Impact of natural disasters on local public finance: Evidence from droughts and floods in Brazil

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July 2024

Abstract

Natural disasters can cause substantial damage to human lives, the environment, and the economy, leading to financial strain on subnational governments. This study examines the impact of extreme weather events on the local public finances in Brazil, focusing on government funding strategies for relief measures and policies to reduce future risks associated with such hazards. We leverage Standard Precipitation and Evapotranspiration Index (SPEI) data to identify extreme floods and droughts in 5,474 municipalities from 1997 to 2019. Then, we estimate the effects of these disasters on local public finance by employing an approach that combines a difference-in-differences estimator with a matching method and allows treatments with switching on and off behavior. Our findings reveal that droughts do not significantly impact intergovernmental transfers, leading to financial strain for the affected municipalities. Conversely, floods increase the grants received by local governments, improving their fiscal balances. However, this better fiscal situation does not affect the spending in flood mitigation areas (urbanism and the environment), suggesting a moral hazard problem related to the overreliance on resources from higher-level governments.

Keywords: *natural disaster; flood; drought; SPEI; local finance; decentralization; Brazil; difference-in-differences; matching.*

JEL Classification: *H71, H72, H74, O13, O54, Q54*

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1 Introduction

Natural disasters, such as floods, droughts, and hurricanes, may have devastating effects on human lives, the environment, and the economy. They impose local fiscal stress by incurring rehabilitation costs while simultaneously lowering tax revenues (Jerch, Kahn, & Lin, 2023). Therefore, higher-level governments typically provide assistance through disaster-related and non-disaster-related transfers (Deryugina, 2017). Nevertheless, it is unclear if local public finance will improve or deteriorate and whether budget allocations will prioritize hazard-prevention measures. The central authority's decision on the amount of financial aid may be influenced by political interests (Garrett & Sobel, 2002) and media attention (Eisensee & Stromberg, 2007). Additionally, local governments might exhibit moral hazard behavior by relying on future expected grants, rather than investing in preventive measures (Goodspeed & Haughwout, 2012; Wildasin, 2008). Furthermore, extreme weather events have distinct characteristics. Droughts develop gradually over time due to prolonged dryness, while floods can occur suddenly, causing immediate and noticeable damage. The speed and magnitude of the response to an event may vary, which poses an empirical question regarding the impact of natural disasters on local public finance and whether there are heterogeneous responses based on the hazard type.

This study examines the impact of extreme weather events on local public finance in Brazil. We aim to understand how governments fund unexpected expenses and whether affected areas reduce spending on policies to mitigate future hazard-related losses. We leverage data from 1997 to 2019, covering 5,474 municipalities[1], and we break down the analysis by floods and droughts. Brazil is an interesting case when it comes to natural disaster relief. The federal and state governments may provide financial assistance, but there is no set formula for how it should be done, making it a political decision. As a developing country with limited financial resources and state capacity, it is unclear whether higher-level governments will have the means to provide assistance. Therefore, previous findings from developed countries may not be directly applicable to this specific context.

The local public financial data from 2000[2] to 2019 was obtained from the Public Sector Accounting and Tax Information System (Siconfi), which is managed by the National Treasury Secretariat (STN). To minimize potential bias related to political interests in reporting natural disasters in Brazil, we utilized the 1981-2022 Standard Precipitation and Evapotranspiration Index (SPEI) dataset, provided by Gebrechorkos et al. (2023) to identify municipalities affected by extreme cases of floods and droughts from 1997 to 2019. This approach is similar to the strategy employed by Albert, Bustos, and Ponticelli (2022) in their analysis of the impacts of Brazilian droughts on labor and capital allocation.

[1] Actually, Brazil has 5,570 municipalities, but some of them were established between 2001 and 2013. In order to maintain consistent data over time, we aggregated the new local jurisdictions with their "parent" municipalities into microregions by using Ehrl (2017) dataset.

[2] There is financial information from 1991 to 1999, but with a significant amount of missing data from the municipalities in the North and Northeast regions, which concentrate the poorer municipalities in Brazil. As a result, we gathered financial data from 2000 onwards.

We estimate the effects of floods and droughts on local public finance by employing Imai, Kim, and Wang's (2023) method, which combines a difference-in-differences estimator with a matching method on panel data, and allows treatments with switching on and off behavior. It involves matching each treated observation (a unit may be treated more than once) with control observations from other units within the same time period that share an identical treatment history. This approach better captures the nature of extreme weather events as floods and droughts tend to frequently occur in the same areas.

Our study has two main findings. First, the amount of higher-level government aid varies between municipalities experiencing droughts and those facing floods. Those affected by droughts do not receive significant transfers from higher-level governments. This does not affect the fiscal balance in the first year of extreme drought. However, if the drought persists into the next year, the financial strain becomes more evident as services tax revenue lowers significantly, and there is a shift of current expenditures to capital investments. In contrast, municipalities affected by floods see a significant improvement in their financial balance due to substantial increases in grants, not only during the flood years but also in the aftermath with the increase in capital transfers.

Second, there is evidence of disaster-related moral hazard associated with intergovernmental financial aid. Even though flood-affected municipalities receive increased grants, their spending on urban development and environmental areas, which are typically related to flood mitigation measures, does not significantly increase. Instead, these resources tend to be allocated towards other capital investments and agricultural activities. Conversely, jurisdictions that experienced extreme droughts, which did not receive increased transfers from higher-level governments during the emergency, maintained higher spending on environmental and agricultural measures in the aftermath. This spending may involve purchasing cisterns and water trucks to deal with the drought, for example.

We contribute to two main strands in the economic literature. The first one is the local financial response to natural shocks, which is a relatively new field that expands the analysis on economic indicators, such as employment, population, and wages (Belasen & Polachek, 2008; Strobl, 2011), to the public sector. Most of its empirical research focuses on hurricanes and floods, which are the hazards that cause the most damage in the United States. It indicates a negative effect on local tax revenue, leading to disaster-related expenditures being primarily financed by an increase in transfers (Deryugina, 2017; Jerch et al., 2023; Miao, Abrigo, Hou, & Liao, 2022). We expand on prior research by examining how floods and droughts affect local public finances in Brazil. Our analysis reveals that droughts have a non-significant impact on transfers and a negative impact on tax revenue, while floods have a positive effect on grants and no significant impact on tax revenue. Additionally, we explore different types of intergovernmental transfers and their mechanisms to provide further understanding of our findings.

We also contribute to the literature on decentralization and natural disasters, which explores the complex interplay among different levels of government in managing and mitigating the impacts of such events. Theoretical models, such as those by Wildasin (2008) and Goodspeed and Haughwout (2012), highlight the potential underinvestment in hazard-preventive infrastructure due to a soft budget constraint (Kornai, 1979; Kornai, Maskin, & Roland, 2003), a situation where a local government is likely to receive financial assistance from the central authority. Empirical studies in this literature yield mixed results on whether decentralization is effective in mitigating the impact of natural disasters. Skidmore and Toya (2013) and (Escaleras & Register, 2012) suggested that decentralized countries tend to experience lower disaster-related fatalities, while Miao, Shi, and Davlasheridze (2021) found that US states with more decentralized natural resource expenditures suffered greater economic losses from floods and storms. We find that municipalities affected by floods do not significantly increase environmental and urbanism expenditures despite receiving substantial intergovernmental transfers, suggesting an underinvestment in hazard-mitigation measures.

