Flood Risks and the Chinese Local Government Debt Crisis: Climate Shocks, Borrowing Behavior, and Fiscal Stress

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Abstract

This study examines how climate risks, particularly floods, exacerbate China's local government debt crisis. Using a staggered difference-in-differences approach, we find that floods lead to a 44.5% increase in municipal corporate bond (MCB) issuance as local governments seek emergency funding. However, heightened investor risk aversion results in an 8.23% rise in issuance costs. Our findings highlight how climate shocks amplify fiscal stress by increasing both borrowing needs and financing costs. By bridging climate finance and municipal debt literature, this study underscores the urgent need for integrated fiscal and environmental policies to enhance financial resilience in climate-vulnerable economies.

Keywords: Climate Risk; Floods; Local Government Financing; Municipal Corporate Bonds; China

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1 Introduction

China's local government debt crisis has intensified since 2012, largely due to the expansive 4 trillion yuan (US$590 billion) stimulus package introduced in response to the 2008 global financial crisis. By 2023, local government debt had surged to 64 trillion yuan—approximately 49% of China's GDP—primarily comprising bank loans and municipal corporate bonds (MCBs) issued through local government financing vehicles (LGFVs). While extensive research examines the estimation, transmission, and macroeconomic consequences of local government debt,[1] little attention has been given to the role of climate risks—particularly extreme weather events—in shaping borrowing behavior and financing costs.

This paper addresses this gap by investigating the impact of flood disasters on local government debt in China. Climate change is increasing the frequency and severity of natural disasters—including floods, droughts, tropical cyclones, and heat waves—causing substantial economic disruptions.[2] Among these, floods pose the most severe climate threat in China, affecting over 47 million people and causing direct economic losses of 192 billion yuan in 2019 alone. To finance disaster recovery and reconstruction, local governments rely heavily on MCB issuance, making this market an ideal setting to assess the fiscal consequences of climate risks.

Our analysis explores how flood risks influence LGFV borrowing and investor behavior in the MCB market. Using a staggered difference-in-differences (DID) model, we find that floods have immediate and significant effects on MCB issuance, with impacts persisting for at least 24 months. Specifically, LGFVs increase MCB issuance by 44.5% relative to the sample mean following a flood. However, investor caution leads to a 23.7 basis point (bps) rise in issuance costs, representing an 8.23% increase from the mean spread of 287.8 bps.

We further examine the mechanisms driving these effects. Floods cause extensive infrastructure damage, widening fiscal deficits and increasing uncertainty over local governments' repayment capacity. As a result, flood-affected MCBs are perceived as riskier, prompting investors to demand higher premiums. This aligns with findings that natural disasters strain local government budgets and heighten investor risk aversion.

[1] See Qu et al., (2023); Zhuo Chen et al., (2020); Deng et al., (2015); and Huang et al., (2020) for more details.
[2] See Billings et al., (2022); Dessaint et al., (2017); Hong et al., (2019); and Huynh et al., (2023), for a more elaborated discussion.

This paper makes three key contributions. First, it advances the literature on Chinese local government debt by identifying climate risk as a crucial factor influencing borrowing dynamics.[3] Unlike in Western economies, where property taxes serve as the primary revenue source, Chinese local governments depend heavily on off-balance-sheet financing via LGFVs, making them particularly vulnerable to climate-induced fiscal shocks. Our findings reveal that in China, climate risks—exemplified by floods—drive LGFVs to increase MCB issuance in affected areas, exacerbating local government debt burdens. At the same time, investors raise issuance costs in response to heightened risk, amplifying public finance costs.

Second, this study bridges the climate finance[4] and municipal debt literatures, demonstrating that acute climate risks—such as floods—intensify fiscal stress in emerging economies. Unlike gradual climate risks like sea-level rise (Goldsmith-Pinkham et al., 2023; Painter, 2020), we find that floods significantly impact MCB issuance and costs in affected regions. In response to floods, LGFVs issue more MCBs with maturities of less than five years to finance repayment and rebuilding efforts. However, investors demand higher risk premiums for these short-term bonds, further exacerbating the liquidity risk of local government debt.

Third, this paper contributes to the broader discussion on financial market responses to environmental risks, showing that climate-related uncertainty increases credit spreads and alters investor behavior in the MCB market. Prior research highlights how climate risk exposure affects asset prices and investment behavior. Huynh et al. (2021) find that corporate bonds with higher climate risk exposure tend to generate lower future returns, as investors require greater compensation for climate-related uncertainties. Mulder (2021) demonstrates that precise flood risk information benefits insurers and encourages homeowners to adopt risk-reducing measures and purchase more insurance. Lee (2021) finds that home seller disclosure requirements lower

[3] Prior studies have examined the factors driving the surge in government debt (Bai et al., 2016; Zhuo Chen et al., 2020), the relationship between local government debt and the property market (Deng et al., 2015), the effects of government debt on investment and credit allocation (Zhuo Chen et al., 2020; Huang et al., 2020), and the financial consequences of government defaults (Gao et al., 2021).

[4] For example, Hong, et al. (2019) show that the stock market underreacts to the long-term implications of drought trends. Painter (2020) and Goldsmith-Pinkham, et al. (2023) find that sea level risk significantly raises municipal bond issuance costs in the United States. Studies by Bernstein et al. (2019) and Giglio et al. (2021) also demonstrate that rising sea levels have a marked effect on real estate prices in coastal regions. Other work has explored how climate risk exposure affects bond and stock markets (Huynh and Xia, 2023), expected returns (Sautner et al., 2023), and firm cash flow (Brown et al., 2021).

population density and flood damage in high-risk areas by 2.8%, underscoring the role of information transparency in adaptation. Building on this literature, we find that flood risks increase both MCB issuance and credit spreads by amplifying uncertainty in expected returns. Moreover, climate risk information disclosure can help reduce this uncertainty, thereby lowering MCB issuance costs.

The remainder of this paper is structured as follows: Section 2 develops the research hypotheses and methodology. Section 3 presents empirical findings on the impact of floods on local public finance. Section 4 explores the mechanisms linking climate risks to municipal borrowing, and Section 5 concludes.

2 Institutional background

2.1 Chinese Local Government Debt and MCBs

A key focus of our study is Chinese local government debt, measured by municipal corporate bonds (MCBs). Our data correspond to prefecture-level cities (henceforth, "cities"), which represent the second tier of China's local government structure, below provinces. The median city spans approximately 14,340 square kilometers, has a population of 3.5 million, and generated a GDP of 176.7 billion yuan in 2019.[5]

Unlike Western economies, Chinese local governments are not permitted to borrow directly from financial markets. Following the 1994 tax-sharing reform, local government financing vehicles (LGFVs)—special-purpose state-owned enterprises (SOEs)—became the primary borrowing channel for local governments, which lack direct access to bond markets. Local governments establish LGFVs, transfer assets to them (typically land), and direct them to secure bank loans or issue bonds, often using these transferred assets as collateral (Deng et al., 2015; He et al., 2023). While legally classified as corporate bonds, MCBs carry implicit local government guarantees, making them as secure as traditional municipal bonds (Zhuo Chen et al., 2020).

Although bank loans remain the dominant source of local government debt, MCB issuance has grown significantly in recent years, as illustrated in Figure 1. MCB investors include commercial

[5] All data are reported by median value, acquired from China City Statistical Yearbook.

banks, insurance companies, public equity funds, and securities firms. Since investors determine MCB credit spreads based on risk assessment, these spreads serve as a crucial market indicator of climate risk perception.

In August 2014, China's central government amended the 1994 budget law, allowing provincial-level governments—including provinces, centrally governed municipalities, and autonomous regions—to issue municipal bonds directly. However, city governments remained restricted to issuing bonds indirectly through LGFVs. In October 2014, Beijing introduced Document No. 43, which weakened the implicit government guarantees on MCBs and strictly limited local governments' ability to repay these bonds. The document also imposed stringent restrictions on LGFVs using MCBs to finance new investments while encouraging the use of MCBs to refinance maturing debt.

Although the new budget law did not directly impact city governments' ability to issue MCBs, it significantly reduced the perception of implicit government guarantees. Some of our empirical results are closely linked to Document No. 43, and we discuss its effects on the MCB market in detail in later sections.

2.2 Flood Management in China

Floods are the most severe natural disaster in China. In 2019 alone, floods affected over 47 million people, resulted in 658 deaths, and caused direct economic losses of 192 billion yuan—equivalent to 0.2% of national GDP. To finance disaster relief and reconstruction, local governments must raise funds, often through MCB issuance.

Figure 1 presents the annual aggregate level of MCB issuance from 2012 to 2019. The left panel shows that LGFVs significantly increased MCB issuance over time, while the right panel, which categorizes cities by flood occurrence, demonstrates that flood-affected cities issue significantly more MCBs than unaffected cities.

The Chinese MCB market provides an ideal setting for assessing the impact of climate risk on local government debt. Unlike corporate bonds, MCBs are issued by LGFVs, with local governments as primary stakeholders. Although legally classified as corporate bonds, MCBs retain implicit government guarantees, making them similar in safety to traditional municipal bonds (Zhuo Chen et al., 2020). Unlike bank loans secured by LGFVs, MCBs not only reflect LGFVs'

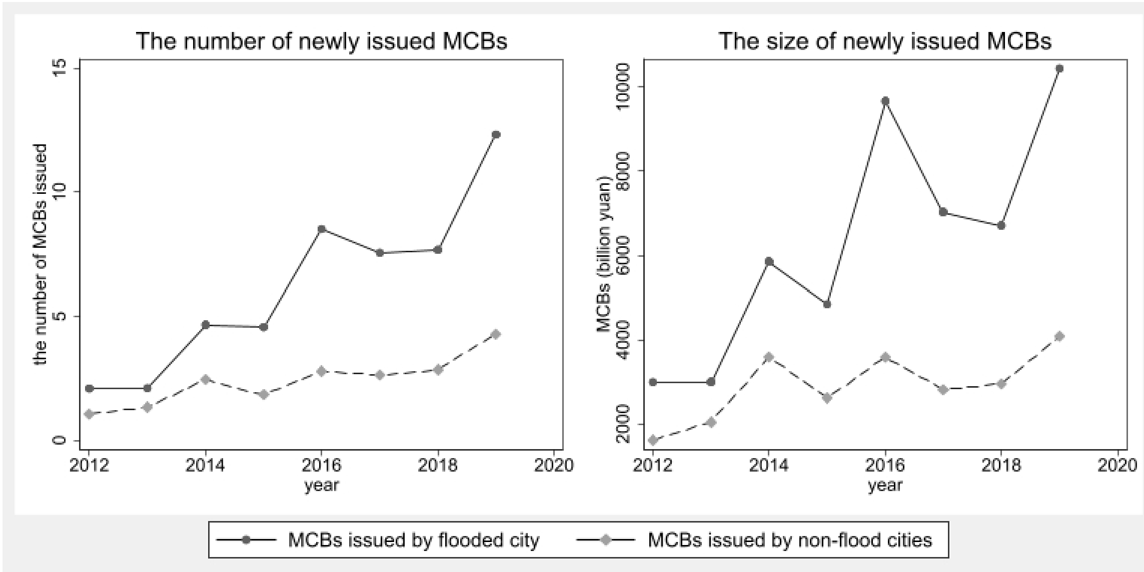

Figure 1: Annual Aggregate Level of MCB Issuance

Note: The left panel displays the yearly aggregate number of MCB issuances per city, while the right panel shows the total issuance amount. The data (2012–2019) is sourced from WIND Co., and flood data is obtained from the Hydrological Information Annual Report (2010–2021).

borrowing behavior but also capture investor risk perceptions, as reflected in credit spreads. Since both borrowing behavior and investor premiums influence the cost and sustainability of local government debt, understanding the relationship between climate risks and MCBs is essential for policymakers and financial market participants (Ang et al., 2018).

