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Pauline Avril

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Natural Disasters and Financial Stability
Catastrophes naturelles et instabilité financière

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General Introduction

General Introduction

“A system maintains a certain fluid stability that can be destroyed by a misstep in just one niche. A system has order, flowing from point to point. If something dams that flow, order collapses. The untrained might miss that collapse until it was too late. That’s why the highest function of ecology is the understanding of consequences.”

Frank Herbert - Dune (1965)

The Great Lisbon Earthquake, which occurred on November 1st, 1755, was characterized as the first modern disaster by Dynes (2003). This renowned calamity reverberated in the collective consciousness for years, primarily due to tremendous human and economic damages it caused. With a population of 275,000 inhabitants, Lisbon experienced the loss of 100,000 lives, representing a devastating 36% fatality rate. Furthermore, this disaster triggered heated debates among the philosophers of that period, making it even more historically significant.

In the weeks following, Voltaire attempted to find meaning to this event through a poem, suggesting that unmerited suffering could be attributed to a divine source: *"Nature is silent; in vain we question her. One day, all will be well, that is our hope; all is well today, that is the illusion."* (Poem on the Lisbon Disaster, 1755).

However, Rousseau disagreed with the idea that the disaster had a divine explanation. He expressed his views in a letter, *Lettre sur la Providence (1759)*, responding to Voltaire. Rousseau claims that the source of the disaster was not the divine will of God but rather the result of human choices and actions. *"Most of our physical afflictions are still of our own making. Without straying from your topic of Lisbon, for instance, acknowledge that nature had not gathered there twenty thousand six or seven-story buildings, and that if the inhabitants of this great city had been more evenly dispersed and lightly housed, the damage*

would have been much less, perhaps even nonexistent". Rousseau's pioneering perspective was remarked for its early recognition of a correlation between physical events and the actions of humanity. By drawing this link, he inadvertently laid the groundwork for what would later evolve into the Anthropocene theory. This theory underscores that human activities have made a deep and lasting impact on the Earth's geological and natural processes, encompassing elements such as deforestation, climate change, and the extinction of species.

Rousseau raised issues that continue to resonate in today's discussions about natural disasters. First, he introduced the concept of vulnerability as emphasized by Dynes (2003) *"to understand the meaning of Lisbon depended . . . on an understanding of the social structure and culture in the specific community in which the earthquake took place"*. At that time, he recognized that the economic and social context played a crucial role, determining that the impact would vary significantly among affected populations. Second Dynes (2003) evokes the role that societies had to play in term of recovery effort making this event the first modern disaster: *"The earthquake was the first disaster in which the government accepted the responsibility for mobilizing the emergency response and for developing and implementing a collective effort for reconstruction"*. Their observations remain relevant in contemporary debates.

Numerous other natural disasters have left their mark in different parts of the globe in the recent decades. They include events such as the 1931 China floods, the 1970 Bhola Cyclone, the 1995 Kobe earthquake, the 2004 Indian Ocean tsunami, the 2005 Katrina storm, the 2020 Australian wildfires, the 2021 Haiti earthquake, the 2022 Pakistan floods, the 2022 Afghanistan earthquake, and, more recently, the September 2023 Morocco earthquake and Libya flooding.

Physical risk: an anthropic risk

Global warming

Climate change encompasses prolonged alterations in worldwide or local weather patterns, specifically involving changes in temperature and precipitation. These shifts can arise from either natural processes or human activities. Abundant scientific evidence underscores the phenomenon of global warming. Jones and Mann (2004) research highlights that the 20th century stands out as a period marked by the most significant temperature fluctuations observed within any century over the past two thousand years. The first Intergovernmental Panel on Climate Change (IPCC, 2001) stress the idea that the observed changes would be highly unlikely without human influence. Later studies reinforced the evidence pointing to the substantial contribution of carbon dioxide emissions to global warming (Houghton, 2005; Florides and

Christodoulides, 2009). The connection between global warming and human impact is firmly established, validating the concept of the Anthropocene era.

Climate change and natural disasters frequency

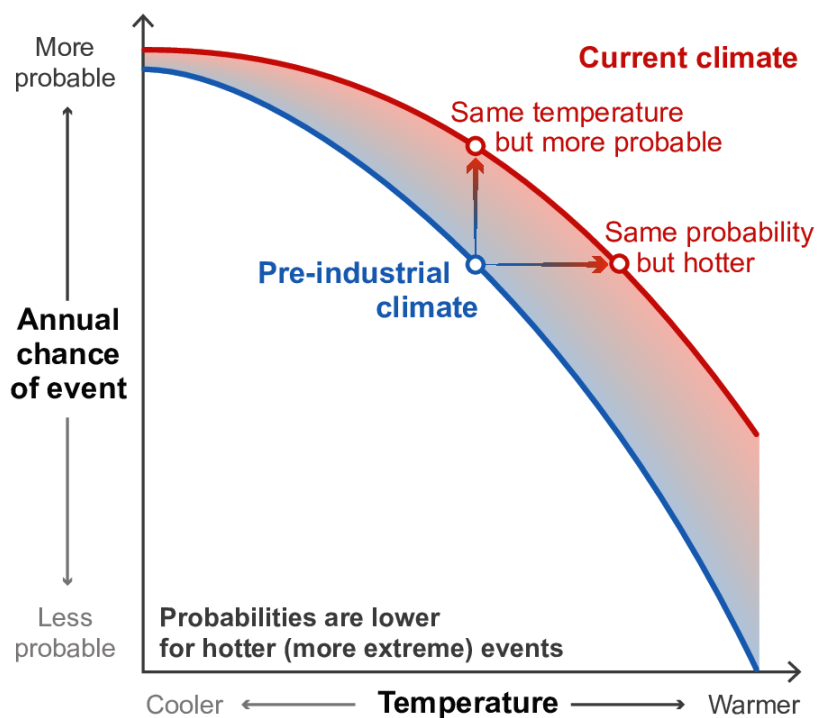
However, it took some time to establish the connection between the frequency and intensity of extreme events and their relationship with human influence. In his article in the journal *Nature*, Allen (2003) suggests using as example an extreme flood in the United Kingdom that certain external factors driving climate change, such as greenhouse gas emissions, may have contributed to an increased risk of extreme events. Building on this insight, several studies have demonstrated that many extreme events fall beyond the scope of earlier predictions (Schär and Jendritzky, 2004). Progressively, evidence appear regarding the influence of human activities on the occurrence of extreme events (Stott et al., 2004; Stone and Allen, 2005; Perkins-Kirkpatrick et al., 2022). Stott et al. (2004) estimate that there is a strong probability that human influence has doubled the chances of the 2003 European heat wave occurring. Schaller et al. (2016) conclude that climate change had increased the chances of the rainfall that caused the 2014 UK flooding by an estimated 43%.

Following a series of scientific findings, the IPCC, in its special report on extreme events (IPCC, 2012), recognize the connection between climate change and natural disaster occurrences. It states that *"A shifting climate brings about alterations in the occurrence, intensity, geographic scope, duration, and timing of extreme weather and climate events, potentially leading to unparalleled occurrences of extreme weather and climate events."* As depicted in Figure 1, the current climate conditions have shifted the curve to the right. Using the average temperature as an example, we observe a significant increase in the likelihood of annual events compared to the pre-industrial climate.

Given the current state-of-the-art, some initiatives like the World Weather Attribution project have arisen, aiming to centralize international endeavors and strengthen the capacity to assess the impact of climate change on extreme weather occurrences. Establishing such a connection is important as it might help to slow down the increasing frequency of these events. This understanding, in turn, will better prepare economic agents and facilitate proactive measures.

In line with the idea that physical risks are an inherent feature of the Anthropocene era, we can further bring into consideration their escalating frequency and intensity, which are closely associated with climate change. As illustrated in Figure 2 from the World Meteorological Organization (WMO), there has been a significant surge in the reported number of natural disasters between 2000 and 2019. On one hand, there is a notable decrease in deaths. On the other hand, there has been a sharp increase

Figure 1: Relation between rising temperature and annual chance of event



Source: IPCC (2021)

in economic losses. The IPCC (2012) report on physical risks made projections regarding the likelihood of events in the 21st century.

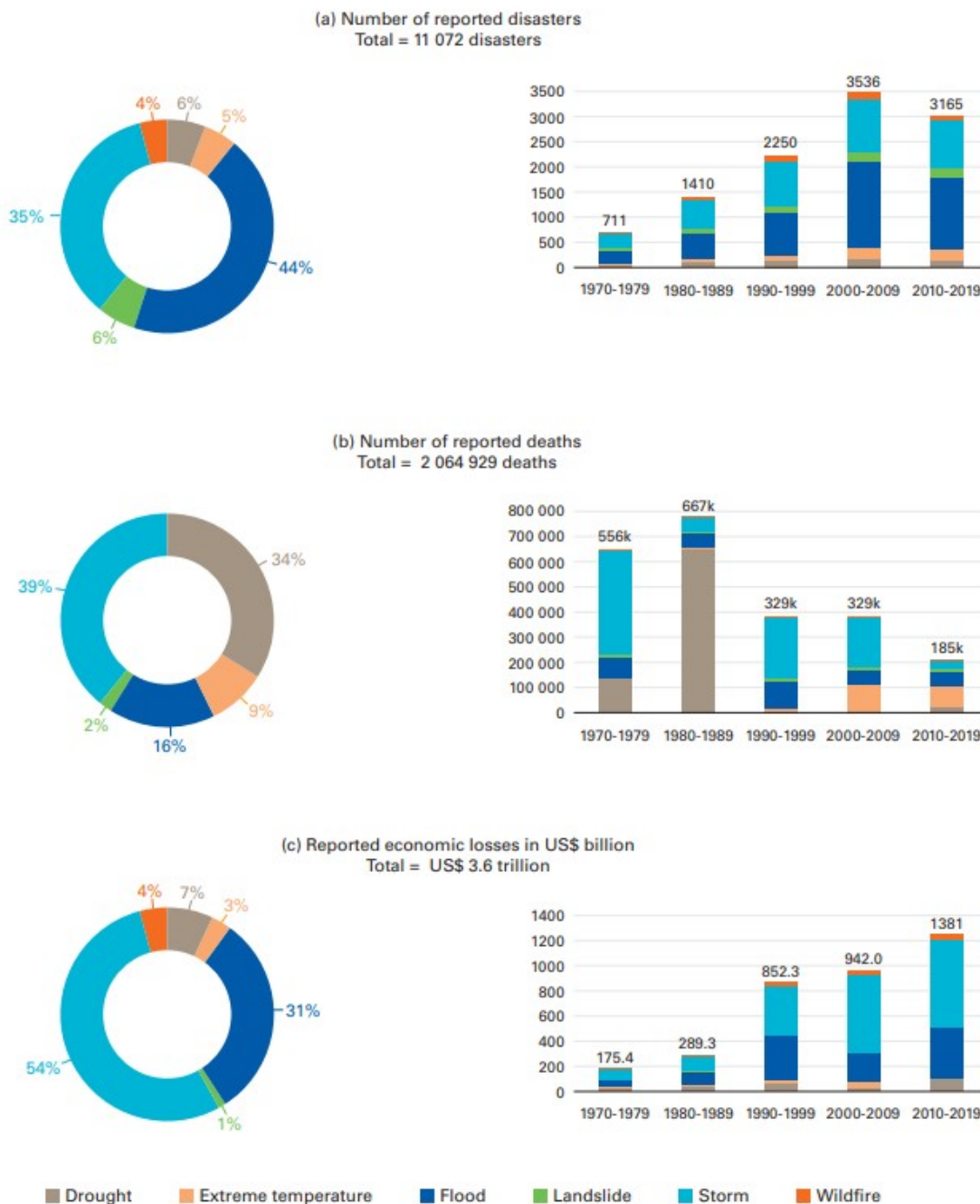
It predicts increased frequency of heavy precipitation and shifts in temperature extremes, leading to extreme events like floods and heatwaves. There is a moderate level of confidence in the intensification of droughts in the 21st century. However, the conclusions regarding extreme winds are less robust, mainly because there are limited models available for such events. Concerning the rise in economic losses due to climate-induced events, the report highlights a significant spatial heterogeneity. Specifically, it points out that economic losses, both insured and uninsured, are more pronounced in developed countries. However, in terms of fatality rates and economic losses as a percentage of gross domestic product (GDP), developing countries experience higher ratios.

Measure and definitions

Hazard, exposure, vulnerability

Following IPCC (2012) definition, we define physical risk as a combination of three components: hazard, vulnerability and exposure. *Hazard* pertains to the potential occurrence of a physical event, whether

Figure 2: Evolution of events, fatalities and damages



Source: WMO - Atlas of Mortality and Economic Losses from Weather, Climate and Water Extremes (1970–2019)

of natural or human origin, capable of resulting in various adverse consequences such as fatalities, injuries, property damage, and disruptions. It represents a threat of adverse effects rather than the physical event itself. *Exposure* refers to the presence of people, livelihoods, environmental services, infrastructure, or

assets in areas that may be negatively influenced by physical events, leading to potential damages. Under exposed conditions, the extent of adverse consequences depend on the interaction between the physical event and socially constructed conditions, known as vulnerability. *Vulnerability* is broadly defined as the inclination to experience adverse effects. It represents inherent characteristics or circumstances that affect the ability to manage and recover from the negative consequences of physical events. Vulnerability is shaped by a range of historical, social, economic, political, cultural, institutional, natural resource, and environmental factors and processes.

Moreover, physical risk may be split into two type of risk : acute and chronic. The Financial Stability Board within the G20 established the Task Force on Climate-related Financial Disclosures (TCFD) to provide a comprehensive understanding of climate-related risks. In TCFD (2017) report, a differentiation is made between acute and chronic physical risks. Acute physical risks are defined as event-driven, encompassing heightened severity of extreme weather events like cyclones, hurricanes, floods, droughts, heatwaves, and fires. Chronic physical risks refer to longer-term changes in climate patterns that may result in sea-level rise, persistent heatwaves, and alterations in precipitation. The Network for Greening the Financial System (NGFS) similarly distinguishes between both types of physical risks, particularly in terms of damages inflicted. Acute impacts arising from extreme weather events can result in business disruptions and property damage. While historically seen as temporary, the situation is evolving with the progression of global warming. These events can heighten underwriting risks for insurers and diminish asset values. On the other hand, chronic impacts, primarily associated with rising temperatures, sea-level increases, and shifts in precipitation, have the potential to affect labor, capital, and agricultural productivity. Addressing these changes will necessitate substantial investments and adaptation efforts from companies, households, and governments (NGFS, 2020).

Historical data and scenario-based data

To evaluate and understand the impact of physical risk, we can rely on historical and scenario-based data. When it comes to physical risk, a significant body of the literature concentrates on past events to analyze their repercussions. This approach is crucial for deriving practical insights for physical climate risk assessment. Examining the past consequences of natural disasters is essential for understanding how to respond in the future. Furthermore, it serves as a tool for assessing the factors contributing to vulnerability. In terms of data sources, there are several comprehensive databases available. EM-DAT from the Centre for Research on the Epidemiology of Disasters (CRED) is the most widely recognized, being a global public database that provides information on the location and damages of disasters. Additionally, it is possible to base analyses on geophysical databases derived from satellite and meteorological station

data. For instance, the National Oceanic and Atmospheric Administration (NOAA) offers numerous databases that enable precise geolocation of meteorological disturbances. These geophysical databases are particularly valuable because they provide external measures of intensity. This allows to separate the hazard component from other factors that may be more closely tied to economic outcomes (Felbermayr and Groschl, 2014).

Scenario-based data plays a critical role due to the considerable uncertainty linked to future climate risks. These scenarios allow to explore a range of possible outcomes and assess how different factors may interact and evolve over time. They are essential to anticipate, prepare and develop effective strategies for climate risk management and adaptation (Dessai et al., 2005). An increasing number of businesses and financial institutions now acknowledge the importance of incorporating physical risk into scenario analysis. They recognize the necessity of resilience strategies to confront climate impacts (BIS, 2021). These scenarios hold particular significance when viewed from an investor's point of view, primarily because investments tend to have a medium to long-term horizon (TCFD, 2017).

Transition risk

While this thesis focus on physical risks, it is important to recognize the presence of transition risks as additional component of climate-related risks. This risk encompasses the challenges associated with transitioning towards a low-carbon economy. The TCFD (2017) report distinguish four drivers of transition risk. (1) Policy and legal risks steaming from changes in the regulation. These changes can drive up operating costs for companies as they must comply with new standards, necessitating investments in technology or resources. Additionally, businesses may be compelled to retire assets prematurely if they no longer meet the updated criteria. Ultimately, these shifts can lead to a reduction in demand; (2) Technology risk that increase uncertainties associated with developing, adopting, and implementing technology solutions to address climate-related issues. This risk can result in asset retirements, decreased demand, increased R&D expenditures, capital investment reductions, and elevated implementation costs; (3) Market risk resulting from shifts in market dynamics that can lead to repricing and lower demand; (4) Reputation risk refer to the potential damage a company's image may suffer if it is perceived as lacking in environmental responsibility. This risk can adversely impact its relationships with investors and then reduce revenue.

According to the findings of Bua et al. (2022), climate risk premiums in the European market, encompassing both transition and physical risks, have risen since the implementation of the Paris Agreement. The survey conducted by Stroebel and Wurgler (2021) among investors indicates that physical risks appear to be of lesser immediate concern when compared to transition risks but are expected to become

a central focus over the next 30 years. Nonetheless, as demonstrated earlier, physical risks are not as distant as they may seem, and their impact is increasing, particularly in terms of the damages incurred. In this thesis, we will show that these risks have already exerted noteworthy impacts on both the real and financial aspects of the economy and will continue to do so if not effectively addressed. Moreover, the worldwide insurance market will encounter constraints in covering all these risks and mitigating the climate crisis, as it cannot offer limitless reinsurance. As an illustration, Munich Re estimates that the most expensive natural catastrophe on record remains the landfall of Hurricane Katrina in Louisiana in 2005. This event is assessed to have incurred a destructive cost of approximately \$150 billion, of which the insurance industry covered \$62 billion. Considering that insured losses are the ones that trigger the most severe consequences, as highlighted by Von Peter et al. (2012), alternative instruments must be implemented. Thus, in order to understand how to manage and mitigate physical risk effectively, it is essential to conduct a thorough assessment of the risk itself and the pathways through which it is transmitted. And this is exactly the aim of the research conducted in this thesis.

Transmission channels of physical risk to the real economy

Global effect on economic growth

Natural disasters are generally expected to be detrimental to growth because they disrupt normal economic activities, lead to substantial financial losses, and divert resources away from productive investments. In the existing body of literature, empirical findings on the relationship between natural disasters and the macroeconomy are not universally conclusive. Some studies have discovered that, on a global scale, the impact of natural disasters is indeed negative and poses a detrimental effect on economic growth (Raddatz, 2009; Strobl, 2011; Felbermayr and Groschl, 2014), particularly in the short term (Noy, 2009). On the other hand, some studies have yielded more ambiguous findings. For instance, Cavallo et al. (2013) discovered that only exceptionally large disasters exhibit a negative impact on economic output. In addition, there are studies that have identified a Schumpeterian "creative destruction" effect associated with natural disasters. This effect, which operates in the short term, implies that certain economic sectors and activities experience a boost due to the need for reconstruction and recovery in the aftermath of the disaster (Skidmore and Toya, 2002; Ramcharan, 2007; Noy and Vu, 2010).

Channels of transmission

As illustrated by the development of Integrated Assessment Models (IAMs), which leverage various academic disciplines to model the interaction between economics and climate change, there are numerous pathways through which climate-related risks can impact the economy (Nordhaus, 1993; Nordhaus and Yang, 1996). In this thesis, we will specifically emphasize the transmission of physical risks.

First, the destructive power of natural disasters can exert tremendous impact on the production process. These events have the capacity to damage physical property, destroy equipment and public infrastructure. Such destruction induce disruptions within supply chains, whose interruptions have a cascading effect (Altay and Ramirez, 2010; Haraguchi and Lall, 2015). The second channel to consider is the impact on productivity. Natural disasters damage firms' capital, as suggested by Kahn (2005). However, this impact is debated. Some studies, like Acevedo et al. (2020) and McDermott (2012), have indicated that both capital and labor may experience reduced productivity following extreme events. Leiter et al. (2009) present nevertheless a contrasting perspective. They argue that, in the short run, regions affected by flooding may experience an upsurge in total assets and employment, suggesting a potentially positive effect on productivity and growth. Third, the impact on firm profitability also yields mixed findings. For instance, Noth and Rehbein (2019) uncovered a positive effect stemming from the 2013 flooding in Germany, which manifested in increased turnover and cash reserves for firms. Conversely, Hsu et al. (2018) indicate that firms with factories situated in areas prone to natural disasters tend to experience lower profitability. Lastly, another dimension in understanding the connection between natural disasters and economic growth is investment. Findings in the literature generally align. It becomes evident that significant natural disasters tend to diminish foreign direct investment (FDI) in the impacted regions (Escaleras and Register, 2011; Friedt and Toner-Rodgers, 2022; Gu and Hale, 2023). Furthermore, Hosono et al. (2016) have observed a negative impact on private investment as a consequence of natural disasters. Overall, it is acknowledged that natural disasters can influence economic growth through multiple channels, although these channels do not consistently operate in the same direction.