The remainder of this paper is organized as follows: Section 2 provides an overview of civil defense in Brazil. Section 3 provides the data used in this study, such as SPEI and local finance variables, and presents descriptive statistics. Section 4 outlines the empirical strategy employed in this study. Section 5 discusses the results of the impacts of droughts and floods on local government finances. Section 6 concludes with a summary of findings, limitations, and policy implications.

2 Civil Defense in Brazil

Brazil experiences two primary natural disasters: floods and droughts. Flooding is a frequent and widespread natural hazard that causes significant socio-economic and environmental damage globally (Barredo, 2009). In particular, urban areas are often highly susceptible to hydrological hazards due to the high density of impermeable surfaces, such as concrete and asphalt, which increases runoff during heavy rainfall and overwhelms drainage systems. On the other hand, droughts are periods of significantly low moisture that typically cover extensive areas, leading to negative impacts on natural systems and economic sectors (Ault, 2020), which accumulate over time.

Climate change is leading to more frequent and severe natural disasters, requiring increased efforts from governments and society. In this context, civil defense plays a vital role in coordinating across various levels of government and non-governmental organizations to implement preventive measures, ensure emergency preparedness, provide rapid disaster response, and support post-disaster recovery. Specifically, the Brazilian civil defense has undergone significant transformations in recent decades, shifting from providing assistance to disaster-affected populations to implementing public policies for hazard prevention and monitoring (Kuhn et al., 2022).

The National System for Civil Defense was established in 1988 and shared responsibilities with all levels of government. In the event of a natural disaster, the mayor of an affected municipality needs to report the hazard's occurrence by declaring an emergency or a state of calamity. The governor may support the local decree by issuing another declaration, which typically occurs when many municipalities in the state are affected by a hazard simultaneously. The federal government, through the Secretariat of Civil Defense (SEDEC) of the Brazilian Ministry of Regional Development, evaluates the decree and decides whether to recognize the disaster. If it does, the central authority issues an order acknowledging the emergency or state of calamity and provides financial and operational assistance to the subnational entity.

There is no public record before 2012 regarding the criteria used to identify an emergency or a state of public calamity, except for the definition of public calamity as "the abnormal situation caused by adverse factors that deprive the population of meeting their basic needs and affect community activities, the preservation of human lives, and the security of material goods" and an emergency as the situation that "may become a public calamity" (Federal Decree No. 97,274/1988). Only in 2012, a normative instruction defined rules to recognize an abnormal situation as a disaster, such as impacting the local government's ability to handle the crisis and resulting in a minimum amount of human, material, environmental, and/or economic losses (Appendix A.1).

The criteria for triggering federal aid have been established, but some are still subjective, such as the ability to handle the crisis. This makes the process still prone to political interests in reallocating financial resources to local governments. Evidence of this includes politically important subnational governments receiving more aid (Cavalcanti, 2018; Larreguy & Monteiro, 2014) in election years (Garrett & Sobel, 2002). Additionally, in the 2007 guide for reporting natural disasters, the federal government explicitly informs municipalities that the decree "should not be made with the sole objective of resorting to the financial resources". Therefore, there is a potential selection bias in natural disaster reporting and recognizing process, which makes SEDEC's hazard records potentially unsuitable for use in causal inference methods.

3 Data

3.1 Standard Precipitation and Evapotranspiration Index (SPEI)

To overcome the potential bias in using the reported disaster dataset, we identify droughts and floods by using the Standard Precipitation and Evapotranspiration Index (SPEI), which is one of the most used indicators to monitor droughts[3]. It is obtained by transforming water balance (= precipitation − potential evapotranspiration) into standard deviations (Vicente-Serrano, Beguería, & López-Moreno, 2010). SPEI values can be categorized into seven levels of dryness/wetness, which provide a standardized framework for

[3]The Standard Precipitation Index (SPI) is the recommended indicator by the World Meteorological Organization for identifying and monitoring droughts (Hayes, Svoboda, Wall, & Widhalm, 2011). It is similar to SPEI, but does not account for temperature changes, which affects the water cycle of regions.

assessing and monitoring moisture conditions (Table 1). These levels range from “extremely wet” conditions, represented by values greater than or equal to 1.83, to “extremely dry” conditions, represented by values less than or equal to -1.65. The system also includes intermediate categories such as “severely wet,” “moderately wet,” “near normal,” “moderately dry,” and “severely dry,” each corresponding to specific ranges of SPEI values.

Table 1: SPEI categories

SPEI	**Categories**
≥ 1.83	extremely wet
1.43 to 1.82	severly wet
1.0 to 1.42	moderately wet
-0.83 to 0.99	near normal
-0.84 to -1.27	moderately dry
-1.28 to -1.64	severely dry
$\leq$ -1.65	extremely dry

Sources: Agnew (2000) and Danandeh Mehr et al. (2020)

This is a flexible index that can be applied in distinct regions with varying sizes and climates, while still allowing for comparison among them. SPEI can also handle different timescales for identifying types of droughts and their impacts (Table 2). The SPEI of 1-month timescale, SPEI-1, can identify meteorological droughts that affect water availability. Using SPEI-3[4] and SPEI-6, it is possible to recognize areas with agriculture stress due to soil moisture deficits (agricultural droughts). Greater timescales, from 12 to 24 months, reveal longer trends in water streams and storages, allowing the identification of hydrological droughts.

Table 2: SPEI timescales, drought types and impacts

Timescale (months)	**Drought type**	**Impacts**
1	meteorological	precipitation/water deficits
3–6	agricultural	crop yield reduction/failure, and soil moisture deficits
12–24	hydrological	water shortage in streams or storages such as reservoirs, lakes, lagoons, and groundwater

Sources: Svoboda, Hayes, and Wood (2012) and IPCC (2023).

In this study, we obtained a high-resolution SPEI dataset from Gebrechorkos et al. (2023) and aggregated the grid cells at the municipality level[5] from 1997 to 2019. Using municipalities' SPEIs and the SEDEC's reported natural disaster dataset, Table 3 classifies declared droughts (floods) based on the lowest (highest) monthly SPEI value of the reported year. Although most of the reported disasters were severe and extreme cases, one-third of the decrees occurred during near normal or moderate wetness/dryness levels, evidencing a potential selection bias due to political interest.

[4]While SPEI-1 is the standardized monthly water balance, SPEIs with longer timescales, SPEI-N, are calculated by averaging N consecutive monthly values before transforming into standard deviations.

[5]Municipalities' administrative borders and their urban areas were obtained from the Brazilian Institute of Geography and Statistics (IBGE).