2.2.1 Flood Monitoring and Structural Mitigation

The Chinese government employs multiple measures to mitigate flood risks, including extensive hydrological monitoring and forecasting. Over 1,400 national hydrological stations are positioned along major rivers to monitor precipitation, water levels, discharge, and sediment. This data is automatically reported to government agencies and made publicly available when necessary, particularly for flood warnings. The Ministry of Water Resources (MoWR) compiles this data in the annual Hydrological Information Annual Report, which defines a flood event as any instance in which a hydrological station's peak water level exceeds the official warning threshold.

Beyond monitoring, the government has implemented structural flood management strategies. Flood detention basins (FDBs) serve as designated areas for temporarily storing floodwaters to prevent widespread damage. These basins are primarily located in midstream and downstream regions. Since 2000, 97 counties have been designated as FDBs, increasing to 98 by 2010. These basins cover 30,443 square kilometers—an area comparable to Belgium—and are home to approximately 15 million people. Under the Temporary Measures for the Use of Compensation in Flood Storage and Detention Areas, the central government compensates up to 70% of damages incurred by floodwater diversion in these basins.

In October 2015, the central government issued the Guiding Opinions on Promoting the Construction of Sponge Cities, selecting 16 cities as pilot sites, with 14 additional cities added in 2016. These pilot cities were required to enhance urban infrastructure to improve flood resilience. However, financing these upgrades fell to local governments, increasing their debt burdens. Our analysis controls for the potential effects of this policy.

2.2.2 Disaster Relief and Fiscal Implications

In cities without FDBs, disaster relief policies vary by region. According to The Interim Measures for the Management of Living Relief Funds for Natural Disasters (Document No. 6, Ministry of Finance, January 20, 2011), the central government covers 70% of disaster relief costs in inland provinces but only 50% in coastal provinces. Consequently, coastal cities rely more heavily on local government funding for post-disaster recovery, which may further drive up their debt levels.

To account for these differences, our analysis examines regional variations in MCB issuance and investor response to flood risks. By differentiating between flood-affected and non-affected cities and considering the fiscal constraints imposed by varying relief policies, we provide a more comprehensive understanding of how climate risks influence local government debt dynamics.

3 Research Design and Methodology

3.1 Hypothesis development

Our primary hypothesis is based on the premise that floods damage homes and infrastructure, increasing the financial burden on local governments as they seek funds for disaster relief and reconstruction (Jerch et al., 2023; Pelli et al., 2023). In flood-affected cities, the demand for funding rises sharply. However, due to the 1994 Budget Law, which prohibits local governments from directly raising debt (Amstad et al., 2019), they must rely on LGFVs to issue MCBs for disaster recovery. This leads to our first hypothesis:

Hypothesis 1: Flood occurrences are positively associated with LGFVs' bond issuance.

Next, we examine how the bond market reacts to flood risks in the context of local governments' fiscal strategies. Previous studies show that natural disasters increase borrowing costs. Painter (2020) and Goldsmith-Pinkham et al. (2023) find that rising sea levels significantly elevate municipal bond issuance costs in the United States. Auh et al. (2022) provide evidence that short-term natural disasters, such as floods, negatively impact municipal bond returns in secondary markets. Similarly, Huynh and Xia (2023) demonstrate that investors devalue firms' bonds and stocks following disaster exposure, leading to higher future returns as compensation for perceived risk. Gao et al. (2023) further show that MCBs exposed to earthquakes carry a significant risk premium due to heightened credit concerns. Building on these insights, we test whether flood risks influence investor perceptions, leading to increased issuance costs or failed issuances in the MCB market. This forms our second hypothesis:

Hypothesis 2: If investors perceive floods as a risk, the probability of failed MCB issuance increases after floods.

We also investigate the mechanisms through which floods impact the MCB market. Jerch et al. (2023) find that hurricanes reduce government tax revenues while increasing public spending and reliance on debt financing. Similarly, floods damage property and infrastructure, necessitating significant funds for rebuilding. In response to budget shortfalls, local governments may issue more MCBs through LGFVs. This leads to our third hypothesis:

Hypothesis 3a: Floods increase local government deficits, affecting the MCB market through LGFVs.

Unlike traditional municipal bonds in the United States, LGFVs primarily repay bondholders through land sales (He and Wei, 2023). Thus, post-flood land market performance significantly influences MCB default risk, prompting investors to demand higher risk premiums. Additionally, floods heighten investor concerns about climate-related financial risks (Muller et al., 2019).

Increased uncertainty about climate risks weakens investor confidence in flood-affected MCBs, raising issuance costs (Goldsmith-Pinkham et al., 2023; Painter, 2020). However, access to risk information reduces uncertainty (Huynh and Xia, 2021; Mulder, 2021), stabilizing investor sentiment and ultimately lowering borrowing costs for affected MCBs. Accordingly, we propose the following hypotheses:

Hypothesis 3b: Floods increase MCB issuance costs by decreasing residential land prices.

Hypothesis 3c: Investors demand a risk premium for flood-affected MCBs due to uncertainty. Publicly available risk information mitigates this uncertainty, reducing MCB issuance costs.

3.2 Data

3.2.1 Municipal corporate bond

We analyze MCBs issued between January 1, 2012, and December 31, 2019—a period of significant growth in MCB issuance (Kaiji Chen et al., 2023; Zhuo Chen et al., 2020). We exclude MCBs issued after 2020 to avoid the confounding effects of COVID-19 on local fiscal conditions. Our dataset, sourced from Wind Information Co. (WIND), includes 13,824 MCBs issued by LGFVs across 276 cities. For each issuance, WIND provides detailed bond-specific information, including issuance yield, credit rating, issuance amount, issuance date, maturity date, external guarantees, issuance location, issuer credit rating, and fund management company holdings in the issuance year.

To further refine our analysis, we manually review each bond's prospectus to determine its issuance purpose, categorizing them into three groups: (1) repayment of bank loans, (2) investment in public housing and infrastructure, and (3) other purposes (e.g., replenishing working capital or refinancing small and medium-sized enterprises). After applying these criteria, our final sample consists of 9,735 MCBs.[6]

[6] There are 3,911 MCBs without prospectuses, provided by WIND.

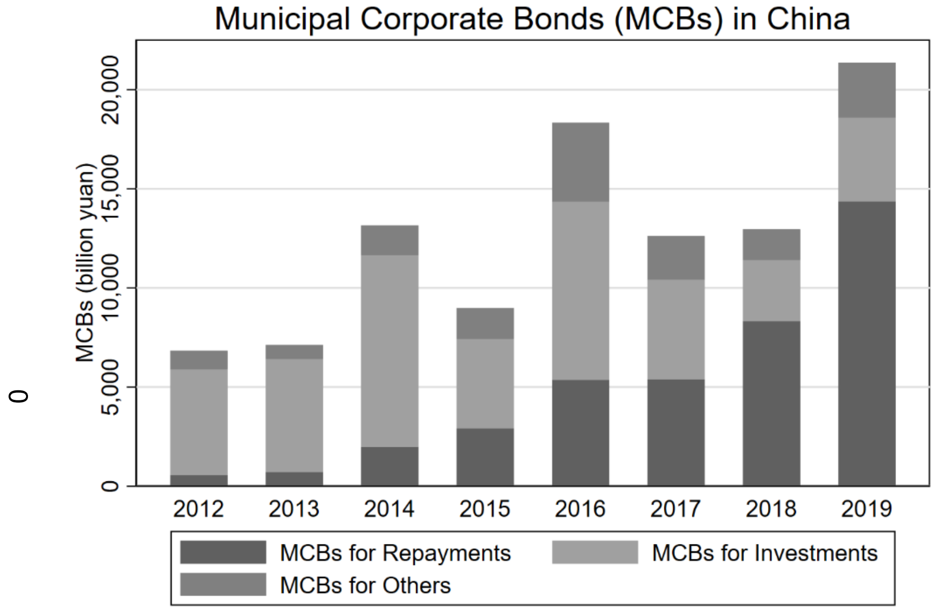

Figure 1: The amounts of MCBs issued for different purposes in China

Note: We manually review the prospectus and classified the issuance purpose into three categories: bank loan repayment, investment for public housing and infrastructure, and others. Data source: WIND.

Figure 1 shows that before 2015, most of the MCBs were issued for investments, including public housing and infrastructure, consistent with Zhuo Chen*, et al.* (2020). Beijing issued the No. 43 Document in October 2014, which imposed strict restrictions on LGFVs raising funds for investments, but still allowed LGFVs to refinance the existing bank loans or other borrowings through MCBs. Therefore, since 2015, there has been a rapid growth of MCBs issued for repayments. In 2019, over 65% of MCBs are issued for bank loan repayments.

We are interested in the local governments' strategies in bond markets to mitigate the flood risks and the market response given the governments' strategies. Specifically, we define a variable of *MCB issuance*, which is the number of MCBs issued by the LGFVs in a given city by the month-of-year. We use *MCB issuance* to measure local government borrowing strategies. On the market side, we measure the issuance costs by the credit spread of each MCB, which is defined as the difference between its issuance yield and the yields of Treasury bonds of the same maturity in the same month-of-year.

3.2.2 Flood and other natural disasters data

To identify cities that are exposed to flood disasters, we manually collect the peak levels of control stations in national primary rivers from the *Hydrological Information Annual Report (2010-2021)*, published by the Ministry of Water Resources in China. The reports also provide the warning water level of each control station. A flood event is defined as the peak level exceeding the warning water level of that control station. We then aggregate the flood data into the city-by-month-of-year level. Figure 2 depicts the spatial distribution of flooded cities as well as the total amount of MCBs issued in each city. Cities with dark blue represent more floods in these cities during the study period. And the larger the size of the orange dots, the larger the total amount of MCBs issued in the city. Obviously, the flooded cities are primarily located in southern China, and the majority of MCBs are issued in eastern and southern China, which are susceptible to flood risks.

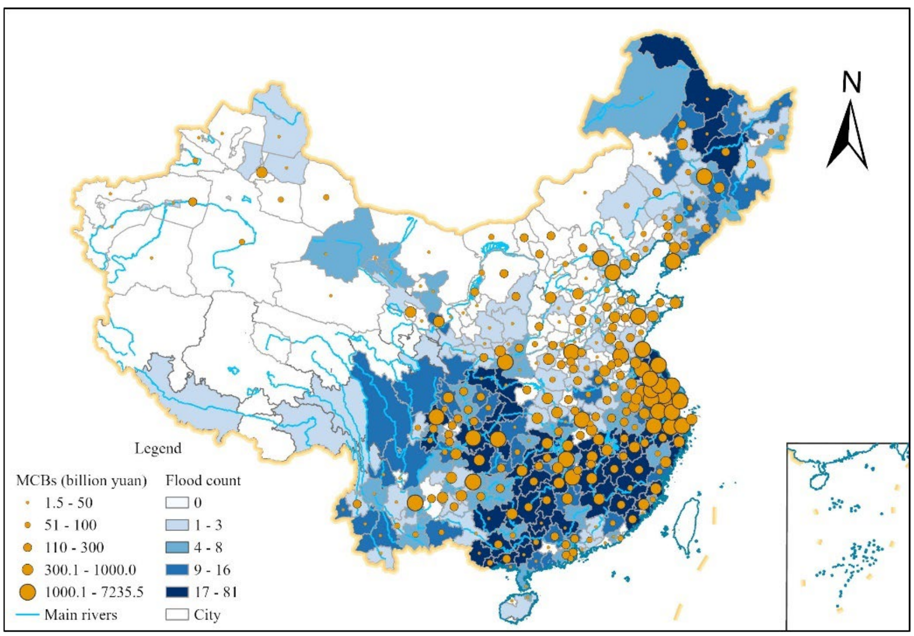

Figure 2: Number of floods and amounts of MCBs in China

Note: This figure maps cities with the number of floods between 2010 and 2021. The darker the city, the more floods occur between 2010 and 2021. The orange circle represents the total amounts of MCBs issued by a city between 2012 and 2019. The larger the size of the circle, the larger the amounts of MCBs issued. Data source: flood data are accessed from the *Hydrological Information Annual Report (2010-2021)*, and the bonds data are accessed from WIND. The administrative map was acquired from the National Geomatics Center of China (NGCC), GS(2023)2767.