Heterogeneity of impacts

Many studies establish specific thresholds arguing that only large natural disasters have an impact (Raschky, 2008; Fratzscher et al., 2020). This practice is rooted in the general consensus that larger-scale events possess a greater potential for disruption, as noted by Hallegatte and Przyluski (2010). Notably, Cavallo et al. (2013) specifically discern that it is only the large disasters that exhibit a negative impact on output, both in the short and the long run. Then, the relation between the size of the disaster and its impacts is non-linear. Another key factor affecting the variation in disaster impacts is the type of disaster itself. Many studies have shown that the nature of the disaster leads to significantly different outcomes

(Felbermayr and Groschl, 2014; Altay and Ramirez, 2010). The final notable source of heterogeneity arises from vulnerability factors defined above. Indeed, the economic and social context within different areas serves as a crucial determinant of the resulting impacts of natural disasters. For instance, income levels have been identified as a clear determinant of the extent of impact, with developing and smaller economies often experiencing more substantial negative consequences than their developed counterparts (Noy, 2009). Some studies delve deeper into this aspect by examining vulnerabilities at a more granular level, such as sector-specific vulnerabilities (Loayza et al., 2012). Additionally, numerous factors, including education levels, openness to trade, the strength of the financial system, and the quality of institutions, can also play pivotal roles in shaping vulnerabilities (Toya and Skidmore, 2007).

As highlighted in this section, there exists a substantial body of literature dedicated to examining the effects of natural disasters on the real economy, exploring transmission channels, and understanding sources of heterogeneity. Nevertheless, the impact of physical risk on financial systems has remained relatively unexplored and often overlooked by regulatory frameworks. Nevertheless, it is well-established that the realization of financial risks can reverberate through the real economy, as demonstrated by recent crisis episodes. Therefore, it is imperative that these risks receive deeper investigation to promote the financial stability and resilience of financial sectors.

Impact of climate-related risks to the financial sector

In 2015, the Governor of the Bank of England, Mark Carney, issued a warning to the financial system regarding its exposure to climate risks, both direct and indirect, encompassing physical risks and transition risks (Carney, 2015).

Different source of risks

The NGFS (2020) underscores five critical environmental risks that have significant implications for the financial sector. The *first risk* examined is operational risk, which is intricately linked to disruptions in business operations and reduced profitability in the aftermath of disasters. We elaborated on this risk in the previous section because of its primary impact on the real economy. Nevertheless, it can also have effects within the financial sector, potentially resulting in an elevation of the Expected Shortfall. Indeed, firms might appear riskier to investors and stakeholders after natural disasters events. The *second risk* is the credit risk (see Figure 1.9.1 in Chapter 1 for details on the channels). Credit risk involves an elevated likelihood of credit defaults and/or a decrease in the value of collateral. For example, Bernstein et al.

(2019) show that exposure to sea-level rise can lead to a reduction in the value of houses that may be used as collateral. Additionally, Fankhauser and Tol (2005) confirm that the debt service capability diminishes after the destruction of physical assets. Consequently, an increase in the ratio of non-performing loans frequently occurs following a natural disaster event (Klomp, 2014). This escalation in credit risk is applicable not only at the level of individual firms and households but also at the macroeconomic level, contributing to an elevated risk of sovereign debt default (Klomp, 2017; Lamperti et al., 2019). The *third risk* that emerges is the underwriting risk faced by insurance companies due to a surge in insured losses. Natural disasters can significantly disrupt the operations of insurance companies, as demonstrated by Benali and Feki (2017), potentially challenging their ability to sustain continuous coverage. Furthermore, while insurance coverage may increase, it primarily aids in post-disaster recovery rather than mitigating the risk in advance (Kousky, 2019). This underscores the notion that insurance is more of an ex-post measure rather than an ex-ante one, emphasizing its role in addressing the consequences of disasters rather than preventing them. The *fourth risk* involves market risk related to repricing dynamics. Gourio (2012) model illustrates that an increased risk of disasters tends to reduce revenue expectations, leading to higher risk premiums. This adjustment in risk perception subsequently triggers repricing effects in the stock market. Additionally, similar repricing mechanisms come into play in the bond market due to portfolio reallocation (Dafermos et al., 2018). The *fifth and final risk* is the liquidity risk, which arises from the requirement for funds to support post-disaster recovery efforts, potentially causing a surge in demand for liquidity. Allen (2003) support this theory and show an increase in withdrawals following a natural disasters. This heightened demand for withdrawals can, in turn, pose challenges for banks and elevate liquidity risk (Nie et al., 2023).

The combined presence of these risks raises a fundamental question regarding climate-related risks as a potential source of systemic risk. As defined by Kaufman and Scott (2003) "*Systemic risk refers to the risk or probability of breakdowns in an entire system, as opposed to breakdowns in individual parts or components.*". The Global Financial Crisis stands as a vivid example of systemic risk materialization: Bernanke (2018) explains it as a disruption caused by a shock into information asymmetries, making risk evaluation more complex. As this section demonstrates, natural disasters introduce a multitude of uncertainties that can significantly worsen information asymmetries. Bolton et al. (2021) assert that natural disasters, by their very nature, represent a source of systemic risk, which is challenging to hedge against due to the inherent uncertainty and limited capacity to share risks among financial actors.

The financial sector: a way to support the mitigation ?

As demonstrated in the preceding section, the financial sector is exposed to physical risks, yet it also

holds the potential for both preventive and responsive solutions. According to UNISDR (2015) report on Disaster Risk Reduction, it was estimated that the annual global costs of disaster damages range from approximately \$250 billion to \$300 billion USD. These substantial damages underscore the urgent need for action. As emphasized by Hammett and Mixter (2017), the financial sector can contribute to mitigating the impacts of climate-related risks. This involvement can encompass both preventive measures (ex-ante) and response measures (ex-post).

On the one hand, the financial sector has the potential to play a significant role in aiding post-natural disaster recovery efforts. Key challenges in this regard revolve around ensuring the availability of adequate funds and the rapidity of response. Certainly, numerous studies demonstrate that following natural disasters, businesses exposed to the event tend to have reduced chances of survival (LeSage et al., 2011; Basker and Miranda, 2018). Therefore, the financial system could potentially contribute to facilitating the recovery process, but it may encounter significant challenges related to information asymmetries. Consequently, certain banks may, in fact, decrease their credit supply due to funding shocks, an elevated ratio of non-performing loans, and substantial withdrawals (Faiella and Natoli, 2018; Brei et al., 2019). The structure of the banking system will also shape the response of banks. Existing literature largely concurs that local banks possess a competitive advantage regarding credit to small businesses (Berger et al., 2015). This advantage becomes particularly pronounced in the aftermath of natural disasters during the recovery phase. This is because local lenders might benefit from reduced information asymmetries and establish long-term relationships (Chavaz, 2016; Koetter et al., 2020).

On the other hand, the financial sector could also implement preventive measures to mitigate the adverse effects of physical risk. We can categorize these preventive measures into three types. Firstly, they can play a significant role in reallocating investments. Certainly, the risk of stranded assets should serve as a catalyst for the redirection of investments towards companies with lower emissions.¹ Furthermore, the transition to low-carbon economies may lead to a decrease in the frequency of physical risks. Therefore, it is essential to establish incentives that promote such investments.²

Secondly, in order to prevent the drastic repricing that can lead to significant destabilization, financial markets should accurately assess and price physical risk. Existing research has not identified any evidence of proper pricing for exposure to physical risk in the non-financial corporate bond market (Hong et al., 2019; Huynh et al., 2020).³ This absence of pricing holds true for stock markets as well, with no discernible

¹In order to restrict global warming to 1.5°C, an annual investment of roughly \$2.4 trillion on a global scale would be required, specifically for the transformation of the energy system. This contrasts with the current investment level of approximately \$1.75 trillion (IEA, 2018; IPCC, 2018)

²Another noteworthy observation pertains to the disparity in "green" investments across sectors. As highlighted in FTSE Russell (2022), it appears that over 75% of the "green" market capitalization is concentrated in sectors such as Technology, Industrial Goods and Services, Automobiles & Parts, Utilities, and Construction & Materials.

³Knowing that the bond market has experienced substantial growth: between 2008 and 2018, the international non-financial corporate bond market exhibited a growth rate of 2% (Abraham et al., 2020), in contrast to the 0.5% growth observed in the credit market.

evidence of risk premiums associated with exposure to physical risk (Faccini et al., 2021; Gostlow, 2021). Considerable efforts towards appropriately pricing physical risk in financial markets are needed.

The final preventative measure that the financial sector can implement relates to the incorporation of climate-related risks into credit ratings. It is well-established that credit ratings play a crucial role in determining the value of financial assets. As emphasized by Ciummo et al. (2022), the disclosure of the influence of climate change risks on credit ratings is of utmost importance. Some research has found that climate change risk is already factored into sovereign credit ratings (Cevik and Jalles, 2020). However, on a global scale, credit agencies often react after an event occurs to adjust the assessment of credit risk (Mathiesen, 2018).

Policy and adaptation measures

Adaptation policies for the real economy

Numerous policies have been implemented to mitigate the impact of climate-related risks on the real economy, with environmental policies and fiscal policies being the most prominent categories. Those policies are mainly oriented toward a reduction of emissions rather than mitigation of physical risk. On one hand, within environmental policies, we can highlight the significance of voluntary agreements. One of the most noteworthy agreements was the Kyoto Protocol, established during the COP3 in 1997. In essence, this protocol encouraged industrialized nations and transitioning economies to curtail and decrease their greenhouse gas (GHG) emissions in line with predetermined individual targets. This protocol was subsequently succeeded by the Paris Agreement in 2015, which aims to restrict the increase in global temperatures to well below +2°C. Additionally, there are "command-and-control" approaches that involve norms and regulations, like the Clean Air Act (CAA). Environmental policies encompass a range of initiatives related to the labeling and certification of products or practices as environmentally friendly, a process commonly referred to as eco-labeling. On the other hand, fiscal policies play a pivotal role in generating public funds to facilitate investments in various sustainability initiatives. This can include sustainable energy, clean technologies, and adaptation capabilities, among others. Key components of these fiscal policies include environmental taxes, budgetary reforms, fiscal incentives, and the augmentation of public revenues. One example is the EU Emissions Trading System (EU ETS), a carbon market in Europe where companies are assigned emissions limits and can trade allowances. The significance of such measures was highlighted by the establishment of the Green Fiscal Policy Network in 2014. Nevertheless, according to Calel and Dechezleprêtre (2016), the EU ETS market does not appear to be significantly

fostering the development of greener technologies.

These measures, when combined, make a significant contribution to the advancement of climate objectives and the facilitation of a shift toward a more sustainable economy. While these transition may, in turn, reduce the frequency of natural disasters, it is evident that environmental policies primarily emphasize the transition risk in the real economy, rather than the physical risk.

The situation is exacerbated when we consider that, in addition to the real economy, the financial sector also faces difficulties in effectively integrating climate-related risks. Alongside the tangible impacts on the real economy, physical risks also give rise to financial risks, as explained in the preceding section. Surprisingly, these financial risks have not received as much attention, resulting in fewer policies and measures being implemented to address them adequately. Recognizing the financial implications of physical risks is a critical step toward enhancing resilience and sustainability in the face of an evolving climate. This will in turn help to develop adequate financial adaptation policies.

Absence of adaptation and regulatory framework

As mentioned earlier, regulations have been established to mitigate the impact of climate risks on the real economy. However, when we shift our focus to the financial sector, it becomes evident that binding regulations are not yet in place.

We can observe the emergence of green financial instruments such as green savings products, green loans, and green bonds. However, their market share remains significantly limited in comparison to conventional financial products. Furthermore, these instruments primarily address transition risk, with limited attention given to physical risk. Importantly, there is a notable absence of comprehensive regulations, except for initiatives like the non-legally binding Green Bond Principles.

Concerning institutions and banks, they are increasingly conducting climate stress tests, which serve the purpose of assessing the resilience and financial stability of entities under various climate-related scenarios, including physical risks. This exercise helps quantify their exposure and vulnerabilities and can, in turn, encourage the adoption of best practices in regulatory frameworks. However, as highlighted by Battiston et al. (2017), the timing of policy framework implementation is crucial. An early and stable policy framework facilitates smoother adjustments in asset values and can lead to potential winners and losers. Conversely, a late and abrupt policy framework could have adverse systemic consequences. Within the essential global banking regulations of Basel III, which are designed to enhance banking system stability and safety, there is no provision addressing instruments that could mitigate climate-related financial risks. In a December 2022 FAQ regarding climate, the Bank of International Settlement emphasize that banks should evaluate how to integrate climate-related financial risks into their understanding

and implementation of the current Basel Framework. Additionally, banks are encouraged to continually enhance their expertise and capabilities concerning climate-related financial risks. There are still no officially established guidelines, even though some studies have attempted to suggest frameworks for incorporating climate considerations into the Basel III pillar (Berenguer et al., 2020). The absence of official guidelines hampers the efficiency of prudential policies in mitigating the impact of climate-related risks. Nieto (2019) highlights the potential value of exploring prudential policies as a means to internalize the negative externalities associated with climate risks for both banks and their supervisory authorities.

Finally, central banks are increasingly called upon to address climate risks that could jeopardize financial stability, questioning the role of monetary policy. During his speech at the Paris Europlace International Financial Forum on July 12, 2022, François Villeroy de Galhau, the Governor of Banque de France, stated *"Central banks' core mandate worldwide is price stability, and climate change already affects the level of prices and activity,"*. Nonetheless, when it comes to integrating climate change into their mandates, central bankers do not all share the same perspective. In a January 2023 statement at the RiskBank conference, J. Powell declared: *"We are not, and will not be, a climate policymaker."* Moreover, some studies indicate that monetary policies may not be entirely neutral in their effects on both brown and green firms. Research findings suggest that monetary policy could have a more pronounced impact on brown firms (Benchora et al., 2023).

Research contributions

We grasp the significant implications of physical risks for the financial sector. The increasing threat of natural disasters due to their greater frequency and severity in the context of climate change presents a challenge to financial stability. These specific shocks have been shown to have destabilizing effects on the real economy. However, there is still a lack of evidence regarding their impact on the financial sphere. Recent financial crises, including the 2008 financial crisis, underscore the fact that financial markets can initiate shocks with substantial consequences for the real economy. Establishing a comprehensive framework that precisely identifies various sources of risk and their respective magnitudes in different markets is of prime importance to provide the adequate regulatory response. In this thesis, we will explore how different levels of the financial sector may be influenced by these shocks. We will begin with a macroeconomic perspective, then develop a banking-system perspective, and conclude with an examination of bond market pricing.

Furthermore, considering the consequences of physical risk and implementing appropriate policy responses can serve not only to facilitate recovery measures but also to proactively mitigate these risks. Such resource savings can enable more effective investments in transitioning to a green economy and curb-

ing the escalation of natural disasters. As a result, this contributes to breaking the cycle of detrimental climate change impacts.

The primary contribution of this thesis is to assess the potential disruptive effects of natural disasters, with a particular focus on potential measures, both reactive (ex-post) and proactive (ex-ante). The first chapter of this thesis focuses on the impact of natural disasters on the external finance premium of countries. Moreover, we look at the potential mitigating impact that macroprudential policies could have in this context. The second chapter centers on post-recovery measures from banks. We analyze the impact of typhoons on the lending activities of banks in China and the role these banks may play in facilitating local-level post-disaster recovery. Finally the last chapter aims to identify the adequate pricing of forward looking physical risk. We investigate the physical risk exposure premium in the Eurozone bond market and explore the potential influence of past natural disasters.

Chapter 1: Natural Disasters and Financial Stress: Can Macroprudential Regulation Tame Green Swans?

Despite a growing literature on climate change, the effects of physical climate risks on financial systems remain largely unexplored. Against this background, we aim to empirically examine if natural disasters (NDs) cause financial stress, and whether the presence of a stringent set of macroprudential measures can dampen this adverse effect. We argue that a strict prudential framework that improves the resilience of borrowers and lenders may dampen the financial impact of climate events. We focus on two climate events that are frequent and damaging: storms and floods.

We use local projections (LPs) with interaction variables to evaluate the macroeconomic impact of NDs, in terms of financial stress, conditional on the stringency of national prudential measures. Financial stress is proxied by the external financial premium, i.e. the spread between the bank lending rate and the monetary (riskless) rate. We construct an original disasters dataset where NDs are gauged by meteorological intensity collected from different sources (i.e. meteorological stations and satellites). Thus, we are able to build objective measures of NDs severity, well suited for causal empirical analysis, contrary to damage-based data, which are more prone to endogeneity issue. Our measure of prudential stringency, computed using information from the Macroprudential Policy (iMaPP) database, captures the number of instruments actually activated over the period (i.e. translating the extensity of macroprudential policy).

The local projections estimated for horizons from 1 to 12 quarters ahead, for a panel of 88 countries over 1996-2016, indicate that interest rate spreads dynamics significantly differs across countries with low vs high level of prudential regulation. The premium on lending rates increases in the wake of storms in countries with lax prudential regulation. On the contrary, countries with strong prudential framework

can benefit from lower agency premium, thanks to the creditworthiness of lenders and borrowers, which possibly facilitate the replacement of capital by more productive technologies. However, in the case of floods the macroeconomic impacts are less clear-cut. Our results are robust to different econometric specifications and alternative measures of prudential regulation.

We conclude that storms have a significant impact on financing conditions at the country level. We also find that a strong macroprudential regulation improves countries' ability to better cope with this financial impact. Hence, macroprudential measures can provide protection against the growing climate-related financial risks, and help saving resources for the transition to a low-carbon economy.

Chapter 2: Typhoons in China: Do bankers want their umbrellas back when it rains?

This chapter explores how typhoons, which are frequent events in China, affects Chinese banks' behaviors. Despite a growing interest regarding those climate related questions there is still much to investigate especially in emerging markets. The bank's role in financing firms and households is crucial. Consequently, any negative impact on their performance can result in unfavorable outcomes for the overall economy. Most of the studies dealing with this topic focuses on the US or advanced countries with a developed insurance market, whereas some evidences show that natural disasters impacts are wider in developing economies.

The Chinese banking system is characterized by some interesting and unique features. First, it has been recently liberalized. For example limits on lending and deposit rates were removed in 2004. Secondly, the Chinese banking system is characterized by mainly four types of banks with specific scope and objectives (Stated-owned Banks, Commercial Banks and Rural Banks). Those features allow us to better identify the response of banks according to their main characteristics.

The main objective of banks is to screen and monitor clients in order to address asymmetries of information. On one hand, a decrease in bank lending after extreme events could be the results of worsening of asymmetries of information, a drop in collateral value and bad economic prospects. On the other hand, thanks to a good and better knowledge of the local environment, banks may not cut lending and even provide recovery lending.

We use difference-in-difference (DID) regression with time and individual fixed effects to assess the impact of typhoons on banks' response. In our identification strategy the "treatment group" is defined as banks which have suffered from significant typhoons. We build an annual measure of banks' exposure to typhoons based on the percentage of branches affected and the severity of the event.

Our difference-in-difference based on a sample of 327 banks between 2004-2019 estimates reveal that,

on average, typhoons trigger a decrease in lending that accounts for 2.8 percent of total bank assets. We show that this decline comes from commercial banks. On the contrary, rural banks act as shock absorbers. This may be the consequence of long-term lending relationships and a better knowledge of local economic and physical risks. Moreover, the absence of rural banks in Chinese prefectures is found to be detrimental to local post-typhoon growth. We also find that state ownership and external political pressure mitigate the relative decline in lending by typhoon-hit commercial banks.

We conclude that typhoons have a significant impact on bank stability. We also find that these effects differ depending on the bank characteristics. Hence, knowing that this type of weather-related natural disasters will increase in time and intensity, we point out that banks are at risk while they play a crucial role for the reconstruction, especially the ones that have a local proximity.

Chapter 3: Is the physical risk priced by the Eurozone bond market ?

This chapter investigates if exposure to physical risk generate a risk premium on the euro area bond market and if past natural disasters events also do. While many studies focus on assessing climate risk in the bond market, they often emphasize transition risk. Conversely, there is a relatively small body of literature that delves into the valuation of physical risks in the bond market. Nonetheless, some research has illustrated that physical risks can significantly impact companies' profitability, financing, and investments. Consequently, an inaccurate pricing of this risk could potentially lead to substantial disruptions.

Our research relies on a dataset of 666 bonds issued by 115 European companies from 2014 to 2022. Using the European Central Bank's yield curve for triple-A rated bonds as the risk-free yield reference, we calculate the monthly yield spread for each individual bond as our dependent variable. This allowed us to assess the associated risk associated with each bond. To gauge the extent of exposure to forward-looking physical risks, we use the Carbon Risk Integration System database provided by Carbon4. This database calculates exposure scores for individual firms, based on IPCC scenarios. The database offers seven separate sub-scores, each designed to address different categories of climate hazards, along with an aggregated overall score.

First, we examine the pricing of forward-looking natural disaster risks in the euro area bond market. Our analysis relies on a panel model, which enables us to account for all conventional factors influencing bond spreads, along with fixed-effects for time, sector, and country. In sum, our results indicate that there has been no significant pricing of forward-looking exposure risks during the examined period. This highlights that the incorporation of physical risk is not a primary concern, as it is not sufficiently reflected

in the pricing dynamics of the euro area bond market, with the exception of exposure to heat waves.

Next, as a follow-up investigation, we examine if occurrences of natural disasters could impact the pricing of companies with substantial future exposure to such events. We compute the cumulative damages over specific prior periods (3 months, 6 months, 1 year) and interact them with exposure costs. Across all climate hazard risks, we notice that there is a pricing reaction for highly exposed firms following a natural disaster event that causes damages. However, it seems that investors tend to have a short-term perspective, as most of the risk pricing diminishes for nearly all types of disasters when considering the cumulative damages over a one-year period.

