). Only reproved and girls variables present significant differences between two groups. In our main specification, we control for both factors, and we test the presence of heterogeneous effects in those variables in section 4.4.

[17] Student age is an important determinant of socioemotional traits during adolescence, see Soto et al. (2011).

(the year 2015), and municipal Human Development Index (HDIm). The former variable captures the municipal development factors. The proportion of elderly people and local inequality may affect the distribution of educational public spending[18]. Municipalities with large elderly populations tend to focus their spending more on health than education. In addition, Colmer (2018) shows the importance attributed to rainfall for agricultural production may be overestimated if we omit a temperature variable. With the exception of the temperature variable, the resting variables were measured in 2010, prior to the drought period. In the robustness check, we also add the square of these local variables to capture the potential nonlinearities.

Following Hsiang (2010); Colmer (2018), we assume that the ϵ_{ims} error term is heteroskedastic and serially correlated within the municipality. Drought shocks have specific effects on each municipality, even if they are of the same magnitude, which can generate heteroskedastic and serial correlation in errors within the municipalities. We then clustered the standard error estimates at the municipal level.

The key identification assumption refers to the exogeneity of municipalities highly exposed to drought shock in relation to students' unobserved characteristics. We checked this assumption by comparing whether exposed students differ in terms of ex-ante socioeconomic factors from control students. Particularly, we test the overlap between the treated and control groups to verify whether these groups are balanced across a wide set of pre-treatment observable characteristics. Our empirical specification is a linear regression that can be sensitive when the covariates between the treatment and control groups are limited. We check for overlap using normalized (or standardized) differences (Rubin, 2001). The normalized difference (ND) for a continuous variable is given by:

$$ND = \frac{(\mu_t - \mu_c)}{\sqrt{\sigma_t^2 - \sigma_c^2}} \tag{3}$$

where, μ_t and σ_t^2 are the mean and variance of treated group, and μ_c and σ_c^2 are the and variance for control group. Imbens and Wooldridge (2009) suggests that the normalized difference should be below 0.25 to consider the sample balanced. The Table 1 presents the overlap difference estimates. We observed no difference greater than 0.25, suggesting that students from non-drought-affected municipalities constitute a good control group for the treatment group.

[18] Particularly, in Ceará, primary education is only offered by municipalities. Since part of the drought occurs during these educational grades, the local spending on education may have an impact on socioemotional skills.

Table 1 - Overlap between treated and control groups

Variables	Treated		Control		Balance Std-diff
	Mean	Variance	Mean	Variance	
Racial Status					
White	0.2007	0.1604	0.1985	0.1591	0.0055
Brown	0.0625	0.0586	0.0620	0.0581	0.0023
Black	0.5847	0.2429	0.5935	0.2413	-0.0178
Demographic Factors					
Age	97.238	15.666	96.394	14.124	0.0692
Girls	0.5897	0.2420	0.5774	0.2440	0.0250
Residents in household	38.747	30.838	39.242	31.865	-0.0279
Prior Education					
Preschool	0.8165	0.1499	0.8290	0.1418	-0.0328
Kindergarten	17.731	0.4579	17.729	0.4608	0.0003
Reproved	0.2328	0.1786	0.2235	0.1736	0.0222
Mother Education					
Never Studied	0.1787	0.1468	0.1721	0.1425	0.0175
Primary Education	0.1618	0.1357	0.1542	0.1304	0.0210
Middle Education	0.2826	0.2028	0.2704	0.1973	0.0273
Secondary Education	0.1597	0.1342	0.1588	0.1336	0.0025
Tertiary Education	0.1537	0.1301	0.1774	0.1459	-0.0638

Source: Elaborated by the authors.
Note: Table 1 presents the overlap difference between the students in treated and untreated municipalities.

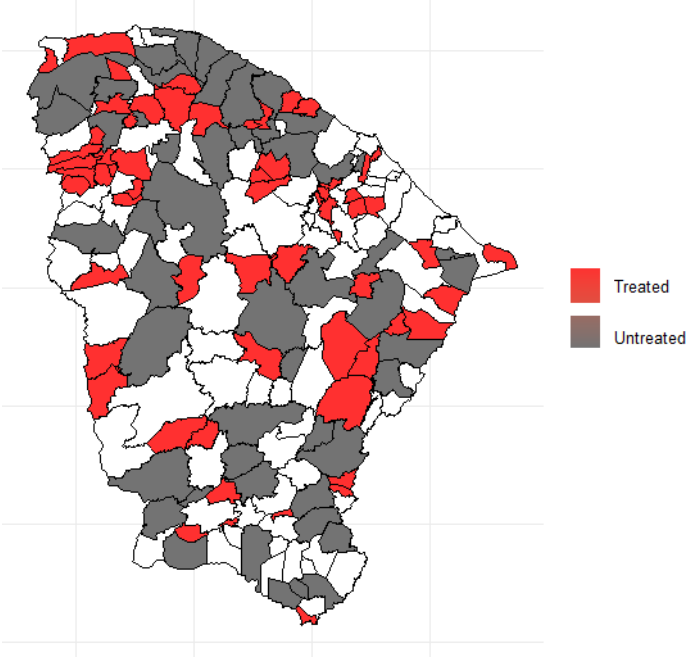
Additionally, a potential threat to identification refers to the geographical differences between exposed and not-exposed municipalities. Figure 2 illustrates the municipalities included in the analysis. We observe that municipalities highly exposed to long-lasting drought are geographically close to non-exposed municipalities. This minimizes the influence of time-invariant, unobserved characteristics of schools and municipalities that potentially affect student socioemotional traits. Moreover, it indicates that students shared similar cultural conditions and economic markets. In the appendix, see Table A1 and Table A2, we check whether there is a difference between treated and untreated according to municipalities' characteristics. We find that the two groups are homogeneous when compared to a set of local indicators.

Third, and perhaps most relevant for the validation of our empirical strategy, cloud formation in the semi-arid makes precipitation during drought a quasi-exogenous event. The cloud (*cumulus nimbus*) that is typical of the semi-arid region is strongly affected by the winds that arrive from the coast. Therefore, the direction and resulting precipitation of these clouds are not correlated with a specific geographical region. Thus, two municipalities that share the same economic, agricultural, and cultural backgrounds can be highly affected or unaffected by

drought. Figure 2 confirms this possibility, as nearby municipalities had different drought exposures over the period[19]. Considering only the treated municipalities, they had on average 55% of the months between 2012 and 2015 classified as moderately dry, this corresponds to approximately 26.4 months on average of drought. We compare the treated municipalities against the municipalities that did not record any months of drought between 2012 and 2015.

A potential source of confounding effects is the severe macroeconomic recession in Brazil between 2014 and 2016. This recession could have an differential impact on the treated and control municipalities, affecting the estimates since economic activity is related to socio-emotional and educational skills (Akee et al. (2018), Barbosa, Araújo and Brito (2024)). However, we expect that this shock has little effect on our estimates because the treated and control municipalities are geographically close, and possibly do not have different economic structures. In fact, the removal of the five largest municipalities from the sample contributes to the municipalities in the sample being quite homogeneous, as can be seen in Table A2, in the Appendix. In other words, considering that the municipalities have the same economic structure, it is not expected that they will have differential effects from the recessionary shock.

Figure 2 - Map of Treated vs Control Municipalities



Source: Elaborated by the authors
Note: Figure 2 shows the geographic distribution of municipalities affected (Treated) and unaffected (Control) by drought during the period. We used the standardized precipitation index (SPI), calculated for each month between 2012 and 2015, to differentiate between the municipalities. A municipality was considered as treated if the proportionof months of drought exposure was above the 75th percentile. In turn, municipalities in the control group were not exposed to any drought months in the period.

[19] The state of Ceará is quite flat, with little variation in height about the sea.

1.4 RESULTS

1.4.1 Main results

Table 2 presents the estimates of students highly exposed to the long-lasting drought shock on the five socioemotional traits in comparison with students not exposed to drought. We convert the socioemotional measures into standardized z-scores to facilitate the presentation of the results. In parentheses are the estimated standard errors, clustered at the municipal level. In brackets are the Romano-Wolf p-values, which provide multiple hypotheses testing correction[20] (Romano and Wolf, 2005, 2016).

We observe that non-cognitive measures are negatively associated with exposure to large drought shocks. However, only Conscientiousness shows significant estimates. The correlation of living in a municipality exposed to drought reduced nearly to 0.054s.d (*p-value* 0.003) the student's conscientiousness skill when compared to the student not exposed to the drought.

The drought shock only affected conscientiousness and a potential mechanism to explain this effect stems from the economic impact of the drought on students' aspirations. Dalton et al. (2016) state that economic shocks affect individuals' aspirations for future success. As a result, in anticipation of a lower expected probability of success in the future, individuals reduce their effort in the present. In turn, the reduction in effort in the present again impacts on aspirations for the future, resulting in a kind of behavioral trap. Effort is strongly associated with the trait of conscientiousness, defined as the ability to be determined, focused and persistent towards a specific goal. Other personality traits do not have a strong association with individuals' aspirations, therefore they are not expected to be impacted by the drought shock. In section 4.5, we estimate the effect of the drought shock on some measures related to what students expect from their future.

The conscientiousness trait includes a range of skills that determine the propensity to be self-controlled, responsible towards others, hardworking, persistent, orderly, and virtuous. Our findings suggest that students' exposure to a long-lasting drought event reduces these skills during a critical period of adolescence. Several studies present evidence that conscientiousness

[20] The Romano-Wolf procedure uses re-sampling methods, such as the bootstrap, to asymptotically control the family-wise error rate (FWER), that is, the probability of rejecting at least one true null hypothesis in the family of hypotheses under test. It is more suitable for our case compared to other methods such as the False Discovery Rate (FDR) procedures because it accounts for any correlation between the outcomes, which is expected among socioemotional skills (Clarke et al., 2020).

skill predicts important long-term outcomes such as college entrance, graduation from high school, earnings, health status, and behaviors (Almlund et al., 2011; OECD, 2017).

Table 2 - Effect of drought shock on socioemotional skills

Variables	(1) Agreeableness	(2) Conscientiousness	(3) Extroversion	(4) Emotional Stability	(5) Openness
Drought Shock	-0.002	-0.054	-0.013	-0.009	-0.004
	(0.019)	(0.026)	(0.019)	(0.017)	(0.023)
Romano-Wolf p-value	[0.940]	[0.003]***	[0.691]	[0.797]	[0.940]
Observations	19,746	19,746	19,746	19,746	19,746
R-squared	0.029	0.024	0.025	0.067	0.033
Municipals controls	YES	YES	YES	YES	YES
Student Controls	YES	YES	YES	YES	YES

Source: Elaborated by the authors

Note: Table 2 presents the estimates of the long-lasting drought period on the variables measuring the social-emotional skills of the Big Five Inventory. Standard errors were clustered at the municipal level. Romano-Wolf p-values are reported in brackets. Significance: *** 1%, ** 5%, and *10%.

Our findings suggest that the long-lasting drought shocks adversely the factors related to effort in school, like persistence, focus, and determination. Shah and Steinberg (2017) found that a short-run negative rainfall shock raises the opportunity cost of students to leave the school. Droughts may impact the local labor markets, particularly in agricultural areas, decreasing the expected returns to child labor. That represents an incentive to stay at school and to learn. As a consequence, the short-run unfavorable rainfall shocks increase the student's test scores. We found contrary evidence when considering long-lasting drought shocks. Even if the drought increased school enrollment and students' progression, simultaneously, it led to a decrease in socioemotional skills among the youth. Our results are analogous to Nordstrom and Cotton (2020) which find that severe short-run droughts negatively impact student non-cognitive skills.

Large periods of droughts may represent a relevant income shock to families in agricultural areas, increasing the cost of staying at school. Akee et al. (2018) find that a positive shock on household income has a beneficial effect on children's personality traits. The mechanisms for this effect include improved relationships between parents and their children, as well as between the parents themselves, along with enhanced mental health and reduced stress levels among parents, all resulting from increased household income. Thus, variations in household income can be a potential channel to explain the relationship between drought shocks and personality.

1.4.2 Robustness

We check the robustness of these results in different ways. The main limitation of our empirical strategy is the possibility of students' families' adaptation to the drought period. One of the main ways to adapt to climate change is migration. For instance, students' families could migrate to municipalities that were not very exposed to droughts, confounding the results. Using administrative student identification provided by the Secretariat of Education of the State of Ceará (SEDUC), we identify students who migrate during the drought period. We then regress the binary variable indicating whether students migrated during the drought period against the treatment. Our goal is to identify whether student migration is correlated with drought exposure.

We consider a student as a migrant if she enrolled in a school in a different municipality between 2012 to 2015, the period of the drought occurrence. We present the results in the Table A5, in the Appendix. The results suggest that student migration is not correlated with the exposure of municipalities to drought. This result is in line with the evidence that, although this drought event has been unprecedented over the past eighty years, there have been several policies that have contributed to mitigating its most severe effects, such as crop insurance, conditional cash transfer programs, and intergovernmental emergency transfer to municipalities most affected by drought (De Oliveira, 2019; De Oliveira et al., 2020). Thus, even if a county has been exposed to drought, such amenities reduce the odds of the student's families choosing to migrate.

In addition, we provide several sensitivity tests to check the robustness of the main findings. First, we consider two alternative measures of drought shock. In our main specification, we define a municipality as being exposed to drought using a binary variable according to the proportion of dry months measured by the SPI. Specifically, municipalities considered to be exposed to drought shock were those above the 75th percentile of dry period months.

We consider as alternative measures the total number of months that a municipality is exposed to a dry period according to the SPI (Alternative Measure I) and the median months of dry periods (Alternative Measure II). The estimates are presented in Table A3. In both cases, the impact of a drought shock is negative on the conscientiousness trait, similar to the main results. The effect of the continuous drought shock has risen to −0.66 s.d (*p-value* 0.222) and the effect of municipalities above the median is −0.35 s.d (*p-value* 0.046). However, despite the similar effect size, the variance also increased, and only Alternative Measure II presented statistical significance. A possible explanation for the increased uncertainty of the estimates is

related to the dynamic occurrence of dry from 2012 to 2015. The municipalities may have been equally affected but in different periods between 2012 and 2015, generating noise in the sample. We tried to mitigate this potential noise by considering as treated only the municipalities that had many dry months (above the 75th percentile).

We also tested the inclusion of nonlinearities in the controls. In particular, we included in the main regression the square of the control variables. The estimates reported in Table A3 are not different from the main results, suggesting that the estimates are stable to the introduction of additional control variables.

Finally, our data present missing control variables. Thus, we impute missing controls by assigning the overall sample mean to each observation with missing information for a continuous control variable and a new missing category to each observation with missing information for an indicator variable. We also included indicator variables to determine whether a variable is imputed. We re-estimated Equation 2 using imputed controls. The results, presented in Table A4, are similar to the main results. Only the conscientiousness skill is negatively affected by the drought shock.

Taken together, our estimates suggest that long-lasting drought shock adversely affects the conscientiousness trait, and this finding is robust to several specification checks.

1.4.3 Estimation on the facets of personality traits

To understand in much more detail the results, we estimate the same empirical strategy on the facets of the effect of conscientiousness traits. A special feature of the SENNA instrument is the possibility to decompose the Big Five personality traits on their facets. The facets represent a narrowly defined factor related to a broadly defined trait (e.g., Conscientiousness). The main advantage of analyzing the facets is the possibility of providing a more precise description of student behavior (Soto and John, 2017). Each broad Big Five domain of the SENNA instrument can be conceptualized as containing several specific facet traits, and the SENNA instrument allows simultaneous access to personality at both the domain and facet levels. A growing body of research has adopted this approach to measure personality traits (Costa Jr and McCrae, 1995; Soto and John, 2017; OECD, 2017). We obtain the facets constructs using the principal component estimator applied to the set of questions associated with each facet. We report the results in Table 3.

We observe from Table 3 that some facets related to Conscientiousness are significantly affected by the shock of the long-term drought. The Organization, Focus, and Persistence facets

are negatively and significantly impacted. Determination is also negatively impacted, but not significantly. When we estimate p-value correcting for multiple testing, Determination is significant at 5%. The estimated size, however, is similar to the other Conscientiousness facets. The largest estimated effects are on Focus, Organization (−0.046*s.d*), and Persistence (−0.050*s.d*), suggesting that students in highly drought-exposed municipalities have difficulty focusing their attention on educational activities, organizing their activities, and persisting in achieving their goals. All estimations presented statistical significance at 1%, except Determination, which was less impacted and statistically significant at 5%.

Some recent evidence points out the impact of poverty on individual cognitive function, like attention (Mani et al., 2013; Shah et al., 2018). For instance, factors related to drought episodes, like malnutrition or money concerns, may affect the mental capacity of the student to concentrate on specific activities. The organization is related to the capacity of planning activities to reach a goal and to manage appointments future. Like the focus and persistence facets, the drought shock affects the student's mental capacity to plan. At last, the drought shock also significantly affects persistence skills, defined as the ability to overcome obstacles to complete tasks, rather than procrastinating or giving up when situations get difficult or uncomfortable.

Table 3 - The effect of long-lasting drought shock on Conscientiousness' facets

Conscientiousness' facets	Determination	Organization	Focus	Persistence
Drought Shock	-0.028	-0.046***	-0.046***	-0.05
	(0.025)	(0.023)	(0.025)	(0.025)
Romano-Wolf p-value	[0.019]	[0.003]	[0.003]	[0.003]
Observations	18,103	18,392	18,188	17,933
Municipal Controls	YES	YES	YES	YES
Student Controls	YES	YES	YES	YES

Source: Elaborated by the authors

Note: Table 3 presents the estimates of the long-lasting drought period on the variables measuring the facets of the Conscientiousness' skills. Standard errors were clustered at the municipal level. Romano-Wolf p-values are reported in brackets. Significance: *** 1%, ** 5%, and *10%.

1.4.4 Heterogeneous Effect

Drought shock events may have varying effects on different groups of students. To explore this possibility, we conducted an analysis focusing on heterogeneous effects. We examined two student characteristics that could potentially influence the impact of extreme low precipitation shocks. The first characteristic is student gender. Previous research suggests that girls may be more vulnerable to economic and natural shocks (Neumayer & Plümper, 2007;

Enarson et al., 2018). The second characteristic relates to educational background. We aimed to determine whether students who have previously repeated a school year might experience a stronger impact from drought shocks. Student quality could potentially mitigate the effect of low precipitation shocks on socioemotional skills.

We measured the heterogeneous effect by interacting with female gender status and whether the student had repeated (repeated) any previous grades with the Treat variable and included both variables in the empirical strategy adopted in Equation (2). The empirical specification is as follows:

$$y_{ims} = \alpha_0 + \alpha_1 Treat_m + \alpha_2 factor_{ims} + \alpha_3 factor_{ims} \times Treat_m + \theta_1' X_{ims} + \theta_2' X_m + \epsilon_{ims} \quad (4)$$

Where: $factor_{ims}$ can be gender status (girls) or students who have repeated a grade. The results are presented in Table 4.

Table 4 - Heterogenous Effect

Variables	(1) Agreeableness	(2) Conscientiousness	(3) Extroversion	(4) Emotional Stability	(5) Openness
Female gender status					
Treat	0.021	-0.047	-0.008	0.007	0.012
	(0.025)	(0.034)	(0.026)	(0.023)	(0.031)
Treat x Girls	-0.025	-0.008	0.010	-0.014	-0.024
	(0.031)	(0.034)	(0.031)	(0.029)	(0.030)
Girls	0.226***	0.131***	-0.082***	-0.510***	-0.114***
	(0.019)	(0.019)	(0.017)	(0.019)	(0.018)
Repeating students					
Treat	0.016	-0.040	0.000	-0.007	0.006
	(0.022)	(0.030)	(0.022)	(0.021)	(0.027)
Treat x Repeated	-0.040	-0.051	-0.013	0.031	-0.036
	(0.024)	(0.033)	(0.027)	(0.033)	(0.029)
Repeated	-0.212***	-0.275***	-0.165***	-0.173***	-0.180***
	(0.023)	(0.025)	(0.022)	(0.023)	(0.026)
Municipal Controls	YES	YES	YES	YES	YES
Student Controls	YES	YES	YES	YES	YES

Source: Elaborated by the authors
Note: Table 4 presents the estimates of the prolonged dry period in the variables that measure the socio-emotional skills of the Big Five Inventory considering the student's gender and whether the student had repeated a previous grade. Standard errors were clustered at the municipal level. Significance: *** 1%, ** 5% and *10%.

We do not find evidence of the presence of heterogeneity in both girls or students with lower prior education. Beside the negative impact estimation for all socioemotional skills, the estimates are non-significative. The results suggest that boys and girls are equally affected by

the drought shock on their socioemotional abilities, and that prior education does not mitigate the effect of low precipitation shocks.

1.4.5 Other results

Socioemotional skills are strongly associated with student aspirations for the future. In turn, aspirations are related to some educational and labor market outcomes, such as student effort, high school graduation, and wages. Recent evidence attributes aspirations as relevant to explaining the psychological causes of poverty traps (Dalton et al., 2016; La Ferrara, 2019).

In this section, we examine whether long-term drought shock also affected some variables that measure student aspiration, such as expected schooling and the decision to continue studying after high school. To measure the student's aspirations, we explore a survey applied in conjunction with the SENNA Instrument. The survey asked about the expected education (the highest educational level the student intends to achieve), whether the student intends to leave school during high school, whether she expects to interrupt her studies after completing high school, and whether she expects to go to university.

The results are reported in Table 5. We obtained the estimates using similar specifications to Equation 2. The drought shock significantly reduced the expected education. Students exposed to the drought period reduce the expectation that they have achieved elevated levels of education in their lifetime. There is an increase in the likelihood of students who indicate that they intend to stop studying right after high school and a reduction in the proportion of students who indicate that they intend to go to university.

Table 5 - Effect of drought shock on student aspirations

Variables	(1) Expected Education	(2) Stop after High School	(3) Go to university
Drought Shock	-0.048	0.012	-0.028
	(0.017)	(0.008)	(0.010)
Romano-Wolf p-value	[0.003]***	[0.019]**	[0.003]***
Observations	19,559	19,746	19,746
R-squared	0.092	0.022	0.080
Municipal Controls	YES	YES	YES
Student Controls	YES	YES	YES

Source: Elaborated by the authors

Note: Table 5 presents the results of the drought exhibit on students' educational expectations. We estimate a similar specification to Equation 2. Romano-Wolf p-values are reported in brackets. Significance level: *** 1%, ** 5%, and *10%.

The effect of drought shock on students' aspirations is in line with the findings on socioemotional skills. Drought reduces student conscientiousness, which is related to focus, persistence, and organization. The reduction of these factors may also contribute to the effects on students' aspirations for educational achievements.

1.5 FINAL REMARKS

This paper documents that a prolonged drought shock affects the socioemotional skills of adolescents. We investigated the effect of a four-year drought on the socioemotional skills of students in the state of Ceará, Brazil. The personality trait of conscientiousness was significantly and adversely affected by the drought. The conscientiousness trait is strongly related to long-term individual outcomes such as salary, enrollment in college, and increased life expectancy (Almlund et al., 2011; Heckman et al., 2019).

Additionally, we analyze the impact of drought on facets associated with these personality traits. The facets measure aspects more closely related to student behavior. The results showed that the facets of organization, persistence, and focus were also negatively affected by the drought shock. Finally, we found that the effect of the drought on conscientiousness skills is related to a reduction in students' aspirations for the future to continue their education.

Our findings provide important insights for public policy-making, especially in areas most vulnerable to drought. While many actions have been developed to reduce the economic damage of drought events, it is necessary to focus on policies that also mitigate the effects of drought on students' socio-emotional skills.

This paper showed that a steep increase in drought can affect students' socioemotional skills, especially at sensitive ages of socioemotional formation. Contrary to existing empirical findings on the impact of precipitation shocks, we provide evidence that the impact of drought can affect other characteristics that make up human capital beyond cognitive skills. Previous literature may subestimate the cost of a drought shock. If climate change intensifies the occurrence of droughts, specific public policies should be designed to address students' socioemotional skills, given their importance to students' well-being.

Two limitations are associated with this paper's conclusions. First, given that our outcome variable is cross-sectional, dynamic effects of temporal variability may affect the estimates. Additionally, spatial regression models may fit the data better by attempting to

control for potential spatial autocorrelation bias. We expect to address these limitations in future studies.

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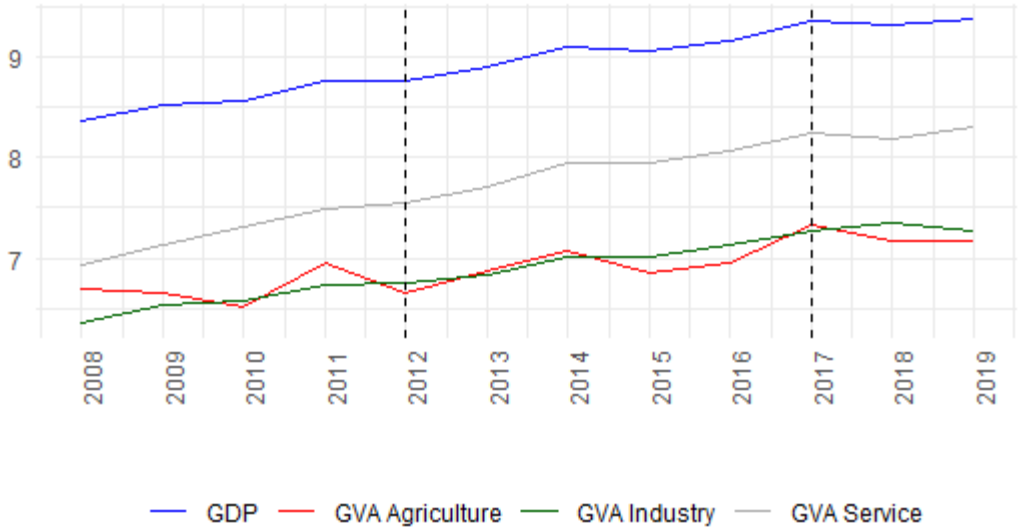
APPENDIX

Figure A1 - Temporal evolution (2008-2019) of GDP and Gross Values Added (GVA)



Source: Elaborated by the authors
Note: Figure A1 presents the temporal evolution (2008-2019) of the average GDP and the average gross value added (GVA) of the agriculture, industry, and services/trade sectors in the municipalities of Ceará. All values have been adjusted on a per capita basis, deflated using the implicit GDP deflator based on 2019, and logarithmized. The dotted lines denote the drought period in the region, according to the Brazilian Ministry of Integration.