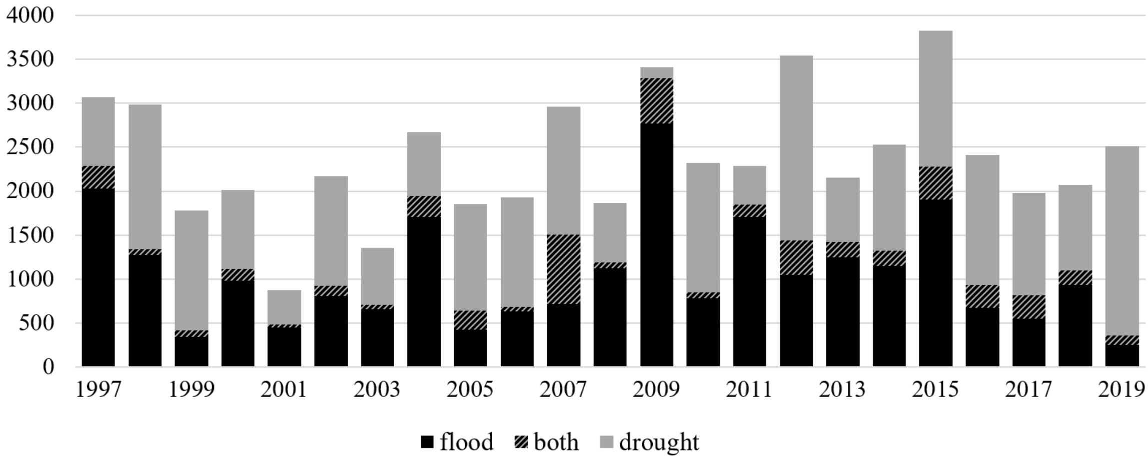
Table 3: SPEI category and reported hazards (1997–2019)

SPEI category	Droughts reported	Floods reported
Extremely wet	–	40.4%
Severely wet	–	27.9%
Moderately wet	–	17.7%
Near normal	12.6%	14.0%
Moderately dry	23.9%	–
Severely dry	29.8%	–
Extremely dry	33.7%	–
Total	23,856	13,854

Notes: Reported droughts categorized using SPEI-3, and reported floods categorized using SPEI-1 (urban).
Sources: SEDEC and Gebrechorkos et al. (2023).

Empirically, a large fraction of total losses are caused by a small number of major events (Wildasin, 2008), so we focused on extreme cases of hazards. We considered that a local government was hit by a flood in a year if there was at least one month with SPEI-1 ≥ 1.83 in its urban areas. For drought recognition, we considered the 3-month timescale SPEI lower than -1.65 to identify periods of agricultural stress that affect the local economy, mainly in rural areas. Using these selected thresholds, Figure 1 presents the 54,598 natural disaster occurrences in municipalities divided by year. There is a significant annual variability in the number of municipalities affected by these disasters. Some years, such as 2009 and 2011, show a higher prevalence of floods, while others indicate a higher incidence of droughts, like 2012 and 2019. At most, 3,826 administrative units were affected by a hazard in a single year, which represents 70.8% of the total municipalities (5,474).

Figure 1: Municipalities affected by natural disasters by year, using SPEI thresholds



Source: Gebrechorkos et al. (2023)

3.2 Local finance

The 1988 Federal Constitution enabled political autonomy and fiscal decentralization (Rodden, 2003), granting the responsibility for providing basic education, primary health care, social assistance, sanitation, water supply, land use management, and public transportation. To fund these public services, a larger proportion of resources started being shared with the municipalities by increasing the amount of existing grants and creating new ones. This process of resource distribution has led to vertical fiscal imbalance, where a subnational entity relies excessively on intergovernmental transfers to fund its operations. As a result, only 6% of the total revenue comes from local tax collection (Table 4), whose main sources are services activities (ISSQN tax) and real estate properties (IPTU tax).

On the other hand, grants account for 86% of municipal revenue, and since there are several of them, we focus on the four major ones, which represent 88% of the total grant revenue (Table 4). First, the Municipal Participation Fund (FPM) is a federal transfer that allocates 24.5% of income tax (IR) and industrialized products tax (IPI) to municipalities. Its primary goal is to reallocate larger funds to smaller jurisdictions, with population serving as the key criterion, which is annually estimated by the Brazilian Institute of Geography and Statistics (IBGE). The second most important grant by volume is the VAT share, which accounts for 25% of the total amount collected of value-added tax (ICMS) on goods and services at the state level. This is a return-type transfer, as the main distribution criterion is the municipality's value-added (at least 75%), with the remaining (at most 25%) determined by state law[6].

Different from the previous two, the Fund for Development and Maintenance of Basic Education and Teacher Valorization (FUNDEB)[7] and Unified Health System (SUS) are conditional grants, so they must be applied to education and public health services, respectively. The Federal Constitution mandates that local governments allocate a minimum of 25% of their own tax and transfer revenues to education. If the spending per enrolled student in public schools falls below a certain level, the federal authority provides additional educational grants to ensure equitable distribution of resources.

The SUS transfer aims to provide universal coverage for health services and has distinct sharing rules. It can be divided into two types: agreement transfers, which are paid on a case-by-case basis, and "fund to fund" transfers, which involve automatic transfers to state and municipal health funds. These transfers support health programs, including basic to high-complexity care, health surveillance, and pharmaceutical care, and the distribution is often based on per capita indicators or health program production levels and is allocated to essential health services across the country (Mendes, Miranda, & Cosio, 2008; Rocha, 2019).

Established in 1969 to mitigate the impact of natural disasters, the Fund for Public Calamity (FUNCAP) has remained inactive due to the absence of a financial source, which has not been defined through federal regulation. In the absence of a specific grant for

[6]For example, the state of Sao Paulo's VAT share criteria is based on value-added (76%), population (13%), local tax revenue (5%), cultivated area (3%), water reservoirs area (0.5%), protected areas (0.5%), and the remaining (2%) is equally distributed among municipalities.

[7]In 2007, FUNDEB substituted the Fund for Development of Fundamental Education (FUNDEF), which covered only the primary and lower secondary educations. Therefore, we used FUNDEF's transfer amounts as FUNDEB's between 2000 and 2006.

hazards, we assume capital transfers as a proxy for disaster-related aid. They typically result from agreements between local administrations and higher-level governments and are related to public investments.

This situation of high reliance on resources from higher levels of government may encourage municipalities' imprudent fiscal behavior, as they anticipate a bailout from the central authority (Aldasoro & Seiferling, 2014; Kornai, 1979; Kornai et al., 2003). In Brazil, borrowing restrictions tightened in the 1990s with the introduction of fiscal rules[8] to tackle subnational debt and hyperinflation. Consequently, municipalities have limited capacity to boost revenue through credit operations[9], in addition to their own tax collection. In the context of natural disasters, local governments may limit their spending on expensive disaster preparedness and avoidance policies, assuming that higher levels of government will likely provide them with financial and operational aid in future hazards (Goodspeed & Haughwout, 2012; Wildasin, 2008). In this study, we assume expenses in urbanism, environment and agriculture as proxies for disaster relief and mitigation measures.

The 2000-2019 financial information was obtained from the Public Sector Accounting and Tax Information System (Siconfi), managed by the National Treasury Secretariat (STN). All monetary values are in 2019 Brazilian reais (R$).

3.3 Descriptive statistics

Considering that extreme natural events frequently reoccur in some regions and have happened numerous times before the period examined in this study, we have set multiple baselines from 2000 to 2019 for comparative analysis. This approach reduces the statistics sensitivity to the selection of a single baseline year and allows for a dynamic comparison between the municipalities affected by a hazard in a given year with those that were not, using the previous year as a reference point (when conditions were normal for both).