Other natural disasters, such as typhoons and earthquakes, may also pose physical risks to cities and potentially hinder the local governments' ability to provide guarantees to MCBs. We obtain landfalling data of tropical cyclones from the China Meteorological Administration Tropical Cyclone Data Center for the Western North Pacific Basin.[7] This data provides specific information on tropical cyclones, including the landfalling location, date, and intensity of each tropical cyclone. We keep tropical cyclones with an intensity of typhoon (TY), severe typhoon (STY), or super typhoon (Super TY), as they can cause significant damage to local facilities. Tropical cyclones with an intensity of TY are encoded by a value of 1, and TCs with the intensity of STY and Super TY are encoded by values of 2 and 3, respectively. The sample period covers the years 2010 to 2021, which is consistent with the flood data.

We obtain earthquake data from the United States Geological Survey (USGS) Earthquake Hazards Program.[8] It reports real-time earthquakes worldwide, including occurred date, location, Mercalli intensity scale and focal depth of each event. The dataset also goes back to 1995. Only earthquakes with an intensity of 5 or above that occurred in China from 2010 to 2021 are included.

We also collect monthly cumulative precipitation data from the National Oceanic and Atmospheric Administration (NOAA), to account for the counterfactor effects from the regular rainfalls. All the data are matched to prefecture cities based on the location and date when observed.

3.2.3 Land transaction data and other variables

Urban land in China, by law, is owned by the state. Local governments typically use residential land as collateral when offering MCBs in the primary market (Amstad and He, 2019, He et al., 2022). To test *Hypothesis 3b*, we use residential land prices as a measure of the repayment ability of local governments. In particular, we acquire residential land transaction data from the China Land Market website.[9] For each land transaction, the land bureau posts detailed information on the website, which typically includes the location, land use type, land area, leasing price, regulatory floor-to-area ratio (FAR) and date, etc. Each land parcel is geocoded to a specific city, based on the land address listed on the post. The data has more

[7] Website: https://tcdata.typhoon.org.cn/en/.
[8] Website: https://www.usgs.gov/programs/earthquake-hazards.
[9] Website: https://landchina.com/.

than 740 thousand residential land parcels from 2010 to 2020. We drop land parcels with negative or zero land areas and negative prices. To eliminate the estimation error caused by outliers, we censorize the land area, price, and FAR, at the lower 5% and upper 95% of the baseline estimation.

We collect provincial specialized transfer payments from the central government for disaster relief from the *China Civil Affairs Statistical Yearbook*. We use the aggregated specialized transfer payments to measure the role of central government aid in mitigating the impact of floods on local financial costs. Other city-level economic and financial data are mainly from *China City Statistical Yearbook*. Specifically, we collect each city's gross domestic product (GDP) per capita, population size, local government general public budget revenue and expenditures, and loads of financial institutions at year-end.

3.2.4 Summary statistics

Table 1 summarizes the statistics of the key variables. Panel A reports the bonds' characteristics. The average credit spread of the issuance MCBs is 2.75%, with an average issued size of MCBs is 1121 million yuan in 2019 price and an average maximum maturity of 5.25 years. Within the 9,735 bonds, approximately 41.7% of them are issued for bank loan repayments, 48% of them are issued for public housing and infrastructure investments, and approximately 12.8% of them are issued for other purpose, such as replenishing working capital and refinancing of small and medium-sized enterprises. Less than 28.3% of them are guaranteed. The average bonds' and issuers' credit rating are below AA- and A+, respectively. On average, within the event window, over 75% of MCBs affected by floods, and over 90% of these MCBs are issued following floods.

Table 1: Summary Statistics.

This table reports the summary statistics for the sample of bonds, natural disasters, land transactions, and city characteristics. The bond sample in Panel A is acquired from WIND, covering bonds issued from January 2012 to December 2019. Bonds that pay with a floating interest or progressive interest rate are excluded. *Purposes of the issuance bonds* are manually review from the prospectus. *Credit spread* is calculated as the difference between the MCB yield and the maturity yield of a risk-free bond (Treasury). *Flood* is a dummy variable that takes a value of one if the bond issued in a city suffered a flood during the event months. *Post* takes a value of one if the issuance month-of-year equals or exceeds the flood year-month. Other bond variables include a numerical scale of credit rating, issued amount, the bond maturity (maturity), the numerical scale of the issuers credit rating (issuer's credit rating), and the share of bond held by fund management Co. in the first year of issued (fund share). Panel B reports the summary statistics for the natural disasters that happened from January 2010 to December 2021. *Number of floods* is the number of floods that happened from 2010 to 2021. *Above_flood_10*, *Above_flood_20*, and *Above_flood_30* are dummy variables indicating the flood line exceeded the warning line by 10%, 20%, and 30%, respectively. *Typhoon* is a dummy that takes a value of one if typhoons hit a city in month of year scale. *Earthquake* is a dummy that takes a value of one if earthquakes occurred in a city by a month of year scale. Panel C reports the summary statistics for residential land transactions from January 2010 to December 2020. *Land price* is converted to the 2019 real price. Land price, area, and regulatory FAR are censored by 5% and 95%, respectively. Panel D reports the summary statistics for characteristics of cities with bonds issued from January 2012 through December 2019, including GDP per capita, population size, loan balance, a dummy of flood zone city, a dummy of sponge city, and a dummy of city with more disaster relief aid from the central government.

Variable	N	Mean	SD	Min	Max
Panel A: Municipal Corporate Bonds					
sYields Spread (%)	9735	2.748	1.331	-3.164	7.872
Offering Yields (%)	9735	6.015	1.517	0.0500	11.30
Yields of Risk-free Bonds (Treasury, %)	9735	3.267	0.526	1.689	4.752
Credit Rating	9735	4.932	2.815	0	8
Issuer's Credit Rating	9735	6.033	1.920	0	8
Guaranteed	9735	0.283	0.450	0	1
Max Maturity (year)	9735	5.253	2.161	0.0411	12
Issued Size (Million yuan, 2019 price)	9735	1121	642.8	116.8	9320

Held by Fund Management Co. (%)	9735	0.014	0.051	0	0.765
Issued purpose: Repayment	9735	0.417	0.493	0	1
Issued purpose: Investment	9735	0.480	0.500	0	1
Issued purpose: Others	9735	0.128	0.334	0	1
Flood	6585	0.745	0.434	0	1
Post	6585	0.908	0.279	0	1
Panel B: Extreme Weather Events					
# of Floods	3313	1.753	1.582	1	12
Above_Flood_10	3313	0.218	0.413	0	1
Above_Flood_20	3313 4	0.082	0.275	0	1
Above_Flood_30	3313 6	0.054	0.227	0	1
# of Floods in Neighbor counties	3313	0.309	1.652	0	28
Precipitation (mm)	3313	13.08	11.70	0	77.25
Typhoons	3313	0.001 1	0.030	0	1
Earthquake	3313	0.004	0.074	0	1
Panel C: Residential Land Transactions					
Flood	297, 335	0.730	0.444	0	1
Post	297, 335	0.817	0.387	0	1

Land Price (10 thousand yuan, 2019 price)	297,335	2663.583	3980.296	0	111311.15
Area (ha)	297,335	2.061	2.857	0.002	10.907
Regulated FAR	297,335	2.564	1.316	0	5
Panel D: City characteristics					
Num. of issued bonds	29,792	0.229	0.926	0	22
GDP per capita (thousand yuan)	325	30.457	21.719	5.181	175.125
Population size (thousand)	325	4038.757	3164.9	96	33034.5
Local government deficits	325	4.030	7.975	0.917	136.047
Loan Balance (billion yuan)	325	142.173	355.936	278	3647.959
Pipe length (km)	325	1227.819	2233.015	59	18191
FDBs city	325	0.10	0.31	0	1
Sponge city	325	0.05	0.22	0	1
Cities with more government aid	325	0.68	0.47	0	1

Panel B reports the summary statistics of natural disasters, including floods, typhoons, and earthquakes, for each city-by-month-of-year. On average, floods hit a city within one month more than one time. Over 20% of floods are with a peak level above the warning level by 10%, 8% of them peaks the warning level by 20%, and 5% of the floods are severely hit the city with a peak level over 30% of warning level. Compared to floods, landfall typhoons and earthquake are much rarer. Only 0.1% city-by-month-of-year had typhoons make landfall and 0.5% city-by-month-of-year hit by earthquakes above metallic intensity of 5. The average monthly cumulative precipitation is 13.08 mm across cities.

Panel C summarizes the statistics of residential land transactions spanning from 2010 to 2020. To exclude the impact of extreme values, land price, area and regulated FAR are censored by 5% bottom and top 95%, respectively. In total, there are approximately 1.5 million residential land parcels over the study period, with an average transaction price of 26.63 million yuan and an average area of 2.06 ha. And the regulated FAR is 2.56. Overall, over 73% of lands suffered floods during the study period, and approximately 39% of them were transacted after floods. Panel D gives the summary statistics of variables for cities that issued MCBs during the study period. The number of newly issued bonds is 0.23. On average, a city's GDP per capita is 30.46 thousand yuan; its population size is 4.04 million, and its loan balance is approximately 142.17 billion yuan in 2011. Approximately 10% of the cities contain flood detention basins (FDBs), less than 5% of them construct sponge cities, and over 66% of the cities lie in provinces that receive more disaster relief funds from the central government.

3.3 Empirical strategy

Floods, by definition, are a common, short-term effect of natural disasters (Goldsmith-Pinkham, *et al.*, 2023). The DID literature has recently highlighted the potential bias in estimations when treatment timing varies across units and periods (Callaway et al., 2021, Goodman-Bacon, 2021, Sun et al., 2021). de Chaisemartin et al. (2020) show that, the traditional group and period fixed effects estimators are a weighted average of all possible two-group/two-period DID estimators in the data. However, some of the control groups in these comparisons may have been treated at later periods, which causes negative weights. The standard DID estimator is thus not robust to heterogeneous treatment effects. Alternative estimators are used to address potential bias. Given the nature of staggered flood events by definition, we employ a staggered DID estimator, proposed by Goodman-Bacon (2021) and Baker et al. (2022). Following Auh, *et al.* (2022) and Pelli, *et al.* (2023), we categorized cities as treated groups if they experienced floods during event months [-*12*, *24*]. Controls are cities located 150 km away from the flooded cities, and were unaffected by natural disasters over the study period. Event months are specified relative to the month when the flood occurred. For example, $\tau = 0$ indicates the month-of-year when the flood hit the city. This ends up 1,150 datasets in 229 cities. That is, over the 1,150 city-by-month-of-year flood events, 229 cities experienced at least one flood. We then append all the 1,150 treated groups into one dataset, resulting in a staggered dataset of 1,409,219 sample. We calculate the number of MCB issuance within a city-by-month-of-year, which is used to measure local government's strategies in bond issuance.