We conclude that the pricing of physical risk is not adequately implemented in the Eurozone bond market. The increase awareness that emerges in the aftermath of significant events tends to be short-lived. Nevertheless, given the growing frequency of large-scale natural disasters, this mispricing could potentially result in significant destabilization within financial markets in the long run, as necessary adjustments will become more costly.

In summary, this thesis investigates the influence of physical risk on credit conditions, bank lending, and bonds. Nevertheless, climate-related financial risks have not received adequate attention from institutions. We do, however, illustrate that regulations, such as macroprudential measures, could offer assistance, yet the current regulatory landscape remains uncertain. Natural disasters needs to be more carefully considered for more robust and transparent regulation in this regard.

Chapter 1

Chapter 1

Natural Disasters and Financial Stress: Can Macroprudential Regulation Tame Green Swans?

Co-written with Grégory Levieuge & Camélia Turcu

1.1 Introduction

While the adverse real economic effects of climate change are now widely acknowledged, its impact on financial systems remains largely unexplored. However, banks and other financial institutions are particularly exposed to physical risks related to climate change damages. They are especially vulnerable to “green swan events”: these are climate hazards that occur outside the normal range of expected events, with increasing frequency and severity. The financial sector may be strongly affected by these hazards that may rise above traditional economic shocks or financial crises. Recently, the latter have motivated the implementation of macroprudential (MP) measures. Whereas, thus far, these policies have been introduced independently of the growing importance of climate-related financial risks, they may help to cope with them.¹

Against this background, the objective of this paper is to investigate the financial impact of natural disasters (NDs), and to empirically assess the extent to which it might be mitigated by a stringent macroprudential framework.

In line with the literature on financial frictions, market failures and crises, *financial stress* can be

¹To the best of our knowledge macroprudential frameworks had never previously been officially developed to address climate-related financial risks. Initiatives intended to take account for climate risks in finance are very recent. For example, the Network for Greening the Financial System (NGFS), which promotes “*the development of climate risk management in the financial sector*”, was created at the end of 2017.

associated with increasing information asymmetries in lending activity, which is conducive to a rise in agency and risk premiums. Identifying how NDs can theoretically induce financial stress is a pre-requisite for our empirical analysis. Hence, as a first step of our investigation, we highlight different channels through which NDs may generate financial stress: a high probability of negative wealth effects, the deterioration of banks and borrowers' balance sheets, and an increase in credit and sovereign risks. The transmission and amplification of NDs effects through these mechanisms might nonetheless be mitigated by a restrictive macroprudential framework. Indeed, if household debt is brought under control, if banks are highly capitalized, if they have sufficient reserves, and if they are not excessively leveraged, any shock to (collateralized) financial or real assets might be smoother than in a situation in which macroprudential regulation is absent or less binding.

To estimate the financial impact of natural disasters, conditional on the degree of stringency of the national macroprudential framework, we use the local projection (LP) method. Financial stress is proxied by the external finance premium (EFP), i.e., the spread between the bank lending rate and the riskless interest rate, in line with the literature that captures financial stress through interest rate spreads (Bernanke et al., 1999; Gilchrist and Zakrajsek, 2012; Christiano et al., 2014). NDs are gauged by meteorological intensity, with the data being collected from different sources stemming from meteorological stations and satellites. The original dataset that we construct focuses on two types of NDs, storms and floods, which are the two most frequent and damaging climate events.² Storm events are gauged with respect to the maximum wind speed registered in the affected areas. The intensity of flooding is measured by rainfall deviation with respect to the long-term average rainfall in affected areas. These two measures are normalized by the country area and correspond to the first category of ND indicators we build. Furthermore, they are augmented by population density, to consider a (exogenous) factor of exposure: these new indexes are our second indicators of NDs. Overall, these measures of severity are well suited for causal empirical analysis, contrary to damage-based data, which are more prone to endogeneity issues. Finally, our measure of prudential stringency refers to the number of macroprudential instruments that have actually been implemented in each country. This “extensity” measure of stringency is based on the recent integrated Macroprudential Policy (iMaPP) database, which provides comprehensive coverage in terms of macroprudential instruments, countries, and time periods.

Our results, based on a panel of 88 countries over the period 1996-2016, show that storms significantly impact the EFP at the macroeconomic level, especially if the macroprudential framework is lax. According to our estimates, a relatively small country (corresponding to the first quartile of the country size distribution) with a lax macroprudential framework would suffer a rise in domestic EFP of 44 basis points

²Conversely, chronic global risks such as rising sea levels and increasing temperatures have a real and financial impact that is much more gradual over time.

(bps), two years after a Katrina-like hurricane. This tightening of credit conditions persists beyond 3 years, which suggests a large overall impact in the long run. Importantly, this impact has increased over time: when focusing on the second decade of our sample, the estimated hike reaches 219 bps. By contrast, we find that a stringent macroprudential framework prevents the EFP from rising. A small country could even benefit from a decrease in the EFP of approximately 67 bps two years after a category 5 hurricane. One potential explanation is that an initially healthy financial environment fosters favorable financing conditions to replace destroyed capital with more productive capital. Further investigation suggests that this situation prevails only for middle-income countries – which can be assumed to have sufficient absorptive capacity to fully exploit new facilities – and only in the most extreme events – which precisely involve significant capital replacement. On the contrary, credit conditions always worsen in low-income countries, irrespective of the stringency of their macroprudential framework. High-income countries with strict macroprudential policies do not benefit neither from a lower post-storm EFP, possibly because no technological leap is expected. Nonetheless, they have to bear an increasing EFP in the case of a lax macroprudential framework.

Finally, our results regarding the financial effects of flooding are not conclusive. As floods are usually clearly located along rivers and coasts, they are also more foreseeable. Hence, this may induce spontaneous discipline (risk avoidance) and greater insurance coverage, which could render macroprudential measures less crucial.

Through this study we connect two strands of literature that have henceforth been distant from one another: the impact of natural disasters and the benefits of macroprudential policy. On the one hand, there is a rich literature on the impact of NDs on the real sector of the economy³. While the negative economic effects of catastrophes appear to increase over time (Klomp and Valckx, 2014), some structural features such as the level of development and the quality of institutions could act as mitigating factors (Kahn, 2005; Loayza et al., 2012). However, the impact of NDs on the financial sector is much less documented. Basic intuitions and warnings are increasingly disseminated by international institutions and central banks. Nonetheless, we still lack clear-cut quantitative evaluations of the consequences of climate-induced financial shocks, especially at the macroeconomic level. Some studies report that local bank performance deteriorated (Berg and Schrader, 2012; Klomp, 2014; Schuwer et al., 2019) or that a possible durable contraction of credit was registered (Noy, 2009; Horvath, 2021). However, others emphasize the existence of a Schumpeterian creative destruction effect in affected regions, with technological innovation (Miao and Popp, 2014) or with recovery lending⁴ driven by investment opportunities in physical capital (Skidmore and Toya, 2002; Crespo Cuaresma et al., 2008; Cavallo et al., 2013; Klomp, 2017).

³See, e.g., Kalkuhl and Wenz (2020), Mohan et al. (2018), the survey of Botzen et al. (2019) and the meta-analysis of Lazzaroni and Van Bergeijk (2014).

⁴See, e.g., the microeconomic investigation of Cortés and Strahan (2017).

On the other hand, our research addresses the growing literature on the macroeconomic effects of macroprudential policy. The benefits of macroprudential measures are already highlighted by the theoretical literature (Farhi and Werning, 2016; Korinek and Simsek, 2016; Bianchi and Mendoza, 2018), especially in a context of low interest rates. Empirical studies tend to confirm that macroprudential measures reduce risks by cleaning balance-sheets (Vandenbussche et al., 2015; Cerutti et al., 2017; De Jonghe et al., 2020).

Our contribution is manifold with respect to these two branches of the literature. First, we theoretically identify key channels through which an ND can cause financial stress. Second, we propose a quantitative macroeconomic evaluation of the effects of NDs on the external finance premium. Third, to this end, we build two new sets of ND indicators based on physical intensity, hazard and exposure. We do this by exploiting granular information from meteorological stations and satellites. Fourth, to the best of our knowledge, we are the first to regard macroprudential tools as possible mitigating features of climate-induced financial shocks. Fifth, by building a bridge between two hitherto independent research avenues, this paper is the first to address the ability of macroprudential policy to ensure the resilience to shocks that are exogenous, which is always a challenge in economics.⁵

The rest of the paper is organized as follows. Section 2 highlights the different transmission mechanisms through which NDs can generate financial stress and theoretically explains how the macroprudential framework can dampen the financial impact of NDs. Our empirical methodology is described in Section 3. Data are presented in Section 4. The results are reported and discussed in Section 5. Robustness checks are presented in Section 6. Section 7 proposes further extensions of our results, dealing with the most recent period, differences in country development and extreme events. Section 8 concludes.

1.2 The financial impact of natural disasters and the role of macroprudential regulation

The aim of our empirical approach is to assess the overall financial effect of NDs. We do not seek to identify the contribution of any particular transmission channel: as there are multiple channels that vary in importance over time and across countries, it is extremely difficult to assess which channel might dominate. However, it is important to pinpoint, at a more general level, the main mechanisms that could theoretically explain climate-induced financial stress. Having identified these mechanisms at stake, we then explain how prudential regulation, particularly macroprudential policy, can mitigate the financial impact of NDs.

⁵In this vein, Fratzscher et al. (2020) investigate the performance of inflation targeting as shock absorber in response to NDs.

1.2.1 How can natural disasters impact credit conditions?

Referring to the literature on the transmission channels of financial shocks, we highlight five theoretical mechanisms through which a natural disaster can generate financial stress. In practice, it is difficult to disentangle these channels within a multi-country framework at the macroeconomic level, as they may interact and reinforce one another. Nevertheless, it seems important to emphasize the theoretical underpinnings of the macro-financial effects of natural disasters and thus to theoretically justify our empirical relations. They are represented in Figure 1.9.1 in Appendix 1.9.

(1) First, NDs affect land, residential and commercial property values (Stern, 2013; Bernstein et al., 2019). This reduces the collateral that households and firms have to pledge when they apply for bank loans. Furthermore, the shock induced by the ND generates more information asymmetry. This implies higher agency premiums through the financial accelerator mechanism (Bernanke et al., 1999; Mian and Sufi, 2011; Cerqueiro et al., 2016) and possibly triggers a Fisherian debt-deflation mechanism.⁶

(2) Moreover, NDs destroy physical capital (see, e.g. Fankhauser and Tol, 2005). Combined with supply-chain breaks (Carvalho et al., 2020), this induces uncertainty and lower production for firms.⁷ The inherent lower profits are conducive to a reduction in firms' debt service capability. This entails higher credit risk.

(3) By lowering the actual and expected profitability of firms, NDs may cause a decline in equity prices. In addition to the slump in real estate prices, this induces negative wealth effects for households (Campbell and Cocco, 2007; Carroll et al., 2011), which impairs their credit worthiness.

(4) The banking sector may also be highly affected by NDs. First, a drop in stock prices has a negative impact on the value of equity portfolios held by banks. Furthermore, the deterioration of economic activity increases non-performing loans (Klomp, 2014; Dafermos et al., 2018). Moreover, banks may suffer from missing savings and immediate withdrawals of deposits used to replace lost physical assets and finance medical care (Brei et al., 2019). Given a maturity mismatch, this worsens liquidity risk. Last, banks themselves are exposed to an operational risk, as NDs may destroy their offices, equipment and information systems. As a consequence, large-scale NDs may significantly increase the likelihood of bank default (Klomp, 2014). Hence, banks have to bear higher funding costs, which they ultimately pass on to firms' credit conditions, as depicted by the bank capital channel (Levieuge, 2009; Gertler and Karadi, 2011). From this perspective, an ND can be regarded as a loan supply shock, which negatively affects private investment (Hosono et al., 2016) and may impair the recovery of the economy.⁸

⁶This channel may explain the relatively stronger effects of NDs in developing countries, where information asymmetry is initially stronger and credit worthiness lower (McDermott et al., 2013).

⁷Baker et al. (2020) find that higher uncertainty – proxied by NDs – lowers growth. Furthermore, Di Tella (2017) shows that weak balance sheets amplify the effects of the uncertainty shocks, further depressing investment and asset prices in a two-way feedback loop. See Weitzman (2009) for further developments on uncertainty about climate change damages.

⁸More generally, see Chava and Purnanandam (2011) and Amiti and Weinstein (2018) for evidence on the impact of idiosyncratic bank shocks on lending conditions.

(5) Finally, NDs lead to an increase in government spending, dedicated to emergency assistance and financial help, for the reconstruction of public infrastructures, medical services, and the bailout of insolvent banks (Lamperti et al., 2019). Since tax revenue also decreases, public debt increases, as does the risk of sovereign debt default (Melecky and Raddatz, 2014; Klomp, 2017; Lamperti et al., 2019).⁹ Interestingly, the sovereign risk and banks' balance sheet adjustments are strongly linked, through a so-called "diabolic" or "doom loop" (Brunnermeier et al., 2016; Farhi and Tirole, 2018). A deterioration of sovereign creditworthiness reduces the market value of banks' holdings of domestic sovereign debt. This reduces the perceived solvency of domestic banks and increases the perceived risk that banks will have to be bailed out by the government. This further worsens sovereign distress.

These five key transmission channels predict an increase in bank lending rates in the wake of an ND, particularly due to the increases in the agency and risk premiums.¹⁰ Further, we analyze how this increase in financial stress can be mitigated by macroprudential regulation. To do so, we will define and characterize the macroprudential policy framework and then explain how it can limit the deepening of financial instability in case of natural disasters.

1.2.2 Why could macroprudential policy dampen the financial impact of natural disasters?

Macroprudential regulation has developed considerably over recent decades through the implementation of quantitative restrictions on borrowing, such as loan-to-value and debt-to-income caps, and with the development of lender-based tools such as capital, reserve and provisioning requirements and surcharges, limits on credit growth, Pigouvian levies, etc.¹¹ These policy tools are intended to protect economies from market failures and externalities related to the activity of financial intermediaries (De Nicolo et al., 2012). They are therefore expected to mitigate financial stress.¹² This is supported by a growing empirical literature, which shows that macroprudential tools are effective in curbing credit cycles, mitigating asset prices fluctuations, and reducing bank risk.¹³

Overall, stringent macroprudential regulation strengthens the resilience of the financial sector by reinforcing balance sheets, restricting risk-taking, reducing leverage, and limiting foreign currency exposure.

⁹As a result, Cevik and Jalles (2020) find that (especially developing) countries with greater vulnerability to climate change pay a higher interest rate on government bonds. At local level, Painter (2020) also finds that an increase in climate risk is associated with an increase in the issuance costs of municipal bonds.

¹⁰The results in the literature regarding credit volume are rather mixed. Several studies report a contraction of credit (Noy, 2009; Berg and Schrader, 2012). On the contrary, Cortés and Strahan (2017), Schuwer et al. (2019) and Koetter et al. (2020) find evidence of recovery lending, especially by local banks. The latter usually have superior local knowledge, notably by engaging in long-term customer relationships; hence, they have an advantage in screening and monitoring local borrowers, as well as in pricing new loans despite depressed collateral values (see, e.g., Berger et al., 2005; Agarwal and Hauswald, 2010). Moreover, as credit supply may have positive externalities on local house prices, local banks may be more prone to continue lending to an area in which they have a high share of outstanding loans (Favara and Giannetti, 2017).

¹¹See Cerutti et al. (2017) and Alam et al. (2019) for a broad assessment of macroprudential tools.

¹²See, for instance, Farhi and Werning (2016), Korinek and Simsek (2016), and Bianchi and Mendoza (2018) who theoretically demonstrate the efficiency of macroprudential regulation.

¹³See, for example, the evidence provided by Vandebussche et al. (2015), Jiménez et al. (2017), Altunbas et al. (2018), Akinci and Olmstead-Rumsey (2018) and Araujo et al. (2020), who consider different policy instruments and objectives.

In such a context, any shock to (possibly pledged) financial or real assets that is likely to worsen financial frictions may have a higher impact in a country where macroprudential regulation is absent or less stringent. Hence, we can expect that an economy with a sound banking sector is likely to better resist to the financial impacts of natural disasters. Moreover, a stringent macroprudential framework allows central banks to respond counter-cyclically to shocks: otherwise, they might be reluctant to cut policy rates when financial conditions tighten, to preserve the stability of the exchange rate and capital flows. Prudential requirements also make economies less sensitive to capital flows (Bergant et al., 2023), which is salutary in the aftermath of an ND.

Finally, macroprudential regulation might even prompt an easing of credit conditions in the wake of an ND. The short-run recovery, driven by the reconstruction, creates lending opportunities (Cortés and Strahan, 2017; Schuwer et al., 2019; Koetter et al., 2020). In addition, the replacement of destroyed capital by modern and more productive technologies may be beneficial to long-term growth (Siodla, 2015; Hornbeck and Keniston, 2017). However, investing in these new capital and infrastructures is not very risky, as they are not necessarily breakthrough innovations. Hence, this context might result in favourable credit conditions, especially if the financial system is resilient. This is more likely to be the case if the prudential framework is stringent. On the contrary, in the absence of macroprudential measures, an affected economy may suffer from highly deteriorated financial conditions and enter a disaster-related poverty trap (Hallegatte and Dumas, 2009).

Against this background, the next section presents the methodology that we use to examine the impact of NDs on the external finance premium, conditional on the stringency of macroprudential regulation.

1.3 Methodology

We denote $D_{i,t}^d$ the variable representing the intensity of a natural disaster d occurring in a country i at time t . The natural disaster d can be associated, alternatively, either with a storm or a flood. We thus are able to capture different disaster types and their potential heterogeneous effects on financial stability. More specifically, $D_{i,t}^d$ is defined as a continuous variable representing the physical intensity, or exposure, associated with a natural disaster d , with $D_{i,t}^d > 0$ if a disaster d occurs and $D_{i,t}^d = 0$ otherwise. Once we control for the geographical position and size of country i , which can influence the occurrence and geophysical intensity of NDs, $D_{i,t}^d$ can be considered as a treatment (or event) variable, with random assignment. In a panel setting, individual fixed effects may control for geographical characteristics that are correlated with the incidence of natural hazards. We denote by $Y_{i,t}$ the dependent variable for country i at time t . In our analysis, Y will represent the external finance premium (EFP), i.e., the spread between the lending interest rate and the risk-free interest rate (details are provided below). By definition, the

average treatment effect (ATE) of a natural disaster d on the evolution of $Y_{i,t}$ with respect to its pre-shock value, $Y_{i,t-1}$, is

$$\text{ATE} = \mathbb{E}_t \left[\mathbb{E}_t (Y_{i,t} - Y_{i,t-1} | D_{i,t}^d > 0; \Omega_t) - \mathbb{E}_t (Y_{i,t} - Y_{i,t-1} | D_{i,t}^d = 0; \Omega_t) \right] \quad (1.1)$$

with \mathbb{E}_t denoting the mathematical expectation operator upon the global information set available at time t (denoted Ω_t). The estimated ATE at time t is equivalent to $\hat{\beta}$, the estimator of β in the following simple linear model:

$$Y_{i,t} - Y_{i,t-1} = \alpha_i + \beta D_{i,t}^d + \varepsilon_{i,t} \quad (1.2)$$

where α_i are country fixed effects and $\varepsilon_{i,t}$ the residuals. We make the reasonable assumption that residuals are uncorrelated with shocks once geographical features are controlled for through country fixed effects. This corresponds to the conditional independence assumption (CIA): conditional on a set of covariates the potential outcomes are independent of the allocation of the treatment. Moreover, including control variables $Z_{i,t}$ in (1.2) is recommended to improve efficiency.

As a shock can have lasting effects that can differ in intensity over time, it is interesting to assess the ATE at different successive horizons, corresponding to quarters in our case. The ATE of an ND on the evolution of $Y_{i,t}$ can be obtained with impulse responses by comparing the variable from the period before the shock occurred ($t - 1$) to the quarters $t + h$, for $h = 0, 1, 2, \dots, H$, such that:

$$\mathcal{R}(h) = \mathbb{E}_t \left[\mathbb{E}_t (Y_{i,t+h} - Y_{i,t-1} | D_{i,t}^d > 0, Z_{i,t}; \Omega_t) - \mathbb{E}_t (Y_{i,t+h} - Y_{i,t-1} | D_{i,t}^d = 0, Z_{i,t}; \Omega_t) \right] \quad (1.3)$$

In line with Jordà (2005) and Jorda et al. (2013), among others, we use local projections (LPs) to approximate ATEs at different horizons, such that

$$Y_{i,t+h} - Y_{i,t-1} = \alpha_{i,h} + \beta_h D_{i,t}^d + \theta_h Z_{i,t} + \varepsilon_{i,t+h} \quad (1.4)$$

In this configuration, we have $\mathbb{E}_t (Y_{i,t+h} - Y_{i,t-1} | D_{i,t}^d > 0, Z_{i,t}) = \alpha_{i,h} + \beta_h D_{i,t}^d + \mathbb{E}_t (\varepsilon_{i,t+h} | D_{i,t}^d > 0, Z_{i,t})$, and $\mathbb{E}_t (Y_{i,t+h} - Y_{i,t-1} | D_{i,t}^d = 0, Z_{i,t}) = \alpha_{i,h} + \mathbb{E}_t (\varepsilon_{i,t+h} | D_{i,t}^d = 0, Z_{i,t})$. Under the CIA, we note that

$\mathbb{E}_t (\varepsilon_{i,t+h} | D_{i,t}^d > 0, Z_{i,t}) = \mathbb{E}_t (\varepsilon_{i,t+h} | D_{i,t}^d = 0, Z_{i,t}) = 0$. Thus, the ATE of natural disasters on the evolution of Y_i , considering h periods after the beginning of the shock, is given by:

$$\mathcal{R}(h) = \beta_h, \quad \forall h \quad (1.5)$$

Then, we denote by $P_{i,t-1}$ the macroprudential context prevailing in country i at time $t - 1$. $P_{i,t-1}$ is an indicator variable equal to 1 in the case of stringent macroprudential regulation and 0 otherwise.