Table 4 reveals municipalities that experienced droughts and floods in the following year already exhibited higher total surpluses, revenues, and expenditures compared to those that did not. Tax revenues are comparable across all four groups, while the transfers are slightly higher in jurisdictions hit by hazards. Borrowing is higher in municipalities hit by flood, and is comparable between non-drought and drought groups. Similarly, the expenditures in local governments are slightly higher in the disaster groups, but the environmental spending in municipalities affected by flood.

The literacy rate, age, working-age population rate, rural household rate, and Gini index show minimal variation across the different groups. In disaster-affected jurisdictions, GDP per capita is slightly lower, and the economy relies more on agriculture and less

[8]After the public state banks were privatized, state governments ceased issuing treasury bills. Consequently, subnational entities had to obtain approval from the federal government for credit operations, which was contingent upon meeting fiscal targets such as financial surplus, capping personnel expenses, and limiting indebtedness.

[9]Although the recognition of a state of public calamity or emergency temporarily suspends the fulfillment of fiscal targets, subnational entities are required to return to meeting these targets within a year.

on industry. Income is considerably higher, and the population is lower in municipalities affected by floods and droughts. These indicators were obtained from the Brazilian Institute of Geography and Statistics (IBGE).

The comparative analysis indicates that municipalities affected by disasters already have distinct characteristics, likely due to the recurring natural disasters in these areas. Therefore, the applied empirical strategy uses a matching technique to obtain a more credible control group and take into account the history of previous disaster occurrences.

Table 4: Municipality baseline statistics by natural disaster (2000–2019)

Variable	**non-drought**	**drought**	**non-flood**	**flood**
Total Surplus$^{\times}$	286.2	331.8	276.1	327.9
Total Revenue$^{\times}$	2,902.9	3,183.6	2,911.8	3,093.6
Tax Revenues$^{\times}$	187.1	187.7	187.7	176.9
Services Tax$^{\times}$	78.1	76.2	77.3	73.6
Property Tax$^{\times}$	40.0	36.8	41.4	32.4
Transfers$^{\times}$	2,503.6	2,770.5	2,510.2	2,705.4
Municipal Participation Fund$^{\times}$	1,027.7	1,174.9	1,032.7	1,149.2
VAT Share$^{\times}$	549.2	612.3	541.9	600.6
Basic Education Fund$^{\times}$	440.9	477.0	450.3	468.0
Health System Transfers$^{\times}$	185.1	205.8	193.2	196.9
Capital Transfers$^{\times}$	113.6	124.2	111.3	134.5
Borrowing$^{\times}$	13.1	13.2	12.5	13.9
Total Expenditure$^{\times}$	2,620.2	2,852.9	2,639.6	2,765.4
Current Expenditure$^{\times}$	2,296.6	2,520.2	2,326.1	2,405.1
Capital Expenditure$^{\times}$	323.9	333.2	314.0	360.5
by function				
Urbanism$^{\times}$	246.8	251.6	245.4	269.8
Agriculture$^{\times}$	68.6	72.1	61.3	75.1
Environment$^{\times}$	16.1	16.5	16.8	14.6
Municipality characteristics				
GDP$^{\times}$	19,560	18,998	19,698	19,020
Agriculture (%)	22.0	22.7	21.4	23.0
Industry (%)	14.2	13.7	14.3	13.4
Services (%)	31.0	31.6	31.8	30.5
Government (%)	32.9	31.9	32.5	33.2
Population	39,662	27,685	38,878	28,445
Income	886.7	943.7	891.7	915.1
Literacy (%)	83.5	84.8	84.1	83.9
Age	30.3	31.1	30.3	30.9
Working age population (%)	64.0	64.7	64.2	64.3
Rural household (%)	37.6	35.3	36.2	37.2
Gini Index	0.53	0.52	0.53	0.52
Observations	61,995	18,018	62,137	17,383

Notes: $^{\times}$R$ per capita. We established different baselines, using years before natural shocks as reference points. The drought and flood groups include municipalities in years that are not experiencing a disaster and are affected by one in the next period. Non-drought and non-flood categories consist of units in years that are not and remain not impacted by a hazard in the following period. Sources: STN, IBGE, and TSE.

4 Empirical strategy

We employ Imai et al. (2023) approach to estimate the impact of natural disasters on public finance, which combines a matching method with a difference-in-difference estimator.

In recent studies on the difference-in-differences (DiD) method, researchers have found that using the standard two-way fixed effects (TWFE) regressions with panel data could lead to biased estimates when dealing with heterogeneous treatment effects (Goodman-Bacon, 2021; Imai & Kim, 2021; Roth, Sant'Anna, Bilinski, & Poe, 2023). This is especially true for complex treatment designs involving non-binary treatments and with switching on and off behavior (de Chaisemartin & D'Haultfœuille, 2023). Some of the newly proposed DiD estimators that address this bias assume staggered treatment (Borusyak, Jaravel, & Spiess, 2024; Callaway & Sant'Anna, 2021; Sun & Abraham, 2021), meaning that once a unit becomes treated, it remains treated until the end of the analysis period. However, they may not be suitable for capturing the effects of natural disasters as these events exhibit switching on and off behavior that may not correspond with the assumptions of the estimators.

To our knowledge, only Imai et al. (2023) and de Chaisemartin and d'Haultfoeuille (2024) proposed DiD estimators that address non-staggered treatment adoption. However, their methodologies differ in defining reference points for estimating contemporaneous and lead effects.

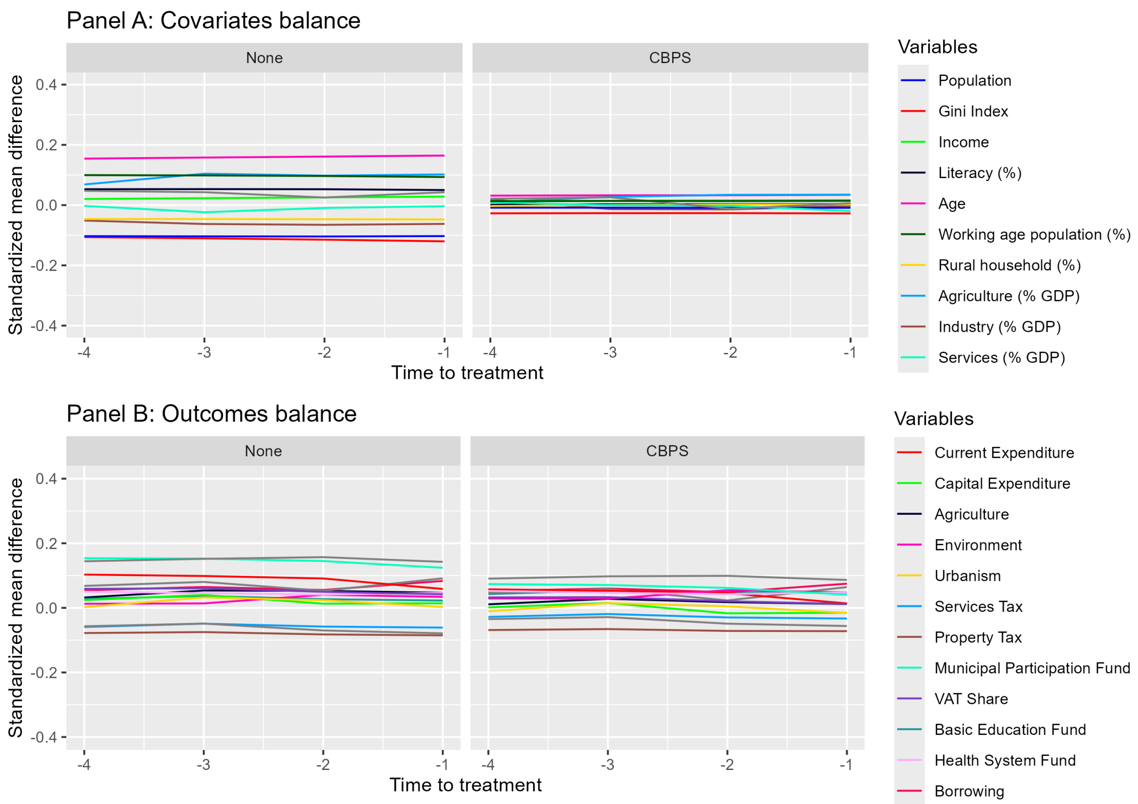
Considering a binary treatment design, the de Chaisemartin and d'Haultfoeuille's (2024) approach initially defines groups of potential switchers-in and potential switchers-out who are, respectively, non-treated and treated in the first period of the panel data. The average treatment effect on the treated (ATT) calculation in the first group is similar to the estimator proposed by Callaway and Sant'Anna (2021) without covariates, as it defines each unit's first treatment status change (becoming treated) as its reference point to compute the event study effects and uses only untreated units of potential switchers-in group as controls. The effect of becoming untreated can also be calculated with the potential switchers-out group, using the treated units as controls.