Finally, we merge MCBs issued within the 1,150 city-by-month-of-year flood events, excluding flood events without MCBs, resulting in a staggered dataset with 6,585 MCBs, and 4,905 of them are treated bonds in the event months [-12, 24], a total of 165,460 observations. The MCBs dataset is used to identify market response in bond pricing. We conduct similar procedures to construct a staggered dataset for land transaction data, which is used for mechanisms analysis.

To explore the impacts of floods on the MCBs, we estimate the following equation on the staggered sample:

$$Y_{c,i,ym}^{g} = \beta_0 + \beta_1 Post_{c,i,ym}^{g} + \beta_2\left(Treat_{c,i,ym}^{g} \times Post_{c,i,ym}^{g}\right) + \vartheta NF_{i,ym} + \theta E_{i,ym} + \eta X_{c,i,ym} + \Theta Z_{i,2011} \times Trend_y + \mathrm{K} Hybasin_i \times \mu_y + \varphi^g + \mu_m + \varepsilon_{c,ij,t}^{g} \tag{1}$$

where c indexes MCB, i indexes city, ym indexes month(m)-of-year(y). $Y_{c,i,ym}^{g}$ are the variables of interest, including *MCB issuance*, or credit spread of MCB. For the explanatory variables, $Post_{c,ij,t}^{g}$ is a dummy that equals one if issuance ym of MCB c equals or is after the flood month, and zero otherwise. The value of $Treat_{c,ij,t}^{g}$ equals one if MCB c issued by city i that hit by a flood in the event month [-12, 24], and zero if MCB c is used as a control in the treated group g. $NF_{i,ym}$ measured the number of floods in cities within 150 km away from the home city i within the flood event g's month [-12, 24]. $E_{i,ym}$ measure the impact from other extreme event, including typhoon, earthquake, and precipitation in city i during the event months [-12, 24]. X are MCBs-specific characteristics, including issuance amount, maximum maturity, guaranteed, purpose of MCBs issued, credit rating of MCBs, and share of bond amount held by fund management Co. when issued. Z are city-specific characteristics, including GDP per capita, population size, the amount of local government's expenditures over its revenues and the loan balance of financial institutions at year-end. To eliminate the counterfactors impacts of city development, we use city characteristics in 2011 times time trends over the study period. We control for a series of fixed effects to account for within-group variations that may bias the estimations. Specifically, the $Hybasin_i \times \mu_y$ are hydro basins-by-year fixed effects to account for the impact of socialeconomic changes within hydro basins over years; φ^g is the treatment group fixed effects to account for within-group unobservable, and μ_m are calendar month (m) fixed effects. $\varepsilon^g_{c,ij,t}$ is heteroskedasticity-robust errors, clustered at the treatment group unit.

4 Results

4.1 Effects of floods on local government borrowing in bond markets

We start by testing *Hypothesis 1*, which predicts a positive relation between flood risk and local government borrowing in the bond markets. Specifically, we use the number of MCBs issuance within the flood event window [-12, 24], to measure local government borrowing in response to flood risks. Table 2 reports the estimated results, using the empirical model of Equation (1). Controlling for city characteristics in Equation (1), including GDP per capital, population size, loan balance and pipe length in 2011 with yearly time trends, the first column shows that flooded cities significantly increase MCB issuance by 10.2% at the 1% level, relative to the benchmark cities that were not affected by floods. Under this specification, the occurrence of floods is associated with an increase in MCB issuance by 44.5% from the sample mean (0.229 per city per month).

Table 2: The effect of floods on MCBs: local government strategies and market responses.

This table presents the estimation results of Equation 1. Columns (1) - (2) use city-by-month-of-year level data, and the dependent variables are MCBs issuance during the event months [-12, 24]. Columns (3) - (6) use bond-by-month-of-year data, and the dependent variables are the credit spreads of MCBs during the event months [-12, 24]. *Flood* takes a value of one if the city (or MCBs) suffered a flood in the event months [-12, 24], and takes a value of zero if the city (or MCBs) located 150 km away from the flooded city, and did not experience any natural disasters, including flood, typhoon, and earthquake over the study period. Columns (1) and (4) use the full sample, and Columns (2) and (4) exclude samples in the four municipalities. Columns (5)-(6) separate the full sample by whether these MCBs held by fund management Co. or not. Bond controls include credit rating, the logarithmic value of maximum maturity, whether the bond is guaranteed, the bond issued for bank repayment, the bond issued for investments, the issuer's credit rating, and share of bond held by fund management Co. City controls are logarithmic GDP per capita, logarithmic population size, logarithmic loan balance in 2011 with yearly trends. We also control for other extreme weather events, including monthly cumulative precipitation, the number of floods in the neighboring cities in event months [-12, 24], whether there is a typhoon or an earthquake in event months [-12, 24]. All regressions include treatment group fixed effects, hydro basin-by-year fixed effects, and issued month fixed effects. Standard errors in parentheses are clustered by treatment groups. *** p<0.01, ** p<0.05, * p<0.1.

	MCBs issuance		Credit Spreads			
VARIABLES	Full sample	Exclude first-tier cities	Full sample	Exclude first-tier cities	Hold by fund management Co.	
					No	Yes
	(1)	(2)	(3)	(4)	(5)	(6)
Flood X Post	0.102***	0.089***	0.237***	0.301***	0.191***	0.200***
	(0.011)	(0.010)	(0.044)	(0.048)	(0.047)	(0.048)
Post	-0.003	-0.001	-0.024	-0.049*	-0.033	0.027
	(0.002)	(0.002)	(0.023)	(0.025)	(0.027)	(0.029)
Chow test					2.169**	
Treatment group	1066	1066	899	899	853	899
Observations	999,134	984,983	147,095	107,111	118,068	28,995
R-squared	0.206	0.093	0.475	0.447	0.438	0.714
Bond controls	No	No	Yes	Yes	Yes	Yes
City controls	Yes	Yes	Yes	Yes	Yes	Yes
Treatment group FE	Yes	Yes	Yes	Yes	Yes	Yes

Hydro Basin-Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Month FE	Yes	Yes	Yes	Yes	Yes	Yes

People may question whether the political tier and the economic conditions of municipalities differ from the other cities, which ultimately affect their public finance conditions (Ang*, et al.*, 2018, Fukang Chen et al., 2024). To address this concern, we exclude the four municipalities and repeat our estimations by Equation (1).[10] The results in Column (2) show that, the coefficient of Flood × Post is 0.089. That is, the occurrence of floods is associated with an increase in MCB issuance by 38.9% from the sample mean.

Together, the results in the first two columns of Table 2 provide evidence that local governments increase borrowing from LGFVs following floods. They issued more MCBs, compared to those cities that did not experience floods and other natural disasters during the study period.

4.2 Flood reactions among LGFVs and investors

Hypothesis 2 predicts a positive relation between market responsiveness and flood risk, given LGFVs' strategies of increasing borrowing following floods. To verify this hypothesis, we replace the dependent variable with *Credit spread* in Equation (1). The results in Column (3) of Table 2 show that, conditional on the city characteristics in 2011 with yearly time trends the treatment group fixed effect, hydro basin-by-year fixed effect, and month fixed effect, the market also demands higher yields from MCBs after floods, resulting in higher credit spreads. Under this specification, the occurrence of floods significantly affects the credit spreads of MCBs, causing 23.7 basic points (bps) increase in the issuance cost of an MCB. This corresponds to a 8.23% increase from the mean spread costs (287.8 bps). The impacts of short-term floods is comparable to the issuance costs caused by long-term risk such as sea level rise (Goldsmith-Pinkham*, et al.*, 2023, Painter, 2020), which found that a one-standard-deviation increase in sea level rise exposure results in a 7% to 10% increase in municipal bond spreads. However, flood strikes happen more widely and frequently than sea level rise risk, which affects coastal cities in fifty to one hundred years, resulting in larger local fiscal costs. In economic terms, a flood would increase the total financial cost of issuing an MCB of average size (CNY 1.18 billion) by CNY 278.95 million per

[10] The four municipalities are Beijing, Tianjin, Shanghai, and Chongqing.

year. There are 4,905 MCBs in 181 cities that experienced flooding during our sample period, which brings an additional annual burden of CNY 1.368 trillion to the issuance cost of MCBs, equaling approximately 1.38% of the national GDP in 2019. Column (4) excludes MCBs issued by LGFVs in municipalities, the credit spreads of MCBs in prefecture cities become slightly larger than the baseline estimations in Column (5), which is consistent with the pattens of government strategies in MCBs issuance following floods. Compared other prefecture cities, the municipalities have larger demand in infrastructure construction and higher implicit government guarantees, LGFVs thus issue more MCBs with lower prices than LGFVs in other cities.

There is still a concern whether the credit spreads measure the true market response to the flood risk. To address this concern, we separate the full sample into two groups: MCBs held by fund management Co. when issued or not. Generally, the higher market acceptance of a bond, the more share of bond held by fund management Co. The results in Columns (5)-(6) show that, the coefficients of Flood×Post are both statistically positive, and the magnitude of the two are also comparable. That is, no matter the market acceptance of the bond, the market responds to the flood risk in the same way.

To ensure the parallel trends in MCB issuance and market response to MCB pricing following floods, we conduct an event study in Appendix A, which provides supportive evidence to the parallel assumptions of stagger DID estimations. We also conduct several robustness checks, including replacing the *Flood* dummy with the *number of floods* in Equation (1) (Table B1 in Appendix B), changing the event months to [-12, 20] and [-12, 28] (Table B2 in Appendix B), and restricting the control cities to being in a distance band of [150, 500] km and [150, 700] from the flooded cities (Table B3 in Appendix B). Further discussions related to the robust analysis are provided in Appendix B.

Overall, the results provide strong evidence that flood risk and event windows are precisely identified. It finds that floods significantly affect local government borrowing through LGFVs. After floods, LGFVs issue more MCBs. However, investors are cautious in providing proceeds, resulting in increased issuance costs of MCBs following floods. The findings align with existing literature, indicating that natural disasters, such as floods, cause immediate harm to local economies by damaging infrastructure and destroying physical capital (Boustan et al., 2020, Deryugina, 2017). As a result, the costs of local public finance are ultimately increased (Jerch*, et* *al.*, 2023).

4.3 Heterogeneity analysis

In this section, we perform a series of heterogeneity tests to gain a deeper understanding of the heterogeneous response of LGFVs and investors to flood events. These tests aim to highlight the impact of floods across regions and among MCBs with varying characteristics.

4.3.1 Bond maturity

We split the sample into long-term and short-term bonds based on the maximum maturity of MCBs. In particular, long-term MCBs refer to bonds with a maximum maturity larger than five years, while short-term MCBs refer to bonds with a maximum maturity of five years or less. The results in Columns (1)-(2) of Table 3 show that, LGFVs issue more short-term MCBs following floods. This may be because local governments need to refinance the local governments' debts to relieve local government deficits pressure caused by floods. And bonds issued for bank loan repayment and refinancing debts are generally with a short-term maturity. We will provide further evidence in section 3.3.2.