The definition of stringency is explained in the next section. The impact of a natural disaster on $Y_{i,t+h}$, conditional on the macroprudential environment, is gauged by the following interactive model:

$$Y_{i,t+h} - Y_{i,t-1} = \alpha_{i,h} + \beta_h D_{i,t}^d + \gamma_h [D_{i,t}^d \times P_{i,t-1}] + \omega_h P_{i,t-1} + \theta_h Z_{i,t} + \varepsilon_{i,t+h} \quad (1.6)$$

As before, we note that $\mathbb{E}_t(Y_{i,t+h} - Y_{i,t-1} | D_{i,t}^d = 0, Z_{i,t}) = \alpha_{i,h} + \omega_h \mathbb{E}_t(P_{i,t-1} | D_{i,t}^d = 0, Z_{i,t})$, while $\mathbb{E}_t(Y_{i,t+h} - Y_{i,t-1} | D_{i,t}^d > 0, Z_{i,t}) = \alpha_{i,h} + \beta_h D_{i,t}^d + \gamma_h \mathbb{E}_t(P_{i,t-1} | D_{i,t}^d > 0, Z_{i,t}) D_{i,t}^d + \omega_h \mathbb{E}_t(P_{i,t-1} | D_{i,t}^d > 0, Z_{i,t})$. As macroprudential frameworks are primarily established to deal with macro-financial imbalances, we can reasonably assume that having a stringent macroprudential framework or not is independent of the occurrence of an ND at time t . For instance, the recommendations of the Basel Committee on Banking Supervision have, since the 1980s, been motivated primarily by major financial and banking crisis, never by NDs *per se*. At most, NDs have very recently started to be a concern for macroprudential authorities, which have included climate risks in banking stress tests.¹⁴ albeit without reforming the macroprudential framework. This implies that $\mathbb{E}_t(P_{i,t-1} | D_{i,t}^d > 0, Z_{i,t}) = \mathbb{E}_t(P_{i,t-1} | D_{i,t}^d = 0, Z_{i,t}) = P_{i,t-1}$.¹⁵ Hence, the ATE derived from equation (1.6), designating the impact of natural disasters on Y at quarter h , conditional on the stringency of macroprudential regulation, is equal to:

$$\mathcal{R}_P(h) = \beta_h + \gamma_h P_{i,t-1} \quad (1.7)$$

Finally, we add L lags of the dependent variable and a set of one-year (four-quarter) lagged control variables ($X_{i,t-4}$) capturing macroeconomic and financial characteristics (see the next section for details). In addition, time fixed effects ($\tau_{h,t}$) are introduced to control for common trends. In particular, they should capture the global downward trend in the natural rate of interest (Holston et al., 2017) which has led to a decline in lending rates and a reduction in intermediation margins, especially after 2008. They may also capture the impact of the increasing use of macroprudential measures over time. Moreover, we add forward values of NDs inside the projection horizon to avoid downward bias, following the recommendations of Teulings and Zubanov (2014). We also control for the possible occurrence of banking crises over the horizon of evaluation ($C_{i,t+h-j}$), as they may explain large movements in the external finance premium that would be unrelated to any natural disaster. Hence, the model actually estimated is the

¹⁴For example, the Network of central banks and supervisors for Greening the Financial System (NGFS), which in part seeks to integrate climate-related risks into supervision and financial stability monitoring, was created very recently, in December 2017.

¹⁵To ensure this hypothesis, we will consider as a robustness check only NDs for which the macroprudential regime remains the same up to 3 years after the disaster (see Section 1.6.1).

following:

$$\begin{aligned}
Y_{i,t+h} - Y_{i,t-1} = & \alpha_{i,h} + \beta_h D_{i,t}^d + \gamma_h [D_{i,t}^d \times P_{i,t-1}] + \omega_h P_{i,t-1} + \sum_{l=1}^L \rho_h \Delta Y_{i,t-l} \\
& + \theta_h Z_{i,t-4} + \sum_{j=1}^{h-1} \delta_h D_{i,t+h-j}^d + \sum_{j=1}^{h-1} \eta_h C_{i,t+h-j} + \tau_{h,t} + \varepsilon_{i,t+h},
\end{aligned} \tag{1.8}$$

with robust standard errors clustered at the country level to overcome the potential problem of heteroscedastic and serially correlated standard errors due to the overlapping structure of the residuals.

It is worth highlighting that local projections are relevant for our investigation, particularly in comparison with VAR models that are often used to compute impulse responses. (i) LPs are simple, as they can be estimated by standard regression techniques. (ii) LPs are flexible, in that one singular model is estimated for each projection quarter (contrary to VAR models with a fixed state-space representation). Hence, LPs are especially appropriate to address potential nonlinearities (Jordà, 2005). Such nonlinearities are possible in our case, as there might be a period of adjustment before the shock is translated to the EFP, depending on the velocity of the transmission channels represented in Fig. 1.9.1. (iii) LPs are a parsimonious method for estimation and inference of the dynamics of a treatment effect, contrary to panel VAR models, the high dimensionality of which can make IRFs' estimation prohibitive (Jorda et al., 2013). Additionally, parsimony gives room for conditioning the estimation on a richer set of control variables, which may improve identification. (iv) Finally, by generating projections that are local to each forecast quarter for which the model has been estimated, LPs may be more robust than VAR models, the specification errors of which can accumulate as the projection horizon increases.

1.4 Data

This section describes the data we use to compute our ND indicators, characterize the macroprudential policy framework and capture financial stability and economic activity in general.

1.4.1 Natural disaster data

This subsection presents our two new country-level quarterly indexes of NDs. Note that in this setting, three concomitant elements make a geophysical event an ND: *hazard*, *exposure* and *vulnerability* (Yonson et al., 2018). As defined by the Intergovernmental Panel on Climate Change (IPCC, 2012), *hazard* corresponds to the occurrence of an event with a given magnitude. *Exposure* refers to the structural characteristics of the area in which a hazard occurs (e.g., population, infrastructure). *Vulnerability* concerns the propensity of exposed elements to suffer adverse effects when impacted by hazard events.

The vulnerability component entails an endogeneity dimension when investigating the economic and financial effects of an ND. Indeed, it is often measured through economic or human damages, which are strongly correlated with the economic, financial and social contexts (Noy, 2009; Felbermayr and Groschl, 2014; McDermott et al., 2013). On the contrary, the geophysical characteristics of natural hazards, such as the wind speed or quantity of precipitation, can be considered as exogenous. Hence, measures of geophysical intensity are preferred to damage-based data for causal empirical analysis (Noy, 2009; Cavallo et al., 2013; Felbermayr and Groschl, 2014). Using this perspective, many studies rely either on the binary occurrence of NDs (Klomp, 2014) or on more granular measures of geophysical intensity (Felbermayr and Groschl, 2014; Acevedo et al., 2019). However, relying solely on amplitude to define events as natural disasters is overly restrictive with regard to the three above mentioned components. In particular, it could lead to considering many insignificant climate events, whereas a relevant identification strategy requires somewhat large shocks.

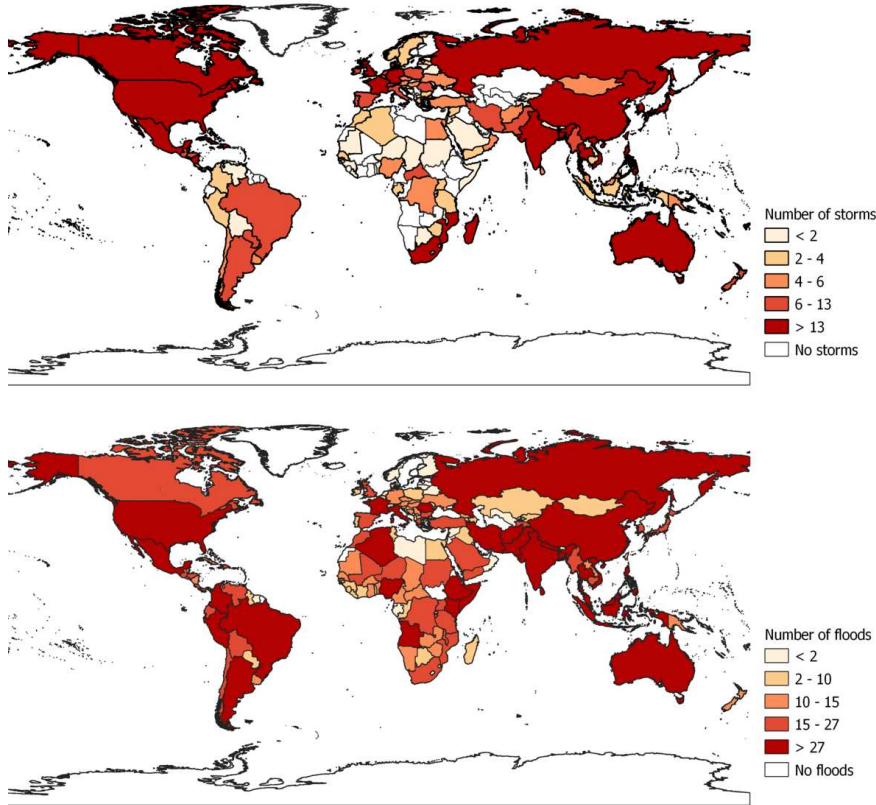
Against this background, we develop and use a new dataset of NDs (i) the types, locations, and dates of which are first identified with the EM-DAT database, (ii) that are gauged by meteorological intensity measures, (iii) which are weighted by potential exposure (country size, population density). Generally, additional information about the data we use and how we combine them is provided in Appendix 1.9.3. Selecting events recorded by EM-DAT as a starting point for our analysis involves considering hazards related to a certain threshold of vulnerability. Moreover, through this approach, we avoid any endogeneity problems, as the geophysical intensity of natural events obviously does not depend on financial conditions, and the identification of events by EM-DAT is not based on the financial consequences of NDs. Hence, we are unlikely to neglect important events that would have few financial effects due to the stringency of the macroprudential framework.¹⁶

Specifically, we focus on the financial impact of storms and floods, which are two of the most frequent and damaging climate events. The measure of their geophysical intensity stems from localized information recorded by satellites and meteorological stations at regional level. A region is defined as the first administrative level area within a country, in line with GADM (version 3.6) maps. While we focus on the geophysical magnitude of the events as in the influential analysis of Felbermayr and Groschl (2014), we extend their setting in several ways: (i) by selecting events first identified in the EM-DAT database, (ii) by adopting a bottom-up approach for assessing the amplitude of floods, with country-level indexes of geophysical intensity built from local measures, (iii) by addressing exogenous exposure (i.e., population density), and thus creating a new index, and (iv) by building quarterly, not annual, indicators. Figure 1.1 depicts the geographical distribution of storms and floods. We observe that all continents and countries

¹⁶In any case, if one were to neglect some events with consequences that would have been mitigated by macroprudential policy, our estimates would underestimate the true effects of macroprudential policy. Overly conservative estimates are preferable to the opposite.

were impacted by at least one disaster over the period 1996-2016.

Figure 1.1: Total number of storms and floods over the period 1996-2016



Note: The legend is determined by the percentiles of the distribution (20th, 40th, 60th, 80th).

We express the geophysical intensity of each storm in terms of wind speed. This information comes from two complementary datasets: the International Best Track Archive for Climate Stewardship (IB-TrACS) provided by the National Climatic Data Center of the National Oceanic and Atmospheric Administration (NOAA), and the Global Surface Summary of Day (GSOD). We select the maximum wind speed recorded by the two datasets within a 5-day window before and after the day of a storm identified in EM-DAT.

The intensity of floods is gauged in terms of rainfall deviation from the long-term average precipitation of the affected areas. First, for any flood event identified by EM-DAT, we compute the total amount of monthly precipitation in the affected area by using the Global Unified Gauge-Based Analysis of Daily Precipitation dataset provided by NOAA Climate Prediction Center (CPC). This dataset gathers weather station rainfall gauge measures and satellite information. Hence, contrary to Felbermayr and Groschl (2014), we compute intensity at a regional level, not a national level: this is done for accuracy purposes, as floods are highly localized. Specifically, as that data are provided in millimeters for 0.5 latitude and longitude degree grid nodes (i.e., over an area of approximately 55m^2), we aggregate precipitation data at

the regional (first administrative) level in each country by using QGIS software and following the GADM maps (version 3.6). Last, we compute the monthly deviation of precipitation from the long-term (i.e., over the years 1990-2016) monthly regional average rainfall.

Finally, we compute quarterly and country-level indicators of geophysical intensity for storms and floods by considering the maximum intensity reported each quarter in all the country's regions, normalized by country area (denoted τ_i , expressed in 1000 km²). This normalization is justified because smaller countries might be more vulnerable if they experience extreme events (Skidmore and Toya, 2002), while larger countries are generally more likely to be affected by natural disasters. Hence, our first measure of hazard, the indicator of geophysical intensity (IGI), is defined as:

$$\text{IGI}_{i,t} = \begin{cases} \frac{\text{geophysical intensity}_{i,t}}{\tau_{i,t}} & \text{if ND occurred in the quarter } t \text{ in country } i. \\ 0 & \text{otherwise.} \end{cases}$$

The worldwide distribution of IGI is represented in Figure 1.9.14 in Appendix 1.9.2.

As a refinement, we construct an additional indicator that consists of augmenting the IGI by a measure of exposure: population density (i.e., This captures the extent to which people might be affected by an ND). This augmented IGI (labeled AIGI) measures the *potential* impact of a natural hazard exogenous to financial stability. It reads as follows:

$$\text{AIGI}_{i,t} = \begin{cases} \frac{\text{geophysical intensity}_{i,t} \times \text{pop. density}_{i,t-1}}{\tau_{i,t}} & \text{if ND occurred in the quarter } t \text{ in country } i, \\ 0 & \text{otherwise,} \end{cases}$$

where population density is rescaled to have the same range as geophysical intensity. Details on how we match population density to the location information provided by EM-DAT are provided in Appendix 1.9.3. Figure 1.9.15 in Appendix 1.9.2 represents the worldwide distribution of AIGI. Comparing it with Figure 1.9.14, we can see that considering the population density may change the measure of NDs' magnitude that countries had to face, on average. For example, India is considered to be affected by shocks of very low intensity, on average, according to IGI. However, given its highly populated areas affected by disasters, India is included in the second percentile of affected countries if the measure of intensity is AIGI.

Table 1.1 combines the descriptive statistics of the geophysical magnitude (IGI and AIGI) with the human and monetary costs reported by EM-DAT. It covers 859 storms and 1,262 floods identified from 1996 to 2016 in our sample of 88 countries, which are listed in Appendix 1.9.7. According to our calculations, storm intensity is equal to 109 km/h on average. Interestingly, some events registered as natural disasters in EM-DAT exhibit low magnitudes: the least severe storm in the sample shows a wind speed of

18km/h. Conversely, the strongest hurricane reaches 300 km/h. The average flood’s deviation for “normal” rainfall is equal to 166.8 mm. Once again, we can see that our sample includes some low-amplitude events. Felbermayr and Groschl (2014) emphasized that EM-DAT sometimes reports substantial damage from low-amplitude events. This entails that our “selection” of NDs has not been very drastic. Turning to our indicators, the mean value of IGI is the same for storms and floods (0.8). In both cases, taking exposure into account, as AIGI does, significantly increases the average value of the indicators (6.8 and 27.5, respectively). Last, we can see that the human and monetary costs of storms reported in EM-DAT are significantly higher than those of floods, although they occur one and a half times less often.

Table 1.1: Our (A)IGI measures and EM-DAT variables: descriptive statistics (1996-2016)

	Our measures					Costs reported in EM-DAT			
	Mean	Sd	Min	Max	Nb ^c	Killed ^d	Affected ^d	Damages ^e	
Storm	Geophysical intensity ^a	109.0	43.8	18.0	305.6				
	<i>IGI</i>	0.8	3.3	0.0	49.4	859	0.0004	0.6392	0.1924
	<i>AIGI</i>	6.8	69.4	0.0	1836.9				
Flood	Geophysical intensity ^b	166.8	174.9	0.2	1541.1				
	<i>IGI</i>	0.8	1.9	0.0	31.5	1262	0.0001	0.5920	0.1109
	<i>AIGI</i>	27.5	250.9	0.0	6769.4				

Note: (a) Expressed in km/h. (b) Expressed in terms of mm of deviation from the regional long-term average rainfall. (c) The total number of events in our sample. (d) The average percentage of killed/affected people over the country’s population affected by ND the year prior to the ND. (e) The average percentage of damages over the nominal GDP of the affected country the year prior to the natural disaster.

1.4.2 Measure of stringency of the macroprudential framework

Our measure of macroprudential stringency is based on the recent integrated Macroprudential Policy (iMaPP) database provided by Alam et al. (2019). By combining information from many sources, this dataset provides comprehensive coverage in terms of macroprudential instruments (17 categories described in Appendix 1.9.4), countries (134 countries), and time spans (from 1990 to 2016). In particular, it delivers information on the tightening, loosening or the lack of change in each macroprudential instrument from quarter to quarter. Nevertheless, the initial value of each instrument and the amplitude of the respective changes are ignored. Moreover, equal weight is attributed to changes in any instrument. As a result, the information delivered cannot be strictly transposed in terms of the stance or intensity of macroprudential policy.

However, we can infer from the iMaPP database the number of instruments that are actually activated in each country. We consider that an instrument is available in a country once it has been changed over the period 1990-2016. Hence, our measure of the stringency of macroprudential frameworks is the cumulative number of macroprudential instruments actually used in each country since 1990. It represents a measure of the *extensity* of the implementation of macroprudential policy (Aizenman et al., 2020): the higher the

number of available instruments is, the stronger the macroprudential requirements.

Countries are differentiated according to whether their macroprudential policy framework is stringent ($P = 1$ in Eq. 1.8) or lax ($P = 0$). At each quarter t , a country i is considered to have a strong (lax) macroprudential framework if it has implemented at least (fewer than) two instruments, which is the median number of instruments implemented over the whole period when considering all the countries in our sample.

Note that we will also study the marginal effects of implementing additional instruments using the number of activated instruments instead of a dummy variable for P . In addition, as robustness checks, the level of macroprudential policy extensity will be replaced by the *prompt corrective action* index provided by Barth et al. (2013). This measures the ability of the regulator to react promptly to shocks. A rigorous prudential framework is supposed to provide more room for maneuvers in the case of shocks.

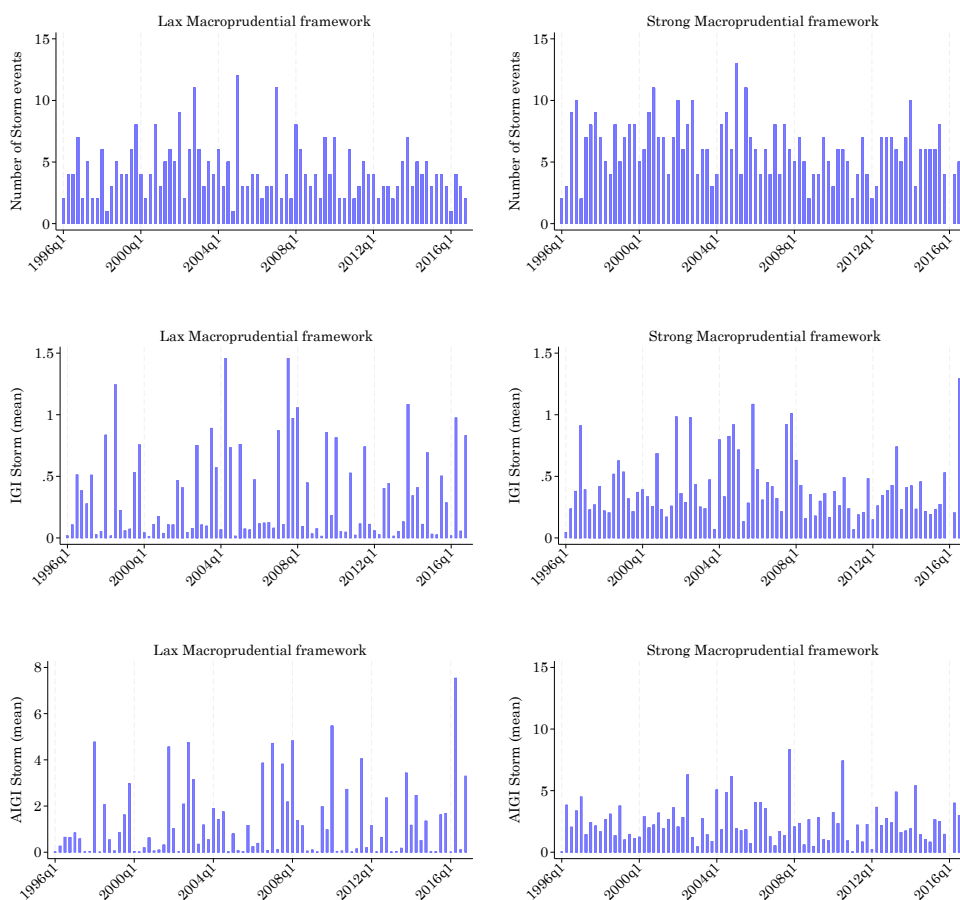
Figures 1.2 and 1.3 report the total number of catastrophes per year, between 1996 and 2016, and the annual mean values of IGI and AIGI for countries with a lax macroprudential framework and those with a strong macroprudential framework. We observe that both groups of countries are equally affected by numerous shocks and are hit by shocks of similar amplitude.¹⁷ Hence, comparison between the two groups is relevant.