Table A1 - Balance checks between students that answered and not answered correctly the SENNA questionnaire

Variables	Answered correctly		Do not answered correctly		Balance Std-diff
	Mean	Variance	Mean	Variance	
Racial Status					
White	0.201886	0.161133	0.203974	0.162377	-0.0051
Brown	0.587751	0.242307	0.081927	0.075219	0.0846
Black	0.059734	0.056167	0.545836	0.247913	-0.0865
Demographic Factors					
Age	9.689.527	148.789	9.791.453	3.556.321	-0.0642
Girls	0.581679	0.243336	0.433043	0.24553	0.3006
Residents in household	3.863.919	3.076.725	3.962.167	3.565.502	-0.0539
Prior Education					
Preschool	0.8322	0.139645	0.808873	0.154606	0.0608
Kindergarten	17.734	0.457373	1.790.201	0.499507	-0.0243
Reproved	0.232924	0.178676	0.365814	0.232007	-0.2933

Source: Elaborated by the authors
Note: Table A1 presents the difference in overlap between students that answered and not answered correctly the SENNA questionnaire

Table A2 - Balance checks between treated and untreated municipalities

Variables	Low Exposure		High Exposure		Difference
	Obs	Average	Obs	Average	
Proportion of 1/4 minimum wage	49	41.614	61	41.971	-0.357
Ratio +10/40-	49	28.08	61	27.005	1.076
Per capita income	49	253.18	61	251.99	1.193
Inequality Gini Index	49	0.538	61	0.534	0.004
Proportion of illiteracy	49	26.371	61	27.025	-0.653
Distance from capital	49	235.47	61	204.45	31.018
Proportion of poor (Head count ratio)	49	24.419	61	24.166	0.253
HDI municipal	49	0.616	61	0.61	0.005
Proportion of elderly	49	12.105	61	12.108	-0.003

Source: Elaborated by the authors

Note: Table A2 presents the balance difference between treated and untreated municipalities socioeconomic factors. The last column (Difference) perform the t-test of equal mean. Significance: *** 1%, ** 5%, and *10%.

Table A3 - Robustness check

Variables	(1)	(2)	(3)	(4)	(5)
	Agreeableness	Conscientiousness	Extroversion	Emotional Stability	Openness
Alternative Measure I	0.035	-0.066	0.007	0.000	0.017
	(0.059)	(0.079)	(0.056)	(0.056)	(0.070)
	[0.946]	[0.222]	[0.930]	[0.930]	[0.946]
Alternative Measure II	0.008	-0.035	0.002	-0.002	0.011
	(0.017)	(0.025)	(0.016)	(0.015)	(0.020)
	[0.900]	[0.046]**	[0.810]	[0.730]	[0.810]
Additional controls	-0.005	-0.06	-0.019	-0.014	-0.010
	(0.019)	(0.025)	(0.019)	(0.019)	(0.022)
	[0.717]	[0.003]***	[0.322]	[0.584]	[0.661]
Municipals controls	YES	YES	YES	YES	YES
Student Controls	YES	YES	YES	YES	YES

Source: Elaborated by the authors

Note: Table A3 presents the robustness exercises for the estimates of the main outcome. Three robustness exercises are performed. The first two exercises consider alternative measures of drought shock, while in the third, we include additional controls for nonlinearities. Standard errors were clustered at the municipal level. Romano-Wolf p-values are reported in brackets. Significance: *** 1%, ** 5%, and *10%.

Table A4 - Effect of drought shock on socioemotional skills - Imputed controls

Variables	(1) Agreeableness	(2) Conscientiousness	(3) Extroversion	(4) Emotional Stability	(5) Openness
Drought Shock	-0.004	-0.058	-0.021	-0.009	-0.012
	(0.018)	(0.024)	(0.018)	(0.016)	(0.022)
Romano-Wolf p-value	[0.717]	[0.001]***	[0.170]	[0.661]	[0.661]
Observations	23,355	23,355	23,355	23,355	23,355
R-squared	0.036	0.032	0.025	0.062	0.032
Municipals controls	YES	YES	YES	YES	YES
Student Controls	YES	YES	YES	YES	YES

Source: Elaborated by the authors

Note: Table A4 presents the estimates of the long-lasting drought period on the variables measuring the social-emotional skills of the Big Five Inventory. The controls included imputed observations on missing values in independent variables. Standard errors were clustered at the municipal level. Romano-Wolf p-values are reported in brackets. Significance: *** 1%, ** 5%, and *10%.

Table A5 - Impact of municipality drought shock on student migration

Variables	(1)	(2)	(3)
Drought Shock	0.0075	0.0104	0.0183
	(0.023)	(0.023)	(0.019)
Observations	32,413	30,200	32,413
R-squared	0.028	0.022	0.025
Municipals controls	NO	NO	YES
Student Controls	NO	YES	YES

Source: Elaborated by the authors

Note: Table A5 presents the estimates of municipal drought exposure on the probability of a student migrate during the drought period. Standard errors were clustered at the municipal level. Significance: *** 1%, ** 5%, and *10%.

Table A6 - Correlation of drought shock on socioemotional skills – All municipalities

Variables	(1) Agreeableness	(2) Conscientiousness	(3) Extroversion	(4) Emotional Stability	(5) Openness
Drought Shock	0.010	-0.044*	-0.018	-0.013	-0.006
	(0.021)	(0.025)	(0.019)	(0.018)	(0.023)
Observations	45098	45098	45098	45098	45098
R-squared	0.027	0.024	0.022	0.069	0.031
Municipals controls	YES	YES	YES	YES	YES
Student Controls	YES	YES	YES	YES	YES

Note: Table A6 presents the robustness exercises for the estimates of the main outcome considering students in all municipalities. Standard errors were clustered at the municipal level. Significance: *** 1%, ** 5%, and *10%.

CHAPTER 2 - DROUGHT, LOCAL FISCAL CONDITIONS AND INFANT HEALTH: EVIDENCE FOR THE NORTHEAST REGION OF BRAZIL

2.1 INTRODUCTION

Climate change emerges as one of the greatest global challenges of the 21st century, imposing a series of complex impacts across various spheres of society (World Bank, 2009; IPCC, 2012). Among these impacts, the high frequency of extreme natural phenomena has directly affected communities around the world. A growing number of studies have documented the adverse effects caused by natural disasters on maternal and child health (Currie and Rossin-Slater, 2013; Rocha and Soares, 2015; Simeonova, 2011; De Oliveira et al., 2021; Andalón et al., 2016). These extreme natural events not only add a layer of risks to the health of pregnant women and newborns but also widen socio-economic disparities shaping the critical period of pregnancy and the early days of life (Bennett and Friel, 2014; Deschênes and Moretti, 2009). Thus, the consequences of these phenomena in the realm of child health become even more pronounced, manifesting in multifaceted and often challenging ways.

In this context, the need for comprehensive approaches to address these challenges becomes evident. Recent economic literature has explored the importance of fiscal capacity in facing crises (Hausmann and Schetter, 2022; Romer and Romer, 2019; Barros et al., 2022), such as in the case of pandemics, recessions, natural disasters, among others. Above all, fiscal capacity aligns with the concept of state capacity, defined as the ability of the state to formulate and implement effective policies, ensure the rule of law, and consistently provide public services (Acemoglu and Robinson, 2012). Thus, governments' ability to mobilize financial resources and implement strategic measures not only influences economic stability during periods of crisis but also plays a crucial role in the resilience of affected communities.

In developing countries, such as Brazil, the existence of fiscal conditions at the local level can be fundamental to address budgetary impacts in times of recession, ensuring the provision of essential public services and the overall well-being of the population. In the Brazilian context, a challenge faced by subnational entities is the absence of fiscal expansion mechanisms in times of economic fluctuations, as they are prohibited from issuing their own debt securities, having fiscal capacity restricted to intergovernmental transfers or their own locally generated revenue (Barros et al., 2022). This restricted condition often hinders municipalities from having the flexibility to increase their revenues or make budgetary adjustments necessary to respond quickly to unforeseen economic shocks.

In a scenario of natural disasters, Brazilian municipalities can request transfers of resources from the Union[21] to provide immediate relief and assistance to the affected areas. However, these transfers are of the ad hoc type, characterized by their non-regular and unpredictable nature. This resource allocation model presents significant challenges, such as a lack of predictability, inconsistency in distribution across different regions, potential political bias, and difficulty in assessing long-term impact. Moreover, excessive dependence on ad hoc transfers can create financial vulnerability in municipalities, compromising their ability to effectively respond and achieve sustainable recovery.

In these circumstances, the fiscal condition of municipalities emerges as an important mechanism capable of addressing the impacts caused by extreme natural shocks. A strong fiscal capacity not only enables the immediate implementation of preventive measures and relief actions but also facilitates the maintenance of essential services, investments in resilient infrastructure, and the promotion of a more robust economic recovery. At the same time, municipal response to crises is still under discussion due to the limited capacity for municipal fiscal expansion, the sharing of the provision of public goods and services with other entities, especially health services[22], and the difficulty of political accountability in crisis response (Barros et al., 2022).

This article seeks to explore the intersection between the incidence of natural disasters, infant health, and the fiscal conditions of municipalities. Particularly, the main objective of this article is to investigate whether the fiscal situation of municipalities in the Northeast region of Brazil contributes to mitigating the effects of idiosyncratic drought shocks during the in-utero period on infant health outcomes, including infant mortality (and its main causes), birth weight, gestation time, among others. The municipality's ability to provide essential resources and services during and after extreme weather events, especially those related to maternal and infant health, plays a fundamental role in mitigating adverse impacts. Thus, understanding the interaction between extreme climatic conditions, newborn health, and local fiscal conditions proves essential for a comprehensive and effective approach to these interconnected challenges.

[21] The law 12,340/2010 "establishes rules for the transfer of resources from the Union to the organs and entities of the States, Federal District, and Municipalities for the execution of actions related to prevention in disaster-prone areas, as well as response and recovery in areas affected by disasters. It also addresses the National Fund for Public Calamities, Protection, and Civil Defense; and provides other measures" (BRAZIL, 2010). For further details, see: https://www.planalto.gov.br/ccivil_03/_ato2007-2010/2010/lei/l12340.htm

[22] From the Federal Constitution of 1988 and regulated by Laws 8.080/90 (Organic Health Law) and 8.142/90, the decentralization of health management and policies in Brazil regulates that the power and responsibility over the sector are distributed among the three levels of government - Federal, State, and Municipal - aiming for more efficient and quality service delivery, as well as oversight and control by society.

We focus our analysis on the Northeast region of Brazil due to its intrinsic vulnerability to the effects of extreme weather events. The vast majority of its territory is located in the semiarid region, characterized mainly by scarce rainfall, making droughts a recurrent and natural phenomenon in the area. Additionally, the region is marked by unfavorable socioeconomic conditions, which, combined with the prevalence of a semiarid climate, renders this territory one of the most susceptible to climate change worldwide (IPCC, 2014). This directly and indirectly affects the health and well-being of families in the region, particularly vulnerable individuals such as newborns.

To measure the fiscal situation of municipalities, we used the Firjan Fiscal Management Index (IFGF), which assesses the financial accounts of Brazilian municipalities, aiming to portray the challenges faced in managing municipal resources, considering their budgetary limitations. The IFGF comprises four indicators that allow for a comprehensive characterization of the municipal fiscal situation. These indicators pertain to municipal autonomy, budgetary rigidity (referred to as personnel expenditures), municipal investments, and liquidity. The score for each indicator ranges from 0 to 1, and the general index is obtained by averaging the four indicators, each of which carries equal weight. Our drought measure is a binary variable indicating whether precipitation in the 12 months prior to the date of birth was more than one standard deviation below the historical average for a municipality. We combined this data with birth and infant mortality records to create a municipal-level panel by month covering the period from 2014 to 2019.

Our main empirical specification compares municipalities that were exposed to drought shocks during the gestational period with those that did not experience such exposure, incorporating local fiscal conditions as a moderating factor in this analysis. The interaction between drought shocks and local fiscal conditions is a distinctive feature of our analysis, allowing us to assess whether resilience to adverse climatic conditions varies significantly according to the fiscal capacity of municipalities. Thus, we aim to explore how variations in the fiscal capacity of municipalities may modulate the impact of drought shocks on infant health outcomes.

Our results demonstrate that the iterated effect of drought shocks and local fiscal conditions on the infant mortality rate presents a negative relationship, but this effect was not statistically significant. However, when considering causes of death, we find that municipalities with better fiscal conditions tend to mitigate the effects of drought shocks during the gestational period on infant mortality caused by conditions of perinatal origin. Perinatal conditions are related to medical conditions or complications that occur during the perinatal period, which

encompasses the end of pregnancy and the first weeks after birth. We do not find significant effects on other infant health outcomes.

We also estimated the iterated effect of local fiscal conditions and drought shocks on infant mortality, considering each of the four indicators that compose our measure of the municipality's fiscal condition separately. We found a negative and significant relationship in the iterated effect between drought shocks and local fiscal conditions on infant mortality for the Autonomy and Personnel Expenditures indicators. The Autonomy indicator measures the municipality's ability to finance its administrative structure, assessing to what extent city halls depend on transfers from States and the Union. On the other hand, the Personnel Expenditures indicator is associated with the concept of budget rigidity, indicating the degree of flexibility in municipal budgets for the implementation of public policies.

In addition to these results, we demonstrated relevant heterogeneous effects. First, we assessed the occurrence of drought shocks in different trimesters of gestation and found that drought in the first trimester of gestation (embryonic period) has a positive and statistically significant effect on infant mortality, and this effect is mitigated in municipalities with better fiscal conditions. Finally, we examined the heterogeneity of our results considering the population size of municipalities and documented that fiscal conditions are relevant in mitigating the effects of drought shocks on infant mortality in municipalities with a population between 20,000 and 40,000 inhabitants.

This article contributes to various aspects of economic literature. Firstly, it aligns with the literature exploring the effects of natural disasters on infant health outcomes. In particular, it adds to a growing body of research that links in utero exposure to extreme weather events. Most of these studies focus on the adverse effects of exposure to negative deviations in precipitation or extremely high temperatures during pregnancy on infant mortality (Kudamatsu et al., 2012; Bauer and Mburu, 2017) and other birth outcomes (Deschênes, Greenstone, and Guryan, 2009; Kumar et al., 2016; Andalón et al., 2016; Abiona and Ajefu, 2023). Evidence also suggests that more developed public health facilities contribute to minimizing these adverse effects (Rocha and Soares, 2015; Lin et al., 2021). Our paper contributes to this literature by demonstrating that drought occurrence in the first trimester of gestation increases infant mortality, and this effect is mitigated in municipalities with better fiscal conditions.

Secondly, we contribute to the literature related to the importance of fiscal capacity, especially its relationship with state capacity. Besley et al. (2013) emphasize that the state's capacity to act depends on how governments generate revenue, which has important implications for various economic outcomes such as education, poverty, economic activity,

among others (Acemoglu et al., 2015; Besley and Persson, 2009). In the context of natural disasters, Jerch et al. (2023) provide evidence that declines in the provision of local public goods comprise a channel through which the damages of climate change are regressive. In our article, we show that greater fiscal capacity at the local level, especially when considering fiscal autonomy, contributes to mitigating the effects of drought on infant mortality.

Thirdly, this article also contributes to the literature that focuses on the relationship between natural disasters and local public finances, such as Miao et al. (2020), Jerch et al. (2023), and Morvan (2022). Understanding how extreme weather events impact municipal budgets has relevant implications for equity, as it can disproportionately affect those who rely more on essential services, such as public transportation and hospitals, and have fewer resources to deal with climate adversities (Glaeser et al., 2008). De Oliveira et al. (2020) demonstrate that improvements in tax revenue and the efficiency of municipal public spending are associated with a lesser impact of natural disasters. This research shows that greater capacity to generate own revenue and less budget rigidity makes municipalities more resilient to extreme weather events, such as drought.

Lastly, we also contribute to the literature addressing the efficiency of fiscal management in achieving social and economic development. In public management, efficiency involves optimizing the use of resources, achieving the maximum possible provision of public goods and services in both quantitative and qualitative terms (Hauner and Kyobe, 2010). This article documents that municipalities with better fiscal management practices moderate the effects of drought occurrences on infant mortality. As a policy recommendation, the research suggests that institutions promoting fiscal soundness can contribute to addressing aggregated exogenous shocks, such as the occurrence of natural disasters.

The remainder of this article is structured as follows. Section 2 discusses the economic, social, and demographic characteristics of the Northeast Region of Brazil, our study area. Section 3 describes the data used in the research and provides descriptive analysis. Section 4 outlines the empirical strategy adopted. Section 5 discusses our main results, the analysis of heterogeneous effects, and robustness. Finally, Section 6 presents the main conclusions.

2.2 BACKGROUNDS

2.2.1 The Brazilian Northeast Region

The Brazilian Northeast comprises nine states and 1,794 municipalities, primarily small-scale jurisdictions focused on agriculture and livestock, with a total area of 1,558,000 km² (around 18% of the Brazilian territory) and a population density of 39.64 inhabitants/km². The majority of its territory is located in the semi-arid region, characterized by scarce, irregular precipitation concentrated within a short period, and average precipitation levels below potential evapotranspiration. These factors contribute to the constant risk of water scarcity, soil degradation, and desertification.

The Northeast Region of Brazil also faces significant socio-economic challenges, including high illiteracy rates, low-income levels, social exclusion issues, and poorer health outcomes, among others. The majority (59.1%) of Brazilians living in extreme poverty reside in the region, with over half (52.5%) of these individuals residing in rural areas. Regarding age, four out of every ten people in extreme poverty are aged between 0 and 14 years old (IBGE, 2010).

Despite a decreasing trend in recent years, with a reduction in infant mortality from 19.1 to 15.2 deaths per thousand live births between 2010 and 2019, the Brazilian Northeast still exhibits one of the highest rates in Brazil, surpassing the national average of 13.3 deaths per thousand live births in 2019 (Brazilian Ministry of Health, 2021). Additionally, the proportion of people without medical health insurance in the Northeast is close to 90% - that is, almost nine out of ten people are dependent on the public health system when they are sick (IBGE, 2019).

Drought occurrences in the Northeast Brazil are recurrent and a natural phenomena. The region experiences two well-defined seasons: the rainy season (December to May), with particularly high precipitation levels from February to April, and the dry season (June to November), characterized by very low monthly precipitation. Drought events typically occur when rainfall during the rainy season is unexpectedly low and irregular (Marengo et al., 2018; Rocha and Soares, 2015).

Historically, drought events in the Northeast Brazil have led to massive losses in agricultural and livestock production, loss of human lives due to famine, malnutrition, and diseases, as well as migration and impacts on local economies (Villa, 2000; Marengo et al., 2016). Figure 1 illustrates the standardized deviation of annual precipitation from the historical average between 1940 and 2019 for the Northeast Region. It is evident that periods of extreme

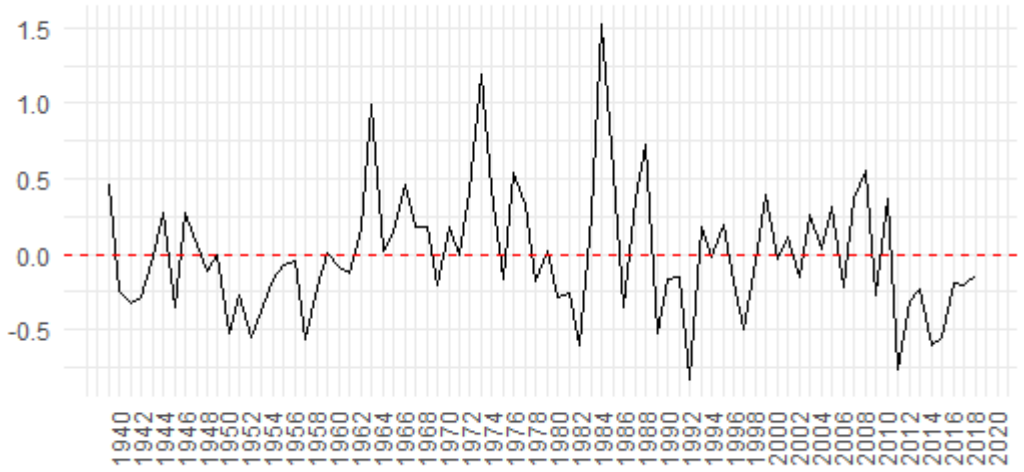
rainfall shortage have been frequent in recent decades, supported by available historical records, including severe droughts in the periods of 1951-1953, 1958, early 1980s, early 1990s, 1998, and more recently, between 2012 and 2017 (SUDENE, 1981; Marengo et al., 2018; Wilhite et al., 2014; Santana et al., 2020).

Particularly, the drought from 2012 to 2017 is considered one of more severe in recent decades. According to the Brazilian Ministry of Integration, during this period, 33.4 million people were affected by the drought, with an estimated loss of R$ 104 billion (approximately US$ 30.0 billion). Moreover, during the same period, over 6,000 states of public calamity (disaster declarations) were issued by Northeast municipalities due to the extreme drought (BRAZIL, 2023), and various municipalities sought federal public assistance to mitigate its impact.

The combination of the geographical, social, and economic characteristics of the Brazilian Northeast makes this territory one of the most susceptible to climate change worldwide (IPCC, 2014). Climate change projections indicate that the region will experience reduced rainfall and increased aridity in the second half of this century (IPCC 2012, 2014; Marengo and Bernasconi, 2015; Vieira et al., 2015). Additionally, water supply in the Region is severely affected by periods of low precipitation, as high evapotranspiration rates and geological characteristics[23] hinder water retention, compromising the livelihood, well-being, and health of families, in particular, individuals in vulnerable conditions.

[23] With low runoff volumes, the Brazilian Northeast, particularly the semi-arid region, features a meager river network. This is attributed to the variability of rainfall over time and the composition of the soil, predominantly shallow and comprised of crystalline rocks. The soil formation results in minimal water accumulation and limited exchange between rivers and adjacent soil, leading to a dense network of intermittent rivers (Rocha and Soares, 2015). Additionally, groundwater wells typically exhibit low flow rates and provide water with high salinity levels (Cirilo, 2008).

Figure 1 - Standardized deviation of annual precipitation from the historical average (1940 to 2019) in Brazilian Northeast Region



Source: Elaborated by the authors
Note: Figure 1 presents the standardized deviation of annual precipitation in relation to the historical average for the Brazilian Northeast region. The historical average is calculated based on the period from 1940 to 2019 and with annual precipitation data from the Global Climate Monitor, from the Climate Research Group at the University of Seville.

2.3 DATA

2.3.1 Data

2.3.1.1 Infant Health Data

To assess the effects of drought shocks and local fiscal conditions during the gestational period on infant health variables, we used microdata from the Information System on Deaths (*Sistema de Informações sobre Mortalidade* - SIM) and the Information System on Live Births (*Sistema de Informações sobre Nascidos Vivos* - SINASC), provided by the Brazilian Ministry of Health[24].

The Information System on Deaths compiles data on all officially registered deaths in Brazil, providing information such as the cause of death, date of birth, municipality of birth, municipality of residence, among others. We selected all deaths of individuals up to one year of age born in the Northeast Region of Brazil between 2014 and 2019) and constructed a municipality-by-month of birth panel for the period 2014-2019. This panel contains information on the number of infant deaths (total and by cause of death) and the number of fetal deaths.

[24] Information on live births records and deaths can be accessed at https://datasus.saude.gov.br/.

In turn, the Information System on Live Births provides information on all live birth records in Brazil, including details such as birth weight, gestational age, Apgar score[25], and type of delivery. The database also offers information such as the exact date of birth, municipality of birth, mother's municipality of residence, as well as sociodemographic characteristics of the newborn (gender and color/ethnicity) and the mother (age, education, and marital status). We also constructed a municipality-by-month of birth panel for the Northeast Region for the period 2014 to 2019, containing information on the number of births, average birth weight, average Apgar score, average gestation period, and the percentage of cesarean deliveries.

In both cases, the reference municipality in the panel is the municipality where the mother resides. According to Rocha and Soares (2015), this is crucial because the municipality of birth may be related to the availability of medical facilities in a specific area, such as when mothers travel between municipalities to give birth in a hospital. Additionally, the period 2014-2019 was chosen due to constraints in data availability to reconcile our analysis across all utilized data sources.

2.3.1.2 Local Fiscal Conditions Outcomes

To measure the local fiscal situation, we used the Firjan Fiscal Management Index (IFGF) for all municipalities in the Northeast Region for the period between 2013 and 2019[26]. The IFGF is developed annually by the Federation of Industries of the State of Rio de Janeiro (*Federação das Indústrias do Estado do Rio de Janeiro* - FIRJAN), a private non-profit organization, aiming to contribute to the debate on the fiscal situation of Brazilian municipalities, with a focus on the management of public resources by local governments.

In general, the IFGF aims to depict the challenges faced in municipal resource management, considering the budgetary limitations confronted by Brazilian municipalities. On the revenue side, the issue involves assessing the municipalities' dependence on intergovernmental transfers. On the expenditure side, the challenge is to evaluate the management of current expenses (especially personnel expenses and debt charges), given that budget rigidity resulting from their high weight in the budgets of Brazilian municipalities can compromise funds earmarked for other purposes, particularly investments. Furthermore, it was

[25] The Apgar score assesses the immediate vital signs of the newborn based on five criteria: skin color, heart rate, breathing, reflex irritability, and muscle tone. Each criterion is assigned a score ranging from zero to two, with a maximum cumulative score of 10 points.

[26] The IFGF has been available for public consultation since 2013 and can be accessed at https://www.firjan.com.br/ifgf/.

observed that many municipalities defer expenses by recording accounts payable without cash coverage, as an alternative form of indebtedness, thus generating a liquidity problem (FIRJAN, 2016).

To effectively encompass all these issues, the IFGF consists of four indicators: Autonomy, Personnel Expenditures, Investments, and Liquidity. The Autonomy indicator refers to the municipality's ability to finance its administrative structure, assessing the degree of dependence of city halls on transfers from states and the federal government. The Personnel Expenditures indicator relates to the concept of budgetary rigidity and indicates the maneuvering space of municipal budgets for the implementation of public policies, especially investments. The Investments indicator measures the portion of municipal budgets allocated to investments, thus referring to the municipality's capacity to generate well-being and competitiveness. Lastly, the Liquidity indicator examines the relationship between the total accounts payable accumulated in the year and the financial assets available to cover them in the following fiscal year, aiming to assess whether municipalities are deferring payment of expenses to the subsequent year without proper coverage.

The score for each of these indicators ranges from 0 to 1, and the general index is obtained by averaging the four indicators, each carrying an equal weight of 25%. As the IFGF comprises revenue and expenditure indicators, for standardization purposes, Firjan performed a parameterization, such that the analysis follows the principle of the higher the indicator, the better the municipality's result. Thus, the closer to unity, the better the fiscal situation of the municipality in that indicator and the general index.

It is important to highlight that the IFGF possesses attributes that make it a robust tool for efficiently measuring the fiscal situation of Brazilian municipalities. Firstly, the index aligns with all guidelines of the Fiscal Responsibility Law (*Lei de Responsabilidade Fiscal* - LRF). Established with the purpose of providing guidance for the administration of public finances, the Fiscal Responsibility Law outlines the need for a deliberate and transparent approach to prevent potential risks and non-conformities that may compromise the stability of public accounts (BRAZIL, 2000). Thus, the IFGF is relevant in its formulation by considering the key issues addressed in the LRF and is entirely constructed based on official fiscal results declared by the municipalities themselves to the National Treasury Secretariat (STN)[27].