Table 3 The heterogeneity effects of floods on MCBs: Different maturity

This table presents the heterogeneous results of flood risks on bonds with different maturity. Columns (1)-(2) use city-by-month-of-year level data, and Columns (3)-(4) use bond-by-month-of-year level data. *Flood* takes a value of one if the MCBs issued in a city suffered a flood in the event months [-12, 24], and takes a value of zero if MCBs issued in cities located 150 km away from the flooded cities and that did not experience any natural disasters, including flood, typhoon, and earthquake over the study period. Bond controls include credit rating, the logarithmic value of maximum maturity, whether the bond is guaranteed, the bond issued for bank repayment, the bond issued for investments, the issuer's credit rating, and share of bond held by fund management Co. City controls are logarithmic GDP per capita, logarithmic population size, logarithmic loan balance in 2011 with yearly trends. We also control other extreme weather events, including monthly cumulative precipitation, the number of floods in the neighboring cities in event months [-12, 24], whether there is a typhoon or an earthquake in event months [-12, 24]. All regressions include treatment group fixed effects, hydro basin-by-year fixed effects, and issued month fixed effects. Standard errors in parentheses are clustered by treatment groups. *** p<0.01, ** p<0.05, * p<0.1.

	MCBs issuance		Credit Spreads	
VARIABLES	Maturity <= 5	Maturity > 5	Maturity <= 5	Maturity > 5
	(1)	(2)	(3)	(4)
Flood X Post	0.077***	0.040***	0.333***	0.156***
	(0.009)	(0.005)	(0.073)	(0.039)
Post	-0.003***	-0.001	-0.015	0.009
	(0.001)	(0.002)	(0.041)	(0.017)
Chow test	-3.009***		1.800*	
Treatment group	1066	1066	857	899
Observations	999,134	1,998,268	58,079	88,991
R-squared	0.378	0.129	0.445	0.661
Bond controls	No	No	Yes	Yes
City controls	Yes	Yes	Yes	Yes
Treatment group FE	Yes	Yes	Yes	Yes
Hydro Basin-Year FE	Yes	Yes	Yes	Yes
Month FE	Yes	Yes	Yes	Yes

The results in Columns (3)-(4) of Table 3 indicate that, different from the slow-moving risks such as sea level rise (Goldsmith-Pinkham*, et al.*, 2023, Painter, 2020), investors respond significantly to salient risks caused by floods, increasing the issuance cost of short-term MCBs. Natural disasters cause short-term negative effects on the local economy (Boustan*, et al.*, 2020, Deryugina, 2017, Pelli*, et al.*, 2023), which ultimately increase the credit spreads of short-term MCBs following floods. We also observe that credit spreads of long-term MCBs affected by floods are significantly smaller than these short-term MCBs, which implies that short-term natural disasters may also place long-term negative shocks to the local economy and, ultimately, increase the market pricing of long-term MCBs. On average, credit spreads of short-term MCBs significantly increase by 33.3 bps, while the credit spreads of long-term MCBs increase by 15.6 bps following floods (Columns (3)-(4) of Table 3). These effect correspond to an 11.57% and 5.42% increase from the mean credit spread of the sample, respectively.

Together, we find that LGFVs issue more short-term MCBs following floods. Local governments need to refinance the local governments' debts to relieve local government deficits pressure caused by floods. Investors are cautious when subscribing to MCBs, and require higher premiums on the short-term MCBs issued following floods, due to the damages to the physical capital, which is also last for a long-term.

4.3.2 Issued purpose of MCBs

Natural disasters, such as floods, heavily damage local economies by destroying homes and infrastructure (Auh*, et al.*, 2022, Jerch*, et al.*, 2023, Pelli*, et al.*, 2023). The results in Table 4 show that, LGFVs issue more MCBs for repayment and investments after floods (Columns (1)-(2) in Table 4). The magnitude of MCB issuances for repayment and investments are also much larger than those issued for other purposes, such as replenishing working capital or environment protections. The results align with Jerch*, et al.* (2023), who found that hurricanes create collateral fiscal damages for local governments by increasing the costs of their debts.

Table 4: The heterogeneous impacts of floods on MCBs: Different issued purposes

This table presents the heterogeneous results of flood risks on bonds with different issued purposes. Columns (1)-(3) use city-by-month-of-year level data, and Columns (4)-(6) use bond-by-month-of-year level data. *Flood* takes a value of one if the MCBs issued in a city suffered a flood in the event months [-12, 24], and takes a value of zero if MCBs issued in cities located 150 km away from the flooded cities and that did not experience any natural disasters, including flood, typhoon, and earthquake over the study period. Bond controls include credit rating, the logarithmic value of maximum maturity, whether the bond is guaranteed, the issuer's credit rating, and share of bond held by fund management Co. City controls are logarithmic GDP per capita, logarithmic population size, logarithmic loan balance in 2011 with yearly trends. We also control other extreme weather events, including monthly cumulative precipitation, the number of floods in the neighboring cities in event months [-12, 24], whether there is a typhoon or an earthquake in event months [-12, 24]. All regressions include treatment group fixed effects, hydro basin-by-year fixed effects, and issued month fixed effects. Standard errors in parentheses are clustered by treatment groups. *** p<0.01, ** p<0.05, * p<0.1.

	MCBs issuance	Credit Spreads

VARIABLES	Repayment	Investment	Others	Repayment	Investment	Others
	(1)	(2)	(3)	(4)	(5)	(6)
Flood X Post	0.078***	0.076***	0.027***	0.461***	0.023	-0.594***
	(0.013)	(0.010)	(0.005)	(0.136)	(0.056)	(0.195)
Post	-0.002*	-0.002	-0.002**	-0.037	0.011	0.005
	(0.001)	(0.003)	(0.001)	(0.030)	(0.017)	(0.032)
Chow test (Repay. - Invest.)	0.673			2.951***		
Chow test (Invest. - Others)		0.971			3.619***	
Chow test (Repay. - Others)			2.686**			4.818***
Treatment group	1066	1066	1066	787	899	808
Observations	986,536	986,536	982,398	32,250	75,758	15,494
R-squared	0.216	0.069	0.052	0.455	0.605	0.653
Bond controls	No	No	No	Yes	Yes	Yes
City controls	Yes	Yes	Yes	Yes	Yes	Yes
Treatment group FE	Yes	Yes	Yes	Yes	Yes	Yes
Hydro Basin-Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Month FE	Yes	Yes	Yes	Yes	Yes	Yes

The results also show that, despite the LGFVs issue more MCBs to relieve local governments financing pressure and rebuild damaged infrastructures, there is no impact on the issuance costs for bonds issued for investments (Column (5) of Table 4). This may be because infrastructure investments can boost local economics (Grimes, 2021), which ultimately increase local governments' repayment ability. The results are also consistent with the heterogeneous effects of bond maturity presented in Table 3. Investors demand higher premiums for bonds issued for bank repayment, which are generally short-term bonds with a mean maturity of 3.62 years (Column (4) of Table 4). Floods destroy local economies, affecting the repayment ability and, ultimately, increasing the default risk of local authorities without re-constructions (Amstad and He, 2019, Auh, *et al.*, 2022). Furthermore, the results in Column (6) show that, floods significantly reduce credit spreads of MCBs issued for other purposes, such as replenishing working capital.

4.3.3 Government aid

Literature shows that government aid can help the local economy recover to trend (Deryugina, 2017), or even build back better (Hallegatte et al., 2018). Auh, *et al.* (2022) further provide evidence that federal disaster aid is very important for alleviating disaster risk to municipal bonds that are backed by undiversified revenue sources in the United States. That is, flood-affected areas with more government aid are expected to recover to trend or even grow better, ultimately reducing the default risk of bonds caused by floods. In this case, the effects of floods on MCBs in areas receiving more government aid are expected to be lower than those receiving less government aid.

To test the role of government aid in mitigating the impact of floods, we separate the samples into two groups: one issued by LGFVs in cities with More government aid, the others are in cities with less government aid. Government aid is measured by the he cumulated transferred payment from the central government for disaster aid, published by the *China Civil Affairs Statistical Yearbook*. Columns (1)-(2) in Panel A of Table 5 shows that, LGFVs in cities with less government aid issue more bonds following floods. Floods affected cities with less government aid have to raise funds by themselves, including issuing MCBs, to re-construct after floods. However, the credit spreads of MCBs in cities with less government aid are much lower than these in cities with more government aid (Columns (3)-(4) in Panel A of Table 5). As we discussion in Section 2.2, the central government is responsible for 70% of the living relief funds for natural disasters in inland provinces, but pays only for 50% of the living relief funds to coastal provinces. Figure C2 in Appendix C shows the consistent pattern that inland provinces receive more government aid for disaster relief, but those provinces are less prone to flooding. The local economic conditions in coastal cities are typically better than cities in other regions, which reduces the creditworthiness of flooded MCBs. The local governments in coastal cities also have sufficient budgets to take adaptation strategies to climate risk, including floods, which ultimately reduce the price impacts on MCBs in those cities.

Table 6: The heterogeneous impacts of floods on MCBs: The role of government aid.

This table reports the heterogeneous role of government aid in mitigating the flood risk on the MCBs. Panel A reports the heterogeneity effects of government aid, measured by disaster relief funds from the central government. Panel B reports the heterogeneous effects of government aid in different regions. *More Gov. Aid* takes a value of one if MCBs are issued in provinces receiving more specialized transfer payments from the central government for disaster aid over the study period, and zero otherwise. *Coastal* takes a value of one if an MCB is issued by a city located in the coastal province, and zero otherwise. *Flood* takes a value of one if the MCBs issued in a city suffered a flood in the event months [-12, 24], and takes a value of zero if MCBs issued in cities located 150 km away from the flooded cities and that did not experience any natural disasters, including flood, typhoon, and earthquake over the study period. Bond controls include credit rating, the logarithmic value of maximum maturity, whether the bond is guaranteed, the bond issued for bank repayment, the bond issued for investments, the issuer's credit rating, and share of bond held by fund management Co. City controls are logarithmic GDP per capita, logarithmic population size, logarithmic loan balance in 2011 with yearly trends. We also control other extreme weather events, including monthly cumulative precipitation, the number of floods in the neighboring cities in event months [-12, 24], whether there is a typhoon or an earthquake in event months [-12, 24]. All regressions include treatment group fixed effects, hydro basin-by-year fixed effects, and issued month fixed effects. Standard errors in parentheses are clustered by treatment groups. *** p<0.01, ** p<0.05, * p<0.1.

	MCBs issuance		Credit Spreads	
VARIABLES	Less gov. aid	More gov. aid	Less gov. aid	More gov. aid
	(1)	(2)	(3)	(4)
Panel A: Government aid				
Flood X Post	0.264***	0.035***	0.182***	0.400***

	(0.029)	(0.008)	(0.047)	(0.059)
Post	-0.008***	0.000	0.028	-0.066**
	(0.002)	(0.002)	(0.028)	(0.026)
Chow test	-0.136		3.920***	
Treatment group	1066	1066	899	890
Observations	393,909	605,225	80,251	66,844
R-squared	0.335	0.103	0.506	0.459
Panel B: Coastal & inland regions				
	Coastal city	Inland city	Coastal city	Inland city
Flood X Post	0.545***	0.221***	0.162**	0.494***
	(0.067)	(0.053)	(0.065)	(0.056)
Post	-0.023**	-0.000	0.006	-0.033
	(0.009)	(0.003)	(0.025)	(0.027)
Chow test	-0.244		-2.290**	
Treatment group	1066	1066	893	889
Observations	255,676	743,458	79,801	67,278
R-squared	0.452	0.079	0.587	0.430

To verify our arguments on the differences of government aid and economic conditions between coastal and inland regions. Panel B of Table 5 shows that, LGFVs in coastal regions do issue more MCBs following floods, investors, however, require lower prices on these flooded MCBs in coastal regions, which have better economic conditions to recover. The results are consistent with these in Panel A of Table 5. In conclusion, aid from the central government significantly alters LGFVs' strategies in bond issuance following floods, investor demand for higher premium for flooded MCBs based on creditworthiness rather than government aid. The results are different from Liao and Kousky (2022), who find that the availability of federally-backed firefighting funds to homeowners could offset negative impacts on house prices or even increase property tax revenue as wildfire disasters stimulate housing re-development.