This approach has two limitations when dealing with recurring natural hazards over a long period of time. First, the de Chaisemartin and d'Haultfoeuille (2024)'s estimator (and other DiD estimators with staggered treatment designs) relies on the first treatment changes, and these tend not to be evenly spread across all time periods when these events occur in the same places (Appendix A.2). Rather, they accumulate at the beginning of the panel. Second, when a municipality is impacted one more time by a hazard in the future, the contemporaneous impact of a new event will be diluted in a lead effect of the first occurrence. Since each treated unit may take different treatment paths (sequence of treated/untreated status) after the first treatment, each lead effect represents a weighted average of the effects of treated and untreated units, compared to control units that did not change their statuses since the beginning of the panel. Therefore, this estimator is sensitive to the chosen initial period of observation in this specific setting.

In the method proposed by Imai et al. (2023), not only the first treatment change of a unit is used as a reference point but every subsequent new treatment of the same unit is also taken into account. This is achieved by pairing each treated observation with control observations with identical treatment histories up to a specified number of lags. Then, each matched set of treated observations and its controls can be refined by applying a matching method to control differences in pre-treatment characteristics. In this study, we applied the Covariate Balancing Propensity Score (CBPS) method (Imai & Ratkovic, 2014) which tends to outperform the traditional propensity score by also minimizing covariate differences within a defined number of lags. Finally, a difference-in-difference estimator can be used to estimate both short-term and long-term average treatment effects (ATT).

In the standard form of this approach, each lead effect is the average effect of both treated and untreated units, similarly to de Chaisemartin and d'Haultfoeuille's (2024) approach. However, Imai et al.'s (2023) estimator allows researchers to define specific treatment paths for the observations. In this study, we use only municipalities thgat were affected by a disaster for two consecutive years to estimate the first lead estimate. This allows for a more straightforward interpretation of the lead effect as a cumulative effect of being treated for two consecutive years, instead of the weighted average of both municipalities that were affected for two years in a row and those who were treated and became untreated in the following year. Since the effects of hazards can last in the aftermath, we also computed the average reversal effect (ART), which shows the effect of becoming untreated. This procedure is similar to calculating the ATT, but it uses treated observations as controls for untreated ones.

Figure 2: Variables balance for drought-affected municipalities and their controls



Notes: The graphs show the standardized mean differences between the treated observations and their matched set without using a matching method (left) and refining through Covariate Balancing Propensity Score (CBPS) (right).

In Figure 2, we can assess the quality of the matching procedure by examining the covariates and outcome variables balance for observations affected by drought and their matched sets. In Panel A, we observe that the standard differences of the covariates between treated observations and their controls decreased as expected since the CBPS minimizes the differences between groups. Moreover, even not using the lagged outcome variables in the matching method, the differences between the groups also decreased for these variables (Panel B). The variable balance for flood-affected municipalities and their control groups is similar to the drought case, so it is provided in Appendix A.3.

5 Results

Tables 5 and 6 display the results for average treatment effects (ATT) and average reversal effects (ART), representing the impact of receiving treatment and no treatment, respectively, on financial variables. For the ATT, the first column represents the contemporaneous effect (0) of every disaster occurrence, and the second one is the lead effect (1), which is the cumulative effect of a municipality being affected by a disaster in two consecutive years. The ART columns display the effects of becoming untreated (reversal), that is, not being impacted for one (+1) and two (+2) years after the disaster years. Note that the reversal effects use treated municipalities as controls and not the same control group of untreated units used for the ATT estimation.

5.1 Droughts

In the first year, extreme droughts have no significant impact on municipalities' fiscal balance. Tax revenue is not impacted, as the non-significant decrease in service tax is offset by a marginally significant increase in IPTU tax revenues (R$0.70). This may represent some local efforts to enhance tax collection on real estate properties during drought occurrences.

The overall impact on transfers is positive but not statistically significant, with two opposing effects. The FPM is positively affected by the drought (R$6.27). This is likely due to the decrease in population size (Appendix A.4), as smaller municipalities generally receive higher per capita amounts of this grant. The SUS transfers have also been positively impacted, possibly due to the increase in demand for public health services.

On the contrary, the basic education fund is negatively affected. The federal government supplements local public educational resources up to a defined minimum value per student, and there are some possible ways to lower it. First, since municipalities are mandatory to spend 25% of some of their tax and transfer revenues, an increase in them could increase educational spending closer to the threshold, lowering the federal supplementation. Second, when students drop out of public school, the local educational funding per enrollment increases. Lastly, when students transfer to another municipality, it also redirects the

FUNDEB resources to this administration. It is likely that the decrease in funding for this grant is caused by multiple factors. This includes the positive impact on FPM, which boosts local educational funding, and the negative impact on population size, indicating a potential emigration flow from drought-affected municipalities.