[27] The Fiscal Responsibility Law (LRF), in its Article 51, mandates that municipalities submit their accounts to the National Treasury Secretariat (STN) by April 30 of the year following the reference fiscal year. From that point, the agency has 60 days to make them available to the public through the Brazilian Public Sector Accounting and Fiscal Information System (Siconfi).

Second, the IFGF has national coverage and annual comparison, making it a supportive tool for public officials across the country to manage their accounts efficiently, while also serving as a tool for social control by citizens over the administration of public resources.

Finally, the IFGF comprises four indicators that enable a comprehensive analysis of the municipal fiscal situation. Although the general index covers the main issues reflecting the fiscal scenario of a municipality efficiently, it is particularly important to separately evaluate the core of each of these issues for the efficient administration of public resources. We used each of the IFGF indicators to assess the effects of drought shocks moderated by municipal fiscal conditions during the gestational period on infant mortality.

2.3.1.3 Cimate Data

To measure drought exposure, we utilized data from the Global Climate Monitor, a global climatic geovisualizer that explores multiple sources of climate data and provides georeferenced global climate data accessible from 1901. It was developed by the Climate Research Group of the University of Seville and is licensed under a Creative Commons Attribution-ShareAlike 4.0 International License (Camarillo-Naranjo et al., 2018). This information source offers monthly values of precipitation (mm) and air temperature (°C) worldwide for a latitude and longitude grid of 0.5 x 0.5 degrees. We employed monthly precipitation and average temperature at the municipal level for the Northeast Brazil.

Our drought exposure measure follows the strategy employed by Rocha and Soares (2015), who investigate the occurrence of a drought episode before an individual's birth. Thus, we define a drought episode as follows:

$$Drought_{i\tau} = 1 \quad if \quad \sum_{t=-11}^{\tau} r_{it} < \left(\overline{r_i} - r_i^{SD}\right), \qquad \text{and 0 otherwise,} \qquad (1)$$

where r_{it} indicates the monthly rainfall in municipality i and month t; $\overline{r_i}$ and r_i^{SD} are, respectively, the average historical yearly rainfall and the historical yearly standard deviation of rainfall for municipality i, and τ indicates an individual's month of birth. Thus, $Drought_{i\tau} = 1$ indicates that precipitation in the 12 months prior to an individual's birth was more than one standard deviation below the historical average for municipality i. As suggested by Rocha and Soares (2015), the mother's nutritional status immediately before conception is also crucial in determining birth outcomes. Therefore, in our drought exposure measure, we consider the 12 months preceding birth instead of the conventional 9 months (average gestation period). Historical average precipitation and historical standard deviation of precipitation are calculated

for each municipality in the period from 1983 to 2012. We also compute the average monthly temperature in the 12 months prior to birth to use it as a climate control.

2.3.1.4 Additional Data

We also use additional data to robustness checks and heterogeneous effects analyses of our main results. We used data from the 2010 Brazilian Census, made available by Brazilian Institute of Geography and Statistics (*Instituto Brasileiro de Geografia e Estatística* - IBGE), to obtain information on: municipal population, average per capita household income, Gini index, illiteracy rate and proportion of elderly individuals. From IBGE, we also use information on municipal GDP in 2013 and geographic variables, such as altitude, longitude and latitude. Finally, we obtain the Human Development Index (HDI), available in the Atlas of Human Development in Brazil.

2.3.2 Descriptive Statistics

Table 1 presents the descriptive statistics for our sample. In it, we observe that the average number of infant deaths is 0.38, with an infant mortality rate of 13.85 per 1000 births. The main cause of infant mortality is affections of perinatal origin, which represents more than half of the causes of infant deaths. The infant mortality rate caused by intestinal infections and malnutrition is 0.24 and 0.14 per 1000 births, respectively. We also observed that the average number of births per month is 28.61, the average birth weight is 3.2 kg and that 89% of births, on average, occur after 36 weeks of gestation. Additionally, the percentage of APGAR scores below 8 is 15% and, on average, 48.7% of births are cesarean deliveries.

Regarding the fiscal conditions of municipalities, we find that, on average, the general index is 0.31. Analyzing each of the indicators that make up the general index separately, we observe that the Investment and Liquidity indicators are the indicators that the ones that municipalities have the highest average scores. The Autonomy indicator, on the other hand, has the lowest average in our sample.

Finally, concerning the climatic factors in our dataset, we observe that the average incidence of rainfall in a typical 12-month period is 866.3 mm. The average temperature is 25.85 ºC. Our drought measure corresponds, on average, to 27% of the observations in our sample. Figure 2 presents the geographical distribution of the percentage of months that a municipality was affected by our drought measure for each year of the sample, highlighting how the intensity of the drought episode varies geographically over the years. We observe a significant spatial variability in the occurrence of droughts over the years, with periods of

widespread droughts that persist throughout the year and periods when municipalities are not affected by drought in any month. We also note that the years 2015, 2016, and 2017 had the highest incidence of severe drought. Particularly in 2016, more than half of the municipalities in our sample were affected by drought for at least 6 months.

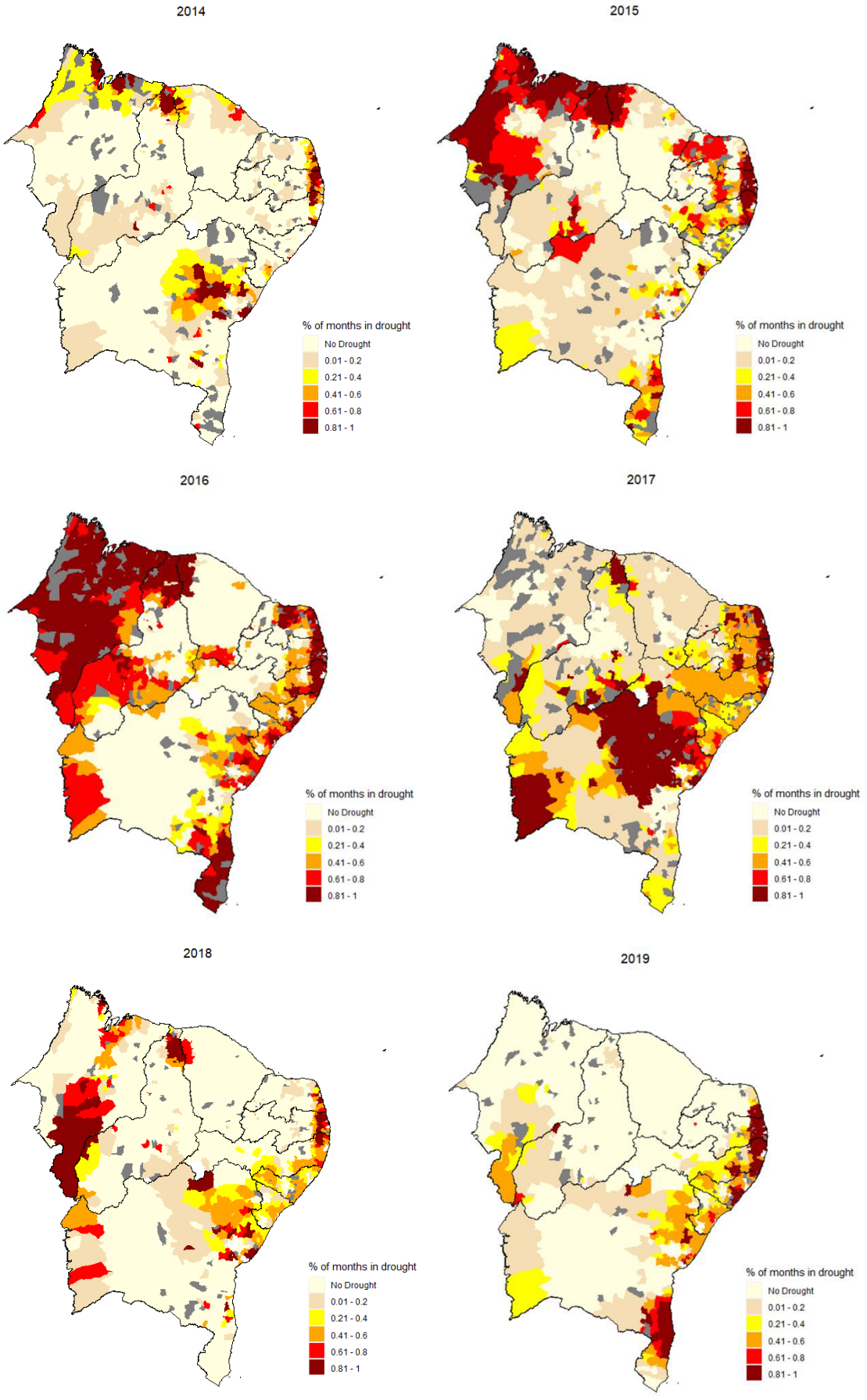
Table 1 – Descriptive Statistics: monthly data from municipalities 2014–2019, Northeast Region of Brazil.

Variables	Mean	Std. Deviation	Min	Max	N
Births and health indicators per month of birth					
Number of births	28.61	42.12	1	429	118,809
Birth weight	3233	194.6	390	5480	118,809
Low birth weight (<2500g)	0.0737	0.0882	0	1	118,809
% of births occurring after 36 weeks of gestation	0.890	0.110	0	1	118,76
APGAR 1	8.223	0.980	0	68.42	118,313
Low APGAR 1 (<8)	0.150	0.157	0	1	118,313
% Cesarean	0.487	0.215	0	1	118,809
Number of infant deaths	0.383	0.842	0	15	118,809
Number of fetal deaths	0.375	0.805	0	12	118,809
Infant mortality rate per month of birth (up to age 1, per 1000)					
Total infant mortality	13.85	40.39	0	1000	118,809
Intestinal infections	0.246	4.455	0	333.3	118,809
Malnutrition	0.140	3.967	0	500	118,809
Respiratory infections	0.771	9.426	0	1000	118,809
Affections of perinatal origin	7.816	30.67	0	1000	118,809
Congenital malformations	2.616	17.41	0	1000	118,809
Other causes	2.264	15.86	0	1000	118,809
Fetal mortality	13.08	35.05	0	666.7	118,809
Local Fiscal Conditions					
IFGF General	0.311	0.163	0	0.986	114,15
IFGF Autonomy	0.0814	0.199	0	1	114,15
IFGF Personnel Expenditures	0.286	0.313	0	1	114,15
IFGF Investments	0.443	0.270	0	1	114,15
IFGF Liquidity	0.435	0.330	0	1	114,15
Drought indicators per month					
Drought in the past 12 months	0.270	0.444	0	1	118,809
Rainfall in the past 12 months (in mm)	866.3	381.1	77.60	3623	118,809
Average temperature in the past 12 months (in ºC)	25.85	1.815	20.70	30.15	118,809

Source: Elaborated by the authors

Note: Table 1 presents descriptive statistics for all variables used in our main specification. Monthly observations by municipality, from 2014 to 2019. Data originally from: (i) the Information System on Live Births (SINASC); (ii) the Information System on Deaths (SIM); (iii) the Federation of Industries of the State of Rio de Janeiro (FIRJAN); and (iv) the Global Climate Monitor, from the Climate Research Group at the University of Seville.

Figure 2 - Percentage of drought months in the year (2014 – 2019)



Source: Elaborated by the authors
Note: Figure 2 shows the geographic distribution of municipalities according to the percentage of months during the year (2014 - 2019) that the municipality was exposed to drought episodes. According to our measure, a drought episode is recorded if precipitation in the 12 months preceding the birth date was more than one standard deviation below the historical average for the municipality. We used monthly precipitation data from the Global Climate Monitor, from the Climate Research Group at the University of Seville. The gray areas represent the municipalities that were excluded from the sample.

2.4 EMPIRICAL STRATEGY

The main goal of this study is to analyze if the local fiscal condition contributes to mediating the impacts of the drought episodes on infant health outcomes during the gestational period. Thus, our empirical analysis consists to understand how the causal relationship between drought shock and infant health indicators varies with the fiscal situation of municipalities. The following equation summarizes our econometric strategy:

$$y_{imt} = \alpha + \beta_1 Drought_{imt} + \beta_2 FiscalCond_{imt} + \beta_3 (Drought_{imt} \times FiscalCond_{imt}) + \pi Temp_{imt} + \phi_{im} + \lambda_t + \varepsilon_{imt} \quad (2)$$

where the dependent variable y_{imt} denotes the health outcomes (municipality average) for children born in municipality i, on month m and year t. We focus our analysis on the infant mortality rate, but also examine other health outcomes, such as birth weight, gestational duration, and Apgar score, in addition to the infant mortality rate by cause of death and fetal mortality rate.

Our main exploratory variables are defined as follows: $Drought_{imt}$, a dummy variable indicating the occurrence of a drought episode in the 12 months prior to birth. It takes a value of one for municipalities where precipitation in the 12 months prior to birth was more than one standard deviation below the historical average, and zero otherwise. $FiscalCond_{imt}$, a continuous variable ranging from 0 to 1, representing the fiscal situation of the municipality in the 12 months prior to the birth date. It is derived from the Firjan Fiscal Management Index (IFGF), considering its general index and its four indicators - Autonomy, Personnel Expenditure, Investments, and Liquidity. The term $(Drought_{imt} \times FiscalCond_{imt})$ represents the interaction between the drought shock and the local fiscal situation. We include the municipality's average temperature in the same 12 months before birth, $Temp_{imt}$, as a control, thereby accounting for other climate variations potentially correlated with local precipitation.

The main parameter of interest is β_3, which indicates how the relationship between the drought shock and infant mortality changes based on the local fiscal situation. Our hypothesis

is that the sign of the estimated parameter is negative, suggesting that the effect of the drought shock on infant mortality is lower in municipalities without fiscal constraints.

There are several reasons to believe that municipalities with better fiscal conditions may mitigate the effects of drought shocks on infant health outcomes. First, and perhaps the most critical factor, is that municipalities with fiscal constraints have more limited budgets to deal with the quality of prenatal and postpartum care, negatively impacting the provision of maternal and neonatal health services. In fact, a lack of resources can result in the reduction or elimination of specific maternal health programs, including awareness campaigns, education, pregnant women screening, and basic healthcare. Moreover, health conditions related to drought, such as dehydration, infections, and exposure to extreme weather conditions, may increase the need for prenatal and postpartum care. Second, during drought periods, health needs may escalate due to conditions related to water and food scarcity. Fiscal constraints can limit municipalities' capacity to allocate resources to effectively respond to health emergencies associated with droughts. Lastly, municipalities with unfavorable fiscal conditions may restrict investments in water supply and sanitation systems. During droughts, water quality may be compromised, increasing the risk of waterborne diseases that can affect pregnant women and newborns. For all these reasons, it is believed that municipalities without fiscal restrictions are likely to mitigate the impacts of drought shocks on infant health outcomes.

Finally, we included municipality-by-month of birth fixed-effects ϕ_{im} and year of birth fixed effects λ_t to our specification. Municipality-by-month fixed effects control for influences related to specific climatic or socioeconomic conditions in certain periods within a given municipality. Thus, recurrent level effects - potentially associated with rainy and dry seasons, harvests, availability of food, etc. - are all washed away in the municipality-by-month fixed effects. Year fixed effects, in turn, control for all unobserved characteristics that vary from year to year and affect health outcomes across all municipalities. This helps account for general temporal trends that impact all municipalities and are not directly related to the drought shock. The term ε_{imt} represents the random error.

Given that the precision of infant mortality measures and other variables associated with birth health is reduced in situations of lower birth numbers, we weight observations by considering the monthly birth average in the municipality (calculated over the entire sample period). Additionally, considering that large urban centers may present distinct characteristics and exert a significant influence on weighted regression results, we follow the strategy of Rocha and Soares (2015) by excluding the top 1% of municipalities from the sample, based on the

distribution of the number of births (above 429 births per month). We cluster standard errors at the municipality level.

2.5 RESULTS

2.5.1 Main Results

Table 2 presents the estimation of the impact of the drought shock during the gestational period mediated by the local fiscal condition on the infant mortality rate in municipalities of the Northeast region. Column (1) presents a specification that includes municipality-by-month of birth fixed-effects and year of birth fixed effects. In column (2), we exclude municipalities in the top percentile of the number of births (above 429), as they are likely large urban centers, and the effects of low precipitation levels would not significantly affect such municipalities, and the results we explore should not be so relevant. Finally, column (3) presents our main specification, in which we include the control for the average temperature in the 12 months prior to birth. This is done to ensure that the observed effect is not attributable to more overarching climatic conditions. Standard errors are reported in parentheses, clustered at the municipal level.

We observe that in all specifications, the coefficient of the iterated term between the drought shock and the local fiscal condition presents a negative sign, suggesting that the effect of a drought episode during gestation on infant mortality is smaller in municipalities with a better fiscal situation. However, in none of the cases were the estimates statistically significant. Thus, at first, there seems to be no evidence that the local fiscal situation is relevant to mitigate the effects of the drought on infant mortality. Recently, Barros et al. (2022) demonstrated that municipalities with greater fiscal capacity were able to expand their healthcare services and facilities to address the challenges posed by the Covid-19 pandemic. This underscores the significance of local fiscal conditions in dealing with crises, whether they be pandemics, as in the case of Covid-19, or of other natures such as natural disasters (droughts, floods, earthquakes), and recessions.

Nevertheless, as mentioned earlier, our measure of local fiscal condition is assessed by a composite index that encompasses four indicators – Autonomy, Personnel Expenditure, Investments, and Liquidity. While the general index efficiently reflects the fiscal scenario in which a municipality is situated, it is pertinent to analyze each indicator individually to gain a more comprehensive understanding of the context in which the fiscal conditions of municipalities, as mediators of the effects of drought on infant mortality, are embedded. Thus,

we estimate specification (1) by considering each of the four indicators separately as a measure of local fiscal condition. Table 3 displays the results of this estimation.

Table 2 - Effect of drought shock mediated by local fiscal condition on infant mortality rate

Variables	Infant mortality rate		
	(1)	(2)	(3)
Drought	0.301	0.425	0.343
	(0.363)	(0.372)	(0.377)
Fiscal condition	1.225*	1.122	1.098
	(0.659)	(0.738)	(0.737)
Drought × Fiscal condition	-0.717	-1.185	-1.160
	(0.826)	(0.944)	(0.946)
Observations	119,922	118,706	118,706
R-squared	0.192	0.190	0.190
Municip × month of birth FE	YES	YES	YES
Year FE	YES	YES	YES
Exclude top 1% in number of births	NO	YES	YES
Temperature Control	NO	NO	YES

Source: Elaborated by the authors

Note: Table 2 presents the estimates of the iterated effect of the local fiscal condition and the drought shock during the gestational period on the infant mortality rate. All regressions include municipality-by-month of birth fixed-effects and year of birth fixed effects, and are weighted by the average number of births per month in the municipality. In columns (2) and (3), we exclude municipalities in the top percentile of the number of births. Column (3) shows our main specification in which we include the control for the average temperature in the 12 months prior to birth. Standard errors are clustered at the municipal level and reported in parentheses. Significance: *** 1%, ** 5%, and * 10%.

In Table 3, it is possible to observe that the coefficient of the interaction term between the drought shock and local fiscal condition is negative when considering the Autonomy, Personnel Expenditure and Investments indicators, while for the Liquidity indicator, the coefficient shows a positive sign. In all these cases, only the estimates for the Autonomy and Personnel Expenditure indicators were statistically significant. The Autonomy indicator refers to the municipality's ability to finance its administrative structure, assessing the degree of dependence of city halls on transfers from states and the federal government. The Personnel Expenditure indicator, in turn, is related to the concept of budgetary rigidity and indicates the maneuvering space of municipal budgets for implementing public policies. Therefore, considering these two concepts, it is evident that the effect of the drought shock on infant mortality is reduced in areas with a higher local fiscal condition.

Two of the most striking characteristics of the Brazilian fiscal federalism, which hinder the channeling of resources for certain public policies, are the high budgetary rigidity and the low self-financing capacity of municipalities (Orair and Albuquerque, 2017). Our findings

suggest that the capacity for financial autonomy of municipalities plays a strategic role in building resilience and response capability during economic crises, such as those resulting from droughts. Thus, we observe that municipalities with greater capacity to finance their administrative structure are less subject to variations in infant mortality due to drought occurrences, indicating that fiscal autonomy provides the flexibility needed to make quick and effective decisions, contributing to mitigating adverse impacts and promoting local sustainability. This result aligns with De Oliveira et al. (2022), who found that a higher proportion of own revenues in relation to total revenues is associated with reducing the impacts of natural disasters.

Some recent evidence has shown that budgetary rigidity can constrain budget consolidation, especially when rigid components exceed what the structure of their economies would require (Muñoz and Olaberria, 2019; Masuya and Yoshida, 2020). A high level of budget rigidity is associated with more inefficient levels of public spending, reducing the quality of public services and, therefore, the well-being of the population (Herrera and Olaberria, 2020; Mattina and Gunnarsson, 2007). Considering the Personnel Expenditure indicator as a measure of local fiscal situation, our results demonstrate that municipalities with greater fiscal space tend to reduce the impact of drought shocks on infant mortality.

Thus, more rigid budget structures can limit municipalities' capacity to allocate resources for public health services, indirectly affecting pregnant women's access to prenatal care, safe delivery, postnatal care, and child health services. In this sense, our findings align with Ribeiro and Gasparini (2022), who observed that the lack of municipal budgetary flexibility negatively influences the public investment capacity of Brazilian municipalities. Beyond this perspective, budgetary rigidity can also leave less room in municipal budgets for adjustments during crises. This may limit municipalities' ability to respond to unforeseen demands during droughts.

Table 4 investigates how the local fiscal condition contributes to mediating the impacts of drought shocks during the gestational period on infant mortality, considering the main causes of mortality and other birth health outcomes. Here, we use the general index as a measure of the local fiscal situation. Panel A displays the results for the fetal mortality rate and the infant mortality rate by cause of death, considering: intestinal infections, malnutrition, respiratory infections, perinatal conditions, congenital malformations, and other causes.

Table 3 - Effect of the drought shock mediated by the local fiscal condition on the infant mortality rate considering the indicators of Autonomy, Personnel Expenditure, Investments and Liquidity

Variables	Infant mortality rate			
	(1)	(2)	(3)	(4)
	Autonomy	Personnel Expenditures	Investments	Liquidity
Drought	0.198	0.224	0.0933	-0.321
	(0.245)	(0.269)	(0.383)	(0.302)
Fiscal condition	0.575	0.849**	-0.419	0.257
	(0.743)	(0.356)	(0.455)	(0.358)
Drought × Fiscal condition	-1.124*	-1.026*	-0.307	0.626
	(0.604)	(0.591)	(0.659)	(0.505)
Observations	118,706	118,706	118,706	118,706
R-squared	0.190	0.190	0.190	0.190
Municip × month of birth FE	YES	YES	YES	YES
Year FE	YES	YES	YES	YES
Exclude top 1% in number of births	YES	YES	YES	YES
Temperature Control	YES	YES	YES	YES

Source: Elaborated by the authors

Note: Table 3 presents the estimates of the iterated effect of the local fiscal condition and the drought shock during the gestational period on the infant mortality rate considering the indicators of Autonomy, Personnel Expenditure, Investments and Liquidity as measures of the local fiscal condition. Standard errors are clustered at the municipal level and reported in parentheses. Significance: *** 1%, ** 5%, and * 10%.

We observe in Panel A of Table 4 that when considering the causes of infant mortality, only the coefficient of the interaction term between drought shock and local fiscal condition for perinatal conditions is negative and statistically significant. Perinatal conditions are related to medical conditions or complications that occur during the perinatal period, which covers the end of pregnancy and the first weeks after birth. This period is critical for the baby's development and health, involving the third trimester of pregnancy, childbirth, and the early postnatal life. Preventing, early diagnosis, and proper treatment of these conditions are crucial for ensuring maternal and neonatal health. Regular prenatal care, diagnosis of pregnancy-related changes, care during labor, and neonatal assistance are essential components of perinatal care.

In this sense, the main challenges leading to unfavorable pregnancy outcomes are associated with deficiencies in prevention and response to complications during pregnancy, childbirth, and the postpartum period, coinciding with the perinatal period (BRAZIL, 2012). Our results align with this perspective, indicating that municipalities with better fiscal conditions tend to reduce the impact of drought shocks on infant mortality caused by perinatal conditions. Municipalities with fiscal constraints have more limited budgets to deal with

prenatal, childbirth, and newborn care, negatively impacting the provision of maternal and neonatal health services, especially during droughts. Recent evidence has shown that efficient prenatal care services have mitigated the effects of extreme weather events on neonatal health outcomes (Banerjee and Maharaj, 2020; Abiona and Ajefu, 2023; Ha, 2022). We did not find significant effects on fetal mortality.

In Panel B of Table 4, the results for other birth variables are presented, including: birth weight (g), the percentage of low birth weight (<2500g), the percentage of births occurring after 36 weeks of gestation, APGAR score (0-10), the percentage of low APGAR (<8), and the percentage of cesarean sections. No significant results were found for any of these variables, except for birth weight, which showed a negative sign contrary to expectations.

In the Appendix, Tables A.1 and A.2 present the same results as shown in Table 4, considering the local fiscal situation by the indicators of Autonomy and Personnel Expenditure, respectively. It is observed that when considering the Autonomy indicator as the local fiscal condition, none of the causes of infant mortality and neither the fetal mortality rate are statistically significant when evaluating the coefficient of the iterated term between drought shock and fiscal situation. Regarding other infant health outcomes, only the APGAR score was positive and statistically significant. Finally, when considering the Personnel Expenditure indicator, Table A.2 shows that the results are similar to when considering the general index, where among all the variables considered, only infant mortality caused by perinatal conditions is negative and statistically significant when evaluating the iteration between drought shock during the gestational period and the local fiscal condition.