4.3.4 Implicit government guarantees

On March 4, 2014, Shanghai Chaori Solar Co., Ltd. announced that it could not pay its one-billion-yuan debt on schedule, which was the first bond that broke out the rigid redemption. In October 2014, Beijing released Document No.43, which weakens the implicit guarantees on MCBs by governments. Document No.43 also imposed strict restrictions on LGFVs raising funds for investments through MCBs. To isolate the effects of the government's implicit guarantees, we split the sample into two groups based on the issuance year, specifically 2015.

The results in Columns (1)-(2) of Table 6 show that, before 2015, LGFVs issued more MCBs after floods. However, investors do not regard floods as a potential default risk, resulting in insignificant coefficients of Flood×Post in Columns (3)-(4). This may be caused by the rigid redemption of bonds guaranteed by governments. After the outbreak of rigid redemption and the weakening implicit guarantees by governments in 2014, LGFVs issued less MCBs following floods, due to strict regulations on MCBs purposes for investments, according to the Document No.43. Investors are cautious about the flooded MCBs, resulting in an increase in the issuance costs of bonds after floods (Columns (3)-(4) of Table 6). The results are consistent with Gao*, et al.* (2023), who find that earthquakes significantly affect the credit spreads of MCBs after 2014.

Table 6: The heterogeneous impacts of floods on MCBs issued before and after 2015.

This table presents the heterogeneous results of flood risks on bonds issued before and after Document No. 43, specifically 2015. Columns (1)-(2) use city-by-month-of-year level data, and Columns (3)-(4) use bond-by-month-of-year level data. *Flood* takes a value of one if the MCBs issued in a city suffered a flood in the event months [-12, 24], and takes a value of zero if MCBs issued in cities located 150 km away from the flooded cities and that did not experience any natural disasters, including flood, typhoon, and earthquake over the study period. Bond controls include credit rating, the logarithmic value of maximum maturity, whether the bond is guaranteed, the bond issued for bank repayment, the bond issued for investments, the issuer's credit rating, and share of bond held by fund management Co. City controls are logarithmic GDP per capita, logarithmic population size, logarithmic loan balance in 2011 with yearly trends. We also control other extreme weather events, including monthly cumulative precipitation, the number of floods in the neighboring cities in event months [-12, 24], whether there is a typhoon or an earthquake in event months [-12, 24]. All regressions include treatment group fixed effects, hydro basin-by-year fixed effects, and issued month fixed effects. Standard errors in parentheses are clustered by treatment groups. *** p<0.01, ** p<0.05, * p<0.1.

	MCBs issuance		Credit Spreads	
VARIABLES	2012-2014	2015-2019	2012-2014	2015-2019
	(1)	(2)	(3)	(4)
Flood X Post	0.548***	0.097***	0.150	0.131***
	(0.094)	(0.014)	(0.156)	(0.031)
Post	-0.016**	0.003	0.033	0.036
	(0.007)	(0.004)	(0.041)	(0.027)
Chow test	-2.347***		-0.755	
Treatment group	322	921	288	788
Observations	337,543	661,591	70,246	76,849
R-squared	0.282	0.243	0.422	0.611
Bond controls	No	No	Yes	Yes
City controls	Yes	Yes	Yes	Yes
Hydro Basin-Year FE	Yes	Yes	Yes	Yes
Month FE	Yes	Yes	Yes	Yes

4.3.5 Heterogeneous impacts of flood levels

Some floods occur around a certain time each year, such as during the summer season, which is more predictable than other natural disasters. Local governments can mitigate economic losses during these normal floods. However, if a flood is unexpectedly severe, it can have a substantial impact on the local economy and infrastructure. For example, on 20 July, 2021, torrential rains struck Henan province, leaving 398 people dead or missing and causing an economic loss of CNY 53 billion. The Henan government has raised CNY 593 billion to help rebuild and recover.[11] We further investigate the heterogeneous response of MCB markets to unexpected, severe floods. In particular, we estimate Equation (1) using subsamples affected by floods that exceed the warming level by 10%, 20%, and 30%, respectively. The results in Figure 3 show that the magnitude of bond issuance increase with increasing flood levels, although the

[11] Data from news in Chinese, https://www.henan.gov.cn/2021/08-23/2299093.html

coefficients are statistically indifferent across the three subsamples. The more severe the floods, the more MCBs the flooded cities issued.

Figure 3 also shows that the more severe the floods, the less risk premiums required by investors, which is out of expectation. We further dig out the mechanism of the diverse impacts of flood risks on the credit spreads of MCBs. There are 2036 MCBs in 64 coastal cities affected by floods, while 2,333 flood-affected MCBs in 105 inland cities. The distributions of affected MCBs are quite equal across space. However, over 42% of the flooded MCBs in coastal cities are affected by severe floods, with a flood level higher than the warning level by 10% and more, and only 9% of the flooded MCBs in inland cities are affected by severe floods. Despite severe floods may destroy local economy and infrastructure, the affected regions mainly located in coastal areas with better economic conditions to recover to trends. The investors ultimately require less risk premiums to these MCBs affected by severe floods. The credit spreads of MCBs affected by floods over the warning level of 20% and 30% are indifferent from those unaffected MCBs.

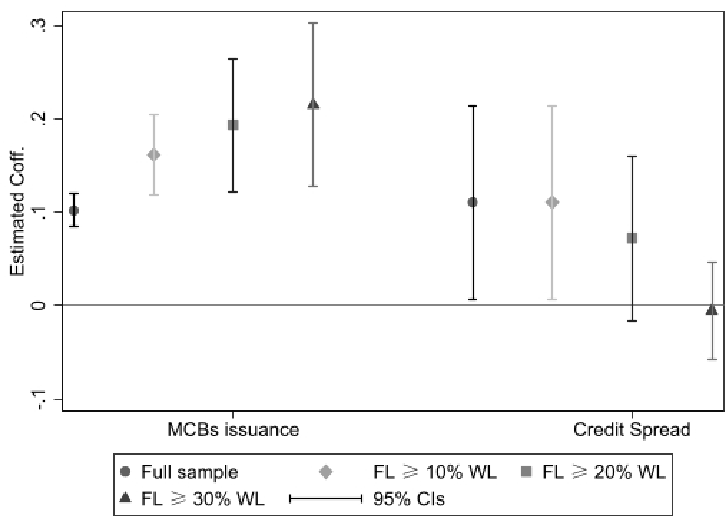

Figure 3: The impact of flooding on MCBs: different flood levels

Each dot represents a separate staggered DID estimation of the coefficient, Flood×Post, by treatment groups struck by floods with different flood levels. The dependent variables are MCB issuance and credit spread, as labeled below the *X* axis. The control group is cities located 150 km away from the flooded cities and that did not experience any natural disasters, including floods, typhoons, and earthquakes before and over the study period. The cap line indicates 95% confidence intervals with standard errors clustered by the treatment group.

Together, we find that the local government issued more bonds following floods. Different from the gradual impacts of sea level rise on coastal cities (Goldsmith-Pinkham*, et al.*, 2023, Painter, 2020), investors measure the salient factors of floods by cautiously processing short-term MCBs in affected regions with higher issuance costs, resulting in higher fiscal costs in affected cities. Aid from the central government and implicit government guarantees also play a crucial role in mitigating local governments' strategies on MCBs issuance. Investors take advantage of government creditworthiness by lowering the prices of flooded MCBs.

5 Mechanism Discussion: The Role of Fiscal Deficits, Repayment Ability, and Risk Uncertainty

We now explore the mechanisms by which floods affect the MCBs. In section 2.1, we proposed a hypothesis suggesting that local government fiscal deficits, repayment capacity, and risk uncertainty are the potential channels through which floods affect MCBs. We examine these three channels in the following discussions.

5.1 Local fiscal deficits

The first channel is local government deficits. Natural disasters reduce government tax revenues, and increase public spending and debt financing, as local governments need to rebuild (Jerch*, et al.*, 2023). *Hypothesis 3a* predicts that floods affect bond markets by increasing local fiscal deficits, which worsens local public creditworthiness. To eliminate the scale effect, we define local fiscal deficits as the ratio of the difference between fiscal expenditures and revenues to fiscal revenues. We then test the local government deficit mechanism by regressing local fiscal deficits on the flood risk, using the same specifications of the staggered DID in Equation (1) at the city-by-month-of-year level. The results are presented in Panel A of Table 7. Column (1) shows that, as expected, floods significantly increase local fiscal deficits compared to cities unaffected by natural disasters. In particular, the scale of local fiscal deficits increases by 0.21% after floods, corresponding to an increase in local public expenditures of CNY 6,247 million per flood. The coefficients of Flood × Post become smaller when excluding the four municipalities, as shown in Columns (2) in Table 7. That is, *Hypothesis 3a* holds.

Table 8: Mechanism analysis I: Fiscal deficit and repayment capacity.

This table reports the mechanisms of flood risk on the MCBs through local government expenditure and repayment ability. Columns (1)-(2) use the ratio of fiscal deficit and fiscal revenues as the dependent variable, where the fiscal deficit is the difference between annual fiscal expenditures and fiscal revenues of a city government; Columns (3)-(4) uses the logarithmic value of residential land price *Flood* takes a value of one if the land sold by the city suffered a flood in the event months [-12, 24], and takes a value of zero if the land sold by cities located 150 km away from the flooded cities, and did not experience any natural disasters, including flood, typhoon, and earthquake over the study period. Land controls include logarithmic land area, the regulated flood-area ratio, and auction type. City controls are logarithmic GDP per capita, logarithmic population size, logarithmic loan balance in 2011 with yearly trends. Treatment group fixed effects, hydro basin-by-year fixed effects, and month fixed effects are included in all regressions. Standard errors in parentheses are clustered by treatment groups. *** p<0.01, ** p<0.05, * p<0.1.

	Government expenditure		Repayment ability	
VARIABLES	Full sample	Exclude municipalities	Full sample	Exclude municipalities
	(1)	(2)	(3)	(4)
Flood X Post	0.364***	0.164***	-0.295***	-0.302***
	(0.040)	(0.039)	(0.071)	(0.075)
Post	0.017***	0.013***	0.029***	0.022***
	(0.003)	(0.003)	(0.009)	(0.008)
Observations	999,134	984,983	8,323,454	8,140,841
R-squared	0.646	0.621	0.591	0.610
City controls	Yes	Yes	Yes	Yes
Treatment group FE	Yes	Yes	Yes	Yes
Hydro Basin-Year FE	Yes	Yes	Yes	Yes
Month FE	Yes	Yes	Yes	Yes

5.2 Repayment ability

The second channel is repayment ability. Floods destroy infrastructure and buildings, leading to a decrease in housing prices and land prices (Beltrán et al., 2019, Fang et al., 2023, Lautrup et al., 2023, Zhang et al., 2018), the primary source for MCBs repayments (Ang*, et al.*, 2018, Zhuo Chen*, et al.*, 2020), and therefore increase MCBs default risks. If a flood reduces the prices of land in the primary market, it could decrease the repayment ability of local governments, ultimately increasing the bond default risks and market responsiveness of those affected MCBs.