1.4.3 Dependent and control variables

As argued in Section 1.2.1, and in line with Figure 1.9.1, our dependent variable is the external finance premium (EFP). It is defined as the difference between the bank lending rate (BLR) and the risk-free interest rate, proxied by the 3-month money market rate. Figure 1.9.16 in Appendix 1.9.2 represents the worldwide average value of the EFP over the period 1996-2016. In light of the geographical breakdown of the NDs shown in Figures 1.9.14 and 1.9.15, countries with a high EFP do not seem to be more prone to disasters than those that exhibit lower EFP on average. Note that the list of countries included in our sample ultimately depends on the availability of the interest rates required to compute this premium. This information is available for 88 countries (see Appendix 1.9.7).

Next, we consider a set of control variables that are likely to explain the EFP. This concerns some traditional the financial characteristics, such as bank concentration and credit-to-GDP ratio. The occurrence of banking crises is also taken into account through a dummy variable, following the events reported by Laeven and Valencia (2020). Moreover, the Chinn-Ito index (KAOPEN) is used to capture the potential effects of financial openness.

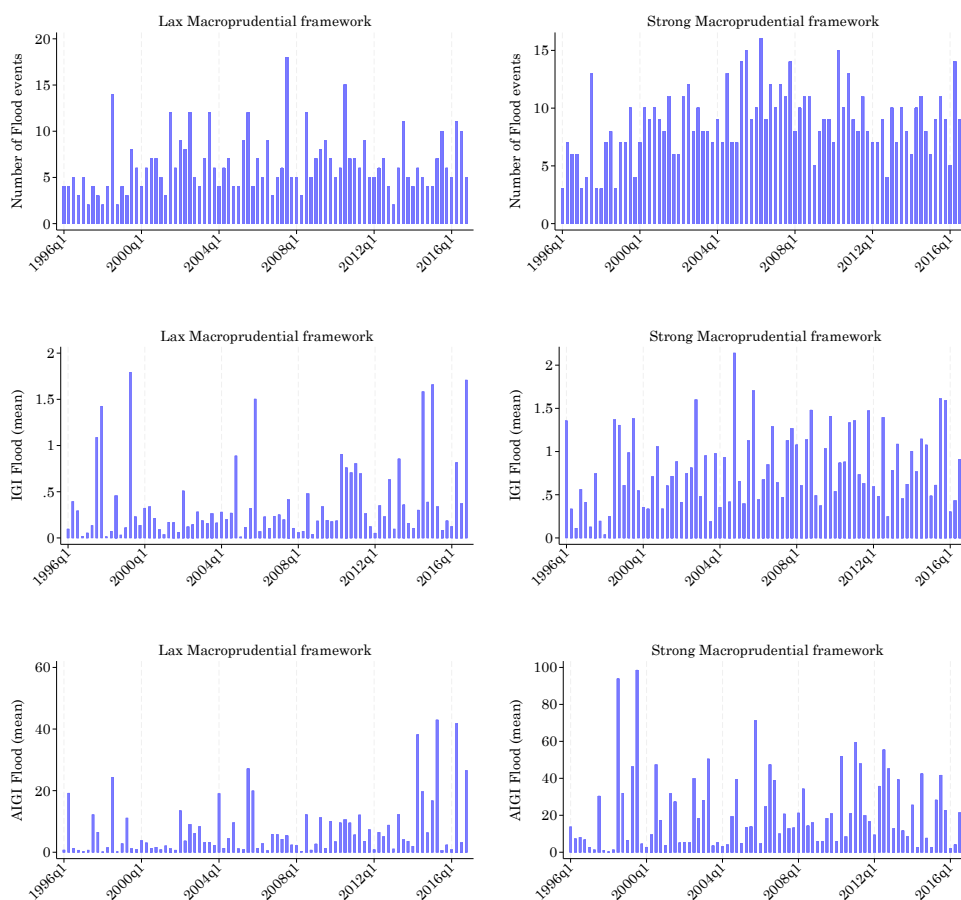
¹⁷The null hypothesis of equal means in the two groups is never rejected except for the IGI flood, which is higher for the strong macroprudential framework group. However, this is not truly an issue in our setting, as we specifically seek to test the ability of macroprudential policies to ensure the financial sector's resilience in the face of NDs that are possibly important.

Figure 1.2: Distribution of storms in countries with lax *vs.* strong macroprudential policies

Note: The x-axis corresponds to the time period in quarters. The left-hand (right-hand) side plots depict lax (strong) macroprudential countries. Plots in the first row represent the number of storms. Plots in the second row refer to the mean IGI-storm. Plots in the third row represent the mean AIGI-storm. The top 1%, or the most intense disasters are excluded from these plots for clarity of representation. These extreme cases are equally distributed between the lax and strong frameworks.

Source: Authors' calculations.

The macroeconomic environment is represented by the annual growth of real GDP and the inflation rate. Furthermore, the level of development is considered, as differences in financial development can induce differences in information asymmetry and, hence, in terms of EFP. It is represented by the logarithm of GDP per capita. Finally, we include institutional quality (POLITY2 score). Details on the definition of data and their sources are available in Appendix 1.9.5. Summary statistics are presented in Appendix 1.9.6.

Figure 1.3: Distribution of floods in countries with lax *vs.* strong macroprudential policies

Note: The x-axis corresponds to the time period in quarters. The left-hand (right-hand) side plots depict lax (strong) macroprudential countries. Plots in the first row represent the number of floods. Plots in the second row refer to the mean IGI-flood. Plots in the third row represent the mean AIGI-flood.

Source: Authors' calculations.

1.5 Results

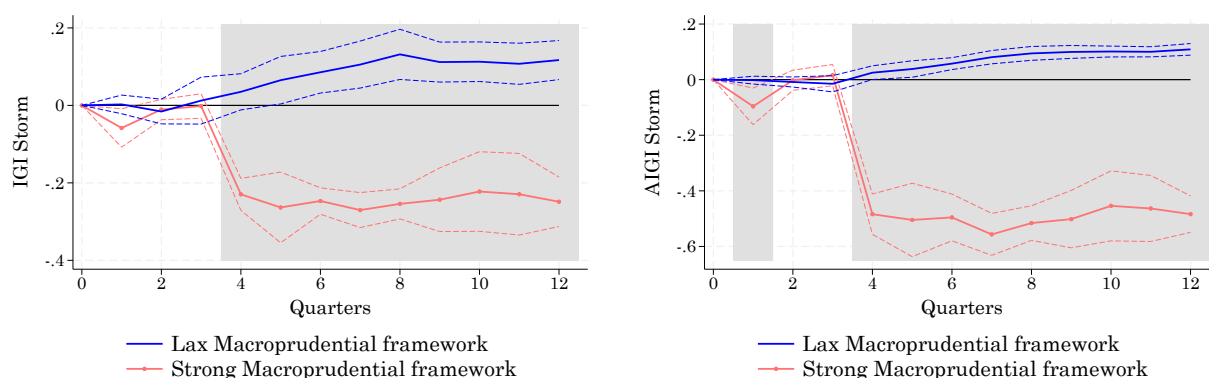
Our empirical investigation is based on a sample of 88 countries over the period 1996-2016, at a quarterly frequency. The impact of NDs on the EFP is gauged by local projections from $h = 1$ to 12 quarters after the initial shock, conditional on the degree of stringency of the macroprudential framework (lax *vs.* strong), following equations (1.7) and (1.8). We first present the results obtained with storms. Then, we show the results obtained for floods. Finally, we assess the marginal effect of implementing additional macroprudential instruments, for the two types of catastrophes.

1.5.1 Storms

Figure 1.4 presents the response of the EFP to a one-standard-deviation shock to IGI (left plot) and AIGI (right plot), according to local projections, from 1 to 12 quarters after a storm. It shows that

this response significantly depends on the stringency of the macroprudential framework. Specifically, we observe that the EFP starts significantly increasing five quarters after the shock to IGI in the case of a lax macroprudential framework (blue line). Credit conditions then continue to tighten for a long time after the storm. The delayed reaction of the EFP, which starts moving after one year, may be the consequence of the time needed to collect information, assess damages and evaluate needs. Moreover, compensation, if any, is not immediate. This obviously influences the timeframe for reconstruction projects and hence for their financing. For example, Berg and Schrader (2012) also find a delay in loan applications for enterprises after NDs.

Figure 1.4: Response of the EFP to storms conditional on the stringency of the macroprudential framework



Note: This figure represents the external finance premium (EFP) response to a one-standard-deviation shock to (A)IGI storms, for a lax *vs.* a strong macroprudential framework, over horizons from 1 to 12 quarters. Dotted lines correspond to confidence bands at 90%. Shaded areas indicate that the interaction term is significantly different from zero at the 5% confidence level.

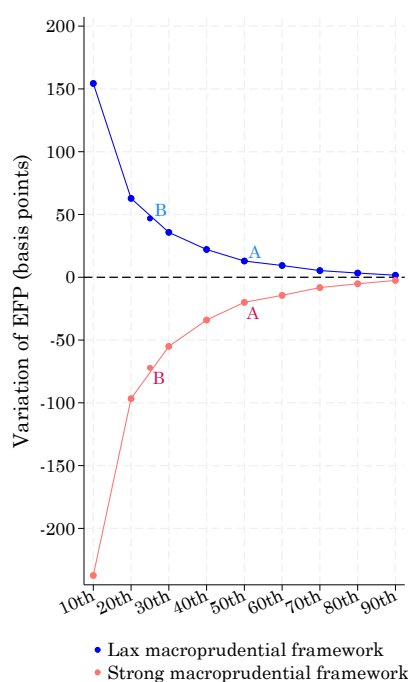
On the contrary, the EFP decreases durably in countries with a strong macroprudential framework (red line). The shaded areas indicate that the difference between the two responses is significantly different. In a strong macroprudential context, a creative destruction process can explain the drop in EFP. Indeed, the destruction of capital stock may provide incentives to re-invest in a more productive capital (Crespo Cuaresma et al., 2008; Leiter et al., 2009; Cavallo et al., 2013; Klomp, 2017; Hornbeck and Keniston, 2017). This creates opportunities for financing productive projects with low risk (past capital has proven its usefulness). Therefore, credit conditions may be eased, especially in the case of strong banking competition. The pattern is the same in the case of a shock to AIGI. Hence, credit conditions tighten following an ND, as found by, e.g., Hosono et al. (2016), but not in those countries that are expected to have a more sound financial system as a consequence of a strong macroprudential framework.¹⁸

To better capture the amplitude of the EFP reaction, we can represent the estimated impact of NDs

¹⁸Figure 1.9.17 in Appendix 1.9.8 shows the response of the EFP irrespective of the stringency of the macroprudential framework. The patterns suggest that it is worth considering interactions with macroprudential regulation to assess the financial effects of NDs.

conditional on the country’s surface area and the density of the population in the affected areas. For illustration purposes, we highlight the response of the EFP two years ($h = 8$) after a storm equivalent to hurricane Katrina. Moreover, we focus on two types of countries: a median-size country called “A” (e.g., the United Kingdom) and a country called “B” corresponding to the first quartile in the distribution of countries’ areas (e.g., Lithuania). According to Figure 1.5, in the case of a lax macroprudential framework, countries A and B would suffer an increase in their EFP of approximately 12.94 and 46.85 basis points, respectively. Conversely, in the case of a strong macroprudential framework, such a storm would entail a 19.91 bps decrease in country A and a 72.08 bps decrease in country B.¹⁹ Although not necessarily dramatic, this magnitude is convincing. In particular, this shows that localized shocks have a clear impact at the macroeconomic level in general (except in the case of the largest countries). Note that this example only considers the impact of a one-shot shock at a specific horizon (2 years after the shock). According to Figure 1.4, the impact of a one-shot shock lasts for more than three years. In addition, other storms may occur in this time period. This implies potentially large effects in the long run.

Figure 1.5: Reaction of the EFP to IGI storms as a function of country area ($h=8$ quarters)

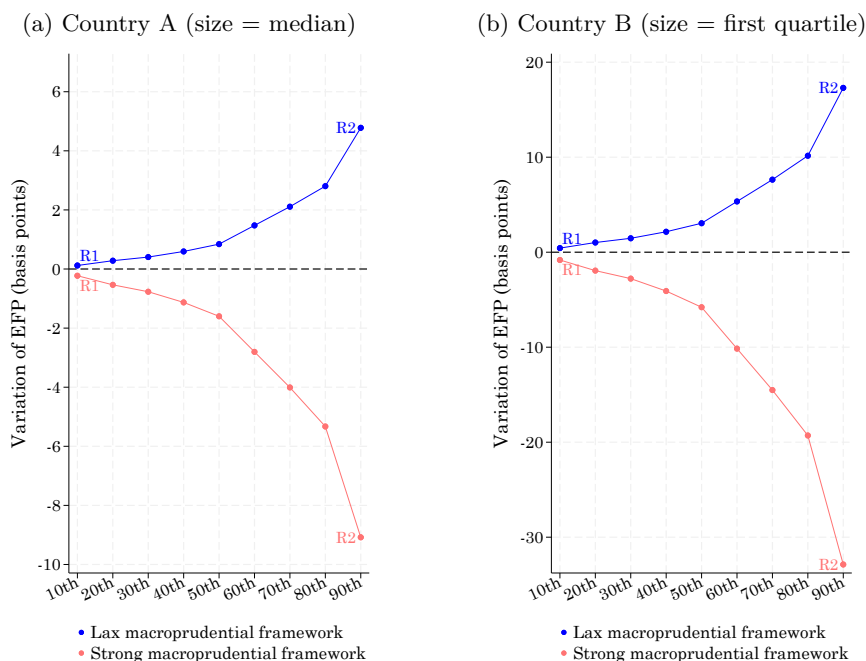


Note: This figure represents the variation in the external finance premium (EFP) two years after a Katrina-like storm, according to the estimates based on IGI, depending on the size of a country and on the stringency of the macroprudential framework. The x-axis represents percentiles of the country’s area. “A” and “B” refer to countries corresponding to the second and first quartiles in the distribution of country areas, respectively.

Next, the AIGI allows us to assess a possible agglomeration effect by evaluating the marginal effect

¹⁹Figure 1.5 represents $\widehat{\mathcal{R}}_{P,IGI}(8) \times \frac{IGI_{t=1}}{\sigma_{IGI}}$ for each percentile of country area (x-axis). $\widehat{\mathcal{R}}_{P,IGI}(h)$ is defined by Eq. (1.7) and estimated following Eq. (1.8). Its estimate is presented in the left plot of Figure 1.4. We focus on its value eight quarter after a shock to IGI . σ_{IGI} denotes the standard deviation of IGI over the period 1996-2016 (equal to 1.18). Following the same approach, Figure 1.6 represents $\widehat{\mathcal{R}}_{P,AIGI}(8) \times \frac{AIGI_{t=1}}{\sigma_{AIGI}}$ for each percentile of population density, with $\sigma_{AIGI}=26.66$.

Figure 1.6: Reaction of the EFP to AIGI storms as a function of the country's area and population density (h=8 quarters)



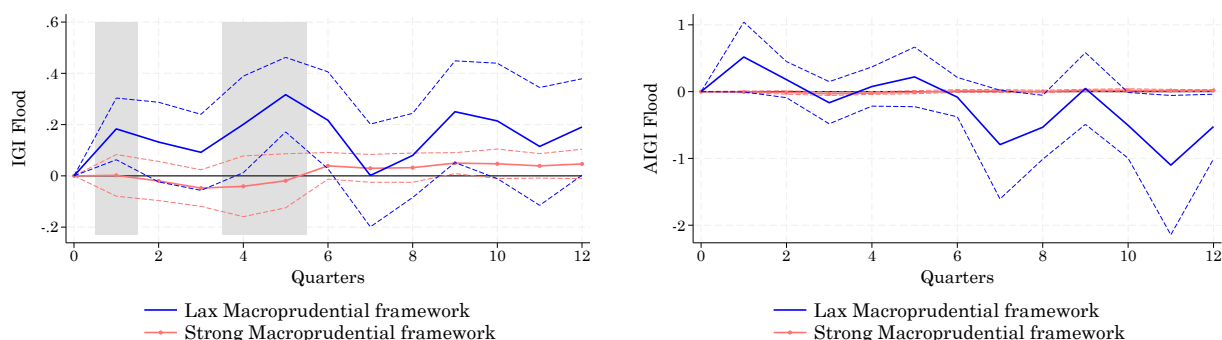
Note: This figure represents the variation in the external finance premium (EFP) two years after a Katrina-like storm, depending on the country's area and population density conditional on the stringency of the macroprudential framework. The x-axis corresponds to the percentiles of population density. The left-hand plot refers to a median-size country ("country A"). The right-hand plot refers to a smaller country, with a size corresponding to the first quartile ("country B"). "R1" and "R2" refer to regions corresponding to the 10th and 90th percentiles of the density distribution, respectively.

of population density in the specific regions impacted by shocks for a given country size. Figure 1.6 provides illustrative insight into the EFP response two years after a Katrina-like shock, depending on whether the latter impacts a more or less populated region. For the sake of the analysis, let us imagine an underpopulated region, corresponding to the 10th percentile of the density distribution, i.e., 15.99 inhab/km² ("region 1", or "R1" Figure 1.6) and a highly populated region, corresponding to the 90th percentile of the density distribution, i.e., 619,77 inhab/km² ("region 2" or R2). In the case of a lax macroprudential framework, the increase in the EFP at the national level of a median-size country (country A) would be 4.23 bps higher if the hurricane occurs in region 2 rather than in region 1. In the smaller country B, the global impact on the EFP would be 16.87 bps larger if the storm affects region 2 rather than region 1. In the case of a stringent macroprudential framework, the EFP would decrease by 8.85 bps more if the storm impacts the highly populated region in country A. This gain would reach 32.07 bps in country B. Although these examples only concern the response at the 8-quarter horizon to a one-shot shock, the main lesson from the AIGI is that population density does not appear to be particularly crucial for the macroeconomic impact of a storm compared to country size.

1.5.2 Floods

Figure 1.7 shows the response of the EFP to a one-standard-deviation shock to IGI (left plot) and AIGI (right panel), following local projections from 1 to 12 quarters after a flood event. According to IGI, flooding seems to significantly raise the EFP if the macroprudential framework is lax (blue line), especially in the short-run (for $h = 1, 4$ and 5 quarters) and for $h = 9$ quarters. In contrast, floods do not affect the EFP in the case of strong macroprudential policy (red line). However, the two conditional effects are not significantly different from one another, except at 3 quarters (see the gray areas for $h = 1, 4, 5$). According to AIGI, the EFP does not respond differently to a strict or to a lax macroprudential framework at any point. Hence, the results for floods are less clear-cut than those for storms.²⁰

Figure 1.7: Response of the EFP to floods conditional on the stringency of the macroprudential framework



Note: This figure represents the external finance premium (EFP) response to a one-standard-deviation shock to (A)IGI-flood for lax *vs.* strong macroprudential frameworks over horizons from 1 to 12 quarters. Dotted lines correspond to confidence bands at 90%. Shaded areas indicate that the interaction term is significantly different from zero at the 5% confidence level.

We conduct further investigations to ensure that our non-statically-significant results concerning floods do not depend on the specific way we measure ND intensity, the database we use, or the type of floods we consider. To do so, first, we recompute our intensity index based on the deviation from the long-term average rainfall of the entire country affected by floods (instead of the region impacted by this ND). Second, we construct our flood-related indexes using an alternative database on rainfall (i.e., from the Global Precipitation Climatology Centre). Third, we differentiate the results according to the flood type (flash flood, riverine flood) identified in line with the EM-DAT classification. The results obtained in the three cases are similar to those from the initial setting: they do not suggest clear-cut conclusions concerning the role of macroprudential policies in mitigating flood effects on financial stability. All these additional results are available upon request.

This apparently insignificant financial impact of floods, even conditional on the extensity of macroprudential policy, has several potential explanations. First, rainfall may not necessarily translate into floods

²⁰Figure 1.9.18 in Appendix 1.9.8 shows the EFP response irrespective of the extensity of macroprudential policy. These results are also not clear-cut. Moreover, given the inconclusive results, we choose not to further present the effects of flooding as a function of the country's area and population density.

at the location where it happens. Second, flood-prone areas are usually easily identifiable (along coasts and rivers). Therefore, it is possible to anticipate a disaster and circumvent its financial impact through greater discipline Noth and Rehbein (2019), including risk abstinence and damage insurance. Garbarino and Guin (2021) show that, consistent with the valuation of the amenity of being close to water, borrowers living near flood prone areas have relatively higher incomes and display lower loan-to-value ratios than borrowers living farther away. Not only do they have below-average credit risk, but they can also afford to take out insurance policies. Third, Faiella and Natoli (2018) provide another possible explanation by showing that lending to nonfinancial firms (especially small and medium enterprises, which are less likely to purchase an insurance policy) is negatively correlated with their flood risk exposure. Hence, banks tend to be less exposed to this type of disaster. Note that, like floods, earthquakes occur in areas that are fairly well aware of the potential for these events. In this respect, Garmaise and Moskowitz (2009) find that the likelihood that a property is financed through bank debt is reduced in earthquake-prone areas, especially when the catastrophic insurance market is poorly developed. Along this line, Bos and Li (2017) show that banks that face strong earthquake experiences reduced their exposure to real estate and were more likely to lend to high-income borrowers.