Table 4 - Effect of drought shock mediated by local fiscal condition on infant mortality by cause of death, on the fetal mortality and other birth outcomes

Panel A — Infant mortality rate by cause of death and Fetal mortality rate

VARIABLES	(1) Intestinal	(2) Malnutrition	(3) Respiratory	(4) Perinatal	(5) Congenital	(6) Other causes	(7) Fetal mortality
Drought	0.0250	-0.0255	-0.0662	0.469	-0.0713	0.0118	0.135
	(0.0515)	(0.0375)	(0.0968)	(0.289)	(0.171)	(0.150)	(0.365)
Fiscal condition	0.158	0.0303	0.265	0.770	0.211	-0.336	-0.695
	(0.0980)	(0.0749)	(0.181)	(0.572)	(0.324)	(0.294)	(0.690)
Drought × Fiscal condition	-0.0936	-0.0484	-0.0855	-1.558**	0.291	0.334	-0.168
	(0.123)	(0.0878)	(0.235)	(0.732)	(0.431)	(0.364)	(0.897)
Observations	118,706	118,706	118,706	118,706	118,706	118,706	118,706
R-squared	0.180	0.182	0.181	0.185	0.179	0.179	0.189

Panel B — Other birth outcomes

VARIABLES	(8) Birth weight	(9) % Low birth weight	(10) % of gestation over 36 weeks	(11) APGAR 1	(12) % Low APGAR 1	(13) % Cesarean	
Drought	4.108*	-0.000201	0.000783	0.0129	0.00213	-0.00696**	
	(2.267)	(0.000977)	(0.00138)	(0.0230)	(0.00252)	(0.00305)	
Fiscal condition	4.376	-0.00105	-0.000658	-0.0557*	0.0129	-0.00119	
	(5.024)	(0.00194)	(0.00357)	(0.0296)	(0.00897)	(0.00773)	
Drought × Fiscal condition	-11.11*	0.000314	0.00141	-0.00642	-0.00878	0.00644	
	(6.394)	(0.00251)	(0.00324)	(0.0515)	(0.00633)	(0.00904)	
Observations	118,706	118,706	118,657	118,210	118,210	118,706	
R-squared	0.282	0.205	0.265	0.598	0.543	0.665	
Municip × month of birth FE	YES	YES	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES	YES
Exclude top 1% in number of births	YES	YES	YES	YES	YES	YES	YES
Temperature Control	YES	YES	YES	YES	YES	YES	YES

Source: Elaborated by the authors

Note: Table 4 presents the estimates of the iterated effect of the local fiscal condition and the drought shock during the gestational period on the infant mortality by cause of death, on the fetal mortality and other birth outcomes. Standard errors are clustered at the municipal level and reported in parentheses. Significance: *** 1%, ** 5%, and * 10%.

2.5.2 Heterogeneous Effects

In this section, we investigate some heterogeneous effects of the impact of drought shock during the gestational period mediated by the local fiscal situation on infant mortality. First, we assess the occurrence of drought shocks considering different trimesters of pregnancy.

Subsequently, we characterize the municipalities according to their population and explore the analyzed effects according to the population size of the municipalities. We measure the heterogeneous effect by estimating the same empirical strategy adopted previously.

2.5.2.1 Timing in pregnancy of drought

In Table 5, we explore the impact of the drought shock mediated by the local fiscal situation in different periods of pregnancy. To do so, we divide the precipitation variable according to the trimester of the gestational period and verify the occurrence of drought at each of these moments. The gestation trimesters can be classified as: pre-conception (one trimester before the beginning of pregnancy), embryonic (first trimester), fetal development (second trimester), and perinatal period (third trimester).

A range of recent studies has explored the impact of extreme climatic events in different phases of the gestational period (Kumar et al., 2016; Rocha e Soares, 2015; Diamond-Smith et al., 2023). Our results, observed in Table 5, suggest that the occurrence of drought in the first trimester of gestation (embryonic period) has a positive and statistically significant effect on infant mortality, and this effect is attenuated in municipalities without fiscal restrictions. In other words, we find evidence that municipalities with better fiscal conditions are less susceptible to variations in infant mortality due to drought shocks occurring during the first trimester of gestation.

During the first trimester of pregnancy, the major organs of the fetus are forming. Thus, dehydration and lack of nutrients associated with drought can increase the risk of complications. Additionally, maternal malnutrition during this critical stage of fetal development can have long-term impacts. Kumar et al. (2016) found that in utero exposure to drought in the first trimester of gestation is the most critical period for child growth. Rocha and Soares (2015), in turn, highlight the relevance of water availability during the early stages of embryo development and organ formation (first two trimesters of gestation). Our findings are aligned with these results, showing that drought occurrence in the first trimester of gestation increases infant mortality in municipalities in the Brazilian Northeast. Furthermore, we emphasize the importance of local fiscal condition as a measure to mitigate the effects of drought during this period.

Table 5 - Effect of drought shock mediated by local fiscal condition on infant mortality rate by trimester of gestation

Variables	Infant mortality rate			
	(1) Trimester before conception	(2) Embryonic	(3) Fetal	(4) Perinatal
Drought	0.0295	1.630***	-0.0857	-0.829
	(0.491)	(0.536)	(0.523)	(0.514)
Fiscal condition	0.771	0.995	0.909	0.663
	(0.712)	(0.697)	(0.709)	(0.697)
Drought × Fiscal condition	-1.372	-3.309**	-0.636	1.056
	(1.193)	(1.347)	(1.363)	(1.331)
Observations	116,132	116,144	116,168	116,162
R-squared	0.193	0.193	0.194	0.193
Municip × month of birth FE	YES	YES	YES	YES
Year FE	YES	YES	YES	YES
Exclude top 1% in number of births	YES	YES	YES	YES
Temperature Control	YES	YES	YES	YES

Source: Elaborated by the authors
Note: Table 5 presents estimates of the iterated effect of the local fiscal condition and the drought shock on the infant mortality rate considering the drought shock in each trimester of pregnancy. The drought shock for each trimester of gestation is calculated in the same way as the standard drought measure, considering the sum of precipitation in each trimester. Standard errors are clustered at the municipal level and reported in parentheses. Significance: *** 1%, ** 5%, and * 10%.

2.5.2.2 Population Size of Municipalities

We also examined the heterogeneous effect when considering the population size of municipalities. The capacity to invest in water infrastructure, health, education, and other services is often greater in municipalities with a more significant population. Drought shocks can impact the availability of these services, and heterogeneity should be taken into account when assessing these effects.

We grouped municipalities in the Northeast region according to population size and classified them as: 1) Small-sized population municipalities - those with a population of less than 20 thousand inhabitants; 2) Medium-sized population municipalities - those with a population greater than 20 thousand and less than 40 thousand inhabitants; and 3) Large-sized population municipalities - those with a population greater than 40 thousand inhabitants. Based on this classification, we assessed the effect of drought shocks mediated by the local fiscal situation on infant mortality according to the population size of municipalities. The results are presented in Table 6.

We observe from Table 6 that the coefficient of the term iterated between the drought shock and the local fiscal condition is negative for small and medium-sized municipalities; however, it is statistically significant only for medium-sized population municipalities. For municipalities with a population above 40 thousand inhabitants, the coefficient of interest showed a positive sign and was not statistically significant.

Our findings suggest that the fiscal condition is relevant to mitigate the effects of drought shocks on infant mortality, especially in medium-sized population municipalities. A plausible explanation for this result is that small-sized population municipalities are usually subject to having more limited budgets and, consequently, have a lower capacity to provide emergency public policies in cases of economic downturns, such as droughts. On the other hand, large-sized population municipalities tend to have more developed infrastructures and a broader supply of public services, making the effects of droughts in these municipalities not as severe.

Table 6 - Effect of drought shock mediated by local fiscal condition on infant mortality rate by the population size of municipalities

Variables	Infant mortality rate		
	(1)	(2)	(3)
	Small-sized	Medium-sized	Large-sized
Drought	0.870	0.754	-0.0741
	(0.808)	(0.727)	(0.550)
Fiscal condition	0.669	2.269	0.798
	(1.462)	(1.470)	(1.057)
Drought × Fiscal condition	-0.831	-4.988**	0.0478
	(2.408)	(2.068)	(1.153)
Observations	79,074	25,512	14,120
R-squared	0.185	0.195	0.211
Municip × month of birth FE	YES	YES	YES
Year FE	YES	YES	YES
Exclude top 1% in number of births	YES	YES	YES
Temperature Control	YES	YES	YES

Source: Elaborated by the authors

Note: Table 6 presents estimates of the iterated effect of the local fiscal condition and the drought shock on the infant mortality rate considering the population size of the municipality. Standard errors are clustered at the municipal level and reported in parentheses. Significance: *** 1%, ** 5%, and * 10%.

2.5.3 Robustness Analysis

We conducted some analyses to assess the robustness of the findings. Firstly, we considered an alternative measure of drought shock. In our main specification, we defined a

drought shock during the gestational period as a binary variable that assigns a value of one to municipalities where precipitation in the 12 months prior to birth was more than one standard deviation below the historical average and zero otherwise. Now, as an alternative drought shock measure, we considered a continuous variable, also proposed by Rocha and Soares (2015), defined as the deviation between the natural logarithm of the total precipitation in the 12 months prior the individual's birth and natural logarithm of the municipality's historical average annual precipitation. Specifically, this alternative measure can be determined by the following equation:

$$Rainfall_{i\tau} = \ln(\sum_{t=\tau-11}^{\tau} r_{it}) - \ln(\overline{r_i}) \quad (3)$$

where r_{it} indicates the monthly precipitation in municipality i and month t, $\overline{r_i}$ indicates the historical annual average precipitation (from 1983 to 2012) in municipality i and τ refers to the birth month of an individual. Thus, the variable $Rainfall_{i\tau}$ can be interpreted approximately as the percentage deviation from the average precipitation, where a negative value of this measure means that the precipitation in the 12 months before an individual's birth was below the historical average. The estimation result for this alternative drought measure is presented in Table 7, where we consider the general index as a measure of the local fiscal situation in column (1), and in the other columns, we consider the four indicators of the general index.

In column (1) of Table 7, we observe that a negative deviation in precipitation during the gestational period increases infant mortality, but this effect is reduced with better fiscal conditions in the municipality. However, similar to what was found when considering the discrete drought shock, this result is not statistically significant. When considering the local fiscal situation by the indicators of Autonomy, Personnel Expenses, Investments, and Liquidity, respectively, we observe a pattern similar to what was found in Table 3 when considering the discrete drought shock. We find that the coefficient of the term iterated between the drought measure and the local fiscal situation indicates that municipalities without fiscal restrictions reduce the effects of negative deviations in precipitation during the gestational period on infant mortality when considering the Autonomy, Personnel Expenses, and Investments indicators, while the opposite was observed when considering the Liquidity indicator. However, in all these cases, only the estimates for the Autonomy indicator were statistically significant.

Table 7 - Effect of drought shock mediated by local fiscal condition on infant mortality rate considering a measure of continuous drought

Variables	Infant mortality rate				
	(1)	(2)	(3)	(4)	(5)
	General	Autonomy	Personnel Expenditures	Investments	Liquidity
Rainfall	-0.590	-0.542	-0.463	-0.0605	0.555
	(0.657)	(0.443)	(0.459)	(0.628)	(0.537)
Fiscal condition	1.100	0.762	0.881**	-0.504	0.182
	(0.765)	(0.747)	(0.384)	(0.464)	(0.368)
Rainfall × Fiscal condition	1.684	2.627**	1.624	0.0883	-1.268
	(1.648)	(1.057)	(1.064)	(1.120)	(0.836)
Observations	118,706	118,706	118,706	118,706	118,706
R-squared	0.190	0.190	0.190	0.190	0.190
Municip × month of birth FE	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES
Exclude top 1% in number of births	YES	YES	YES	YES	YES
Temperature Control	YES	YES	YES	YES	YES

Source: Elaborated by the authors

Note: Table 7 presents estimates of the iterated effect of local fiscal condition and drought shock on the infant mortality rate considering a measure of continuous drought, defined as the deviation between the natural logarithm of total precipitation in the 12 months prior to the individual's birth and the natural logarithm of the municipality's historical average annual precipitation. Standard errors are clustered at the municipal level and reported in parentheses. Significance: *** 1%, ** 5%, and * 10%.

In addition to the alternative drought shock, we provide several other sensitivity tests to check the robustness of our main findings. The results of the estimates considering these tests are presented in Table 8. In column (1), we consider precipitation from the 9 months before the individual's birth instead of the 12 months previously defined in our standard drought shock. Also, in column (2), we examine a broader window of precipitation concerning the birth date, considering 18 months before in our main drought measure. We can observe that when considering the precipitation of the 9 months before birth, the interaction coefficient between the drought shock and the local fiscal situation maintains the pattern observed in our main estimates. However, when considering in our drought shock measure the 18 months before the birth date, the same pattern is not observed, going in the opposite direction to our main findings. This result can be seen as an indication that drought occurrence during the gestational period affects infant mortality, not its occurrence in periods prior to pregnancy.

In Table 8, we also tested whether the addition of municipal control variables affects our results. We added socioeconomic and geographic control variables to our main specification. The socioeconomic variables considered were: GDP per capita, per capita income, Gini index, Human Development Index, percentage of elderly, and illiteracy rate. As

geographic variables, we added altitude, longitude, and latitude. In column (3), we can see that the addition of socioeconomic and geographic controls does not alter our main results.

We also tested the inclusion of non-linearities in the variable of the average temperature of the 12 months before the date of birth. In particular, we included the square and cube of the average temperature in the main regression. The estimates reported in column (4) of Table 8 do not differ from our main result, suggesting that the estimates are robust to the introduction of additional control variables.

Table 8 - Robustness Check

Variables	Infant mortality rate			
	(1)	(2)	(3)	(4)
Drought	0.373	-0.260	0.371	0.353
	(0.421)	(0.793)	(0.379)	(0.377)
Fiscal condition	1.043	0.742	0.967	1.105
	(0.952)	(0.683)	(0.750)	(0.736)
Drought × Fiscal condition	-0.455	0.341	-1.081	-1.182
	(1.071)	(2.050)	(0.946)	(0.949)
Observations	118,706	118,706	118,706	118,706
R-squared	0.190	0.190	0.190	0.190
Municip × month of birth FE	YES	YES	YES	YES
Year FE	YES	YES	YES	YES
Exclude top 1% in number of births	YES	YES	YES	YES
Temperature Control	YES	YES	YES	YES

Source: Elaborated by the authors

Note: Table 8 presents robustness exercises for the estimates of the main outcome. Four robustness exercises are conducted. The first two exercises consider precipitation from the 9 months and 18 months, respectively, prior the individual's birth instead of the 12 months as defined in our standard drought shock. In the third, we include socioeconomic and geographical variables as controls in our main specification. Finally, in the fourth, we test the non-linearity of the average temperature control. Standard errors are clustered at the municipal level and reported in parentheses. Significance: *** 1%, ** 5%, and * 10%.

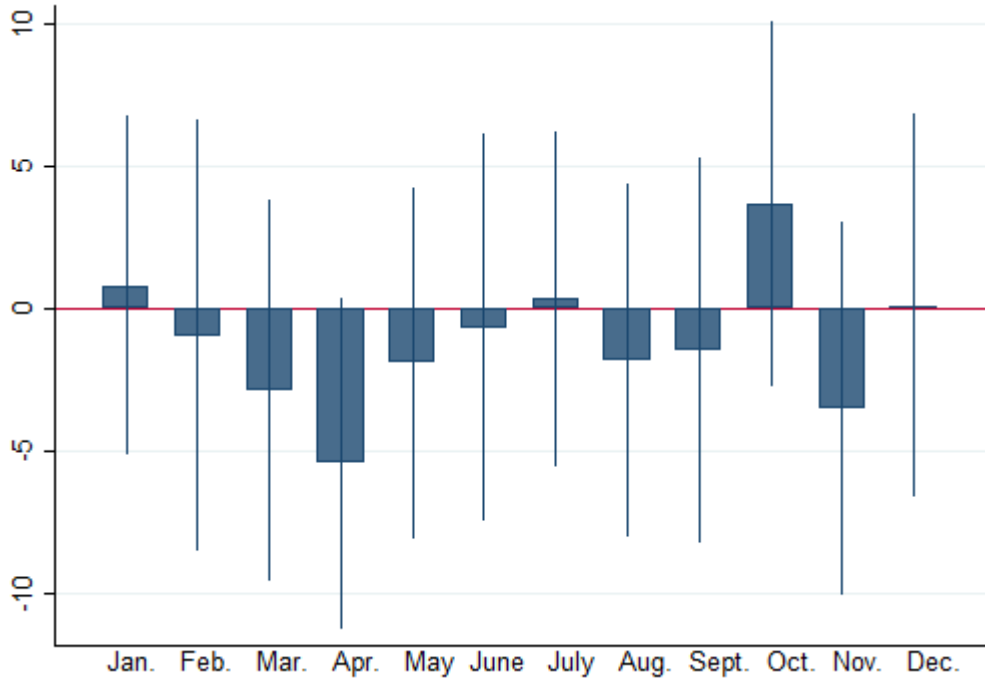
Another important aspect to be considered in our analysis concerns the specific timing of the drought shock impact. To address this aspect, we will undertake two analyses. First, we will examine the iterated effect of the drought shock in conjunction with the local fiscal situation on infant mortality throughout the months of the year. Subsequently, we conduct a year-by-year analysis to examine the temporal dynamics of this effect. We present both results graphically.

Figure 3 presents the results of our analysis across the months. We observe that for most months of the year (except for January, July, October, and December), the iterated effect between the drought shock and the local fiscal situation has a negative impact on infant mortality. However, this effect is significant only for the month of April. When considering the

rainy seasons (from December to May) and the dry season (from June to November), characteristic of the Northeast region of Brazil due to the predominance of a semi-arid climate, we find that the negative effects of the iteration between the local fiscal condition and the drought shock are concentrated on births occurring during the rainy season (mainly between March and May). For individuals born at the end of the rainy season, the first trimester of pregnancy would have occurred during the dry season. Thus, the fiscal condition of municipalities seems to be relevant, especially in mitigating the effects of drought during the dry season that impact later periods of pregnancy and, consequently, infant mortality.

Finally, the results of the year-by-year analysis of the iterated effect of the local fiscal situation and the drought shock on infant mortality are presented in Figure A.1 in the Appendix. It can be observed that the iterated effect was not significant in any of the years when analyzed separately.

Figure 3 - Iterated effect of drought shock and local fiscal condition on the infant mortality rate by month of birth



Source: Elaborated by the authors
Note: Figure 3 presents the iterated coefficient between the drought shock and the local fiscal condition on the infant mortality rate by month of birth. We considered the estimation of the main specification with a fixed-effects of municipality instead of a municipality-by-month of birth fixed-effects. The lines represent the confidence interval (95%) and the bars the magnitude of the estimation coefficient for each month.

2.6 FINAL REMARKS

The present study aimed to assess the importance of municipal fiscal capacity as a mediator of the effects of exposure to drought shocks on infant health outcomes in the Northeast region of Brazil. To do so, we compared municipalities that were exposed to drought shocks during the gestational period with those that did not experience such exposure, incorporating local fiscal condition as a moderating factor in this analysis.

The results suggest that municipalities with better fiscal situations tend to mitigate the adverse effects of in utero exposure to drought shocks on infant mortality caused by perinatal conditions. We also found that municipal fiscal capacity is a relevant factor in mitigating the effects of drought shocks during the gestational period on infant mortality when considering fiscal autonomy and budgetary rigidity indicators as measures of fiscal condition. Additionally, we found that the occurrence of drought in the first trimester of gestation has a positive and statistically significant effect on infant mortality, and this effect is mitigated in municipalities with better fiscal conditions. Finally, we demonstrate that the iterated effect between municipal fiscal capacity and exposure to drought during the gestational period is negative and significant in medium-sized municipalities.

This article sheds light on the importance of local fiscal conditions in coping with aggregate exogenous shocks, such as the occurrence of natural disasters. It is emphasized that a solid fiscal foundation not only strengthens the financial resilience of local communities in the face of adverse events but also plays a crucial role in the ability to implement effective response measures, ensuring the continuity of essential services. Furthermore, it highlights the need for policies that promote fiscal autonomy for local entities, providing them with the flexibility and resources necessary to address unforeseen challenges that can significantly impact the well-being of the local population, especially concerning the reduction of infant mortality associated with adverse natural events.

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APPENDIX

Table A.1 - Effect of drought shock mediated by the Autonomy indicator on infant mortality by cause of death, fetal mortality and other birth outcomes

Panel A — Infant mortality rate by cause of death and Fetal mortality rate							
VARIABLES	(1) Intestinal	(2) Malnutrition	(3) Respiratory	(4) Perinatal	(5) Congenital	(6) Other causes	(7) Fetal mortality
Drought	0.00554	-0.0377	-0.0621	0.0495	0.0757	0.167*	0.228
	(0.0336)	(0.0247)	(0.0575)	(0.184)	(0.106)	(0.101)	(0.228)
Fiscal condition	0.0733	0.0680	0.198	0.346	0.191	-0.301	-0.695
	(0.0802)	(0.0616)	(0.145)	(0.600)	(0.366)	(0.267)	(0.615)
Drought × Fiscal condition	-0.0553	-0.0196	-0.149	-0.502	-0.213	-0.186	-0.674
	(0.0670)	(0.0454)	(0.132)	(0.485)	(0.271)	(0.205)	(0.497)
Observations	118,706	118,706	118,706	118,706	118,706	118,706	118,706
R-squared	0.180	0.182	0.181	0.185	0.179	0.179	0.189

Panel B — Other birth outcomes							
VARIABLES	(8) Birth weight	(9) % Low birth weight	(10) % of gestation over 36 weeks	(11) APGAR 1	(12) % Low APGAR 1	(13) % Cesarean	
Drought	0.668	0.000107	0.00112	-0.00516	0.000319	-0.00511***	
	(1.291)	(0.000536)	(0.000906)	(0.00645)	(0.00154)	(0.00158)	
Fiscal condition	5.892	-0.00114	-0.000490	0.0122	-0.000389	-0.0100	
	(4.958)	(0.00213)	(0.00341)	(0.0731)	(0.00888)	(0.00859)	
Drought × Fiscal condition	-1.624	-0.000903	0.000640	0.0705**	-0.00516	0.00166	
	(3.702)	(0.00139)	(0.00204)	(0.0347)	(0.00435)	(0.00566)	
Observations	118,706	118,706	118,657	118,210	118,210	118,706	
R-squared	0.282	0.205	0.265	0.598	0.543	0.665	
Municip × month of birth FE	YES	YES	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES	YES
Exclude top 1% in number of births	YES	YES	YES	YES	YES	YES	YES
Temperature Control	YES	YES	YES	YES	YES	YES	YES

Source: Elaborated by the authors

Note: Table 4 presents the estimates of the iterated effect of the local fiscal condition and the drought shock during the gestational period on infant mortality due to death, on fetal mortality and other birth outcomes, considering the Autonomy indicator as a measure of condition local tax. Standard errors are clustered at the county level and reported in parentheses. Significance: *** 1%, ** 5% and * 10%.

Table A.2 - Effect of drought shock mediated by the Personnel Expenditure indicator on infant mortality by cause of death, fetal mortality and other birth outcomes

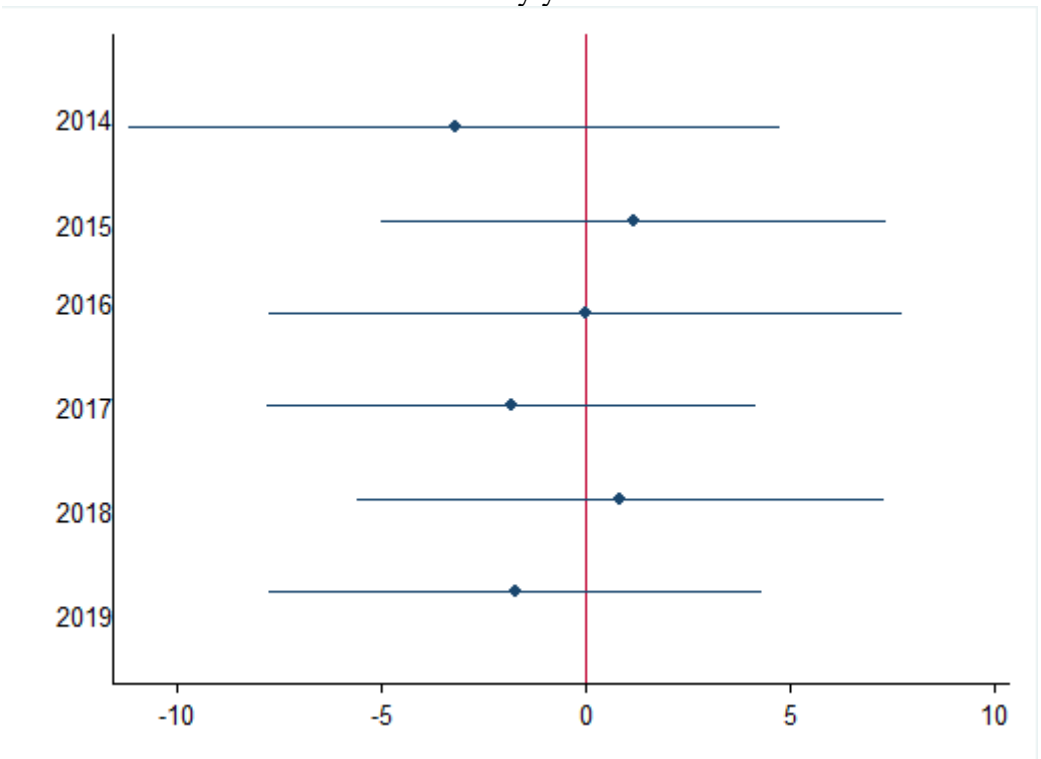
Panel A — Infant mortality rate by cause of death and Fetal mortality rate							
VARIABLES	(1) Intestinal	(2) Malnutrition	(3) Respiratory	(4) Perinatal	(5) Congenital	(6) Other causes	(7) Fetal mortality
Drought	0.0207	-0.0193	-0.0560	0.236	-0.0521	0.0947	-0.00545
	(0.0344)	(0.0242)	(0.0631)	(0.194)	(0.113)	(0.102)	(0.230)
Fiscal condition	0.0596	0.000897	0.141	0.518*	0.100	0.0295	-0.697**
	(0.0476)	(0.0347)	(0.0882)	(0.281)	(0.149)	(0.149)	(0.355)
Drought × Fiscal condition	-0.102	-0.0856	-0.144	-1.117**	0.307	0.116	0.295
	(0.0756)	(0.0555)	(0.146)	(0.451)	(0.229)	(0.250)	(0.587)
Observations	118,706	118,706	118,706	118,706	118,706	118,706	118,706
R-squared	0.180	0.182	0.181	0.185	0.179	0.179	0.189

Panel B — Other birth outcomes						
VARIABLES	(8) Birth weight	(9) % Low birth weight	(10) % of gestation over 36 weeks	(11) APGAR 1	(12) % Low APGAR 1	(13) % Cesarean
Drought	1.370	-9.41e-05	0.00110	0.0262	-0.000966	-0.00399**
	(1.368)	(0.000591)	(0.000991)	(0.0229)	(0.00170)	(0.00172)
Fiscal condition	-1.019	0.000161	-0.000706	-0.0112	0.00389	0.00672*
	(2.334)	(0.000948)	(0.00198)	(0.0133)	(0.00343)	(0.00349)
Drought × Fiscal condition	-3.986	-5.24e-06	0.000599	-0.0591	0.000569	-0.00278
	(3.414)	(0.00141)	(0.00238)	(0.0603)	(0.00432)	(0.00429)
Observations	118,706	118,706	118,657	118,210	118,210	118,706
R-squared	0.282	0.205	0.265	0.598	0.543	0.665
Municip × month of birth FE	YES	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES
Exclude top 1% in number of births	YES	YES	YES	YES	YES	YES
Temperature Control	YES	YES	YES	YES	YES	YES

Source: Elaborated by the authors

Note: Table 4 presents the estimates of the iterated effect of the local fiscal condition and the drought shock during the gestational period on infant mortality due to death, on fetal mortality and other birth outcomes, considering the Personnel Expenditure indicator as a measure of condition local tax. Standard errors are clustered at the county level and reported in parentheses. Significance: *** 1%, ** 5% and * 10%.