Table 5: Impact of extreme droughts on local public finance

	SPEI ≤ -1.65 Threshold			
	ATT		**ART**	
Outcome variable	**0**	**1**	**+1**	**+2**
Total Surplus	-4.93	-14.96*	-8.00	-19.84
	(7.4)	(8.1)	(17.5)	(26.8)
Expenditures				
Current Expenditure	1.72	-13.27**	18.18	-14.48
	(4.5)	(8.1)	(13.5)	(21.1)
Capital Expenditure	0.01	13.77**	-1.53	-24.41
	(3.2)	(5.8)	(6.9)	(18.9)
by function				
Agriculture	0.97	10.32***	1.79	3.94
	(1.3)	(2.5)	(1.7)	(3.5)
Environment	1.42***	-1.38**	2.20*	2.01
	(0.5)	(0.7)	(1.4)	(2.2)
Urbanism	4.75	27.35**	1.25	-20.55
	(4.5)	(20.6)	(6.2)	(13.5)
Revenues				
Tax Revenue	-0.27	-5.37	3.70	-3.88
	(1.4)	(4.7)	(3.7)	(5.4)
Services Tax (ISSQN)	-0.73	-7.02**	4.00	2.31
	(1.1)	(4.4)	(3.9)	(3.9)
Property Tax (IPTU)	0.70**	1.01	-0.44	-1.54
	(0.3)	(1.0)	(0.7)	(1.5)
Transfers	2.58	-7.15	11.73	-49.85
	(5.9)	(10.1)	(14.7)	(38.5)
Municipal Participation Fund (FPM)	6.27***	7.53*	-3.88	6.39
	(1.9)	(4.5)	(6.7)	(12.5)
VAT Share (ICMS)	-0.29	3.03	5.60	-9.07
	(2.4)	(3.4)	(3.9)	(11.3)
Basic Education Fund (FUNDEB)	-5.22***	-18.06***	6.62	-11.21
	(2.0)	(4.5)	(6.6)	(17.4)
Health System Transfers (SUS)	3.39***	-3.43	3.36	-2.71
	(1.1)	(2.4)	(3.1)	(7.4)
Capital Transfers	-1.97	3.33	-0.67	-46.70***
	(2.2)	(3.4)	(6.8)	(21.1)
Borrowing	-0.71	-0.03	-1.00	4.81
	(0.7)	(1.6)	(1.6)	(4.4)
Observations	17,237	5,036	10,059	6,148

Notes: $^{*}p < 10\%$, $^{**}p < 5\%$, $^{***}p < 1\%$. Block bootstrapped standard errors in parenthesis. All monetary values are in R$ per capita. ATT columns (0) and (1) represents the contemporaneous and first lead effects. ART columns (+1) and (+2) are the aftermath effects.

With consecutive years of extreme droughts, the local finances become under increased stress. There is a significant decrease in fiscal balance, mainly due to a further decrease in educational grants and ISSQN tax collection. Given that the services sector was not significantly impacted by the hazard (Appendix A.4), it is likely that tax avoidance has increased, or tax collection efforts were lowered.

Additionally, the affected municipalities shifted part of their current expenditures to capital investments in response to the drought. Some of these increased expenses are in agriculture and urban development, which includes the acquisition of assets like cisterns and trucks for water storage and transportation.

Some of the reversal effects are not significant, indicating that the impacts extend beyond the drought period, such as on agriculture spending. Remember that ART is the effect of becoming untreated, using treated units as control. Therefore, it builds up on the contemporaneous (0) or the first lead (1) effects. For example, if we consider the reversal effects on agriculture in a region affected by drought for one year (0.97) or two consecutive years (10.32), both become more positive (+1.79). This means that there is no apparent ATT reversal in the aftermath.

On the other hand, some effects are reversed, such as the investment in capital and urban development, although these are insignificant. The decrease in spending on assets and infrastructure seems to be related to the financial difficulties faced by municipalities, as shown by the negative impact on fiscal surplus and the insignificant impact on transfers.

The results have shown that in the initial year of extreme drought, expenditures and revenues are not substantially impacted. However, when the drought persists into a second year, reductions in local tax revenue and transfers become apparent. Moreover, municipalities tend to reallocate funds from current expenditures to essential capital expenditures for mitigation strategies, probably impacting the public services provision in the affected area. Additionally, local governments do not engage in extra borrowing during or immediately after the drought events, indicated by non-significant effects.

5.2 Floods

In contrast to droughts, municipalities affected by floods frequently experience a significant improvement in their financial balance, primarily due to an increase in grants, whereas the impact on local tax revenues is typically insignificant during and after flood events.

The transfer impact was positively significant, not just during disaster years (R$13.78 and R$21.37), but it also extended into subsequent years with positive and non-significant effects. The ICMS and FUNDEB grants experienced a positive impact from the extreme floods. Given that the former is collected and allocated by the state government in relation to economic activity, and considering that the affected municipalities recorded non-significant or negative GDP effects (Appendix A.4), it is likely that the increased distribution was an intentional act of financial assistance by the governor.

Table 6: Impact of extreme floods on local public finance

	SPEI ≥ 1.83 Threshold			
	ATT		**ART**	
Outcome variable	**0**	**1**	**+1**	**+2**
Total Surplus	4.97	17.02	2.18	3.62
	(11.0)	(26.1)	(9.9)	(18.0)
Expenditures				
Current Expenditure	9.11	10.64	-6.83	0.77
	(9.5)	(24.5)	(9.4)	(24.5)
Capital Expenditure	3.60	6.31	6.99	23.68
	(4.0)	(8.9)	(7.5)	(15.4)
by function				
Agriculture	-0.24	-0.73	2.23	8.96***
	(1.3)	(3.8)	(2.7)	(3.8)
Environment	0.66*	-2.33**	1.03*	2.74
	(0.5)	(1.1)	(0.7)	(2.1)
Urbanism	1.56	-8.71	-2.94	1.62
	(3.2)	(11.3)	(7.5)	(12.4)
Revenues				
Tax Revenues	0.34	3.92	1.91	4.44
	(1.3)	(3.0)	(3.1)	(6.6)
Services Tax (ISSQN)	1.44	2.70	3.18	5.82
	(1.6)	(2.5)	(2.7)	(5.6)
Property Tax (IPTU)	-0.15	-0.06	-0.03	-0.24
	(0.3)	(0.5)	(0.4)	(1.2)
Transfers	13.78***	21.37*	6.79	27.56
	(5.6)	(11.8)	(11.5)	(31.0)
Municipal Participation Fund (FPM)	-3.02	-14.16***	10.31***	8.50
	(2.0)	(3.9)	(3.5)	(11.2)
VAT Share (ICMS)	5.73***	10.42**	-6.53	-8.73
	(2.4)	(5.1)	(5.6)	(9.8)
Basic Education Fund (FUNDEB)	4.33**	6.48	-13.50**	-25.94
	(1.9)	(6.4)	(6.3)	(17.5)
Health System Transfers (SUS)	0.88	-0.60	2.46	-3.20
	(1.1)	(3.6)	(3.3)	(9.6)
Capital Transfers	-0.28	5.28	15.53***	13.23*
	(2.3)	(5.0)	(5.2)	(10.8)
Borrowing	-0.15	-2.77***	3.20***	-1.48
	(0.6)	(1.1)	(1.2)	(6.1)
Observations	16,594	3,850	11,819	6,631

Notes: $^{*}p < 10\%$, $^{**}p < 5\%$, $^{***}p < 1\%$. Block bootstrapped standard errors in parenthesis. All monetary values are in R$ per capita. ATT columns (0) and (1) represents the contemporaneous and first lead effects. ART columns (+1) and (+2) are the aftermath effects.

In the flood years, the impact on FPM transfer was negative, mainly in the second year (R$-14.16). The allocation of this grant is based on the size of the population, where typically, larger populations receive smaller per capita amounts. Nonetheless, there was a negative effect on the population (Appendix A.4). This can be happening because each population bracket is allotted a fixed grant sum. Consequently, as the population within a bracket grows, the per capita grant diminishes. Conversely, when a municipality transitions to a different population bracket, the per capita grant amount decreases if the municipality moves to a lower bracket and increases if it advances to a higher bracket (Boueri, Monasterio, Mation, & Silva, 2013).