We test the repayment ability hypothesis by regressing land prices on the flood risks, using the staggered DID in Equation (1). We use only residential lands, which are the primary source of local government revenue. Similarly, the treated units are staggered at the city-by-month-of-year level. The results are shown in Column (3) of Table 7. Compared to the land prices in natural disaster-unaffected cities, the land prices in flood-affected cities significantly decrease by 29.5% after floods. The price reduction effects increase to 30.2% when we exclude lands sold in the four municipalities.

Overall, the results in Columns (3)-(4) of Table 7 provide supportive evidence to *Hypothesis 3b* that floods decrease the repayment ability of the flooded cities, which in turn increases the financial costs of local government in the bond market.

5.3 Risk uncertainty

Floods may introduce or enhance investor concerns about the damage caused by climate changes in affected areas. The increasing uncertainty about climate risk thus reduces investors' confidence in the repayment of the flood-affected MCBs, which ultimately increases the issuance cost of the affected MCBs (Muller and Hopkins, 2019). Public availability of risk information reduces the uncertainty of potential risks (Huynh and Xia, 2021, Mulder, 2021), which increases the confidence of risk-takers and ultimately reduces the cost of affected assets. In this section, we verify *Hypothesis 3c* of risk uncertainty as follows.

On the one hand, in China, there is no flood information like the flood maps used in the United States. Without credible climate risk information, investors rely on historical flood records and technical assessments by hydrological models to predict future flood risks. This lack of credible climate risk information increases the uncertainty of future bond returns. To hedge this uncertainty, investors demand higher future returns for bonds with higher uncertainties in climate risks, resulting in higher credit spreads of MCBs. To verify this mechanism, we separate the samples into two subsamples according to the median value of floods over the study period. The results in Panel A of Table 8 provide supportive evidence that more floods cause high uncertainty in the MCBs issuance and the future returns of these MCBs. The LGFVs in cities with more floods issued fewer bonds after floods, compared with those in cities with rare floods (Columns (1)-(2)). The credit spreads of flooded MCBs in cities with more floods also significantly increase, compared with MCBs in cities with rare floods (Columns (3)-(4)). Overall, by measuring risk uncertainty by the frequency of floods over the studied period, we provide supportive evidence that risk uncertainty is one of the driving factors in the local governments' strategies and market responsiveness to floods in the bond market.

Table 8: Mechanism analysis II: Risk uncertainty.

This table presents the mechanism analysis of flood risks on MCBs due to risk uncertainty. *Flood* takes a value of one if the MCBs issued in a city suffered a flood in the event months [-12, 24], and takes a value of zero if MCBs issued in cities located 150 km away from the flooded cities, and did not experience any natural disasters, including flood, typhoon and earthquake over the study period. *More floods* is a dummy variable equal to one if the number of floods striking a given city is more than the median value in all flooded cities. *Disclosure* is a dummy variable equal to one if the MCB's issued month-of- year is after March 2017, when the central government disclosed the flood-prone location in each city for the first time. Bond controls include credit rating, the logarithmic value of maximum maturity, whether the bond is guaranteed, the bond issued for bank repayment, the bond issued for investments, the issuer's credit rating, and share of bond held by fund management Co. City controls are logarithmic GDP per capita, logarithmic population size, logarithmic loan balance in 2011 with yearly trends. We also control other extreme weather events, including monthly cumulative precipitation, the number of floods in the neighboring cities in event months [-12, 24], whether there is a typhoon or an earthquake in event months [-12, 24]. All regressions include treatment group fixed effects, hydro basin-by-year fixed effects, and issued month fixed effects. Standard errors in parentheses are clustered by treatment groups. *** p<0.01, ** p<0.05, * p<0.1.

VARIABLES	MCBs issuance	MCBs issuance	Credit Spreads	Credit Spreads
	(1)	(2)	(3)	(4)
Panel A: More floods				
	More floods	Less floods	More floods	Less floods
Flood X Post	0.348***	0.074**	0.247***	0.138**

	(0.051)	(0.032)	(0.049)	(0.055)
Post	-0.003	-0.008	0.006	0.003
	(0.006)	(0.006)	(0.044)	(0.038)
Chow test	0.481		2.836***	
Treatment group	742	226	356	130
Observations	568,275	323,070	66,468	33,192
R-squared	0.268	0.247	0.448	0.502
Panel B: Information disclosure				
	Before disclosure	After disclosure	Before disclosure	After disclosure
Flood X Post	0.307***	1.130***	0.176***	0.270
	(0.091)	(0.381)	(0.064)	(0.233)
Post	-0.031	-0.023	-0.000	-0.167**
	(0.020)	(0.032)	(0.019)	(0.071)
Chow test	0.0343		0.490	
Treatment group	832	99	832	99
Observations	80,493	13,072	121,900	25,197
R-squared	0.551	0.708	0.519	0.505

On the other hand, the Chinese government disclosed a list of flood-prone locations in each city in March 2017. We use the disclosure of flood-prone locations in China to explore whether the risk information disclosure eases the uncertainty caused by frequent floods. Similarly, we separate the sample into two groups based on the issued time. Panel B in Table 8 shows that, after the risk information disclosure, floods affected LGFVs increase the MCBs issuance following floods, but the coefficients between the two subgroup are insignificant (Columns (1)-(2) in Panel B of Table 8). This is may because the local governments are already well-informed regardless of whether the information was disclosed or not. The coefficient of Flood×Post in Column (3) of Panel B are statistically positive before the risk information disclosure, while it is statistically insignificant in Column (4) of Panel B. This suggests that investors are willing to accept lower prices when subscribing to flooded MCBs after the disclosure of flood-prone information, which eases risk uncertainty.

In conclusion, *Hypothesis 3c* is supported by the results in Table 9. Frequent flooding increases the uncertainty of future returns of bonds, which increases investor demand for the issuance costs of flooded MCBs. The disclosure of flood-prone information reduces this uncertainty, thereby reducing the market responsiveness to the issuance costs of MCBs. The responsiveness of LGFVs to flood-prone information is minor, as they are already well-informed, regardless it was disclosed or not.

6 Conclusion

Climate change is increasingly straining local government finances by driving more frequent and severe natural disasters. While previous research has primarily focused on macroeconomic and policy dimensions of local government debt, this paper provides novel insights into how flood risks affect municipal financing in China. By analyzing MCB issuance patterns, we find that floods significantly increase local government borrowing, with post-disaster bonds facing higher issuance costs due to investor risk aversion. Using a stacked DID approach, we find that floods significantly increase local government borrowing through LGFVs, with more bonds issued post-flood. Investor caution toward flood-affected MCBs results in increased issuance costs, reflected in a 8.23% rise above the mean spread cost of 287.8 basis points per MCB.

Our findings have crucial implications for policymakers and financial markets. As extreme weather events escalate, local governments in emerging economies—already facing constrained adaptation budgets—will encounter mounting fiscal pressures. Unlike gradual climate risks such as sea-level rise, floods impose immediate and acute financial burdens, necessitating urgent policy responses. Strengthening climate resilience through improved financial risk management and enhanced transparency in climate risk disclosure could mitigate the adverse impacts of climate change on local government debt sustainability.

By linking climate risks to municipal borrowing, this study underscores the urgent need for integrated fiscal and environmental policies. Future research should explore long-term adaptation strategies and the effectiveness of climate risk pricing in municipal bond markets, particularly in developing economies facing heightened climate vulnerabilities.

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Appendix A. Event study

To determine the appropriate empirical strategy, we use an event study to test whether floods affect the local government costs, and how long the effects last for. We consider an event study specification of the following type:

$$Y_{c,ij,t} = \sum_{\tau=-T,\tau\neq-1}^{T} \gamma_\tau I\left(t - F_{ij} = \tau\right) + \sum_{\tau=-T,\tau\neq-1}^{T} \delta_\tau\left[Treat_{c,ij,t} \times I\left(t - F_{ij} = \tau\right)\right] + \eta X_{c,ij,t} + \theta Z_{ij,t} + \lambda_j E_t(t \in y) + \mu_t + \varepsilon_{c,ij,t} \quad \text{(A.1)}$$

where c index MCBs, i indexes cities, j indexes provinces, t indexes month-of-year. $Y_{c,ij,t}$ are the variables of interest, including *MCBs issuance* or *credit spread of the issued MCB*. For the explanatory variables, F_{ij} is the specific month-of-year that city i experienced a flood. $I(\cdot)$ is an indicator that equals one when $t - F_{ij} = \tau$, and zero otherwise. $Flood_{c,ij,t}$ is a dummy of treatment that equals one if MCB c issued in city i suffered a flood in the event months [-T, T], and zero if the MCB c is issued in the benchmark cities. X are MCBs-specific characteristics, including issuance amount, maximum maturity, guaranteed, purposes of issuance MCBs, and issuer's credit rating. Z are city-specific characteristics, including GDP per capita, population size, the amount of local government is expenditure over its revenue, loads of financial institutions at year-end, and road and pipe length. The $\lambda_j E_t(t \in y)$ are province- by-year fixed effects, μ_t are calendar-month fixed effects, and $\varepsilon_{c,ij,t}$ is the error term.

Using this specification, the goal is to estimate the time windows that a flood may affect local governments' financial costs in the bond markets. Previous studies show that the effect of floods persist for different durations. For example, Auh et al. (2022) find that *ex post* effect of floods on the average return of municipal bonds last for 20 weeks. And Pelli et al. (2023) show that other natural disasters, such as tropical cyclones, temporarily affect firm productions, and the effects disappear after one year. Taking housing prices as the interested financial costs, Bin and Landry (2013) find that flood risk discounts decayed over time, disappearing approximately 5 or 6 years after a severe flood. The local real estate market significantly affects the capability of local governments to offer the guarantee to MCBs (Ang et al., 2018). Following the literature, we set the event months to be [-*12*, *24*] in the event study.

The results in Figure A.1 show that, taking $\tau = 0$ as the reference month, floods significantly increase the probability of issuing bonds at a city level, and the issuance credit spreads of MCBs also increase. There is no significant pretends in both MCBs issuance and credit spreads, conditionally on control variables and a series fixed effect, as described in Equation (A.1). We also observed that the significant effects of floods on MCBs generally disappears in two years after the flood. The results also motivate our main empirical strategy of exploiting the affected period of floods on the financial cost of MCBs by setting the event months to be [-12, 24]. We also set the event months to be [-12, 20] and [-12, 28] in the robustness analysis.

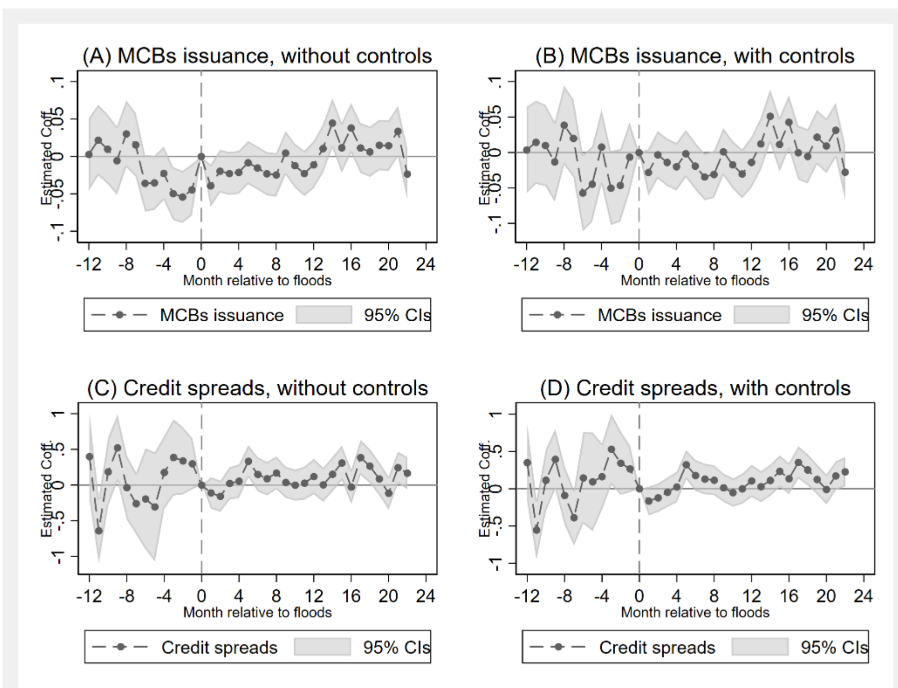

Figure A.1: The impacts of floods on MCBs: Estimated by event study.
This figure depicts the coefficients estimating the effects of floods on the MCBs over time, using the Equation A.1. Panel (A) and (B) uses city-by-month-of-year level data; Panel (C) and (D) use bond in city-by-month-of-year level data. Dots represent the coefficients estimated, and the cap lines indicate 95% confidence intervals with standard errors clustered by treatment group.