Figure A.1 - Iterated effect of drought shock and local fiscal condition on the infant mortality rate by year



Source: Elaborated by the authors

Note: Figure 4 presents the iterated coefficient between the drought shock and the local fiscal condition on the infant mortality rate considering each year of the sample. We consider the main specification estimate for a simple regression for each year. The lines represent the confidence interval (95%) and the points represent the magnitude of the estimate coefficient for each year.

CHAPTER 3 - NATURAL DISASTERS AND LOCAL PUBLIC FINANCES: ANALYSIS OF A LONG-LASTING DROUGHT IN THE SEMIARID REGION OF NORTHEAST BRAZIL

3.1 INTRODUCTION

The incidence of natural disasters has affected different spheres of society, causing a series of challenges to social and economic development around the world, especially in a scenario where projections indicate an increase in climate changes (IPCC, 2012). These extreme natural events can cause damage to housing and infrastructure, human and social losses, halt economic activities, representing direct economic shocks to society, as well as a public problem that requires government interventions and imposes risks on the budgets of different levels of governments. Although the literature has highlighted the substantial social costs that natural disasters impose on federal governments through emergency response, humanitarian aid, and assistance for the recovery of affected communities (Deryugina, 2017; Miao, Hou, and Abrigo, 2018), there is limited evidence of the effects of extreme weather events on the finances of municipal governments.

Municipal governments are the main providers of essential public goods and services, which directly impact the lives of citizens at the closest governmental level, and are also primarily responsible for dealing with crises, such as the occurrence of natural disasters. In Brazil, the financing of these municipal operations is mainly based on the generation of local tax revenue and intergovernmental transfers from federal and state governments. These financial dynamics highlight the importance of understanding the budgetary implications of extreme weather events at the local level. Such events not only affect the municipal government's ability to provide essential goods and services, but also have distributional consequences (Jerch et al., 2023), unequally impacting different segments of the population.

The objective of this article is to contribute to this literature exploring the fiscal and budgetary implications of natural disasters at the local level, providing empirical evidence of the impact of a long-lasting drought on the finances of Brazilian municipalities. We focus our analysis on the semiarid region of Northeast Brazil, which is a region characterized by unfavorable socioeconomic conditions, with the highest concentration of individuals in extreme poverty in the country (IBGE, 2010). Additionally, this region is marked by low rainfall, low water retention by the soil and he recurrent occurrence of droughts, although persistent periods of drought are very rare.

From 2012 and 2017, the Brazilian semiarid region, especially in the Northeast, experienced an unprecedented and prolonged drought episode primarily caused by three exogenous factors: abnormally high sea surface temperature (SST), the successive events of La Niña (2010-2011) and El Niño (2015-2016). The combination of these factors produced a period of six consecutive years of drought in the region. We explore this unique and exogenous episode to estimate its impact on municipal budgets.

We employ a panel event study strategy to analyze the causal and dynamic effect of drought on municipal government finances. We compare (before and after) the fiscal and budgetary implications of municipalities with different intensities of drought shocks, while controlling for similar socioeconomic and geographic characteristics. Our identification assumption is that municipalities more exposed to the long-lasting drought period would exhibit a similar trend in outcomes to those less exposed in the absence of drought.

Our results indicate that the long-lasting drought shock leads to a decrease in current expenditures, which gradually intensifies in the early years of the drought and stabilizes in the final years. Additionally, we observe a significant and negative effect on specific expenditure categories, notably in public administration and legislation, culture and sports/leisure, and education. These findings suggest an adaptation by local governments to address the financial challenges imposed by drought, impacting even investments in priority areas, albeit to a lesser extent compared to other categories. We also find a negative effect on current revenues and transfer revenues in the initial years of the drought, although this effect is not statistically significant.

In addition to the main results, we document relevant heterogeneous effects. We observe that the effects of the prolonged drought shock on municipal budgets are concentrated in municipalities with a higher income level, primarily indicating a decline in current expenditures. Additionally, we find that municipalities with a higher proportion of individuals in poverty are significantly more affected by drought in terms of reducing current expenditures than municipalities with a lower poverty rate. This observation suggests that extreme weather events can cause disparities in fiscal outcomes for demographically different municipalities, emphasizing considerations of environmental justice in understanding who bears the costs of natural disasters.

The findings of this study contribute to two main strands of economic literature. The first strand refers to the economic impacts of natural disasters. Most of this literature has explored aggregate macroeconomic impacts, often at the country level (Schumacher and Strobl, 2011; Toya and Skidmore, 2007; Loayza et al., 2012). Assessment based solely on aggregate

effects, while relevant, may not fully reveal the real impact of these events, failing to provide a comprehensive understanding of which sectors and social groups are most affected. Our article analyzes the effects of a severe and prolonged drought on local-level public budgets in an area with high socioeconomic vulnerability. Thus, our results also inform about the distributive implications of extreme weather events.

Secondly, we contribute to the literature on public finance that analyzes the effects of economic shocks on public budgets (Skidmore and Scorsone, 2011; Shoag et al., 2019). Specifically, our work is related to the literature exploring the fiscal and budgetary consequences of natural disasters at the local level (Masiero and Santarossa, 2019; Miao et al., 2020; Jerch et al., 2023). Understanding how extreme weather events impact municipal budgets has relevant implications for equity, as it can disproportionately affect those who rely more on essential services and have limited resources to deal with climate-related adversities. Our article contributes to this literature by showing how a severe and persistent drought affects the expenditures and revenues of Brazilian municipalities in an area of high socioeconomic vulnerability.

The remainder of this study is structured as follows. Section 2 provides a literature review. Section 3 presents the characteristics of our study area and discusses the drought that occurred in the Brazilian semi-arid region from 2012 and 2017. Section 4 introduces the data and discusses the empirical strategy adopted. Section 5 analyzes and discusses the results, and Section 6 concludes the study.

3.2 LITERATURE REVIEW

The consequences of natural disasters have been studied in various aspects of economics, such as their effects on economic growth, income, the labor market, poverty, among others. Another aspect that has been the focus of interest in the literature is the fiscal and budgetary implications of natural disasters. As highlighted by Miao, Hou, and Abrigo (2018), the fiscal consequences of natural disasters are shaped by their direct effects on economic activities, as well as by disaster management policies, fiscal institutions, and other behavioral responses adopted by the government in response to these impacts. In this regard, this literature has documented mixed results depending on the context of each situation, such as the type and duration of the disaster, the level of development in the affected area, the capacity to mobilize resources, among others. Furthermore, most studies have concentrated on cross-national

analyses, with recent and growing research focusing on analyzing the fiscal effects of environmental shocks at the subnational level.

At the transnational level, various studies have investigated the consequences of extreme natural shocks on the finances of central governments. For instance, Lis and Nickel (2010) explored the impact of large-scale extreme weather events on changes in national public budgets and found a negative impact, with the fiscal effect of these disasters being approximately 0.23% of the gross domestic product (GDP). The study also suggests that developing countries face much larger budget deficits than developed countries after the occurrence of these events. In the same vein, Noy and Nualsri (2011) used quarterly data for a panel of forty-two countries and found that natural disasters lead to increased expenditures and decreased revenues in developed countries. However, developing countries respond to the occurrence of natural phenomena in a pro-cyclical manner, with a decrease in expenditures and an increase in revenues.

Examining a sample of high and middle-income countries from 1975 to 2008, Melecky and Raddatz (2014) investigate how different types of natural disasters (geological, climatic, and others) affect government expenditures, revenues, and fiscal deficits. Using a panel VAR model, the authors conclude that natural disasters, especially climate shocks, result in significant increases in budget deficits, with this effect being more pronounced in low-middle-income countries. Furthermore, they observe that the magnitude of disaster consequences in terms of budget deficits is mitigated by the presence of a more robust insurance protection. In turn, Ouattara and Strobl (2013) analyzed the fiscal effects in a group of eighteen Caribbean countries during the period from 1970 to 2006 and conclude that hurricanes led to a short-term increase in government expenditures but did not have significant effects on public investment, tax revenues or debt. Koetsier (2017) investigated the impact of natural disasters on the government accounts of 163 countries from 1971 to 2014. Applying a panel synthetic control methodology, the study finds a considerable increase in public debt following a natural catastrophe, except in the case of droughts. In contrast to other types of disasters, after a drought, there is a decline in public debt.

In the case of the fiscal implications of natural disasters at the subnational level, studies have focused their analyses on the self-financing capacity of local governments and/or their dependence on central government grants in post-disaster economic and social recovery. Miao, Hou, and Abrigo (2018) examined the fiscal implications of damages caused by natural disasters at the U.S. state level between 1970 and 2013. They found that natural disasters increased total expenditures of state governments and federal transfers to states, with little

impact on the states' own-source total revenues. This discovery suggests that the additional spending induced by disasters at the state level is primarily funded through federal transfers, which include not only humanitarian aid funds but also public social assistance unrelated to disasters. Similarly, Miao et al. (2020) examined the fiscal impact of natural disasters in a set of thirty Chinese provinces from 1994 to 2014. Using a panel VAR model, the study found that natural disasters increase a province's total government expenditures and intergovernmental revenues received from the central government, with little effect on its fiscal revenues. The authors also observed that governments of higher-income provinces in China experience larger increases in expenditures and intergovernmental transfers after natural disasters compared to governments of lower-income provinces.

Also, in a municipal-level study, Masiero and Santarossa (2019) explore fiscal data from Italian municipalities for the period between 2000 and 2015 to investigate the response of local government expenditures to the occurrence of earthquakes. They found that an earthquake increases local government expenditures immediately after the shock by around 2%, following an inverted U-shaped trend that persists for about 11-12 years after the disaster. This increase is primarily driven by financial transfers from central and regional governments. Additionally, the authors found asymmetric responses from conditional and unconditional resource transfers and heterogeneous "flypaper" effects across the country. From this same perspective, Morvan (2022) analyzed the effects of natural disasters on the public budgets of French municipalities and found evidence of increased expenditures for about 10 years after the disaster, along with increased revenues and debt. The study also observed that prevention allows municipalities to effectively mitigate the catastrophe's effect on public expenditure. Municipalities with an active natural disaster risk prevention plan did not increase their expenditures and long-term debt.

In contrast, Jerch et al. (2023) compared municipalities in the southeastern United States that were exposed to hurricanes against those that were not - within the same state - to estimate how the occurrence of hurricanes affects municipal budgets. The authors found that local governments experience declines in revenues, expenditures, and debts over the 10 years following a hurricane. These declines are initially offset by intergovernmental transfers soon after a hurricane but increase significantly after 6 to 10 years. It was also observed that declines in local revenues led to subsequent decreases in the provision of local public goods. Furthermore, the authors noted greater revenue and expenditure losses in public goods among local governments that are, on average, poorer, less educated, and have a higher percentage of racial minorities in the population.

Our paper falls within the literature aiming to assess the fiscal implications of natural disasters at the local level, as we evaluate the impact of a long-lasting drought on the budgetary behavior of Brazilian municipalities. Particularly, the literature addressing the effects of natural disasters on public finances in Brazil is still quite scarce. As exceptions, De Oliveira et al. (2020) demonstrated that improvements in tax collection and the efficiency of municipal public spending are associated with a lesser impact of natural disasters and De Oliveira et al. (2021) investigated the impacts of the state of abnormality declared by municipalities due to natural disasters on local public finances. The results of the latter show an increase in current expenditures and a reduction in tax revenues with the declaration of abnormality due to droughts and floods. However, there is also an observed increase in transfers to municipalities, as they start receiving discretionary funds from federal and state governments to mitigate the adverse effects of disasters, offsetting the decline in tax revenues and generating a positive balance in current revenues. Additionally, there is also a reallocation of municipal expenditures, as the local abnormal situation leads municipalities to increase per capita spending on social and health focuses while reducing per capita expenses on communication and transportation.

3.3 BACKGROUNDS

In this section, we provide a brief description of the social, economic, and demographic characteristics of the Semiarid Region of Northeast Brazil and discuss the determinants of the persistent drought that affected the region from 2012 and 2017.

3.3.1 The Semiarid Region of Northeast Brazil and the Drought of 2012-2017

The Semiarid Region of Northeast Brazil comprises 1,048 municipalities[28] and covers an area close to 900,000 km^2 (approximately 10% of the Brazilian territory). It is characterized by low rainfall, low water retention by the soil, and severe droughts. In 2010, the population of the region exceeded 20 million inhabitants (around 11% of the national population), making it the most densely populated area among drylands worldwide, with approximately 53% of its residents living in rural areas.

[28] In this study, we consider the delineation of the semiarid region from 2005, established by Ordinance No. 89, dated 16/03/2005, from the Ministry of National Integration, and remained in effect until 2017. The current delimitation of the semiarid region consists of 1,427 municipalities, with 1,212 of them belonging to the Northeast Region. For further information, please refer to: https://www.gov.br/sudene/pt-br/centrais-de-conteudo/02semiaridorelatorionv.pdf

Furthermore, the semiarid region of Northeast Brazil is characterized by low socioeconomic factors, where the illiteracy rate was approximately three times higher than the national level, and the per capita GDP was three times lower than the national level (Da Mata and Resende, 2020) and has the highest concentration of individuals in extreme poverty in the country (IBGE, 2010). The economy of the region still relies predominantly on extensive agricultural practices aimed at subsistence and animal husbandry, characterized by limited productivity and significant susceptibility to soil degradation.

In climatic terms, the semiarid region of Northeast Brazil is primarily characterized by scarce, irregular precipitation concentrated in a short period of time, with averages below potential evapotranspiration, elements that together contribute to the constant risk of water scarcity, soil degradation, and desertification. The combination of these characteristics makes this region one of the most vulnerable territories in the world to climate change (IPCC, 2014).

Drought is a natural and recurring phenomenon. Episodes of drought have plagued the semiarid region of Northeast Brazil since the 16th century, with devastating consequences such as mass migrations to other regions of the country, massive losses in agricultural production, famine, and deaths. Drought episodes in the semiarid area are often associated with large-scale phenomena, such as El Niño and La Niña events, or related to an intense meridional gradient of sea surface temperature (SST) over the tropical Atlantic (Marengo et al., 2018). Although droughts are common in the region, periods of persistent low rainfall (more than three consecutive years) are very rare.

From 2012 and 2017, the Brazilian semiarid region was impacted by a prolonged period of low precipitation. According to data from the Brazilian Ministry of Integration, during this period, approximately 33.4 million people were affected by drought, with estimated losses of R$ 104 billion (around US$ 30.0 billion). Table 1 shows the quantity of municipalities per state in the semiarid region of Northeast Brazil that declared a state of emergency due to drought or water scarcity between 2010 and 2017. It is observed that in 2012, the number of municipalities declaring a state of emergency increased by 850% compared to 2011 and around 150% compared to 2010, remaining elevated in the subsequent years, with at least 60% of municipalities issuing emergency declarations each following year. In 2013, for instance, 98% of municipalities in the Northeastern semiarid region had declared a state of emergency due to drought.

It is noteworthy that once a state of emergency is declared, municipalities may request additional support resources from the Federal Government for emergency response actions, such as the distribution of water by trucks (carros-pipa) in rural and urban areas affected by

drought. It is worth noting that, as outlined by the Federal Government, the state of emergency encompasses events classified as level I and II disasters, characterized by human, material, and environmental damages that can be promptly restored through local resources or made available by other federal entities. In contrast, level III disasters require the declaration of a state of public calamity, a condition only restorable to normalcy through the collaboration of all three government levels.

Table 1 - Number of municipalities per State in the Semiarid Region of Northeast Brazil that declared a state of emergency due to drought between 2010 and 2017.

State of the Northeast Semiarid	No. of municipalities in the semiarid	2010	2011	2012	2013	2014	2015	2016	2017
Alagoas	38	0	0	37	38	37	12	38	38
Bahia	265	83	52	86	254	182	246	189	246
Ceará	150	86	6	141	147	146	136	128	110
Paraíba	170	46	3	170	170	170	170	169	170
Pernambuco	122	26	13	112	121	119	12	120	121
Piauí	127	79	7	115	125	124	11	126	88
Rio Grande do Norte	147	0	0	129	144	146	22	147	147
Sergipe	29	5	4	17	27	16	13	23	22
Total municipalities	1.048	325	85	807	1026	940	622	940	942

Source: Elaborated by the authors using data from the Digital Atlas of Disasters in Brazil, from the Ministry of Integration and Regional Development

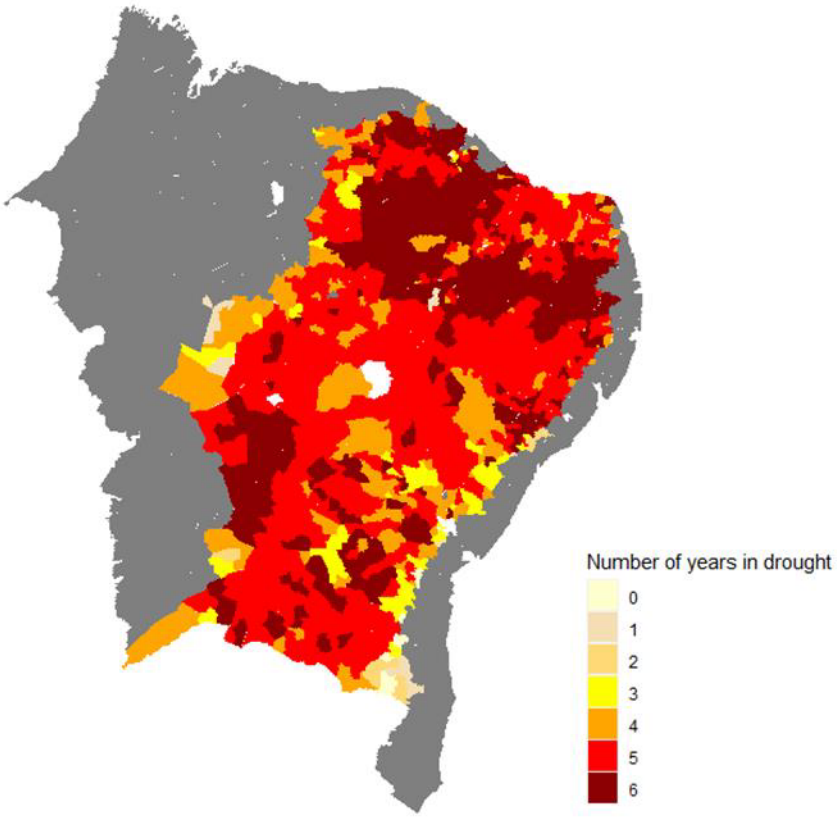
The drought from 2012 to 2017 was caused by a combination of three main factors that occurred sequentially during this period. First, the La Niña phenomenon, which began in 2012, triggered a reduction in rainfall below average between the years 2012 and 2014. Previously, from 2009 to 2010, the Atlantic Intertropical Convergence Zone (ITCZ) migrated to an atypical position, indirectly contributing to the scarcity of rainfall in the semiarid region (Rodrigues and McPhaden, 2014; Marengo and Bernasconi, 2015). Both of these events were followed by the El Niño of 2015-2016, extending the period of drought until 2017. The combination of these three factors is extremely rare. According to the National Institute of Meteorology (INMET), since tracking began in 1845, there had never been a period of six consecutive years with below-average rainfall and prolonged drought in the region, which already typically has a reduced rainfall index compared to other places in the country.

We analyzed how the budgets of municipalities were affected by the occurrence of this prolonged and unexpected period of drought. Figure 1 shows the geographical distribution of municipalities according to the number of years between 2012 and 2017 in which the municipality declared at least one state of emergency due to drought or water scarcity in the year. It can be observed that over 80% of municipalities declared a state of emergency due to

drought in at least 5 years of the period in question, highlighting the persistence and unpredictability of this event due to its extended duration.

The impacts of prolonged droughts not only affect human consumption but also impact productive activities, requiring immediate actions from local governments to mitigate their effects, as they are the government level closest to citizens and are on the front lines in managing these major climatic events and associated damages. Thus, this event is useful for exploring how municipalities reacted and adapted their budgets to cope with this potentially exogenous shock caused by global climate anomalies.

Figure 1 - Number of years from 2012 to 2017 in which a municipality declared at least one state of emergency due to drought



Source: Elaborated by the authors
Note: Figure 1 shows the geographical distribution of municipalities according to the number of years between 2012 and 2017 in which a municipality declared at least one state of emergency due to drought. We used data from the Digital Atlas of Disasters in Brazil, from the Ministry of Integration and Regional Development. The gray areas represent municipalities in the Northeast region that are not part of the semiarid region.

3.4 DATA AND EMPIRICAL STRATEGY

3.4.1 Data Base

In this study, we utilize three main datasets: (a) fiscal data from local governments, (b) climatic data to measure exposure to the drought shock, and (c) data on the socioeconomic characteristics of municipalities. The analysis period ranges from 2008 to 2019, thus covering both pre and post-drought periods. Our study area encompasses all 1,048 municipalities that make up the semiarid region in Northeast Brazil, according to the delineation established by Ordinance No. 89, dated 16/03/2005, from the Ministry of National Integration[29].

The fiscal information was obtained from the National Treasury Secretariat (STN), through the municipalities' accounting database - FINBRA (*Finanças do Brasil*) - for the years 2008 to 2019. Here, we collected information about our set of main dependent variables, namely: Current Expenditures, Investments Expenditures, Current Revenues, Tax Revenues, and Current Transfer Revenues. Information on expenses by functions was also obtained, including expenditures related to public administration and the legislature, social assistance and security, health, education, sanitation, agriculture, urbanism, transportation, culture, and sports/leisure, and communication. Finally, we also collected information on tax revenues from municipal taxes - Urban and Territorial Property Tax (IPTU), Service Tax (ISS), and Tax on Transmission of Real Estate (ITBI) - and current transfer revenues, broken down between those from the Union and State Governments. All these variables were deflated by the General Price Index - Internal Availability (IGP-DI), from the Getulio Vargas Foundation (FGV), based on 2019, and were adjusted on a per capita basis, based on the population of the municipalities available in FINBRA.

Regarding climate data, we used information obtained from the Global Climate Monitor, developed by the Climate Research Group at the University of Seville. The respective information source provides monthly and annual values of precipitation (mm) and air temperature (°C) worldwide for a latitude and longitude grid of 0.5 x 0.5 degrees. We used the annual accumulated precipitation for the period between 1950 and 2019 at the municipal level to measure our drought shock, as reported in the following subsection. We also used the average annual temperature of the municipalities between 2008 and 2019.

The municipality characteristics, including average household income, rural population, Gini index, unemployment rate, proportion of elderly, and proportion of poor, were collected

[29] The delimitation of the semiarid region from 2005 remained in effect until the year 2017. We chose to adhere to this delineation because it covers the period of the drought we are analyzing (2012–2017).

from the 2010 Brazil Demographic Census provided by the Brazilian Institute of Geography and Statistics (IBGE). We also used the Human Development Index (HDI) available in the Atlas of Human Development in Brazil. Additionally, we utilized annual municipal Gross Domestic Product (GDP) data from IBGE for the period between 2008 and 2019[30].

3.4.2 Measuring the Drought Shock

Our drought shock measure takes into account the chronic nature of this climatic phenomenon in our study area. As reported earlier, the semi-arid region is characterized by scarce, irregular rainfall concentrated in a short period, making drought a natural and recurrent event in the area. However, although droughts are common in the region, periods of persistent low rainfall are very rare, as in the case of the 2012-2017 drought, which lasted for six consecutive years with below-average rainfall and prolonged drought in the region.

In light of this, as we assess this prolonged and unexpected extreme climatic event, our drought shock measure is designed to capture the areas most and least exposed to this event, based on the strategy proposed by Oliveira (2021). Specifically, we measure drought based on the ratio between the average annual precipitation from 2012 to 2017 and the long-term average annual precipitation before the drought (1950-2011), obtained from the Global Climate Monitor. First, we measure the fluctuation of precipitation during the drought, defined by the following equation:

$$DS_i = 1 - \frac{\bar{R}_i^{12-17}}{\bar{R}_i^{hist}} \quad (1)$$

where $\bar{R}_i^{12-17}$ is the average rainfall intensity from 2012 and 2017 for municipality i, and $\bar{R}_i^{hist}$ is the historical average from 1950 and 2011 for municipality i. Thus, DS_i is defined as one minus the fraction between the average precipitation over the six drought years and the historical average precipitation in municipality i. When the value tends to one, it means that the municipality was heavily affected by the drought. However, when it tends to zero, it means that the municipalities did not experience a drop in rainfall compared to the historical average, while negative values indicate that the average precipitation between 2012 and 2017 exceeded the historical average. Panel (A) of Figure 2 shows the spatial distribution of municipalities according to DS_i. It can be observed that municipalities that were heavily affected by the prolonged drought are geographically close to less affected municipalities.

[30] We deflated the GDP using the implicit GDP deflator based on 2019 and adjusted it on a per capita basis.

Once the measure exploring the intensity of the 2012-2017 drought in municipalities is defined, we use the median of DS_i as a threshold measure to indicate the municipalities most and least exposed to the prolonged period of low precipitation. Thus, municipalities are considered highly exposed to drought (treated) if they are above the median of DS_i, while municipalities in the control group are considered less exposed to the prolonged drought, i.e., those below the median of DS_i. The idea of our identification strategy is to treat the drought as a negative shock that affected the entire semiarid region of northeastern Brazil, exploring its intensity through the exposure of municipalities to this event. Panel (B) of Figure 2 displays the spatial distribution of municipalities belonging to the treatment and control groups. It can be observed that municipalities with high and low exposure to drought are distributed throughout the entire semiarid region. There is a high concentration of highly exposed municipalities throughout the extended period of low precipitation in the northern part of the states of Bahia and Rio Grande do Norte. We tested an alternative threshold measure of DS_i for robustness.