Overall, this suggests that coping strategies are developed in areas identified as risky (at the microeconomic level). As a consequence, macroprudential policy is less decisive in this context.

1.5.3 Marginal effects of the number of macroprudential instruments

While the analysis thus far has been based on comparing two groups of countries, according to their macroprudential framework extensity (lax *vs.* strong), we now focus on the effect of adding a macroprudential instrument, regardless of the initial number of instruments. To this end, the macroprudential context $P_{i,t-1}$ in Eq. (1.8) now represents the number of instruments in country i at time $t - 1$.

For the sake of parsimony, Table 1.2 only reports the coefficients estimated for the direct effect of a geophysical shock on the EFP (i.e., β_h in Eq 1.6) and its effects when interacting with the number of instruments (i.e., $\gamma_h P_{i,t-1}$) for horizons of 1 to 12 quarters. While a one-standard-deviation increase in IGI-storm triggers an increase in the EFP of approximately 29 bps, on average from 5 to 12 quarters after the shock, the implementation of an additional instrument significantly mitigates this tightening by approximately 20 bps. The interaction term is also significant with AIGI-storm from 5 to 12 quarters after the shock. In this case, having adopted an additional instrument reduces the impact of a one-standard-deviation increase in AIGI by 40 bps on average (against an average increase of 47 bps in the EFP as a direct impact of the AIGI shock).

In contrast, as previously found, the direct effect of IGI floods is rarely significant (except for horizons of 5, 6, 9, and 12 quarters). Moreover, the marginal impact of having one additional macroprudential

instrument (interaction term) is never significant (except for $h = 5$) in the case of flooding.

Table 1.2: Effects of natural disasters conditional on the number of macroprudential instruments

	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12
IGI Storm _t	-0.00 (0.05)	-0.04 (0.05)	0.00 (0.07)	0.11 (0.09)	0.19* (0.10)	0.25*** (0.08)	0.36*** (0.08)	0.37*** (0.08)	0.29*** (0.10)	0.28*** (0.10)	0.27** (0.11)	0.29*** (0.11)
IGI Storm _t × Number of instrument _{t-1}	-0.01 (0.03)	0.02 (0.03)	-0.00 (0.04)	-0.13* (0.07)	-0.18** (0.07)	-0.21*** (0.06)	-0.29*** (0.06)	-0.28*** (0.06)	-0.23*** (0.08)	-0.22** (0.09)	-0.21** (0.10)	-0.23** (0.09)
AIGI Storm _t	0.03 (0.06)	-0.02 (0.04)	-0.07 (0.05)	0.33* (0.17)	0.37** (0.17)	0.43** (0.17)	0.58*** (0.15)	0.55*** (0.15)	0.50** (0.21)	0.45* (0.23)	0.49** (0.20)	0.51*** (0.18)
AIGI Storm _t × Number of instrument _{t-1}	-0.04 (0.06)	0.01 (0.03)	0.05 (0.04)	-0.32* (0.16)	-0.35** (0.16)	-0.39** (0.16)	-0.51*** (0.15)	-0.47*** (0.14)	-0.42** (0.20)	-0.37* (0.21)	-0.41** (0.19)	-0.42** (0.17)
IGI Flood _t	0.09* (0.05)	0.03 (0.05)	-0.03 (0.07)	0.06 (0.08)	0.17** (0.08)	0.15* (0.09)	0.01 (0.09)	0.04 (0.07)	0.18** (0.09)	0.14 (0.10)	0.10 (0.10)	0.14* (0.08)
IGI Flood _t × Number of instrument _{t-1}	-0.02* (0.01)	-0.01 (0.01)	-0.00 (0.02)	-0.02 (0.02)	-0.05*** (0.02)	-0.03 (0.02)	0.00 (0.02)	0.00 (0.02)	-0.03 (0.02)	-0.02 (0.03)	-0.02 (0.03)	-0.03 (0.03)
AIGI Flood _t	0.04 (0.03)	-0.01 (0.04)	-0.05 (0.06)	-0.01 (0.05)	0.05 (0.05)	0.01 (0.07)	-0.05 (0.10)	-0.05 (0.08)	0.02 (0.10)	-0.12 (0.09)	-0.16 (0.16)	-0.12 (0.13)
AIGI Flood _t × Number of instrument _{t-1}	-0.02 (0.02)	0.00 (0.02)	0.01 (0.02)	-0.00 (0.02)	-0.02 (0.02)	0.00 (0.03)	0.03 (0.04)	0.02 (0.04)	0.00 (0.05)	0.07 (0.04)	0.09 (0.07)	0.07 (0.06)

Note: This table represents the direct impact of a one-standard-deviation shock to (A)IGI (storms, floods) and its indirect impacts in interaction with the number of macroprudential instruments. Columns correspond to the horizons h . All regressions include control variables (see Section 1.4.3) as well as time and country FEs. Standard errors in parentheses are corrected for heteroskedasticity and clustered at the country level. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

1.6 Robustness checks

1.6.1 Reverse causality check

As underlined in Section 1.3, our strategy relies on the assumption that the stringency of the macroprudential framework does not depend on the occurrence of NDs. To check that our results do not suffer from reverse causality bias, we re-estimate the impact of NDs on the EFP by excluding cases in which the extensity of the macroprudential framework changed the three years following an ND. This concerns 22 storms and 35 floods in our initial sample.

Figure 1.9.19 in Appendix 1.9.8 shows that when excluding countries, their estimates that changed their extensity group in the wake of a storm are highly similar to the baseline results. Concerning floods, Figure 1.9.20 shows that these results are also not notably impacted, as we still do not find clear-cut significant differences between lax and restrictive countries (only for IGI with $h = 4, 5$).

1.6.2 Robustness to alternative mitigating factors

We test whether the attenuating effects of macroprudential policies are robust to the inclusion of alternative possible mitigating factors. This means that an interaction term $\chi_h(D_{i,t}^d \times X_{i,t-1})$ is included in Equation (1.8), with X designating a possible mitigating factor, in addition to the interaction term representing macroprudential extensity $\gamma_h(D_{i,t}^d \times P_{i,t-1})$.

Several potential shock absorbers are successively considered, following the broad literature on the economic impact of NDs. First, we add an interaction capturing the logarithm of GDP per capita as the level of development may affect the capacity of a country to cope with NDs (Noy, 2009; Felbermayr and Groschl, 2014; Loayza et al., 2012). Next, as the effects of NDs may be alleviated when institutions are strong (Noy, 2009; Acevedo et al., 2019), we include an interaction with variables that account for the quality of institutions: *polity2* and the control of corruption index. We also consider whether countries have an inflation targeting (IT) regime, in line with Fratzscher et al. (2020), who find that this monetary policy arrangement acts as an ND absorber. In this case, X is a dummy variable that is equal to one once a country has adopted IT, zero otherwise. Moreover, in line with Ramcharan (2007), we consider the nature of the exchange rate regime by adding an interaction term based on the *de facto* exchange rate classification provided by Ilzetzki et al. (2017). Additionally, we account for the role of financial development, which can be a determinant of the impact of NDs, as reported by Botzen et al. (2019) in their literature review. Financial development is measured through the financial markets depth (FMD) index provided by the IMF. Finally, we go deeper into the analysis and assess whether the dampening effects of macroprudential policies still hold in the presence of balanced budget rules. By enhancing discipline and credibility, fiscal rules can help to reduce the impact of (financial) shocks (Levieuge et al., 2021). X is a dummy variable equal to one when a country follows a fiscal rule, zero otherwise. Further details on these data are provided in Appendix 1.9.5.

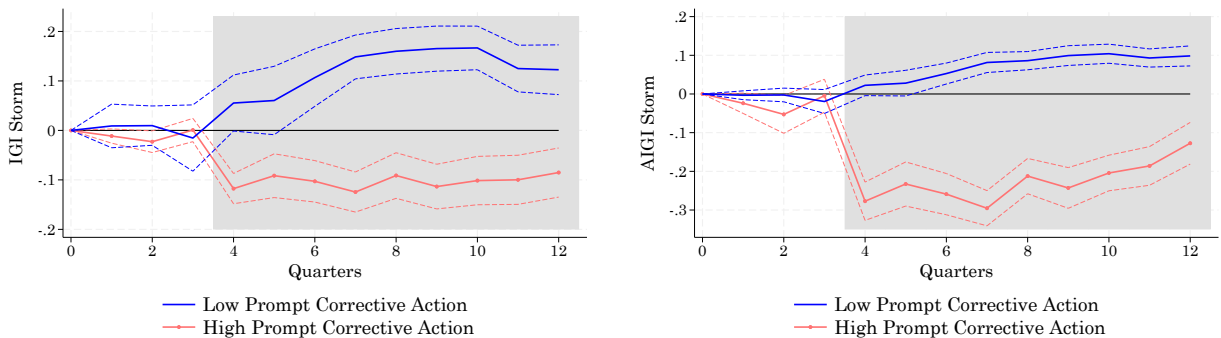
Table 1.9.7 in Appendix 1.9.8 reports the dampening effects of macroprudential extensity, i.e., γ_h , while these potential shock absorbers X are also in interaction with NDs. The impact is reported for horizons of 1, 4, 8, and 12 quarters. The first part of the table addresses IGI, while the second part concerns AIGI for storms. It appears that the attenuating effect of stringer macroprudential framework holds even when we include other potentially mitigating factors, both for IGI and AIGI shocks. The magnitude of the effect does not seem to be affected either, even when all the alternative shock absorbers are simultaneously included in the regression (last row labeled “All”). This means that the beneficial effects of macroprudential policies that we have found thus far in the case of storms are truly due to the properties of this policy *per se*, not to other factors for which our measure of macroprudential stringency might have proxied.

The results for floods are reported in 1.9.8 in Appendix 1.9.8. In the few cases where it is significant (i.e., for $h = 1$), the dampening effect of macroprudential policy is also robust to the inclusion of other mitigating factors.

1.6.3 Impact of *ex-post* prudential action

Macroprudential policies can be viewed as *ex-ante* prudential measures: thus, we now check whether the *ex-post* reaction of the regulator mitigates an NDs' effect on credit conditions. To this end, we consider the *prompt corrective action* index provided by Barth et al. (2013) as a key explanatory variable. This index measures whether supervisors have the requisite and appropriate powers to take automatic enforcement actions based on predetermined levels of bank solvency deterioration. Hence, $P_{i,t} = 1$ for countries that have a high *prompt corrective action* index (PCA), i.e., higher than the median value of PCA in the sample over the full analysis period. Otherwise, $P_{i,t} = 0$ (i.e., low PCA).

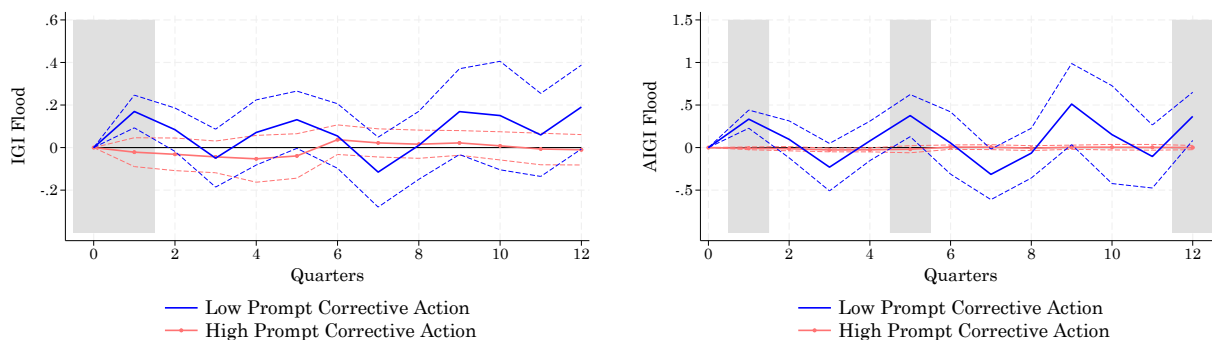
Figure 1.8: Response of the EFP to storms conditional on prompt corrective action



Note: This figure represents the external finance premium (EFP) response to a one-standard-deviation shock to (A)IGI storms for low *vs.* high levels of *prompt corrective action* over horizons from 1 to 12 quarters. Dotted lines correspond to confidence bands at 90%. Shaded areas indicate that the interaction term is significantly different from zero at the 5% confidence level.

Figure 1.8 shows that *ex-post* prudential actions significantly mitigate the impact of storms on the EFP, as it was the case with macroprudential measures (similar amplitude). Figure 1.9 shows that the restrictive effect of flooding on the EFP is immediately reduced by PCA in the quarter following the shock. However, for all other horizons, *ex-post* prudential actions do not alter the financial impacts of floods. This confirms the previous results and interpretations. As flood risk is fairly well identified and anticipated, self-discipline may render prudential requirements (*ex-ante*) and support (*ex-post*) less crucial if the risk occurs. In contrast, the financial impact of storms is sensitive to both *ex-ante* and *ex-post* measures.

Figure 1.9: Response of the EFP to floods conditional on prompt corrective action



Note: This figure represents the external finance premium (EFP) response to a one-standard-deviation shock to (A)IGI floods for low *vs.* high levels of *prompt corrective action* over horizons from 1 to 12 quarters. Dotted lines correspond to confidence bands at 90%. Shaded areas indicate that the interaction term is significantly different from zero at the 5% confidence level.

1.7 Extensions

This section proposes three extensions to further explore the results according to the estimation period, the income level of the countries and the intensity of the events.

1.7.1 Recent period: 2006-2016

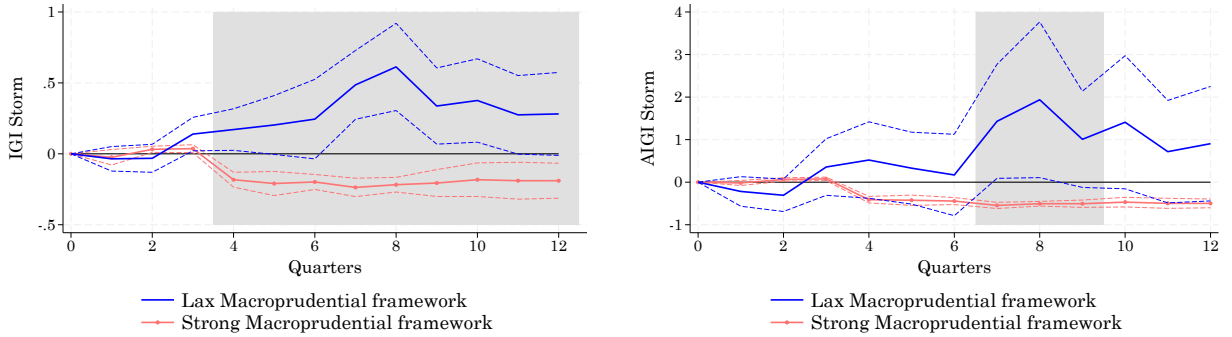
Since macroprudential policy has been designed and used rather recently, and since the intensity and frequency of natural disasters are increasing, it is worth focusing on the most recent period for which data are available, *i.e.*, 2006-2016 (the second decade of our sample).²¹

We note from Figure 1.10 that for IGI-storm the differential effect between the lax and the strong macroprudential frameworks remains significant (after 4 quarters). A similar pattern is found for AIGI-storm, although somewhat less conclusive in the short-run than in the baseline estimates. Importantly, while according to both indicators the extensity of the prudential framework has helped to cope with storm damages, it seems that the financial impact of storms has increased under a lax macroprudential framework in the most recent period. This is shown in Figure 1.11, where we compare the magnitude of the effects of a Katrina-like storm (2 years after the shock) as estimated over the entire period (solid lines) with that estimated over the most recent decade only (dashed lines).

The left-hand side plot of Figure 1.11 concerns IGI-storm. It shows that the rise in the premium in the case of lax policy setting is much higher in the recent period. For example, the surge in premium is nearly 5 times higher for a median-sized country. The difference from the estimate obtained over the full period can reach more than 5 percentage points for a small country belonging to the first decile. In contrast, the sensitivity of the EFP to a storm has not changed over time when the macroprudential regime is

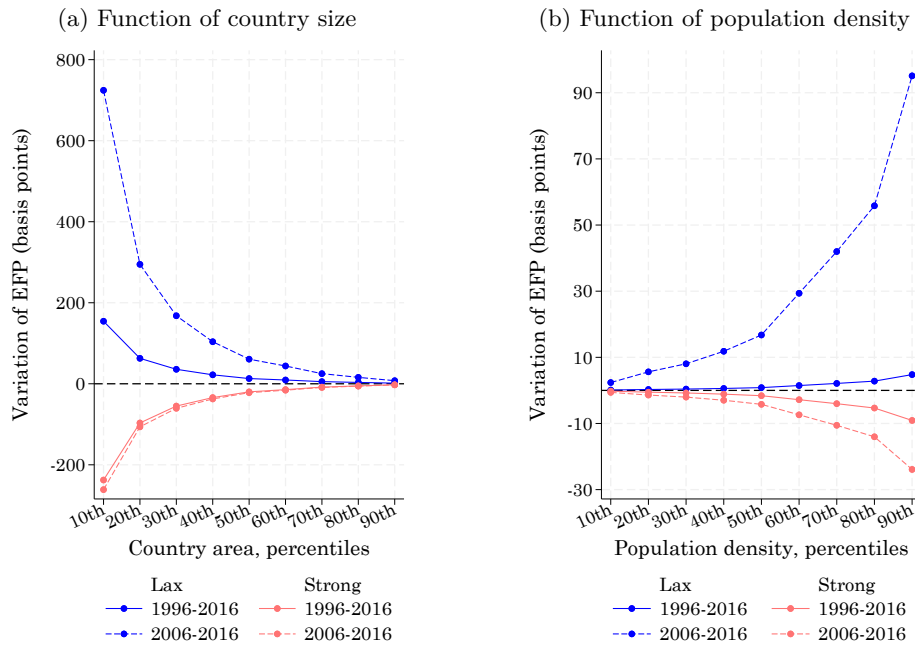
²¹We could also run regressions over the first decade (1996-2006) only for comparison purposes; however, this seems less relevant because macroprudential policy was still in its infancy before the Global Financial Crisis.

Figure 1.10: Response of the EFP to storms - recent period



Note: This figure represents the response of the external finance premium (EFP) to a one-standard-deviation shock to (A)IGI-storm, for a lax *vs.* strong macroprudential framework, over horizons from 1 to 12 quarters. Dotted lines correspond to confidence bands at 90%. Shaded areas indicate that the interaction term is significantly different from zero at the 5% confidence level. Estimation period: 2006-2016.

Figure 1.11: Reaction of the EFP as a function of country area, population density and estimation period (h=8 quarters)



Note: The left-hand side plot represents the variation in the external finance premium (EFP) two years after a Katrina-like storm, according to the estimates based on the IGI, and depending on the size of the country. The x-axis represents the percentiles of country area. The right-hand side plot represents the estimated variation in the EFP based on the AIGI for a median-sized country, and depending on the population density in affected areas. The x-axis represents the percentiles of population density.

stringent. The right-hand side plot represents the impact of a Katrina-like storm on a median-sized country, according to the estimates obtained with the AIGI, and depending on the population density in affected areas. Once again, we observe that the increase in the EFP in lax countries is dramatically higher over the recent period than over the full sample. For example, for a country with a median population density, the estimated rise in EFP over the past decade is almost 19 times larger than the estimated increase found over the full period. On the contrary, the decrease in EFP is not significantly different from that observed in the entire sample.

This growing financial impact of storms can be explained by at least two complementary factors. On the one hand, the absence of a rigorous prudential framework leads to the accumulation of financial imbalances and thus increases the vulnerability of the concerned countries to climate shocks.²² On the other hand, the number of natural disasters is increasing over time. As we have seen, their effects on the EFP may be long-lasting in the case of a lax macroprudential regime. Hence, no sooner have the financial effects of one shock been absorbed than another shock is possible. From this point of view, the absence of a rigorous prudential framework would create a climate vulnerability trap.

Finally, the results obtained for floods over the period 2006-2016 are presented in Figure 1.9.21 in Appendix 1.9.8. It appears that the effects of flooding are not significant overall, regardless of macroprudential policy extensity, similar to the estimates obtained over the entire period.