Within the expense functions, environmental spending exhibit significant but mixed effects, while agriculture shows positive reversal effect (R$8.96), which was the sector most negatively affected by the hazard (Appendix A.4). Urbanism expense is not affected, despite the substantial increase of capital transfer revenues for municipalities affected by extreme floods (R$15.53 and R$13.23).

Moreover, the significant ATT on FPM, ICMS and FUNDEB transfers are reverted, resulting in insignificant and positive ART on total transfers. This means that the previously positive effect is not reversed in the subsequent two years after the extreme event.

When it comes to financial management, municipalities affected by floods often see an improvement in their financial balance due to increased grants. However, the impact on local tax revenues during and after flood events is insignificant. Specifically, the positive impact on transfers extends into subsequent years, mainly by the increase on capital transfer. Interestingly, despite this increment flood-affected municipalities, expenses for urban development and infrastructure remain unaffected.Additionally, local administrations tend to increase their borrowing in the first year following a natural disaster (R$3.20), indicating their dependence on intergovernmental transfers for disaster relief and rehabilitation efforts.

6 Conclusion

This study assessed the impact of extreme floods and droughts on local public finances. Specifically, we examined how affected municipalities fund their unforeseen natural disaster expenses and whether there is evidence of moral hazard behavior in local administrations that receive intergovernmental transfers, potentially reducing spending on costly projects aimed at preventing and mitigating future hazard damages.

The findings highlight the differing fiscal consequences of droughts and floods on Brazilian municipalities, particularly in terms of the volume of grants received and the allocation of resources for future disaster mitigation. Initially, droughts may not present a significant fiscal impact, but a recurring event can result in higher deficits and lower local tax revenues in the following year. As there is no significant increase in transfers, the situation often compels municipalities to reallocate current to capital expenditures, mainly in agriculture and urbanism areas. The adverse effects on fiscal balance persist, apparently limiting further investments in drought prevention measures.

On the other hand, floods lead to better fiscal balances due to enhanced financial aid for up to two years post-disaster. However, despite the rise in capital transfers, there is no significant application for environmental and urban planning projects, which are typically utilized for flood mitigation measures like constructing retention basins, enhancing drainage systems, and increasing surface permeability in urban zones. Conversely, there has been an increase in agricultural spending and in capital expenditure after the extreme event, although the latter is insignificant. This indicates a potential moral hazard issue arising from the excessive dependence on intergovernmental transfers to manage natural disasters.

While this study provides valuable insights into the impact of natural disasters on local government finance, it is important to consider the limitations in which this study was conducted. SPEI is a widely used indicator to monitor drought, but it is not commonly applied to identify floods. At least, there seems to have a high correlation between the extreme SPEI levels and the reported floods in Brazil (Table 3). In addition, heavy precipitation does not always lead to flooding as there are other contributing factors such as topography, impervious surface density, infrastructure, and proximity to bodies of water (IPCC, 2023). Furthermore, because we established SPEI thresholds to identify extreme hazards and utilized a matching method (CBPS), it's likely that the treated units are mainly being compared to "almost treated" cases of severe disasters. As a result, we might be underestimating the effects.

To simplify the interpretation of results, we chose to calculate the lead effects by including only cases where a municipality endured consecutive years of disaster. Therefore, this approach limited the number of observations available for assessing the lead effects over a prolonged period. Exploring the long-term cumulative impact of these hazards in future studies would be valuable for understanding the dynamics of local finance after a natural shock.

Our findings highlight the need for targeted fiscal policies that address the unique financial challenges posed by different types of disasters. For drought-affected municipalities, policies should focus on providing direct financial support to mitigate revenue losses. In contrast, flood-affected administrations need better incentives for the effective application of transfer aids into disaster-mitigation measures. Wildasin (2008) proposed the establishment of mandatory disaster reserves in each state, funded by contributions from the subnational governments. This approach could help alleviate soft budget constraints by shifting the financial burden from the central authority to the local and regional governments. These insights can be used to design more robust fiscal frameworks and disaster management strategies, ultimately strengthening local public finance systems in the face of increasing climate risks.

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Appendices

A.1 Criteria for disaster recognition (2012)

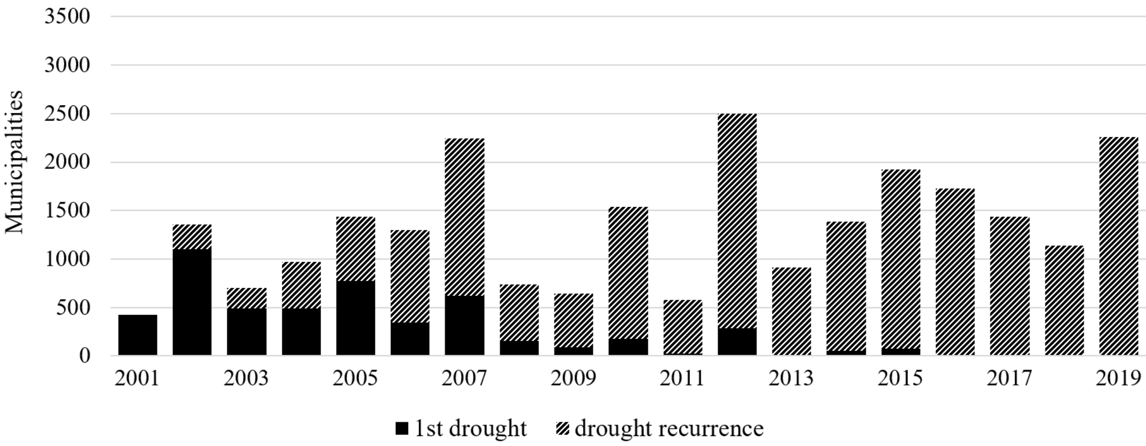
	Emergency	Calamity
(a1) Human damages		
deaths	1 to 9	10 or more
affected persons	up to 99	100 or more
(a2) Material damages		
damaged public health or education facilities	1 to 9	10 or more
damaged housing units	1 to 9	10 or more
damaged infrastructure works	1 to 9	10 or more
damaged public facilities for community use	1 to 9	10 or more
(a3) Environmental damages		
population affected by pollution and contamination of water or soil*	5% to 10%	more than 10%
population affected by reduction or depletion of water*	5% to 10%	more than 10%
destruction of parks, environmental protection areas or permanent preservation areas	up to 40% of the area	more than 40% of the area
(b) Economic losses		
public (in essential services)	above 2.77% of net revenue	above 8.33% of net revenue
private	above 8.33% of net revenue	above 24.93% of net revenue
(c) Local government capacity to respond and manage the crisis	affected	exceeded

Source: Regulatory Instruction No. 1, of August 24, 2012.