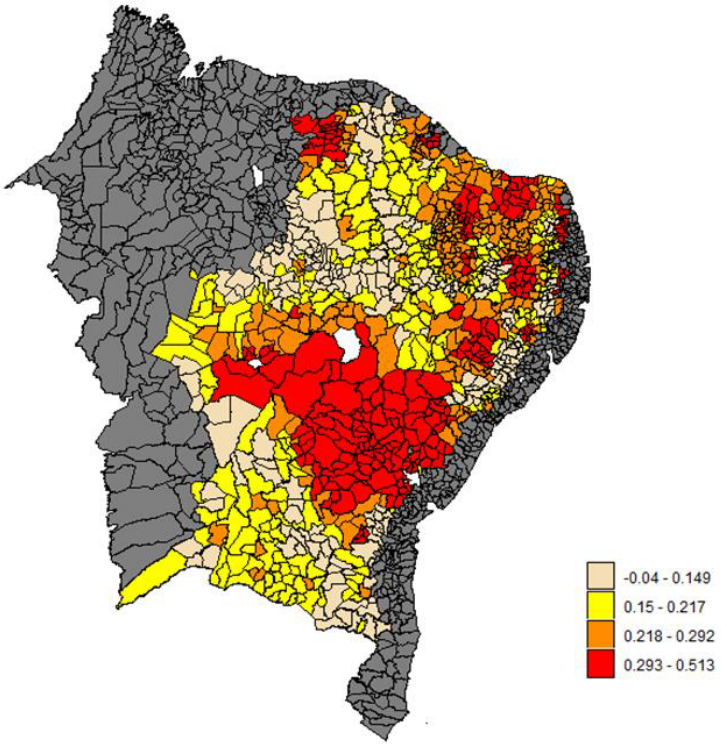
3.4.3 Descriptive Evidence

The drought did not spread uniformly across the semiarid region. As shown in panel (A) of Figure 2, it is evident that some areas were disproportionately affected compared to others. To understand how this prolonged extreme climatic event impacted the budgetary behavior of municipalities, we compared the municipalities that were more exposed to this event, that is, our treatment group, with those municipalities less exposed, the control group. Figure 3 illustrates the temporal evolution of our main budgetary variables for the different groups of municipalities.

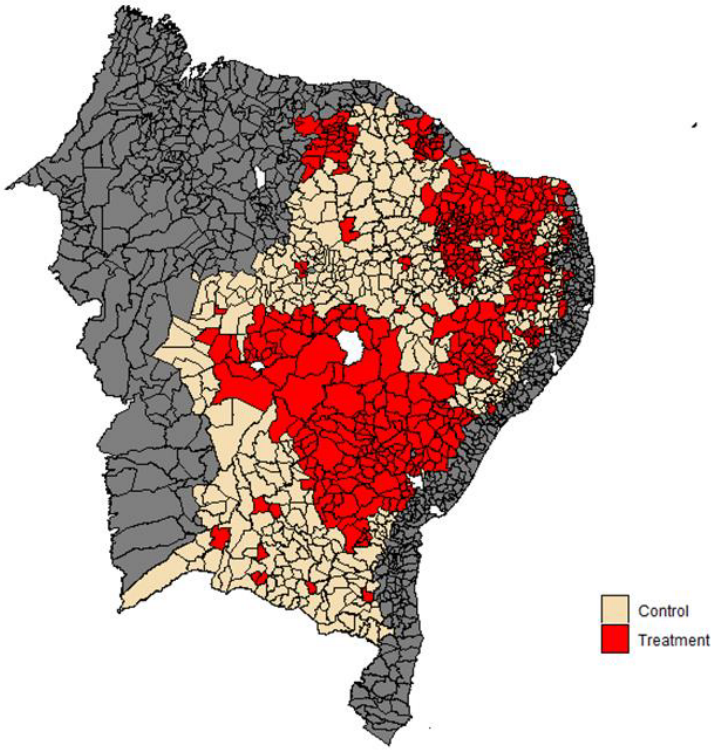
It can be observed from Figure 3 that the municipalities in the treatment group have, on average, higher current expenditures and revenues than the municipalities in the control group throughout the period in question. Transfer revenues from municipalities that were most exposed to the drought shock are also slightly higher than those from less exposed municipalities. In all the variables mentioned above, we can observe similar trends for both groups. For the investment and transfer revenue variables, we observed an alternation over the period between the groups of municipalities that have a higher average value, although their trends are also relatively similar between the two groups. However, it is noteworthy that in this first analysis, no variable is controlled, we observe all municipalities regardless of their characteristics.

Figure 2 – Maps of Drought Intensity and Treated vs. Control Municipalities

(A)



(B)



Source: Elaborated by the authors

Note: Figure 2 shows the geographic distribution of our measurement and drought. Panel (A) shows the intensity of the drought in the municipalities measured by DS_i. Panel (B) shows the municipalities most exposed to drought (Treated) and the municipalities least exposed (Control). The gray areas represent municipalities in the Northeast region that are not part of the semi-arid region and were not included in the sample.

Figure 3 - Local government per capita expenditures and revenues over time (2008–2019).

Source: Elaborated by the authors
Note: Figure 3 shows the temporal evolution of average per capita expenses and revenues of municipal governments (2008–2019). The graphs compare the group of municipalities most exposed to the drought shock (treatments - blue line) with the group of municipalities least exposed (control - red line). Panel (a) refers to Current Expenses, (b) Investment Expenses, (c) Current Revenues, (d) Tax Revenues, and (e) Current Transfer Revenues. All variables are deflated at 2019 prices.

Table 2 provides descriptive statistics for the two groups of municipalities in comparison. Regarding municipal expenditures, it is observed that, on average, municipalities in the treatment group have higher expenditures than municipalities in the control group in all expenditure categories, except for sanitation and transportation. It is also noted that

expenditures in education and health are the most representative expenditure categories among those considered. In terms of municipal revenue, it is found that for all revenue classes, municipalities more exposed to the drought period have higher average values compared to less exposed municipalities. It is further observed in both groups that transfer revenues represent about 93% of current revenues, and of these, just over 60% are related to transfers from the Federal Government, highlighting the high dependence of municipalities in the Northeast semi-arid region on Union transfers.

Regarding socioeconomic characteristics, it is observed that municipalities more exposed to the long-lasting drought shock have, on average, higher per capita GDP and household income than less exposed municipalities. Additionally, municipalities in the treatment group have, on average, a lower poverty rate, lower Gini index, and higher HDI than municipalities in the control group. On the other hand, less exposed municipalities have, on average, a lower unemployment rate. Regarding climatic characteristics, treated and control municipalities share the same average temperature during the analyzed period. However, as expected, municipalities that were more exposed to the drought shock had lower levels of accumulated precipitation than less exposed municipalities, on average.

These preliminary evidences suggest that comparing expenditures and revenues between municipalities more and less exposed to the extreme drought shock should carefully address differences in terms of characteristics that may confound the budgetary variations of municipalities. The following empirical strategy controls for these observable characteristics, as well as other time-invariant unobservable characteristics.

Table 2 - Descriptive Statistics: Municipality characteristics

Variables	Control Group			Treatment Group		
	N	Mean	Std. Deviation	N	Mean	Std. Deviation
Municipal Expenditure						
Current Expenditure	6,152	1,863	810.0	6,100	1,929	973.7
Investment Expenditure	6,135	161.8	153.0	6,081	163.0	145.8
Expenditure Categories: Public Administration and Legislature	5,832	375.9	254.5	5,697	384.2	274.8
Assistance and Social Security	2,761	171.0	131.3	2,457	187.7	131.5
Health	6,121	469.6	218.5	6,045	489.2	269.3
Education	6,123	748.5	302.7	6,054	755.2	331.6
Sanitation	3,786	38.42	93.50	3,214	34.69	63.83
Agriculture	5,626	32.54	48.84	5,626	39.82	56.31
Urbanism	6,033	156.8	122.0	5,975	179.1	148.6
Transport	4,601	26.22	37.15	3,986	24.23	39.84
Culture and Sports/Leisure	5,005	41.30	44.96	4,945	45.20	47.78
Communication	997	5.736	11.35	635	5.924	14.20
Municipal Revenues						
Current Revenues	6,151	2,136	952.2	6,099	2,227	1,154
Tax Revenues	6,142	69.06	69.65	6,092	75.59	110.3
ISS	6,009	34.61	56.25	5,903	41.21	96.20
IPTU	5,922	3.645	8.863	5,842	3.919	9.780
ITBI	5,813	2.520	5.623	5,709	2.611	8.149
Transfers Revenues	6,137	1995	898.5	6,084	2084	1078
Federal Transfers	6,138	1,242	664.0	6,081	1,317	759.0
State Transfers	6,099	233.0	191.2	6,016	259.6	402.0
Socioeconomic Characteristics						
GDP per capita	6,153	7,245	4,206	6,102	8,13	6,924
Median Income per capita	524	263.1	63.96	524	270.2	71.99
Gini Index	524	0.531	0.0453	524	0.522	0.0487
HDI	524	0.589	0.0359	524	0.591	0.0406
% Eldery Population	524	12.44	1.962	524	12.29	2.083
Rural Population	524	7727	6456	524	7687	7595
Unemployment Rate	524	7.377	3.318	524	7.832	3.743
Poverty Rate	524	41.95	9.075	524	40.31	10.16
Climate Characteristics						
Annual Precipitation	6,288	738.5	235.1	6,288	663.5	278.6
Average Temperature	6,288	25.50	1.678	6,288	25.51	1.426
Drought Shock (DS_i)	524	0.133	0.0708	524	0.306	0.0655
Municipalities	524			524		

Source: Elaborated by the authors

Note: Table 2 presents descriptive statistics for budgetary, socioeconomic and climatic characteristics for the period from 2008 to 2019 of the municipalities in the treatment group and the control group.

3.4.4 Empirical Strategy

To assess the impact of the long-lasting drought shock on the budgets of local governments over time, we employed a flexible estimation strategy aligned with a panel event study design. These models, as a generalized extension of 'difference-in-differences' or two-way fixed-effects (TWFE) models, enable the estimation of dynamic lags and account for fixed factors (often) across space and time (Clarke and Schythe, 2020). We estimated the following event study specification:

$$Y_{it} = \alpha + \sum_{k<0} \beta_k D'_{it} + \sum_{k>0} \beta_k D'_{it} + \mu_i + \lambda_t + X'_{it}\Gamma + \varepsilon_{it} \quad (2)$$

$$\text{with } D'_{it} = 1\,[t - 2011 = k > 0]$$

In which: Y_{it} refers to the dependent variables related to the expenditures and revenues of municipality i in year t, D'_{it} is an event study dummy variable, μ_i and λ_t denote municipality and year fixed effects, X'_{it} is a vector of control variables, and ε_{it} is the idiosyncratic error term. Specifically, our set of main dependent variables includes the natural logarithm of current expenditures, investment expenditures, current revenues, tax revenues, and current transfer revenues, all in per capita terms.

The term $D'_{it} = 1\,[t - 2011 = k > 0]$ refers to a dummy variable that takes the value one in the years when the drought shock occurred (from 2012 onwards) and 0 in the years preceding this event. The year 2011 was used as a reference and removed from the sample to capture the baseline difference between the municipalities in the treatment and control groups. The sample consists of municipalities in the semi-arid region of the Northeast, and the treatment group comprises municipalities with high exposure to drought - the top 50% most affected municipalities.

The covariates comprising the vector X'_{it} are a set of predetermined socio-economic variables, including average per capita household income, municipal inequality index (Gini index), proportion of elderly population, proportion of poor population, municipal Human Development Index (HDI), rural population, and unemployment rate. We also include the natural logarithm of annual per capita GDP, annual precipitation, and annual average temperature as time-varying controls, capturing additional aspects of economic and climatic conditions that may influence local dynamics.

The municipality fixed effects μ_i absorb time-invariant characteristics, disentangling the shock from many possible sources of omitted variable bias, while the annual fixed effects λ_t

capture common trends, thus helping ensure that effects are identified from idiosyncratic local shocks. Standard errors are clustered at the municipality level to account for serial correlation.

In Equation (2), three periods before the onset of the prolonged drought shock (2008 to 2010) and seven periods after (2012 to 2019) the reference year, 2011, are considered. The main hypothesis of validity of our empirical strategy is the parallel trends hypothesis, in which the behavior of municipalities should follow a common trend in the absence of the drought-induced shock. Although it is not possible to test such a hypothesis in practice, a way to approximate its validity is to observe whether there are trend differences before the occurrence of the drought. Thus, it is expected that the estimated parameters before 2012 do not show different trends.

3.4.5 Sample Balancing and Empirical Validation

Our identification strategy relies on analyzing differential variations in outcomes between municipalities with different levels of exposure to drought. Our identification assumption is that, in the absence of drought, the more exposed municipalities would have trends in outcomes similar to those of less exposed municipalities. We conduct a more formal check of pre-trends in our event study analysis in the next section.

In this subsection, to verify whether the treatment and control groups are balanced on observable characteristics before treatment, we test the overlap between these groups in the years prior to the prolonged drought period for our main dependent variables and socioeconomic characteristics of municipalities. When the overlap of covariates between treatment and control groups is limited, results based on linear regression methods can be sensitive to changes in specification (Imbens and Wooldridge, 2009). We formally check the overlap using normalized (or standardized) differences (Rubin, 2001). The normalized difference (ND) for continuous variables is given by:

$$ND = \frac{(\mu_t - \mu_c)}{\sqrt{\sigma_t^2 - \sigma_c^2}} \quad (3)$$

where μ_t and σ_t^2 are the mean and variance of the treated group, and μ_c and σ_c^2 are the mean and variance of the control group. Imbens and Wooldridge (2009) suggest that the normalized difference should be less than 0.25 to consider the sample balanced. Table 3 presents the estimates of the overlap difference. We do not observe differences greater than 0.25 in any of the considered variables, suggesting that less exposed municipalities to drought shock constitute a good control group based on observables.

Table 3 - Overlap between treated and control groups

Variables	Treatment Group		Control Group		Balance Std-Diff
	Mean	Std. Deviation	Mean	Std. Deviation	
Municipal Accounts					
Current Expenditure	1,282	538.84	1,216	419.54	0.137
Investment Expenditure	136	123.59	132.3	149.72	0.027
Current Revenues	1,521	675.65	1,439	526.81	0.136
Tax Revenues	47.26	70.672	41.45	26.17	0.109
Transfers Revenues	1,438	642.24	1,360	516.97	0.133
Socioeconomic Characteristics					
GDP per capita	5,423	4,361.6	4,786	2,227.5	0.184
Median Income	270.2	72.005	263.1	63.971	0.103
Gini Index	0.5217	0.0488	0.5306	0.0453	-0.188
HDI	0.5908	0.0406	0.5892	0.0359	0.041
% Eldery Population	12.29	2.083	12.44	1.962	-0.074
Rural Population	7687	7595.9	7727	6457.1	-0.005
Unemployment Rate	7.832	3.747	7.377	3.318	0.128
Poverty Rate	40.31	10.157	41.95	9.077	-0.169

Source: Elaborated by the authors.
Note: Table 3 presents the difference in overlap between the group of municipalities most exposed to prolonged drought shock (treated) and the group of municipalities least exposed (control).

Additionally, another potential concern for identification relates to geographic differences between more and less exposed municipalities. Our sample covers municipalities located in a common climatic area, the semiarid region of the Northeast. Thus, we can assume that exposure to extreme weather events occurs independently of municipal characteristics. Furthermore, we observed in panel (B) of Figure 2 that municipalities more exposed to prolonged drought are geographically close to less exposed municipalities. This also minimizes the influence of unobserved time-invariant characteristics that potentially affect municipal budgetary behavior.

Finally, another relevant aspect for the validation of our empirical strategy concerns cloud formation in the semiarid region, which makes precipitation during the drought an almost exogenous event. The typical cloud (*cumulus nimbus*) in the semi-arid region is strongly influenced by winds coming from the coast. Therefore, the direction and resulting precipitation from these clouds are not correlated with a specific geographic region. Thus, two municipalities that share the same economic, agricultural, and cultural origins may be highly affected or unaffected by the drought. Figure 2 confirms this possibility, as nearby municipalities were differently affected by the drought over the period.

3.5 RESULTS

3.5.1 Main Results

We begin by presenting the estimates from the event study for the relationship between municipal finances and exposure to the prolonged drought period. We define our treatment group as the municipalities that were highly exposed to drought – the 50% most affected municipalities. Figure 4 presents the estimates of Equation 2, reporting results for current expenditures, investment expenditures, current revenues, tax revenues, and transfer revenues. The blue dots represent the estimated parameters for each post-treatment year, while the green dots represent the parameters for each pre-treatment year, along with their respective 95% confidence intervals. The year 2011 was used as a reference and excluded from the sample to avoid collinearity, represented by the value zero in the figure. The results of the Average Treatment Effects on the Treated (ATTs) are presented in Table 4.

The results reported in Figure 4 suggest an absence of pre-existing trends for all variables of interest, implying that high exposure to the prolonged period of severe drought may have been the main factor differentiating the temporal behavior of these variables, even though the semiarid region is susceptible to recurrent droughts. This result supports the validity of the parallel trends assumption and provides support for our identification strategy.

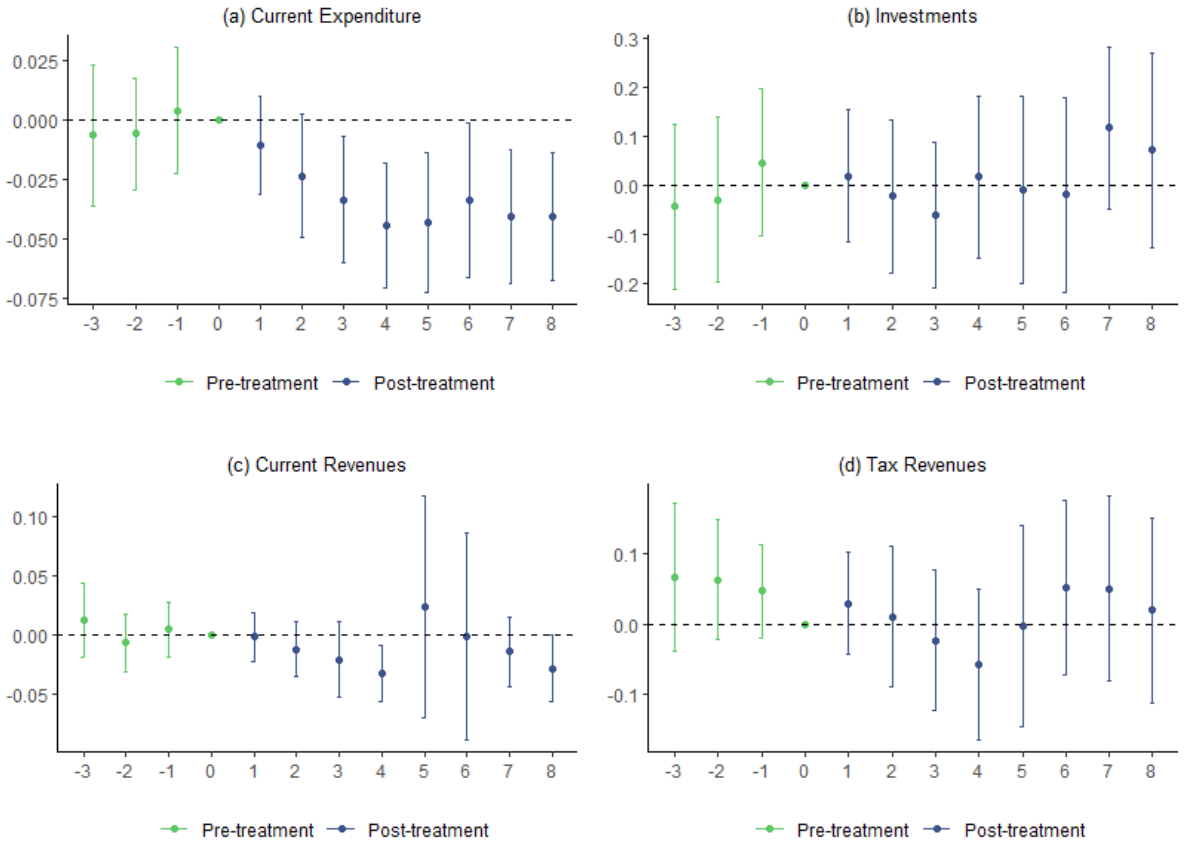
Regarding the main results, we observe in panel (a) of Figure 4 a decline in current expenditures after the onset of the drought in 2012, and this decline is accentuated over the years, persisting until the fourth year of exposure and remaining constant until the end of the analyzed period. The estimates of the ATT in Table 4 show a significant negative average effect of 3.37% between 2012 and 2019. A similar result was found by Jerch et al. (2023), who observed a decline in expenditures for municipalities affected by hurricanes compared to those not affected. In panel (b), no significant trend is observed in relation to investments, and their average effect estimates were not statistically significant.

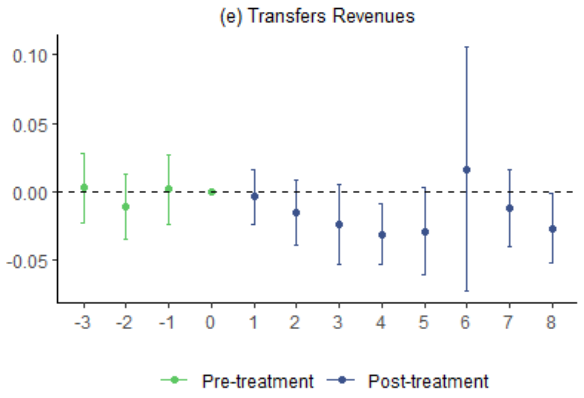
As for current revenues, we can observe in panel (c) of Figure 4 a decline in the first four years of severe drought; however, the effect is significant only for the year 2015. This effect is similar to what was found for revenues from transfers received by municipalities, in panel (e). We do not observe significant changes in tax revenues. The average effect estimates for all revenue variables presented did not show statistical significance.

In summary, our main results suggest that high exposure to the prolonged period of drought led the most affected municipalities to adopt budgetary adjustment measures, notably through the reduction of their current expenditures. This result can be interpreted as a strategic

response from local public managers to offset the decline in current revenues in the early years of severe drought, mainly attributed to the drop in transfer revenues, as tax revenue has little influence on current revenue due to its low representation in the budgets of municipalities in the Northeastern semi-arid region. It is worth noting that, although the reduction in current expenditures may have provided a temporary mitigation of the financial challenges faced by municipalities, such a strategy raises questions about potential long-term repercussions. A possible decrease in spending in essential areas may have negative implications for the sustainable development of these localities, raising concerns about the social well-being and quality of life of the local population.

Figure 4 – Event study analysis: Effects of the long-lasting drought shock on municipal expenditures and revenues





Source: Elaborated by the authors
Note: Figure 4 plots the estimated coefficients in Equation (2), reporting the results for the natural logarithm of the variables of (a) Current Expenditures, (b) Investment Expenditures, (c) Current Revenues, (d) Tax Revenue, and (e) Transfer revenues. The blue dots indicate the estimated parameters for each post-treatment year, while the green dots indicate the parameters for each pre-treatment year, with their respective 95% confidence intervals. The year 2011 was used as a reference, represented by the value zero.

Table 4 - Effects Average Treatment on the Treated (ATT) on municipal expenditures and revenues

	Current Expenditure	Investments	Current Revenues	Tax Revenues	Transfers Revenues
ATT	-0.0337*	0.0143	-0.0114	0.0104	-0.016
	(0.0085)	(0.0486)	(0.0101)	(0.0317)	(0.0093)
Year FE	Yes	Yes	Yes	Yes	Yes
Municipality FE	Yes	Yes	Yes	Yes	Yes
Control Variables	Yes	Yes	Yes	Yes	Yes

Source: Elaborated by the authors
Note: Table 4 presents the Effects of Average Treatment on Treaties (ATT) on municipal expenditures and revenues. Standard errors are clustered at the municipal level and reported in parentheses. Significance: * 5%.

3.5.2 Analysis of Expenditures by Function and Disaggregated Current Revenues

For a better understanding of our main results, we examined expenditures for different types of functions and disaggregated tax revenues by considering municipal taxes. We also broke down transfer revenues by associating the level of government that made the transfer to municipalities.

- Effects on Expenditures by Functions

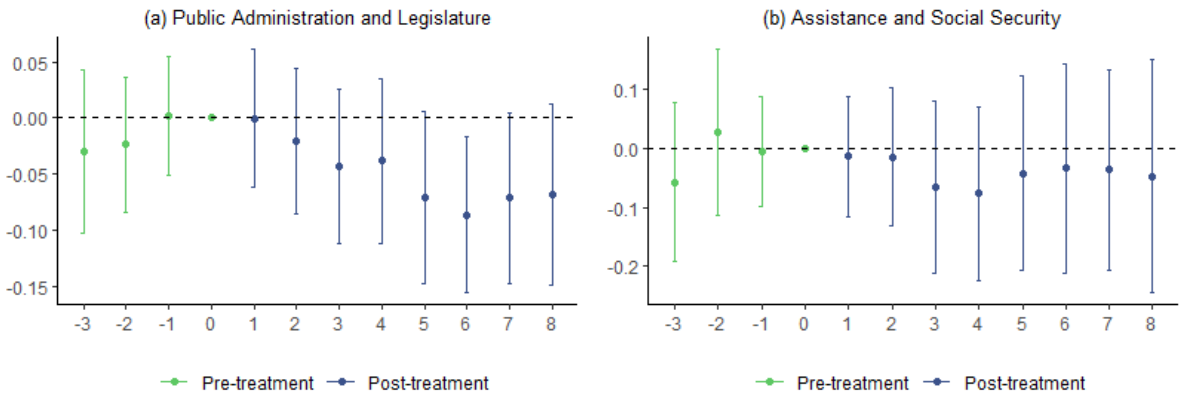
Regarding expenditures by functions, we considered the main categories of municipal budgets, such as education, health, social assistance, public administration, among others. The event study estimates for expenditures by functions are displayed in Figure 5. We found no significant trends prior to the onset of severe drought for all categories of expenditure functions,

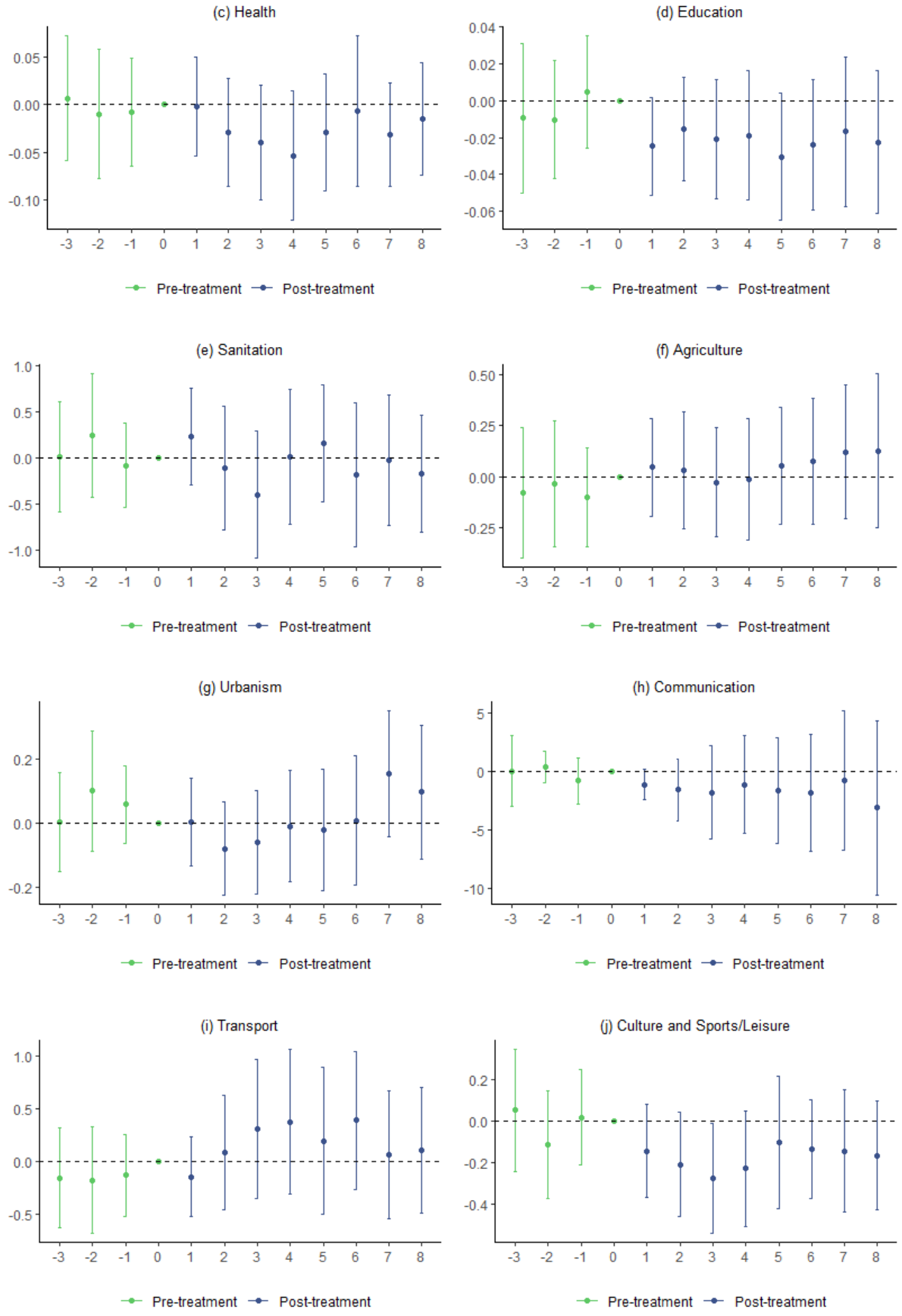
satisfying the parallel trends assumption. The ATT results are presented in Table A1 in the Appendix.