1.7.2 Heterogeneity by country income

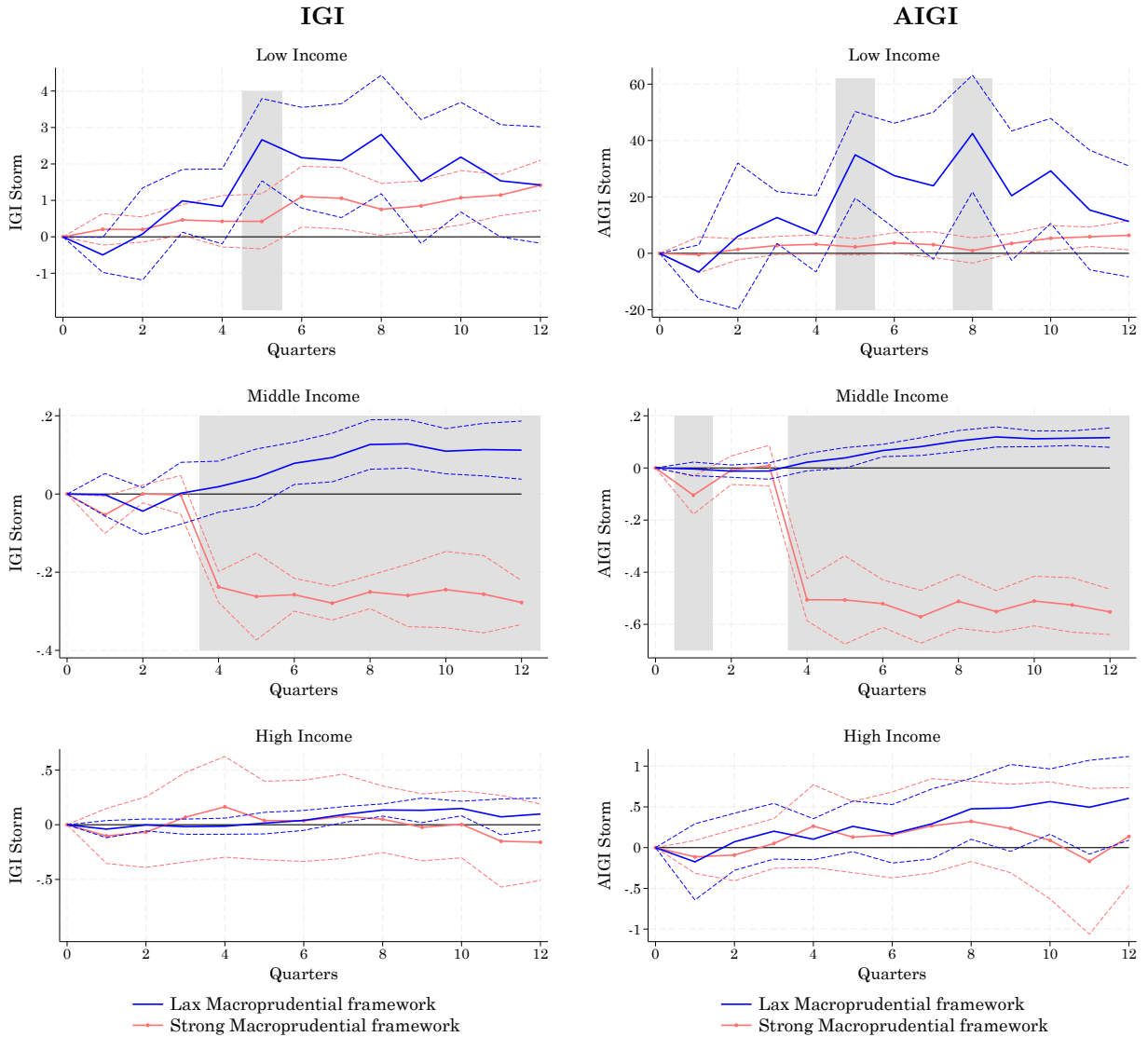
We now assess whether the impact of NDs and the dampening effect of macroprudential policy depend on the level of economic development. To this end, we divide our sample into three groups of countries, following the World Bank classification: low-income (10 countries), middle-income (43) and high-income countries (35).

Figure 1.12 shows that, in the case of lax macroprudential policy, the EFP significantly increases in the wake of a storm in low- and middle-income countries but not in high-income countries. In these most developed countries, the EFP also does not significantly change when the macroprudential framework is stringent. The findings are less clear-cut for low-income countries. On the one hand, the results with IGI suggest that an extensive macroprudential policy does not prevent the premium from rising. On the other hand, the results based on AIGI indicate that a stringent setting ensures that the premium does not increase; in this case, the response of the EFP is sometimes significantly different between the two groups with different macroprudential stringency (for $h = 5, 6, 8, 10$). Finally, only in middle-income countries a strong macroprudential setting significantly does lower the EFP post-storm. Thus, it is mainly

²²For example, between the first and second decades of our sample, total debt to GDP increased by 55 percent on average in countries with a lax macroprudential regime, as opposed to only 9 percent in countries with a strong macroprudential framework.

for these countries that the responses of the EFP differ significantly depending on the extensity of the macroprudential framework.

Figure 1.12: Response of the EFP to storms depending on country income level



Note: This figure represents the response of the external finance premium (EFP) to a one-standard-deviation shock to IGI-storm in the first column of plots and to a one-standard-deviation shock to AIGI-storm in the second column of plots, for a lax *vs.* strong macroprudential framework, over horizons from 1 to 12 quarters, depending on country income level. Dotted lines correspond to confidence bands at 90%. Shaded areas indicate that the interaction term is significantly different from zero at the 5% confidence level.

Therefore, the patterns of local projections represented in Figure 1.12 suggest that the baseline results are driven by middle-income countries. This is perfectly consistent with our interpretation based on the fact that the destruction of capital provides an incentive to reinvest in more productive capital. Specifically, middle-income countries can be presumed to have the required absorption capacity to fully exploit new facilities. This creates opportunities for financing productive replacement projects (Cavallo et al., 2013; Klomp, 2017), which do not involve a high level of risk for lenders. Indeed, if the destroyed

capital must be replaced, it is because it has a proven utility. Moreover, the replacement investment is not necessarily a breakthrough innovation, but maybe already proven equipment. Thus, there is no reason for the premium associated with replacement capital funding to increase. Accordingly, a sound financial system, supported by a rigorous macroprudential framework, is likely to offer favorable financing conditions. Moreover, middle-income countries are the ones that attract large international capital flows (Hannan, 2018). The presence of a strong macroprudential regulation in these countries might (i) make them less exposed to sudden stops (Bergant et al., 2023) following a shock as a ND and (ii) even attract further foreign capitals (Cortés and Strahan, 2017) due to the perspective of higher profit opportunities. Furthermore, as shown previously, the smaller the country and/or the more densely populated the area affected by a disaster is, the more the aggregate financing conditions at the country level are driven by the easing of the EFP for replacement investments. However, possibly because there is no expected technological leap, high-income countries with stringent macroprudential policy do not significantly benefit from a decline in the EFP. Indeed, since the damaged capital might have already been highly productive, the introduction of new (replacement) capital after a disaster may generate few marginal gains. Finally, from this perspective, the failure of macroprudential policy to have a mitigating effect in low-income countries may be the result of insufficient absorptive capacity (Crespo Cuaresma et al., 2008).

Finally, Figure 1.9.22 in Appendix 1.9.8 shows that macroprudential policy extensity does not significantly influence the impact of flooding in any country group. Eventually, an effect of the macroprudential framework may be observed in high-income countries when considering IGI and in middle-income countries if AIGI is used, albeit with too much volatility for this result to be conclusive. Thus, the conditional impact of floods does not seem to depend on the level of development. Dividing the sample does not shed new light on the lack of a macroprudential effect on financial stress following floods.

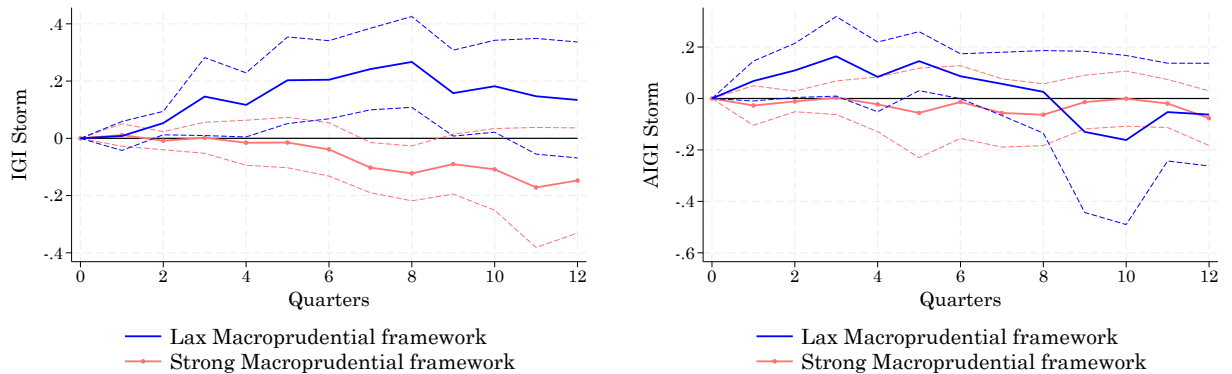
1.7.3 Excluding the most extreme events

According to the empirical literature, creative destruction is possible specifically in the case of extreme events. For instance, Siodla (2015), Hornbeck and Keniston (2017) and Okazaki et al. (2019) document the significant technological and building upgrades occasioned by the reconstructions that followed the 1906 San Francisco earthquake, the 1872 Boston fire, and the 1923 Great Kanto earthquake, respectively.

Against this background, we examine whether our results – particularly the easing of credit conditions – still hold when the 1% strongest storms are excluded from the regressions. This concerns nine events that are reported in Table 1.9.9. The results are represented in Figure 1.13. Interestingly, it appears that in this case, the response of the EFP is not significantly different from zero for both IGI and AIGI when the macroprudential framework is stringent. Hence, an easing of credit conditions cannot be visible any

longer. This suggests that the favorable effect of NDs on financing conditions, due to creative destruction, is limited. Only extreme disasters are likely to result in the reconstruction of infrastructures and physical capital that will be radically more productive than the pre-existing ones. Nevertheless, the results still indicate that the EFP increases significantly in the case of a lax macroprudential policy (albeit slightly less convincingly for AIGI), in line with the baseline results.

Figure 1.13: Response of the EFP to storms - without the 1% strongest storms



Note: This figure represents the response of the external finance premium (EFP) to a one-standard-deviation shock to (A)IGI, for lax *vs.* strong macroprudential framework, over horizons from 1 to 12 quarters while excluding the 1% most intense storms from the initial sample. Dotted lines correspond to confidence bands at 90%. Shaded areas indicate that the interaction term is significantly different from zero at the 5% confidence level.

Thus, financing conditions remain at best unchanged following a storm when the macroprudential framework is rigorous, while they get significantly tightened in case of a lax macroprudential policy.

1.8 Conclusion

In this paper, we empirically investigate the impact of natural disasters on financial conditions, conditional on the degree of stringency of the macroprudential framework. In line with the literature on financial frictions and crises, financial conditions are measured by the external finance premium (EFP). Our investigation is based on local projections for a panel of 88 countries over the period 1996-2016 and relies on original indicators of the geophysical intensity of storms and floods.

Our results show that storms, although affecting only a part of the territory, have a significant macroeconomic impact on financial conditions. More precisely, we find that the EFP durably increases following a storm in countries where the macroprudential framework is lax. For example, a relatively small country (corresponding to the first quartile of the country size distribution) would suffer of an increase in the EFP of 44 basis points (bps), two years after a Katrina-like hurricane. This tightening of credit conditions persists beyond 3 years, which suggests a large impact in the medium-long run. Importantly, this adverse effect is more severe when assessed over the most recent decade, as the estimated hike reaches

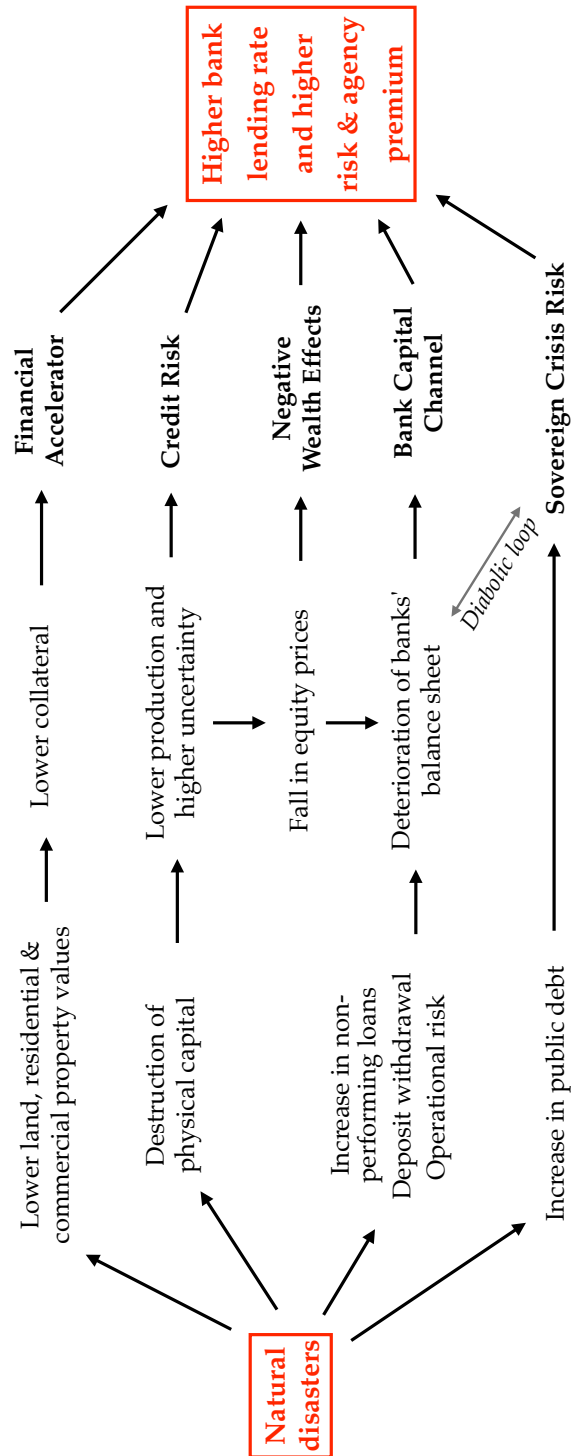
219 bps. In contrast, we find that a stringent macroprudential framework, by improving the resilience of the financial system, prevents the EFP from rising. The baseline results suggest that the EFP could even decrease. A key explanation is that an initially sound financial environment fosters favorable financing conditions to replace destroyed capital with new and more productive capital. However, further investigation shows that this mainly concerns the middle-income countries, which have sufficient absorptive capacity to fully exploit these new facilities (more than low-income countries) and are expected to benefit from a technological leap (more than high-income countries). Moreover, we find that such an easing of credit conditions occurs in the wake of extreme events, which are more likely to induce significant capital replacement. These findings are robust to different econometric specifications and alternative measures of macroprudential regulation.

The results are less conclusive regarding the financial effects of flooding. As they are more geographically isolated (along rivers and coasts), floods are more foreseeable. This may induce spontaneous discipline and greater insurance coverage, as highlighted by some recent studies. Hence, this could render macroprudential measures less crucial. This plausible hypothesis would deserve to be checked with micro-banking and insurance data, as an extension of this study.

Finally, while a strong macroprudential regulation improves countries' ability to better cope with the financial impact of some natural disasters, macroprudential policy by itself cannot directly address climate change related issues. However, by containing the financial impact of green swans, macroprudential regulation can help to save resources that are needed to finance the energy transition. In particular, it might limit major financial shocks that might occur and require a bailout that could overshadow other economic policy objectives, including the objective of transitioning to a low-carbon economy.

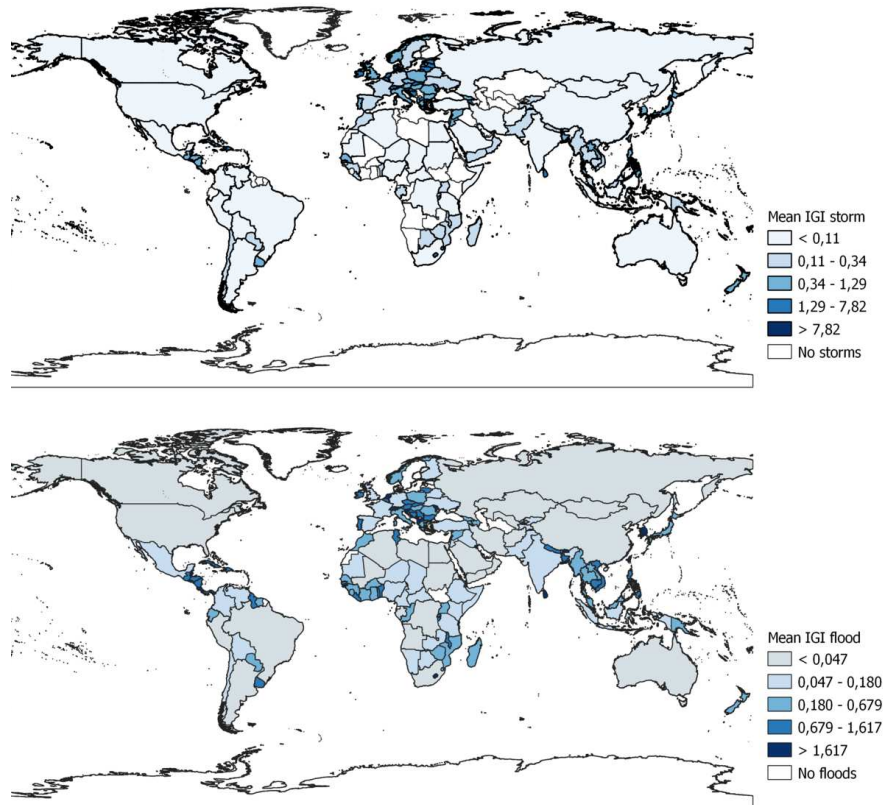
1.9 Appendix

1.9.1 Transmission channels of natural disasters on credit conditions



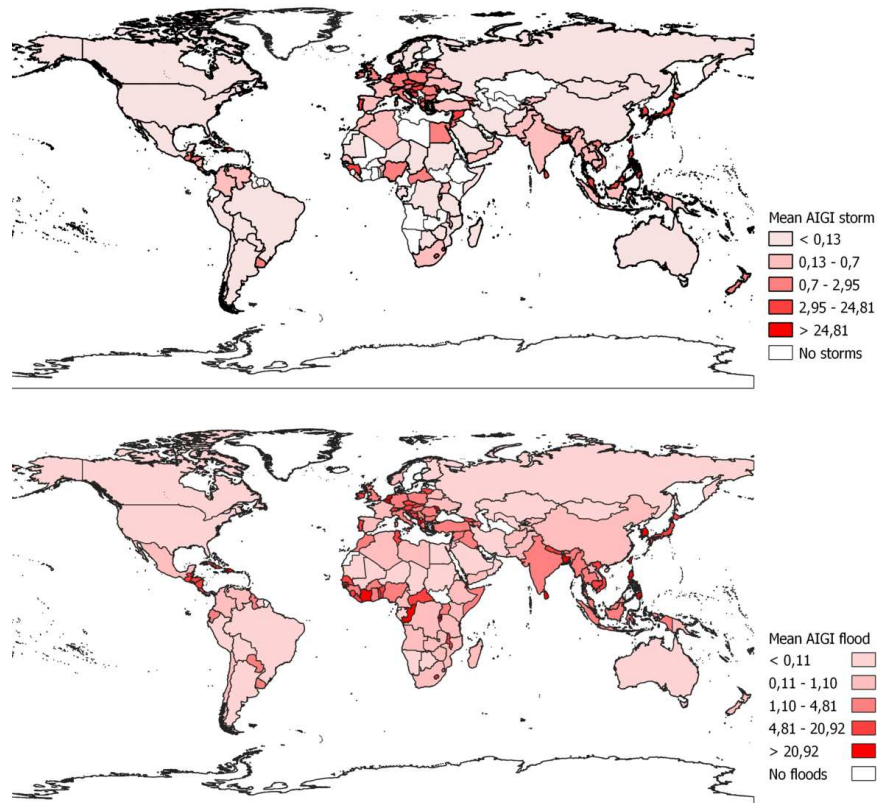
1.9.2 World mean values of IGI, AIGI and EFP over the period 1996-2016

Figure 1.9.14: World mean value of IGI over the period 1996-2016



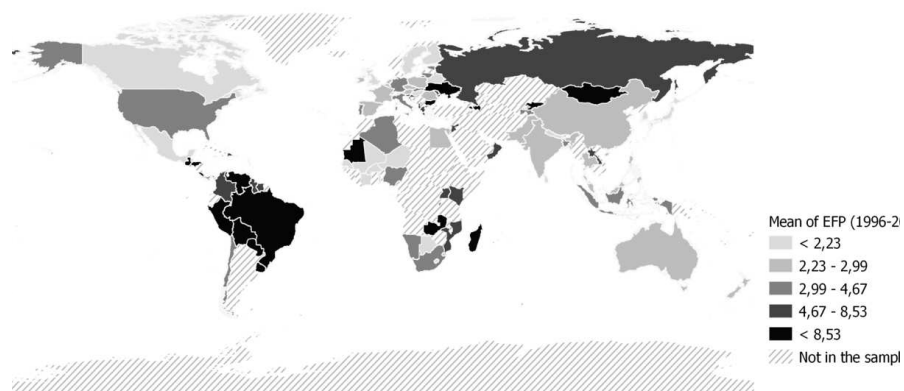
Note: The legend is determined by the percentiles of the distribution (20th, 40th, 60th, 80th).

Figure 1.9.15: World mean value of AIGI over the period 1996-2016



Note: The legend is determined by the percentiles of the distribution (20th, 40th, 60th, 80th).

Figure 1.9.16: World mean value of the EFP over the period 1996-2016



Note: EFP = external finance premium. The legend is determined by the percentiles of the distribution (20th, 40th, 60th, 80th).

1.9.3 Additional information on the database on natural disasters

On EM-DAT The Emergency Disasters Database (EM-DAT) supported by the Centre for Research on the Epidemiology of Disasters (CRED) covers most of the disasters registered at world level. To be considered in the EM-DAT database, a disaster has to fulfil at least one of the following criteria : (1) 10 or more people are reported killed, (2) 100 or more people are reported affected, (3) a declaration of a state of emergency was issued (4) and/or there is a call for international assistance.