Appendix B. Robustness Checks

Even after controlling for both observables and some unobservables by the stacked DID approach in a restricted sample, there are still some concerns regarding whether the results in Tables 2 are robust in estimating the impacts of floods on MCBs. We discuss the robustness of our identification in this section.

One concern is the possibility that the damage caused by several floods are much larger than one single flood. Using a dummy of treat may bias the estimated results. We address this concern by replacing the Treat variable with the logarithmic number of floods during the event months in Equation 1. On average, there are 2 floods in the event months. The results in Table B1 show that, compared to disaster-unaffected cities, local governments increase borrowing through LGFVs after floods. Investor responsiveness is also negative to the flooded MCBs. Regardless of the measurement of flood risk, the impacts of floods on the MCBs market remain.

Table B1: Robustness I: Different measurement of flood risk.

This table reports the effects of flood risk on MCBs, using the logarithmic number of floods over the event months [-12, 24] as treatment variables. The control group is MCBs issued in cities located 150 km away from the flooded cities and did not experience any natural disasters, including floods, typhoons, and earthquakes over the study period. Bond controls include credit rating, the logarithmic value of maximum maturity, whether the bond is guaranteed, the bond issued for bank repayment, the bond issued for investments, the issuer's credit rating, and share of bond held by fund management Co. City controls are logarithmic GDP per capita, logarithmic population size, logarithmic loan balance in 2011 with yearly trends. We also control other extreme weather events, including monthly cumulative precipitation, the number of floods in the neighboring cities in event months [-12, 24], whether there is a typhoon or an earthquake in event months [-12, 24]. All regressions include treatment group fixed effects, hydro basin-by-year fixed effects, and issued month fixed effects. Standard errors in parentheses are clustered by treatment groups. *** p<0.01, ** p<0.05, * p<0.1.

	MCBs issuance		Credit Spreads	
VARIABLES	Full sample	Exclude first-tier cities	Full sample	Exclude first-tier cities
	(1)	(2)	(3)	(4)
Log(numb. of floods) X Post	0.446***	0.388***	0.215***	0.281***
	(0.129)	(0.050)	(0.033)	(0.045)
Post	-0.013	0.004	-0.022	-0.044*
	(0.018)	(0.014)	(0.024)	(0.026)

Treatment group	899	896	899	899
Observations	93,526	85,202	147,095	107,111
R-squared	0.549	0.096	0.475	0.446
Bond controls	No	No	Yes	Yes
City controls	Yes	Yes	Yes	Yes
Treatment group FE	Yes	Yes	Yes	Yes
Hydro Basin-Year FE	Yes	Yes	Yes	Yes
Month FE	Yes	Yes	Yes	Yes

Another concern is whether the results are driven by the selection of event months [-12, 24]. We choose the event window based on the results in Figure A.1 in Appendix A, estimated by an event study model. Moreover, we also observed that the credit spreads of flooded MCBs are significantly positive in 18 months after floods. We thus change the event months to be [-12, 20] or [-12, 28] in the robustness. The results are reported in Panel A and Panel B of Table B2, respectively. Regardless of the measurements of flood risk and event window, local government intend to issue more MCBs following floods, and investors cautiously provide proceeds to the flooded MCBs, resulting in a higher probability of failed issuance and increasing credit spreads of MCBs.

Table B2: Robustness II: Different event window

This table reports the effects of flood risk on MCBs, using a dummy of Flood X Post or the logarithmic number of floods over the different event months as treatment variables. The control group is MCBs issued in cities located 150 km away from the flooded cities and did not experience any natural disasters, including floods, typhoons, and earthquakes over the study period. Bond controls include credit rating, the logarithmic value of maximum maturity, whether the bond is guaranteed, the bond issued for bank repayment, the bond issued for investments, the issuer's credit rating, and share of bond held by fund management Co. City controls are logarithmic GDP per capita, logarithmic population size, logarithmic loan balance in 2011 with yearly trends. We also control other extreme weather events, including monthly cumulative precipitation, the number of floods in the neighboring cities in event months [-12, *t*], whether there is a typhoon or an earthquake in event months [-12, *t*]. All regressions include treatment group fixed effects, hydro basin-by-year fixed effects, and issued month fixed effects. Standard errors in parentheses are clustered by treatment groups. *** p<0.01, ** p<0.05, * p<0.1.

	(1)	(2)	(3)	(4)
VARIABLES	MCBs issuance	MCBs issuance	Credit Spreads	Credit Spreads
	Panel A: Event month [-12, 20]			
Flood X Post	0.464***		0.245***	
	(0.129)		(0.049)	
Log(# of floods) X Post		0.452***		0.079**
		(0.132)		(0.032)
Post	-0.001	0.006	-0.026	-0.022
	(0.016)	(0.016)	(0.023)	(0.024)
Treatment group	883	883	884	884
Observations	84,173	84,173	131,727	131,727
R-squared	0.129	0.129	0.480	0.471
	Panel B: Event month [-12, 28]			
Flood X Post	0.495***		0.070	
	(0.121)		(0.043)	
Log(# of floods) X Post		0.495***		0.072**
		(0.127)		(0.033)
Post	-0.050***	-0.049***	-0.024	-0.025
	(0.018)	(0.018)	(0.023)	(0.023)
Treatment group	898	898	898	898
Observations	102,359	102,359	161,253	161,253
R-squared	0.129	0.130	0.456	0.457

There is also a concern about whether the results are driven by the selection of control cities. We restrict the control cities as the disaster-unaffected cities that are located between 150 km and 500 km or 700 away from the flooded cities. We then repeat the baseline estimations using the extended control groups. The results are shown in Table B3. Regardless of control groups and selection of event window, the impacts of floods on the MCBs remain.

Table B3: Robustness III: Different definitions of control groups.

This table reports the effects of flood risk on MCBs, using different definitions of control groups. Bond controls include credit rating, the logarithmic value of maximum maturity, whether the bond is guaranteed, the bond issued for bank repayment, the bond issued for investments, the issuer's credit rating, and share of bond held by fund management Co. City controls are logarithmic GDP per capita, logarithmic population size, logarithmic loan balance in 2011 with yearly trends. We also control other extreme weather events, including monthly cumulative precipitation, the number of floods in the neighboring cities in event months [-12, *24*], whether there is a typhoon or an earthquake in event months [-12, *24*]. All regressions include treatment group fixed effects, hydro basin-by-year fixed effects, and issued month fixed effects. Standard errors in parentheses are clustered by treatment groups. *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

	(1)	(2)	(3)	(4)
VARIABLES	MCBs issuance	MCBs issuance	Credit Spreads	Credit Spreads
Panel A: Control group within 150 - 500 km from the treated group				
Flood X Post	0.482***		0.145***	
	(0.071)		(0.051)	
Log(# of floods) X Post		0.483***		0.183***
		(0.077)		(0.045)
Post	-0.094*	-0.065	-0.144***	-0.142***
	(0.049)	(0.051)	(0.044)	(0.048)
Treatment group	608	608	639	639
Observations	9,687	9,687	14,286	14,286
R-squared	0.339	0.339	0.404	0.401
Panel B: Control group within 150 - 700 km from the treated group				
Flood X Post	0.597***		0.099*	
	(0.118)		(0.053)	
Log(# of floods) X Post		0.574***		0.112**
		(0.118)		(0.047)
Post	-0.056	-0.038	-0.070*	-0.068
	(0.034)	(0.035)	(0.041)	(0.043)
Treatment group	705	705	729	729
Observations	17,757	17,757	25,811	25,811
R-squared	0.194	0.195	0.411	0.411

Together, these robustness tests provide strong evidence that flood risk and event window are precisely identified, suggesting a causal link between the flood risks and local public financing costs.

Appendix C. Additional Results

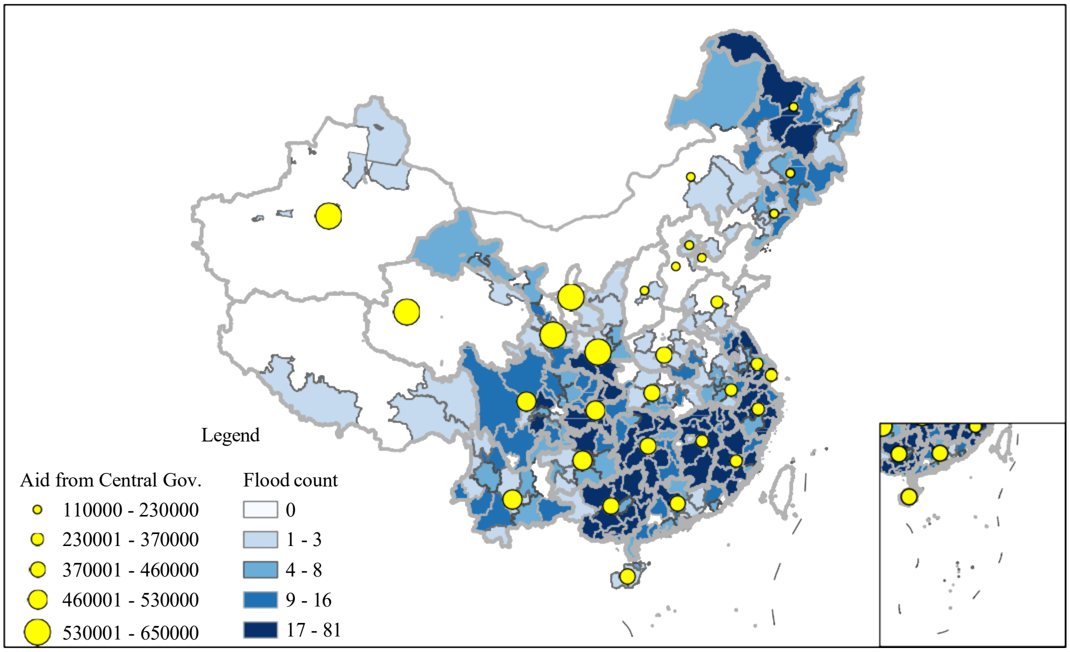

Figure C1: The specialized transfer payments from the central government for disaster relief.

Note: The yellow circle represents the total size of transferred payments from the central government for disaster relief between 2012 and 2018. The blue areas represent the number of floods that hit a given city between 2010 and 2020. Data source: flood data are accessed from the *Hydrological Information Annual Report (2008-2020)*, and the transferred payments for disaster relief are accessed from the *China Civil Affairs Statistical Yearbook (2011-2019)*. It has discontinued publishing disaster relief data since 2019.