We observe in Figure 5 that among the expenditure categories, Public Administration and Legislature (panel (d)) and Culture and Sports/Leisure (panel (e)) showed the greatest changes, both with a reduction in spending after the onset of severe drought persisting until the final period. The average reduction for Public Administration and Legislature is about 5%, while for the Culture and Sports/Leisure category, the average reduction for the period is 17.7%. Considering only the average effect, we also find a negative and statistically significant effect of 2.1% in the Education category.

In general, the observed reduction in the categories of Public Administration and Legislature, as well as Culture and Sports/Leisure, suggests an adaptation by local governments to address the financial challenges imposed by the drought, possibly redirecting resources to critical priorities at the expense of non-essential areas during periods of water crisis. For instance, the decision to significantly cut resources in Culture and Sports/Leisure may have been influenced by the need to reallocate resources to sectors considered more crucial for the local community. However, the reduction in Education spending indicates that the persistence of the drought had a profound impact on the entire municipal budget, affecting investments in priority areas, albeit to a more modest extent compared to other categories. Thus, the analysis of changes in expenditure categories highlights the complexity of decisions made by municipal managers in response to extreme climatic events.

Figure 5 - Event study analysis: Effects of the long-lasting drought shock on municipal expenditures by functions





Source: Elaborated by the authors

Note: Figure 5 represents the coefficients estimated in Equation (2), reporting the results in different expenditures categories. The blue dots indicate the estimated parameters for each post-treatment year, while the green dots indicate the parameters for each pre-treatment year, with their respective 95% confidence intervals. The year 2011 was used as a reference, represented by the value zero.

- *Effects on Disaggregated Current Revenues*

We also disaggregated tax revenues and transfer revenues. In the case of tax revenues, we considered the effect of the prolonged drought shock on the collection of municipal taxes, which include the Urban and Territorial Property Tax (IPTU), the Service Tax (ISS), and the Tax on the Transfer of Real Estate (ITBI). Regarding transfer revenues, we considered transfers from the Federal Government and State Governments. The study's event results for this case are presented in Figure 6, and the corresponding ATT results are displayed in Table A2.

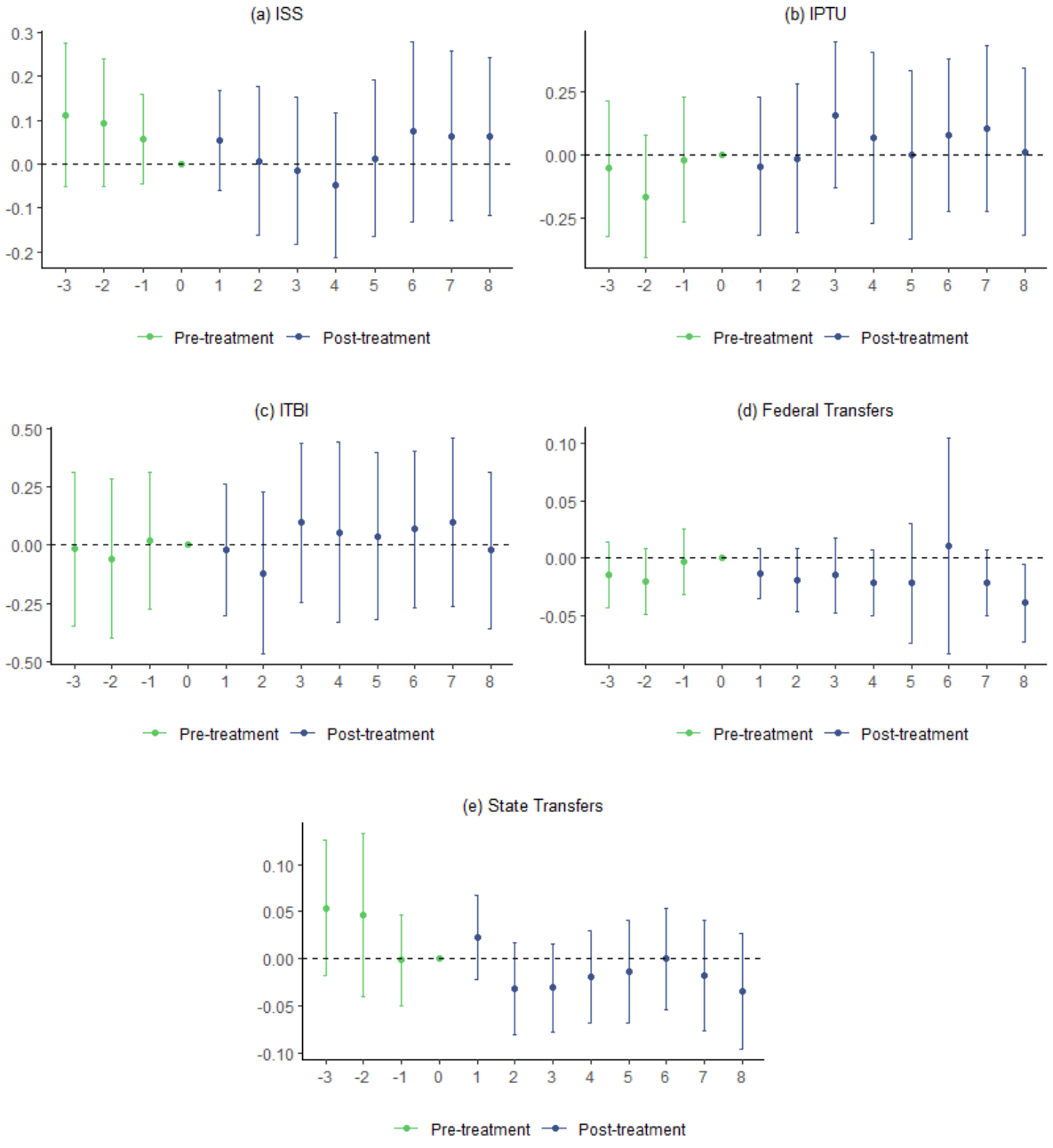
We can observe in Figure 6 that no changes in the temporal trajectory were identified for all types of municipal taxes after the onset of the prolonged drought, thus not showing significant differences compared to less exposed municipalities. This result reflects the low representativeness that tax revenue has on the municipal budgets of the semiarid region, highlighting the dependence of municipalities in this region on intergovernmental transfers.

Regarding intergovernmental transfers, we can see in panel (d) of Figure 6 that transfers from the Federal Government maintained the same pattern as before the onset of severe drought in 2012. In the case of resources from transfers via State Governments, we can observe in panel (e) a slight decline one year after the onset of the drought, which gradually diminished until the end of the prolonged period of low precipitation in 2017. Thus, this result suggests that the earlier decline in transfer revenues can be explained by the reduction in resources from State Governments. We may infer that the intensity of the prolonged drought triggered a series of factors, including a decrease in economic activity (Oliveira, 2021), an increase in unemployment, and the consequent reduction in the tax base of state governments, which, in turn, led to a decrease in resource allocation to municipal governments.

It is surprising that Federal Government transfers did not have a positive and significant effect, as it was expected that the transfer of resources from the Federal Government would serve as support for emergency response actions in municipalities most affected by the prolonged drought. One possible explanation for this unexpected result is that the Union's assistance to municipalities exposed to extreme weather events does not necessarily occur through direct financial transfers that would be accounted for in municipal budgets. Instead, it may manifest through assistance actions, such as water distribution by water trucks, which is

the responsibility of the Brazilian Army, and through other federal support programs, such as the Safra Guarantee and Water for All.

Figure 6 - Event study analysis: Effects of the long-lasting drought shock on disaggregated municipal current revenues



Source: Elaborated by the authors
Note: Figure 6 represents the coefficients estimated in Equation (2), reporting the results in different revenues classes. The blue dots indicate the estimated parameters for each post-treatment year, while the green dots indicate the parameters for each pre-treatment year, with their respective 95% confidence intervals. The year 2011 was used as a reference, represented by the value zero.

3.5.3 Heterogeneous Effects

In this section, we investigate some heterogeneous effects in our analysis. First, we assess the effects of the prolonged drought shock on municipal finances considering the income level of the municipalities. Additionally, we also investigate how municipal budgets reacted to the extended period of low precipitation considering the proportion of poor individuals in the municipalities.

3.5.3.1 Municipal Income Level

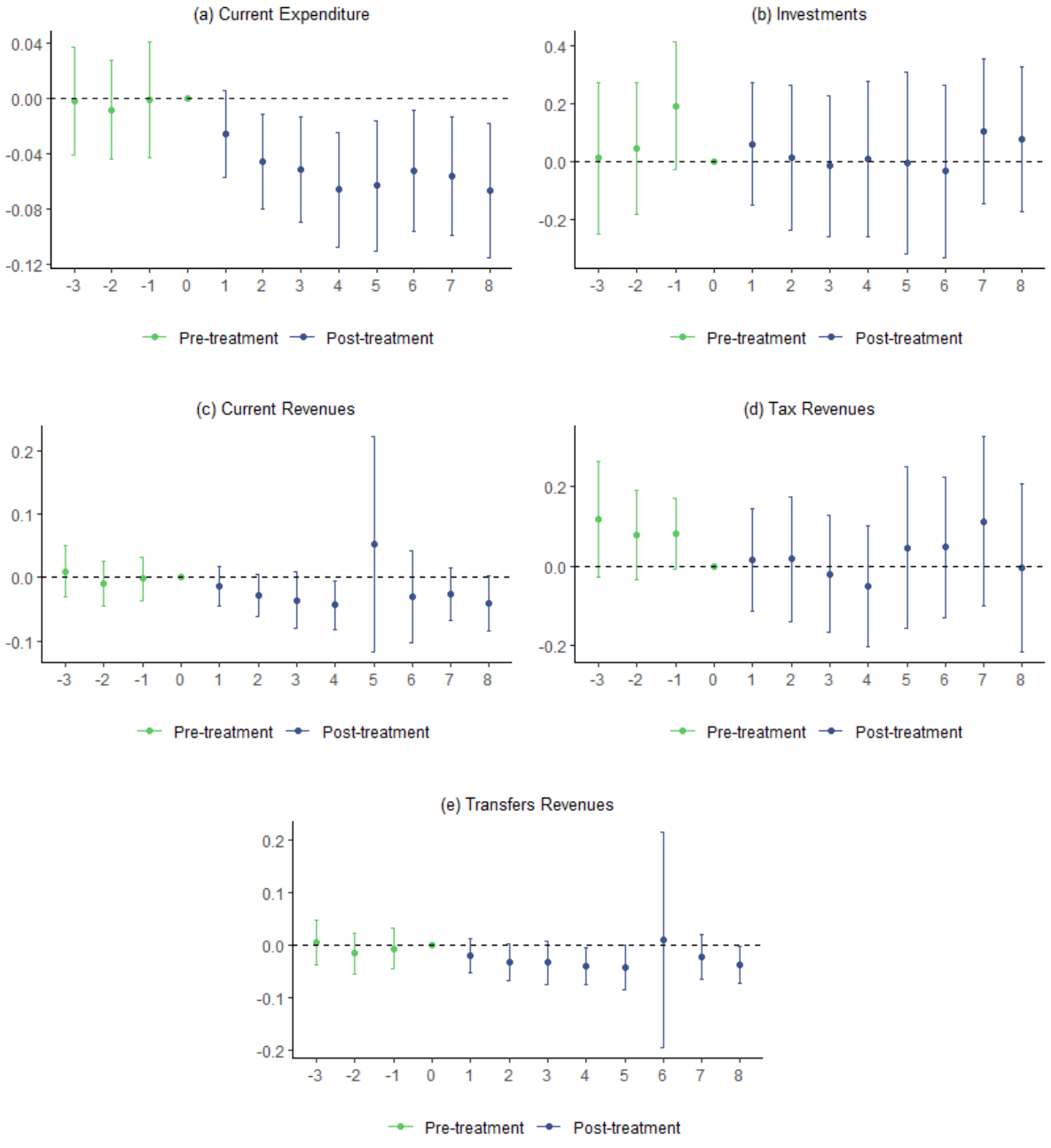
The literature has documented that countries at different levels of economic development may respond differently to shocks from natural disasters (Miao, Hou, & Abrigo, 2018). Based on this assumption, we examined how the income level could influence the effects of extreme weather events on municipal budgets. To do so, we divided our sample into two groups of municipalities based on the average per capita GDP (from 2008 to 2019), considering its median as a threshold. We re-estimated our event study model separately for each group of municipalities, considering the same dependent variables as our main results. The results are displayed in Figures 7 and 8. The results of the corresponding Average Treatment Effects on the Treated (ATTs) are presented in Tables A3 and A4, in the Appendix.

Figure 7 shows the estimates for the group of municipalities with higher average per capita GDP. In it, we can observe the same response pattern observed in the main results, in Figure 4, for all analyzed variables. Specifically, we observe a reduction in current expenditures from the beginning of the drought period, with this decrease intensifying over the years, persisting until the fourth year of exposure, and remaining stable until the end of the analyzed period. The average reduction in current expenditures over the period was 5.3%. Regarding current revenues, we also observe a decline in the early years of severe drought, similar to the effect seen in transfer revenues. We did not observe significant changes for investments and tax revenues.

When analyzing the group of municipalities with lower average per capita GDP in Figure 8, we did not observe significant changes in any of the analyzed variables. This result suggests that the effects of a prolonged drought shock on municipal budgets are concentrated in municipalities with a higher level of income, indicating primarily a decrease in current expenditures. Initially, this result may seem surprising, as we expect drought to have more pronounced effects on less developed communities. However, a limitation when using GDP in this context is that it tends to underestimate the contribution of informal economic activities

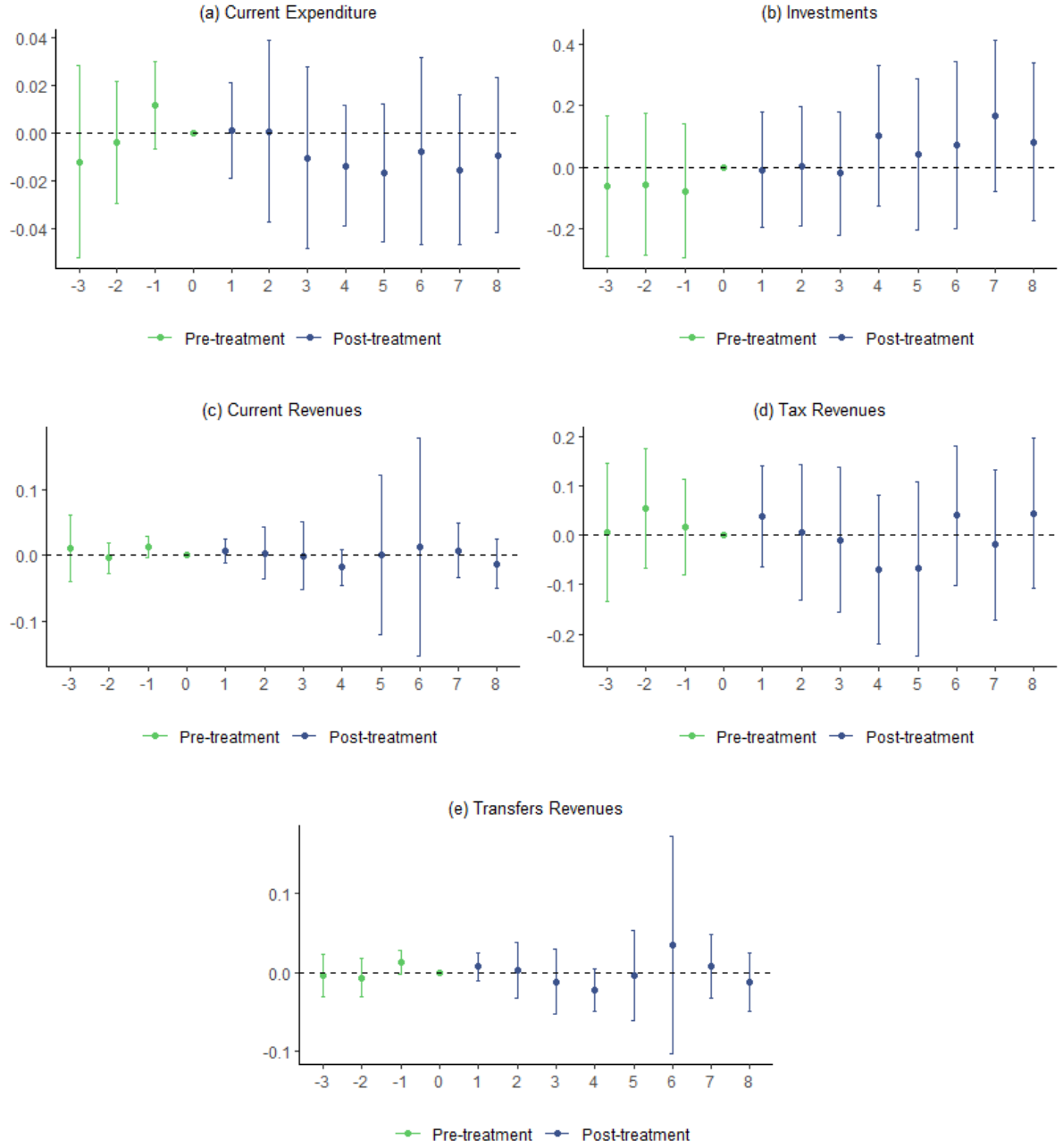
that are not officially recorded. This is especially relevant in areas where a significant part of the economy operates outside the formal sector, as is the case in the Semiarid Region of the Northeast. As mentioned earlier, the economy of the semi-arid region is predominantly based on extensive agricultural practices aimed at subsistence and livestock farming, characterized by limited productivity and significant susceptibility to soil degradation. Thus, the effects of drought tend to be more pronounced in these communities, and average per capita GDP may not capture this impact.

Figure 7 - Heterogeneous Analysis: Effects of Drought Shock on Expenditures and Revenues of Municipalities with Higher Average Per Capita GDP



Source: Elaborated by the authors
Note: Figure 7 plots the event study estimation coefficients of the effect of the prolonged drought shock on expenditures and revenues considering the group of 50% of municipalities with the highest average GDP per capita. The blue dots indicate the estimated parameters for each post-treatment year, while the green dots indicate the parameters for each pre-treatment year, with their respective 95% confidence intervals. The year 2011 was used as a reference, represented by the value zero.

Figure 8 – Heterogeneous Analysis: Effects of Drought Shock on Expenditures and Revenues of Municipalities with Lower Average Per Capita GDP



Source: Elaborated by the authors
Note: Figure 8 plots the event study estimation coefficients of the effect of the prolonged drought shock on expenditures and revenues considering the group of 50% of municipalities with the lowest average GDP per capita. The blue dots indicate the estimated parameters for each post-treatment year, while the green dots indicate the parameters for each pre-treatment year, with their respective 95% confidence intervals. The year 2011 was used as a reference, represented by the value zero.

3.5.3.2 Proportion of Poverty in Municipalities

The literature has shown that areas with high concentrations of minorities and low-income families tend to be, on average, disproportionately affected by adverse environmental risks (Hanna, 2007; Banzhaf et al., 2019; Jerch et al., 2023). Our previous result indicates that the average per capita GDP may not be sufficient to capture the social vulnerability of municipalities that were highly exposed to the prolonged drought shock.

In view of this, we employed the same strategy as in the previous section, considering the proportion of the population below the poverty line in municipalities as a measure of our analysis. Specifically, we divided our sample into two groups of municipalities based on the poverty rate in 2010, where we considered the 50% of municipalities with the highest share of poor individuals and the 50% with the lowest proportion. We re-estimated our event study model for each of these groups of municipalities for our main dependent variables. The results of this analysis are presented in Figures 9 and 10. The results of the corresponding ATTs are shown in Tables A5 and A6, in the Appendix.

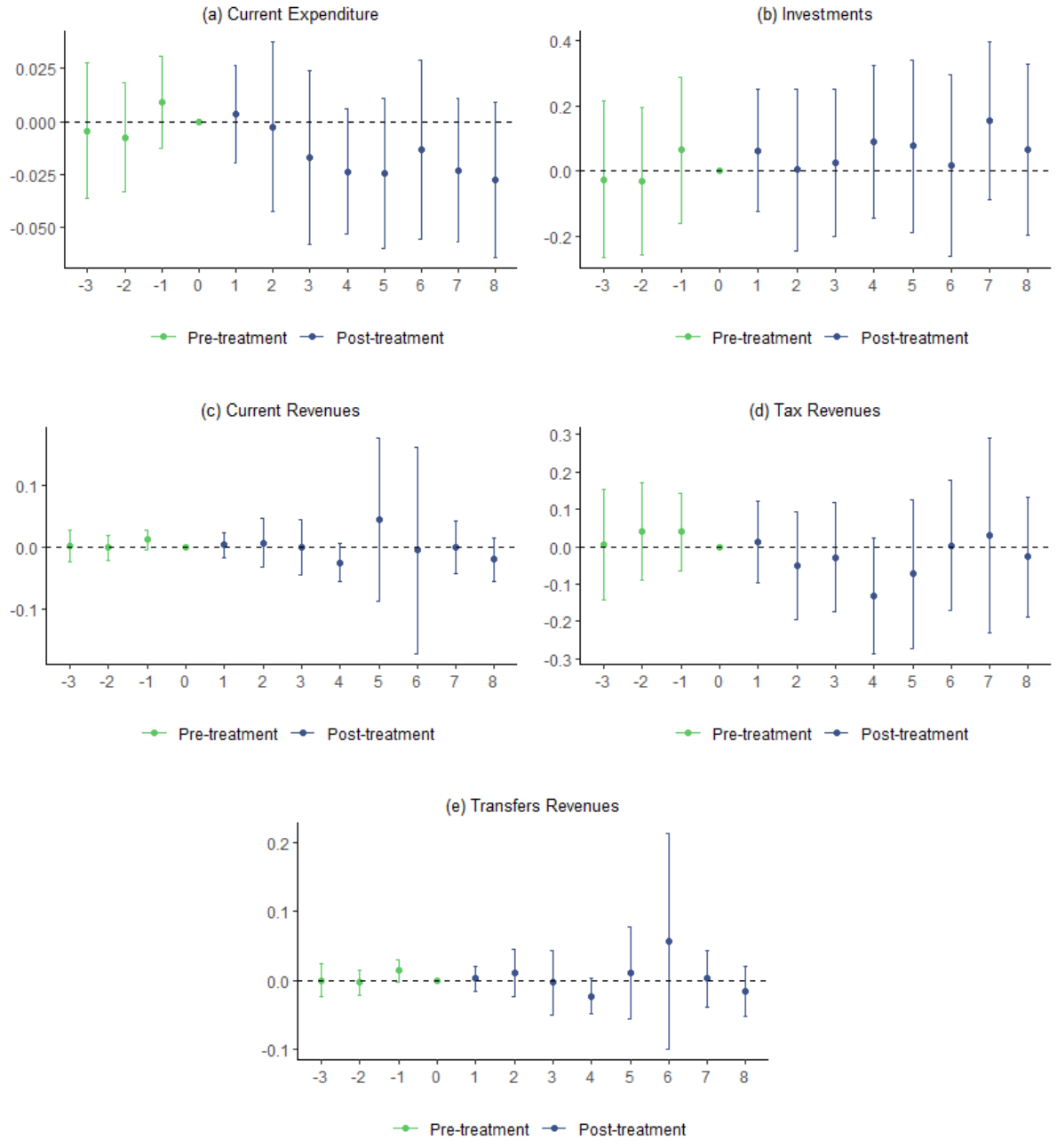
When analyzing the group of municipalities with a lower proportion of poor individuals, in Figure 9, we observe the absence of pre-existing trends for all variables of interest; however, no significant changes in the effect of the prolonged drought shock are observed in any of the analyzed variables compared to less exposed municipalities.

When considering the group of municipalities with a higher incidence of poverty, in Figure 10, the absence of pre-existing trends is also notable, and we observe effects similar to those reported in the main results. In particular, we observe a decline in current expenses that is accentuated over the years and remains constant after the fourth year of drought. It is noteworthy that the effect observed here in terms of magnitude is higher than identified in the main results, with an average reduction of 4.7% over the period. We also observe a decline in transfer revenues after the start of the prolonged period of low precipitation, persisting until the final years of the drought, with a negative and significant average effect of 3.5%. Occasionally, current revenues are also negatively affected in the early years of the drought. We also do not observe significant changes for investment and tax revenue variables.