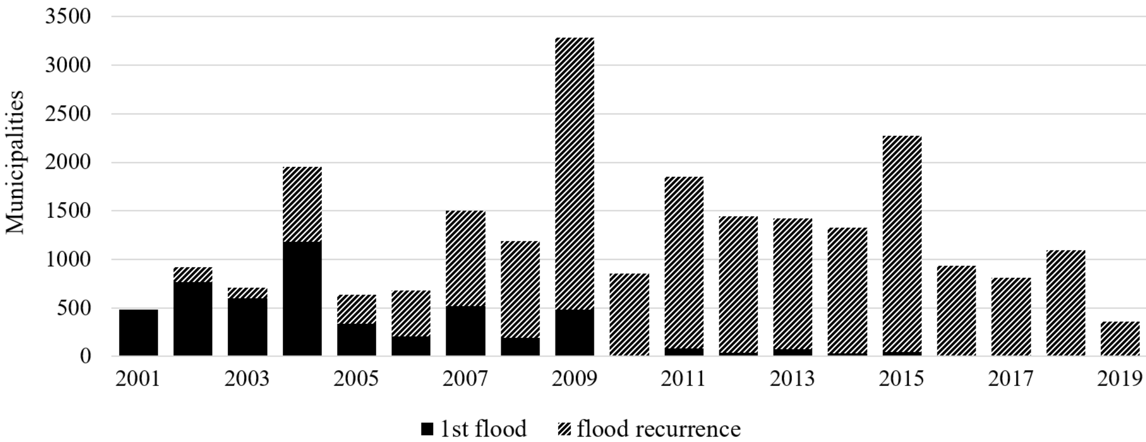
Notes: *Double if municipality has fewer than 10,000 inhabitants. For a recognition, the following must occur: (a) two of the three damages (human, material and environmental), (b) economic loss, and (c) affect local government capacity.

A.2 Distribution of the first and new disaster occurrences (2001–2019)

Droughts

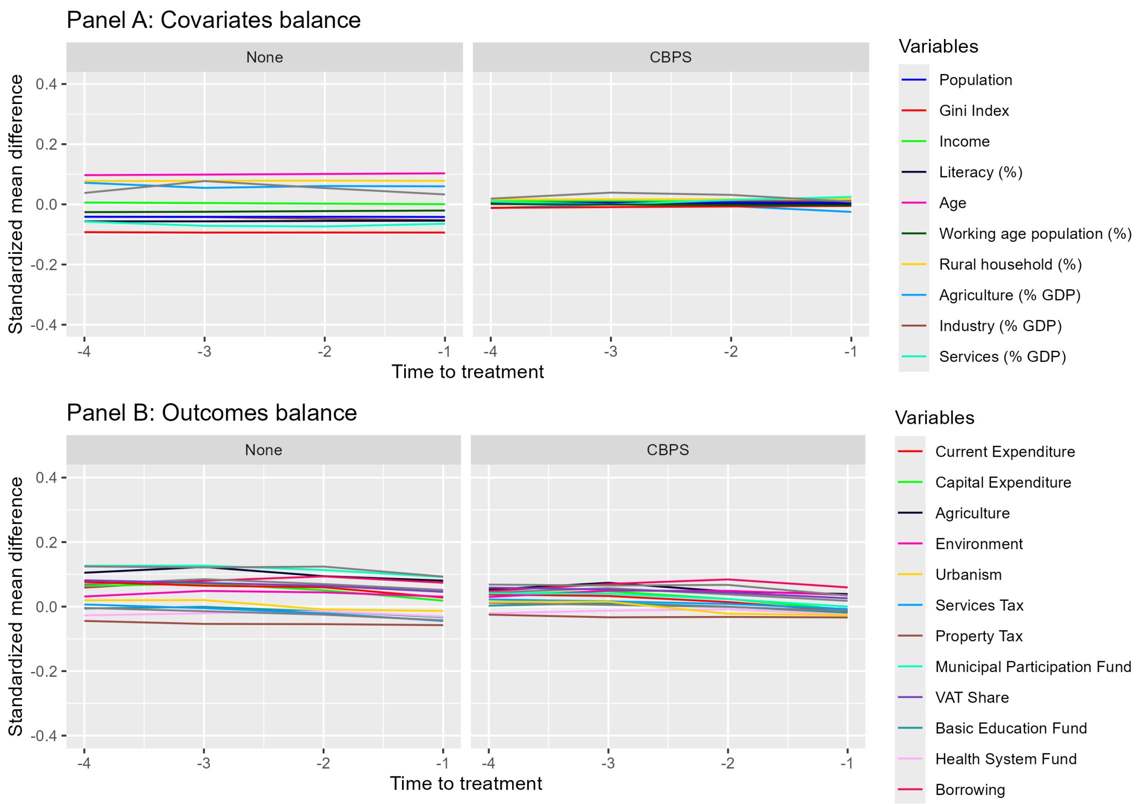


Floods



Notes: The figures above show the distributions of the natural disasters between 2001 and 2019. The solid black bars indicate the number of municipalities experiencing a disaster for the first time since 2001, while the hatched bars show the number of municipalities affected by the same hazard again. Adopting an empirical approach that uses the first occurrence as a reference for an event study, the contemporaneous and early lead effects predominantly capture the natural shocks that occurred at the start of the period.

A.3 Variables balance for flood-affected municipalities and their controls



Notes: The graphs show the standardized mean differences between the treated observations and their matched set without using a matching method (left) and refining through Covariate Balancing Propensity Score (CBPS) (right).

A.4 Impact of disasters on GDP and population

Table 7: Impact of extreme droughts on population and GDP

	SPEI ≤ −1.65 Threshold			
	ATT		ART	
Outcome variable	**0**	**1**	**+1**	**+2**
Population	-49.63**	-111.41**	86.70*	101.75
	(24.3)	(59.4)	(39.1)	(124.7)
GDP by sector				
Agriculture	-333.03***	-410.33***	52.89	-161.22
	(31.9)	(54.0)	(48.2)	(308.9)
Industry	-91.41	-123.59	-23.22	-118.05
	(70.6)	(143.4)	(223.4)	(144.9)
Services	-41.10*	11.03	9.53	-263.22***
	(26.8)	(43.2)	(36.8)	(119.0)
Government	4.21	42.39***	23.78***	8.20
	(3.8)	(9.4)	(9.4)	(33.6)
Observations	18,018	5,432	16,789	10,929

Notes: $^{*}p < 10\%$, $^{**}p < 5\%$, $^{***}p < 1\%$. Block bootstrapped standard errors in parenthesis. All monetary values are in R$ per capita. ATT columns (0) and (1) represents the contemporaneous and first lead effects. ART columns (+1) and (+2) are the aftermath effects.

Table 8: Impact of extreme floods on population and GDP

	SPEI ≥ 1.83 Threshold			
	ATT		ART	
Outcome variable	**0**	**1**	**+1**	**+2**
Population	-82.97***	-48.18	8.08	159.10
	(23.1)	(200.8)	(99.7)	(139.7)
GDP by sector				
Agriculture	24.51	-201.70**	-137.92**	-155.56
	(24.1)	(118.8)	(63.3)	(149.6)
Industry	42.14	-166.16	-53.78	54.82
	(47.6)	(128.2)	(75.6)	(147.8)
Services	-12.67	-187.26***	-11.12	32.72
	(14.9)	(76.8)	(10.0)	(112.7)
Government	18.30***	29.59***	-16.44	6.40
	(4.2)	(11.6)	(16.4)	(22.5)
Observations	17.383	4,161	18,141	11,831

Notes: $^{*}p < 10\%$, $^{**}p < 5\%$, $^{***}p < 1\%$. Block bootstrapped standard errors in parenthesis. All monetary values are in R$ per capita. ATT columns (0) and (1) represents the contemporaneous and first lead effects. ART columns (+1) and (+2) are the aftermath effects.