In general, this result indicates that municipalities with a higher proportion of individuals below the poverty line are significantly more affected by drought, suggesting that extreme climatic events can cause divergences in fiscal outcomes for municipalities that differ demographically, even within the same region. Thus, to the extent that shocks induced by extreme climatic events affect municipal budgets, our findings suggest that the spatial

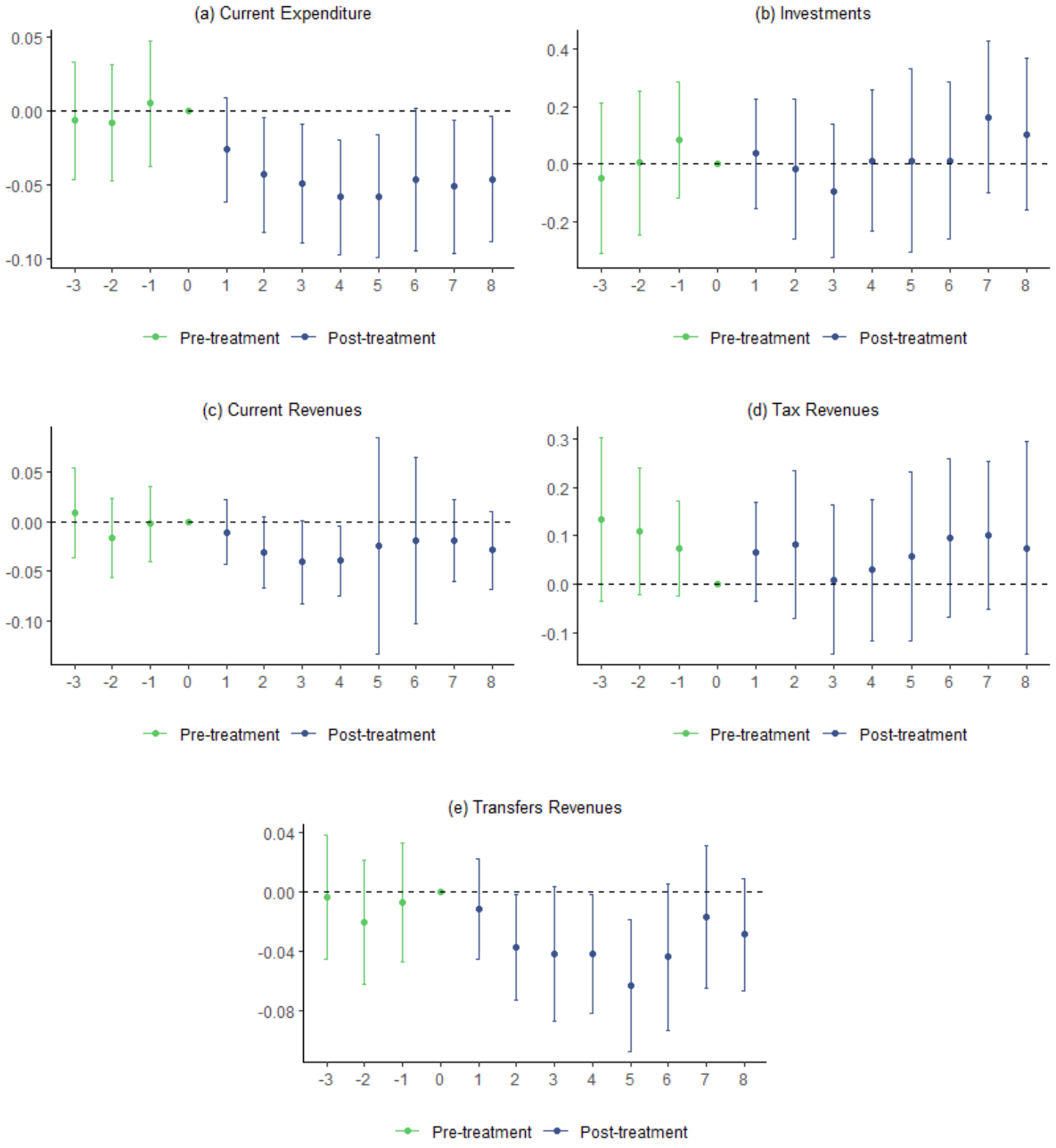
distribution of climate risk can contribute to the socioeconomic inequality in the Northeast region.

Figure 9 – Heterogeneous Analysis: Effects of Drought Shock on Expenditures and Revenues of Municipalities with Lower Proportion of Poverty



Source: Elaborated by the authors
Note: Figure 9 presents the event study estimation coefficients of the effect of the prolonged drought shock on expenditures and revenues considering the group of 50% of municipalities with the lowest proportion of poor individuals. The blue dots indicate the estimated parameters for each post-treatment year, while the green dots indicate the parameters for each pre-treatment year, with their respective 95% confidence intervals. The year 2011 was used as a reference, represented by the value zero.

Figure 10 – Heterogeneous Analysis: Effects of Drought Shock on Expenditures and Revenues of Municipalities with Higher Proportion of Poverty



Source: Elaborated by the authors
Note: Figure 10 presents the event study estimation coefficients of the effect of the prolonged drought shock on expenditures and revenues considering the group of 50% of municipalities with the highest proportion of poor individuals. The blue dots indicate the estimated parameters for each post-treatment year, while the green dots indicate the parameters for each pre-treatment year, with their respective 95% confidence intervals. The year 2011 was used as a reference, represented by the value zero.

3.5.4 Robustness Analysis

We also perform some robustness exercises in this analysis. First, we examined an alternative threshold measure of the drought shock to define the treatment and control groups of municipalities. In our main approach, we used the median of DS_i to indicate the municipalities comprising the treatment group – the top 50% most exposed to the drought shock – and the control group - the bottom 50% less exposed. As an alternative measure, we considered the upper and lower quartiles of DS_i to define the treated and control groups, respectively. The results are presented in Figure A1.

When we execute the same empirical strategy, we observe in Figure A1 that the results for this alternative measure are similar to those found in the main results, where the absence of previous trends in all analyzed variables is noted, along with a post-drought downward trend in current expenditures, current revenues, and transfer revenues. Thus, even when considering a more restricted group of municipalities, our results remain consistent.

Another robustness exercise we conducted was to analyze the treatment of the drought shock by comparing the control group municipalities (those in the semiarid region of the Northeast less exposed to the prolonged drought) with other municipalities that are part of the Northeast Region but are not in the semiarid region. The idea is to demonstrate that exposure to the prolonged drought should not be a significant concern for either the control group or the non-semiarid Northeastern municipalities. The results of this analysis are shown in Figure A2.

We did not identify changes in the temporal trajectory in any of the analyzed variables, suggesting that the severe drought shock did not substantially alter the fiscal behavior of the control group municipalities and the non-semiarid municipalities in the Northeast. This result reinforces the validity of the parallel trends hypothesis, supporting the conclusion that the effects of the drought shock on the financial health of municipalities are consistent and independent of geographical peculiarities.

3.6 FINAL REMARKS

This article documents that a prolonged drought shock affects the fiscal and budgetary behavior of municipal governments. We investigate the effects of a severe and persistent drought on the expenditures and revenues of municipalities in the semi-arid region of northeastern Brazil. Our results show that the prolonged drought shock leads to a decrease in current expenditures, which is accentuated in the early years of the drought and stabilizes in the

final years. Current and transfer revenues also react negatively to the drought shock in the initial years, although their effects are not significant.

When we disaggregate municipal expenditures, we find a negative and significant effect on expenditures related to public administration and legislature, culture and sports/leisure, and education. We do not find significant effects of the prolonged drought shock on municipal taxes. In the case of intergovernmental transfers, we observe that transfers from the Federal Government did not undergo significant changes compared to the period before the onset of the drought.

These results can be interpreted as a strategic response by local public managers to the prolonged period of severe drought, leading the most affected municipalities to adopt budgetary adjustment measures, notably through the reduction of their current expenditures, including in priority areas such as education. This strategy raises questions about potential long-term repercussions that may have negative implications for the sustainable development of these localities, generating concerns about the social well-being and quality of life of the local population.

In addition to these results, we also document that municipalities with a higher proportion of individuals in poverty are significantly more affected by drought in terms of reducing current expenditures than municipalities with a lower rate of poverty. This finding suggests that extreme weather events can contribute to socioeconomic inequality in the Northeast region, highlighting considerations of environmental justice in understanding who bears the costs of natural disasters.

In general, our results demonstrate the complexity of municipal government responses to extreme weather events, emphasizing the need for public policies and budgetary strategies adapted to the diverse socio-economic realities of the semiarid region. It is important to highlight that a solid fiscal framework not only strengthens the financial resilience of local communities in the face of adverse events but also plays an essential role in the ability to implement effective responses, ensuring the continuity of essential services. In terms of policy implications, it is recommended to integrate disaster risk reduction (DRR) measures into municipal development plans and policies, such as contingency or emergency plans for disasters, aiming to prevent significant damage during extreme natural events. This proactive approach would not only reduce the costs associated with post-disaster recovery and emergency expenditures but also contribute to the sustainable development of the region.

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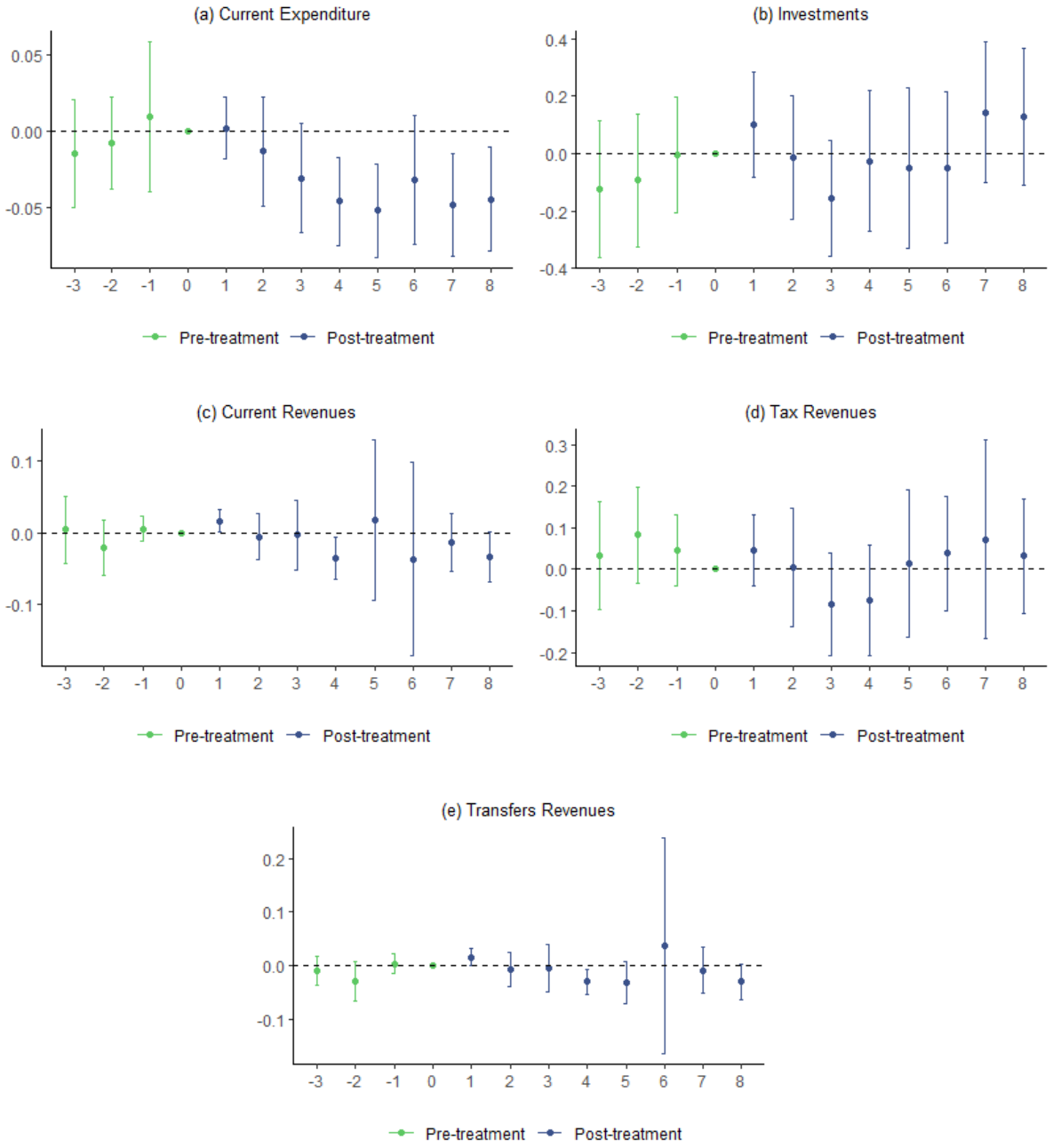
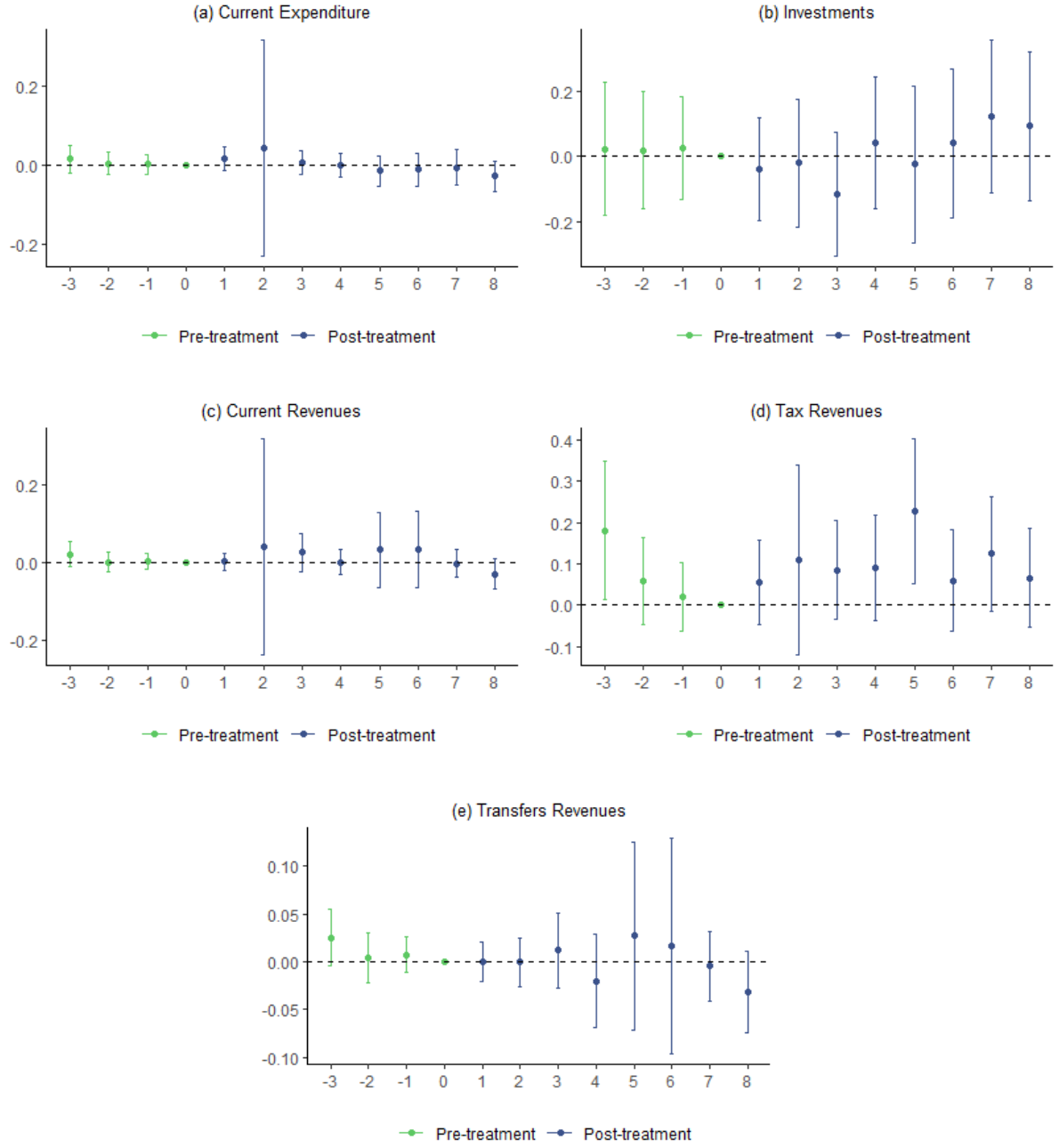
APPENDIX

Figure A1 - Robustness check: Alternative Treatment and Control Group



Source: Elaborated by the authors
Note: Figure A1 presents the event study estimation coefficients of the effect of the prolonged drought shock on expenditures and revenues considering the 25% of the most exposed municipalities (treated) and the 25% least exposed (control). The blue dots indicate the estimated parameters for each post-treatment year, while the green dots indicate the parameters for each pre-treatment year, with their respective 95% confidence intervals. The year 2011 was used as a reference, represented by the value zero.

Figure A2 - Robustness check: Comparing the municipalities in the control group with municipalities in the non-semiarid Northeast



Source: Elaborated by the authors
Note: Figure A presents the event study estimation coefficients of the effect of the prolonged drought shock on expenditures and revenues comparing the municipalities in the control group with municipalities in the non-semiarid Northeast. The blue dots indicate the estimated parameters for each post-treatment year, while the green dots indicate the parameters for each pre-treatment year, with their respective 95% confidence intervals. The year 2011 was used as a reference, represented by the value zero.

Table A1 - Effects Average Treatment on the Treated (ATT) on expenditures by functions

	Public Administration and Legislature	Assistance and Social Security	Health	Education	Sanitation	Agriculture	Urbanism	Communication	Transport	Culture and Sports/Leisure
ATT	-0.0498*	-0.0417	-0.026	-0.0217*	-0.0632	0.0511	0.0104	-1.6314	0.1744	-0.1772*
	(0.0236)	(0.0508)	(0.0205)	(0.0097)	(0.1875)	(0.0863)	(0.0477)	(1.5068)	(0.1731)	(0.0809)
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Municipality FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Control Variables	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Source: Elaborated by the authors

Note: Table A1 presents the Effects of Average Treatment on Treaties (ATT) on municipal expenditures by functions. Standard errors are clustered at the municipal level and reported in parentheses. Significance: * 5%.

Table A2 - Effects Average Treatment on the Treated (ATT) on Disaggregated Current Revenues

	ISS	IPTU	ITBI	Federal Transfers	State Transfers
ATT	0.0266	0.0452	0.024	-0.0175	-0.0156
	(0.0519)	(0.0764)	(0.1125)	(0.0098)	(0.0161)
Year FE	Yes	Yes	Yes	Yes	Yes
Municipality FE	Yes	Yes	Yes	Yes	Yes
Control Variables	Yes	Yes	Yes	Yes	Yes

Source: Elaborated by the authors

Note: Table A2 presents the Effects of Average Treatment on Treaties (ATT) on Disaggregated Current Revenues. Standard errors are clustered at the municipal level and reported in parentheses. Significance: * 5%.

Table A3 – ATT on Expenditures and Revenues of Municipalities with Higher Average Per Capita GDP

	Current Expenditure	Investments	Current Revenues	Tax Revenues	Transfers Revenues
ATT	-0.0533*	0.0253	-0.0209	0.0202	-0.0268
	(0.0139)	(0.0652)	(0.0154)	(0.0545)	(0.0158)
Year FE	Yes	Yes	Yes	Yes	Yes
Municipality FE	Yes	Yes	Yes	Yes	Yes
Control Variables	Yes	Yes	Yes	Yes	Yes

Source: Elaborated by the authors

Note: Table A2 presents the Effects of Average Treatment on Treaties (ATT) on Expenditures and Revenues of Municipalities with Higher Average Per Capita GDP. Standard errors are clustered at the municipal level and reported in parentheses. Significance: * 5%.

Table A4 – ATT on Expenditures and Revenues of Municipalities with Lower Average Per Capita GDP

	Current Expenditure	Investments	Current Revenues	Tax Revenues	Transfers Revenues
ATT	-0.0088	0.0547	0.0000	-0.005	0.0003
	(0.009)	(0.0569)	(0.0111)	(0.0406)	(0.0088)
Year FE	Yes	Yes	Yes	Yes	Yes
Municipality FE	Yes	Yes	Yes	Yes	Yes
Control Variables	Yes	Yes	Yes	Yes	Yes

Source: Elaborated by the authors

Note: Table A4 presents the Effects of Average Treatment on Treaties (ATT) on Expenditures and Revenues of Municipalities with Lower Average Per Capita GDP. Standard errors are clustered at the municipal level and reported in parentheses. Significance: * 5%.

Table A5 – ATT on Expenditures and Revenues of Municipalities with Lower Proportion of Poverty

	Current Expenditure	Investments	Current Revenues	Tax Revenues	Transfers Revenues
ATT	-0.0159	0.062	0.0013	-0.0329	0.0057
	(0.0096)	(0.0623)	(0.0115)	(0.0505)	(0.0101)
Year FE	Yes	Yes	Yes	Yes	Yes
Municipality FE	Yes	Yes	Yes	Yes	Yes
Control Variables	Yes	Yes	Yes	Yes	Yes

Source: Elaborated by the authors

Note: Table A5 presents the Effects of Average Treatment on Treaties (ATT) on Expenditures and Revenues of Municipalities with Lower Proportion of Poverty. Standard errors are clustered at the municipal level and reported in parentheses. Significance: * 5%.

Table A6 – ATT on Expenditures and Revenues of Municipalities with Higher Proportion of Poverty

	Current Expenditure	Investments	Current Revenues	Tax Revenues	Transfers Revenues
ATT	-0.047*	0.0291	-0.0268	0.0645	-0.0356*
	(0.0149)	(0.068)	(0.0148)	(0.0455)	(0.0137)
Year FE	Yes	Yes	Yes	Yes	Yes
Municipality FE	Yes	Yes	Yes	Yes	Yes
Control Variables	Yes	Yes	Yes	Yes	Yes

Source: Elaborated by the authors

Note: Table A6 presents the Effects of Average Treatment on Treaties (ATT) on Expenditures and Revenues of Municipalities with Higher Proportion of Poverty. Standard errors are clustered at the municipal level and reported in parentheses. Significance: * 5%.

OVERALL CONCLUSIONS

This thesis comprises three essays aiming to provide evidence of the impacts of drought on various socio-economic aspects, focusing on the Northeast Region of Brazil, an area with a high level of social and economic vulnerability in the face of the pressures of climate change.

The first article, titled "Long-Lasting Drought and Adolescents Socioemotional Skills" investigates the impact of the prolonged drought that occurred between 2012 and 2017 on the socioemotional characteristics of students in Ceará in 2015. The findings suggest that the episode of long-lasting drought negatively affects the conscientiousness skill, which is related to the ability to focus attention and behavior on relevant things when complying with standards. We also document that mothers with a university degree moderate the impact of the drought shock on socioemotional skills, significantly reducing its influence, highlighting the importance of parental investment in the accumulation of non-cognitive skills in students. Finally, we estimate the effect of drought on other non-cognitive variables related to conscientiousness, such as students' aspirations, and find evidence that the drought shock negatively affects students' aspirations to continue studying during and after high school.

In the second chapter, titled "Drought, Local Fiscal Conditions, and Infant Health: Evidence for the Northeast Region of Brazil," we investigate whether the fiscal situation of municipalities contributes to mitigating the effects of drought shocks during the gestational period on child health outcomes, with a focus on infant mortality. The results suggest that municipalities with better fiscal conditions tend to reduce the adverse effects of in utero exposure to drought shocks on infant mortality caused by perinatal conditions. We also find that the fiscal capacity of municipalities is a relevant factor in mitigating the effects of drought shocks during the gestational period on infant mortality when considering fiscal autonomy and budget rigidity indicators as measures of fiscal condition. Additionally, we find that the occurrence of drought in the first trimester of gestation has a positive and statistically significant effect on infant mortality, and this effect is mitigated in municipalities with better fiscal conditions. Finally, we demonstrate that the interactive effect between the fiscal capacity of municipalities and exposure to drought during the gestational period is negative and significant in medium population size municipalities.

The third and final essay of this thesis, titled "Natural Disasters and Local Public Finances: Analysis of a Long-Lasting Drought in the Semiarid Region of Northeast Brazil," examines the causal and dynamic effects of the drought from 2012 to 2017 on the finances of municipal governments. The observed results show that the prolonged drought shock leads to

a decrease in current expenditures, which is more pronounced in the initial years of the drought and stabilized in the final years. Current revenues and transfers also react negatively to the drought shock in the initial years, although their effects are not significant. We also find a negative and significant effect on expenditures related to public administration and legislature functions, culture, sports/recreation, and education. These results can be interpreted as a strategic response from local public managers to the prolonged period of severe drought, leading the most affected municipalities to adopt budgetary adjustment measures, notably through the reduction of current expenditures, including in priority areas such as education.

In addition, in the third article of the thesis, we also observe that municipalities with a higher proportion of poverty are significantly more affected by drought in terms of reducing current expenditures than municipalities with a lower rate of poor population. This finding suggests that extreme climatic events can contribute to the socioeconomic inequality in the Northeast region, emphasizing considerations of environmental justice in understanding who bears the costs of natural disasters.

Overall, the results found throughout this thesis provide important insights for the economic literature on natural disasters, addressing intersections that have been little explored in both national and international literature. First, we document the effects of drought on socioemotional skills. To my knowledge, there are very few studies in economics that address this relationship; exceptions include Nordstrom and Cotton (2020) and Ortiz (2022). Additionally, the literature linking natural disasters and public finances has focused its analysis at the aggregate level, with few recent articles exploring this relationship at the local level. We contribute to this literature by addressing the impact of a prolonged drought on the budgetary behavior of Brazilian municipalities in an area highly vulnerable socioeconomically to climate change. Finally, by exploring the interaction between drought shocks and local fiscal conditions on infant mortality, this work is the first (to my knowledge) to address local fiscal capacity as a mechanism for mitigating the adverse effects of natural disasters, contributing to the recent and growing literature investigating the importance of fiscal capacity in addressing economic crises (Hausmann and Schetter, 2022; Romer and Romer, 2019; Barros et al., 2022).

As a policy recommendation, this thesis also provides important implications for the development of public policies, especially in areas more vulnerable to drought. In the first chapter, we show that a sharp increase in drought can affect students' socioemotional skills, especially at sensitive ages for socioemotional development. Thus, if climate change intensifies drought occurrence, specific public policies should be designed to address students' socioemotional skills, given their importance for student well-being. In the second chapter, by

highlighting the importance of local fiscal conditions in the face of drought shocks, it is recommended that institutions promoting fiscal resilience can contribute to addressing aggregate shocks, such as the occurrence of natural disasters. Finally, given the fiscal and budgetary implications of prolonged drought presented in the third chapter, the integration of Disaster Risk Reduction (DRR) measures into municipal development plans and policies is recommended. These measures could include contingency or emergency plans for disasters, aiming to prevent significant damage during extreme natural events. This proactive approach would not only reduce costs associated with post-disaster recovery and emergency expenditures but also contribute to the sustainable development of regions vulnerable to climate change.

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