Link to EM-DAT data: <https://www.emdat.be/>

On GSOD Global Surface Summary of Day (GSOD) measures the wind speed from over 9000 world-wide stations. GSOD uses daily summaries of hourly observations contained in the Integrated Surface Data (ISD). If information on timing is incomplete with regard to the initial information provided by EM-DAT (e.g., the month and the year are available but the day is missing) we consider the highest value of the wind speed recorded during the relevant month.

Link to GSOD data: <https://www.ncei.noaa.gov>

On the geophysical intensity of floods The geophysical intensity of floods impacting several regions within a country is computed as the maximum of the monthly rainfall deviation among the affected territorial units. Moreover, for events lasting more than one month, intensity is computed as the maximum of the monthly deviations over the duration of the event.

On matching population density with location information Information on the affected regions is based on EM-DAT. Further, we use QGIS software to compute the population density at the first administrative level area. This is done in line with the maps from GADM (version 3.6) and the information from the UN WPP-adjusted population count rasters (Gridded Population of the World - GPW) collection provided by the Center for International Earth Science Information Network (CIESIN). Information is available every 5 years and consists of estimates of human population (number of persons per pixel), consistent with national censuses and population registers with respect to the relative spatial distribution. We hypothesize exponential population growth in between the 5-year database updates.

In general, all the disaster location information in EM-DAT is available at the first administrative level. However, when this is not the case we aggregate data at the first administrative level if they are only available initially at the second administrative or municipal levels. Moreover, if according to EM-DAT, an event spreads over a large area that includes several regions defined at the first administrative level, we associate the available information to each of these regions. For example, all the following regions are supposed to be concerned by an event affecting “North Portugal”: Viana Do Castelo, Braga, Porto,

Vila Real, and Braganca. Finally, if initial information related to the location of the disaster is available only at country level and not at regional level in EM-DAT, we construct the measure of exposure by considering the mean of population density within the country.

Link to GADM maps: <https://gadm.org/>

Link to UN WPP-adjusted population count rasters: <https://sedac.ciesin.columbia.edu>

1.9.4 Integrated Macroprudential Policy (iMaPP) Database - details

Table 1.9.3: Macroprudential instruments in iMaPP dataset: definitions

Instrument	Definition
CCB	A requirement for banks to maintain a countercyclical capital buffer. Implementations at 0% are not considered as a tightening in dummy-type indicators.
Conservation	Requirements for banks to maintain a capital conservation buffer, including the one established under Basel III.
Capital	Capital requirements for banks, which include risk weights, systemic risk buffers, and minimum capital requirements. Countercyclical capital buffers and capital conservation buffers are captured in their sheets respectively and thus not included here. Subcategories of capital measures are also provided, classifying them into household sector targeted (HH), corporate sector targeted (Corp), broad-based (Gen), and FX-loan targeted (FX) measures.
LVR	A limit on leverage of banks, calculated by dividing a measure of capital by the bank's non-risk-weighted exposures (e.g., Basel III leverage ratio).
LLP	Loan loss provision requirements for macroprudential purposes, which include dynamic provisioning and sectoral provisions (e.g. housing loans).
LCG	Limits on growth or the volume of aggregate credit, the household-sector credit, or the corporate-sector credit by banks, and penalties for high credit growth. Subcategories of limits to credit growth are also provided, classifying them into household sector targeted (HH), corporate sector targeted (Corp), and broad-based (Gen) measures.
LoanR	Loan restrictions that are more tailored than those captured in "LCG". They include loan limits and prohibitions, which may be conditioned on loan characteristics (e.g., the maturity, the size, the LTV ratio and the type of interest rate of loans), bank characteristics (e.g., mortgage banks), and other factors. Subcategories of loan restrictions are also provided, classifying them into household sector targeted (HH), and corporate sector targeted (Corp) measures. Restrictions on foreign currency lending are captured in "LFC".
LFC	Limits on foreign currency (FC) lending, and rules or recommendations on FC loans.
LTV	Limits to the loan-to-value ratios, including those mostly targeted at housing loans, but also includes those targeted at automobile loans, and commercial real estate loans.
DSTI	Limits to the debt-service-to-income ratio and the loan-to-income ratio, which restrict the size of debt services or debt relative to income. They include those targeted at housing loans, consumer loans, and commercial real estate loans.
Tax	Taxes and levies applied to specified transactions, assets, or liabilities, which include stamp duties, and capital gain taxes.
Liquidity	Measures taken to mitigate systemic liquidity and funding risks, including minimum requirements for liquidity coverage ratios, liquid asset ratios, net stable funding ratios, core funding ratios and external debt restrictions that do not distinguish currencies.
LTD	Limits to the loan-to-deposit (LTD) ratio and penalties for high LTD ratios.
LFX	Limits on net or gross open foreign exchange (FX) positions, limits on FX exposures and FX funding, and currency mismatch regulations.
RR	Reserve requirements (domestic or foreign currency) for macroprudential purposes. Please note that this category may currently include those for monetary policy as distinguishing those for macroprudential or monetary policy purposes is often not clear-cut. A subcategory of reserve requirements is provided for those differentiated by currency (FCD), as they are typically used for macroprudential purposes.
SIFI	Measures taken to mitigate risks from global and domestic systemically important financial institutions (SIFIs), which include capital and liquidity surcharges.
Other	Macroprudential measures not captured in the above categories—e.g., stress testing, restrictions on profit distribution, and structural measures (e.g., limits on exposures between financial institutions).

Source: Alam, Z., Alter, M. A., Eiseman, J., Gelos, M. R., Kang, M. H., Narita, M. M., ... & Wang, N. (2019). Digging deeper—Evidence on the effects of macroprudential policies from a new database. International Monetary Fund.

1.9.5 Our variables: further details

- **External finance premium.** Difference between the bank lending rate (all maturities) and the 3-month money market rate. The discount rate or the policy rate is considered if the 3-month money market rate data are not available. Source: IMF - IFS.
- **Extensivity of macroprudential framework.** Number of macroprudential instruments that have been activated in a country. Source: Alam et al. (2019).
- **Prompt corrective action** A discrete variable measuring whether a law establishes predetermined levels of bank solvency deterioration that force automatic actions, such as government interventions. It ranges from 0 to 6, with a higher value indicating more promptness in responding to problems. The database contains five surveys (1999, 2003, 2007, 2011 and 2019). To conserve the panel structure of our data, we consider time span according to the description of the authors. The first survey for the years 1990-2000, the second survey for the years 2001-2003, the third survey for the years 2004-2007, the fourth survey for years 2008-2011 and the fifth survey for the years 2012-2016. Source: Barth et al. (2013).
- **Banking concentration.** Assets of the three largest commercial banks as a share of total commercial banking assets. Total assets include total earning assets, cash and due from banks, foreclosed real estate, fixed assets, goodwill, other intangibles, current tax assets, deferred tax assets, discontinued operations and other assets. Source: World Bank - Global Financial Development.
- **Credit-to-GDP ratio.** Ratio of bank loans to the private sector on GDP at current prices. When necessary, a linear interpolation was implemented to have a GDP at quarterly frequency. Source: IFM-IFS (line 22d, FOSAOP), World Bank - World Development Indicators.
- **Annual growth of real GDP.** Growth of real GDP (in constant US\$). Source: World Bank - World Development Indicators.
- **GDP per capita.** Logarithmic transformation of GDP per capita (in constant US\$). Source: World Bank - World Development Indicators.
- **Inflation.** Index computed as the growth of Consumer Price Index (CPI). Source: IMF - International Financial Statistics.
- **The Chinn-Ito index.** Index measuring a country's degree of capital account openness. Source: Chinn and Ito (2006).
- **Polity2.** The Polity2 score ranges from +10 (strongly democratic) to -10 (strongly autocratic). Source: Polity5 Project, Political Regime Characteristics and Transitions, 1800-2018.
- **Banking Crisis.** Dummy variable equal to 1 when a country is in a situation of financial crisis at time t and 0 otherwise. Source: Laeven and Valencia (2020).
- **Control of corruption** Perceptions of the extent to which public power is exercised for private gains, including petty and grand forms of corruption. The indicator lies between -2.5 and 2.5. Source: World Bank - Worldwide Governance Indicators.

- **Inflation targeting.** Dummy variable equal to 1 once a country has adopted inflation targeting (0 otherwise). Source: Roger (2009); Schmidt-Hebbel and Carrasco (2016); Adler et al. (2021).
- **FX regime.** De facto exchange rate arrangement classification, set from 1 (fixed) to 6 (more flexible). Source: Ilzetzki et al. (2017).
- **Financial markets depth index.** Composite index that compiles data on stock market capitalization to GDP, stocks traded to GDP, international debt securities of government to GDP, and total debt securities of financial and non-financial corporations to GDP. Source: IMF - Financial Development Index Database.
- **Budget Balance Rule.** Dummy variable that is equal to 1 if fiscal policy operates under a budget balance rule in a country i at time t (0 otherwise). Source: Lledó et al. (2017).

1.9.6 Descriptive statistics

Table 1.9.4: Summary statistics

Variable	Mean	Std. Dev.	Min.	Max.	N
Change in spread ($h=1$)	-0.06	3.43	-55.17	59.58	5433
Change in spread ($h=6$)	-0.08	4.5	-54.43	61.54	4986
Change in spread ($h=12$)	-0.19	4.76	-52.73	57.57	4461
IGI Storm	0.09	1.18	0	49.36	5526
AIGI Storm	0.88	26.65	0	1836.88	5526
IGI Flood	0.14	0.87	0	31.55	5526
AIGI Flood	5.22	96.06	0	6769.45	5526
Number of instruments (dummy)	0.61	0.49	0	1	5526
Prompt corrective action (dummy)	0.55	0.5	0	1	4745
Banking concentration	66.09	18.63	20.19	100	5494
Credit-to-GDP ratio (%)	51.98	42.12	2.13	267.64	5484
GDP growth (%)	0.91	0.94	-4.17	8.62	5526
Logarithm of GDP per capita	8.80	1.44	5.39	11.11	5526
Inflation	1.22	2.02	-12.99	28.21	5522
Chinn-Ito index	0.83	1.52	-1.92	2.35	5526
Polity2	5.93	5.39	-9	10	5526
Banking crisis	0.07	0.26	0	1	5526
Control of corruption	0.15	1	-1.5	2.46	4927
Inflation targeting (dummy)	0.24	0.43	0	1	5526
Exchange rate regime	2.07	1.04	1	6	5524
Financial markets depth	0.31	0.3	0	0.99	5526
Budget balance rule in place (dummy)	1	0	1	1	2377

Table 1.9.5: Cross-correlation table

Variables	Change in spread ($h=6$)	Logarithm of GDP p.c.	Polity2	Banking concentration	Credit- to-GDP	Chinn-Ito index	Inflation	GDP growth
Change in spread ($h=6$)	1.000							
Logarithm of GDP p.c.	-0.004	1.000						
Polity2	-0.045	0.397	1.000					
Banking concentration	0.034	-0.079	-0.157	1.000				
Credit-to-GDP	0.076	-0.023	-0.121	0.051	1.000			
Chinn-Ito index	-0.009	0.604	0.299	0.020	-0.074	1.000		
Inflation	0.025	-0.097	-0.061	0.018	0.186	-0.129	1.000	
GDP growth	-0.043	-0.250	-0.180	0.029	0.034	-0.154	-0.027	1.000

1.9.7 Country list

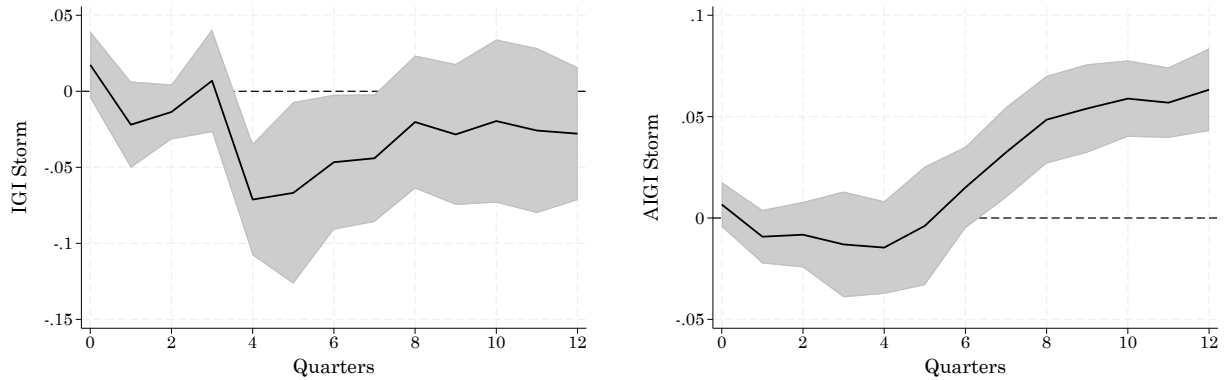
Table 1.9.6: List of Countries

Countries		
<i>Albania</i>	(Guatemala)	Nigeria
<i>Algeria</i>	(Guyana)	Oman
Armenia	Honduras	Pakistan
Australia	Hungary	(Panama)
Austria	India	Paraguay
<i>Azerbaijan</i>	Indonesia	Peru
Bahrain	Ireland	Philippines
Bangladesh	Italy	Poland
Belarus	<i>Jamaica</i>	Portugal
Belgium	Japan	Romania
(Bolivia)	Jordan	Russia
Botswana	Kenya	Senegal
Brazil	Korea	Singapore
Bulgaria	Kuwait	Slovak Republic
Burkina Faso	Kyrgyz Republic	Slovenia
Burundi	Laos	South Africa
Canada	Lebanon	Spain
Chile	Lesotho	Sri Lanka
<i>China</i>	Lithuania	(Suriname)
Colombia	(Madagascar)	Sweden
Coasta Rica	Malaysia	Tajikistan
Ivory Coast	Mali	Thailand
Croatia	<i>Mauritania</i>	Togo
Cyprus	Mauritius	Trinidad & Tobago
Czech Republic	Mexico	Uganda
<i>Dominican Republic</i>	Moldova	<i>Ukraine</i>
(Egypt)	<i>Mongolia</i>	United Kingdom
Estonia	<i>Mozambique</i>	United States
Finland	(Namibia)	Uruguay
France	<i>Nepal</i>	(Venezuela)
Gambia	Netherlands	<i>Zambia</i>
Germany	New Zealand	
Greece	Niger	

Countries in italics correspond to those that are considered in the baseline estimates but not in the robustness estimates with the “prompt corrective action” measure as interactive variable. Countries in brackets are those that are considered in these robustness estimates, but not in the baseline estimates. The sample size is governed by data availability concerning EFP. We keep in our sample countries for which we have at least 50% of consecutive observations over the period 1996-2016.

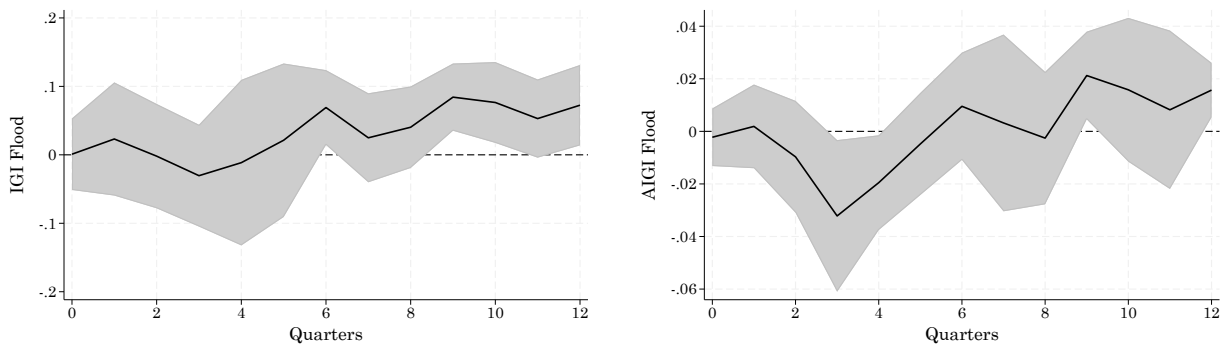
1.9.8 Additional results and robustness checks

Figure 1.9.17: Response of the EFP to storms (no interaction with macroprudential framework)



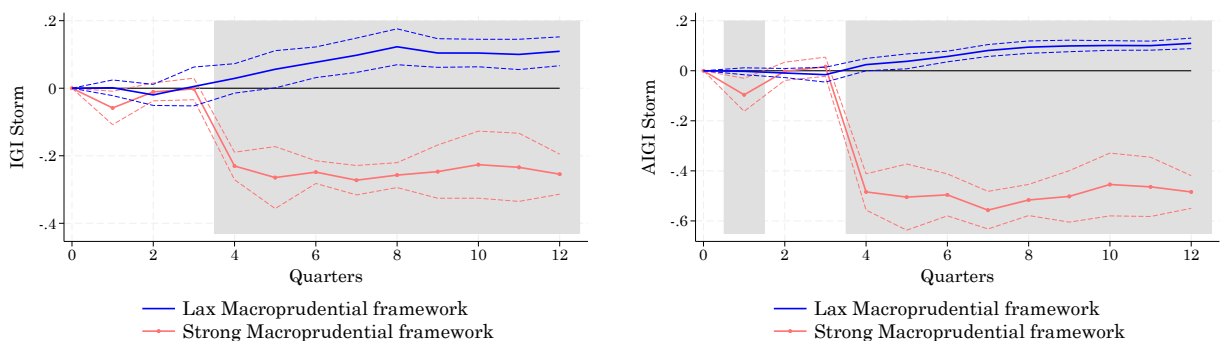
Note: This figure represents the response of the external finance premium (EFP) to a one-standard-deviation shock to (A)IGI-storm, over horizons from 1 to 12 quarters. Shaded areas correspond to confidence bands at 90%.

Figure 1.9.18: Response of the EFP to floods (no interaction with macroprudential framework)



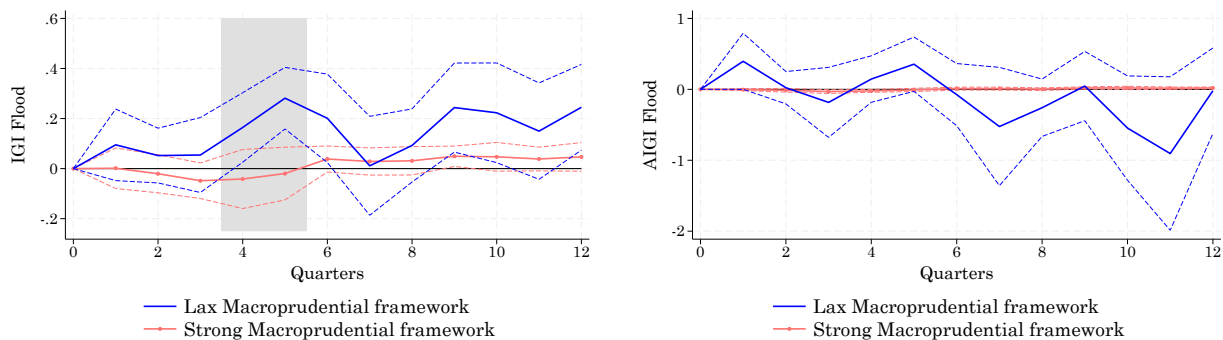
Note: This figure represents the response of the external finance premium (EFP) to a one-standard-deviation shock to (A)IGI-flood, over horizons from 1 to 12 quarters. Shaded areas correspond to confidence bands at 90%.

Figure 1.9.19: Response of the EFP to storms - reverse causality checks



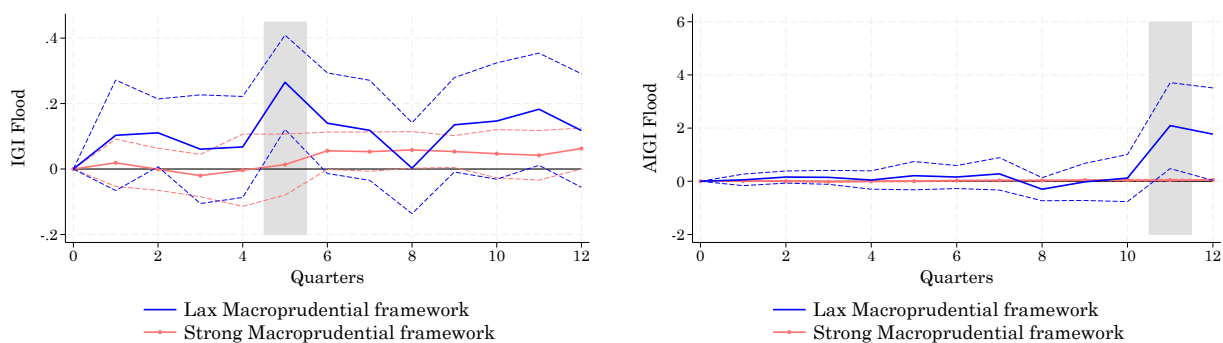
Note: This figure represents the response of the external finance premium (EFP) to a one-standard-deviation shock to (A)IGI, for lax *vs.* strong macroprudential framework, over horizons from 1 to 12 quarters. Dotted lines correspond to confidence bands at 90%. Shaded areas indicate that the interaction term is significantly different from zero at the 5% confidence level.

Figure 1.9.20: Response of the EFP to floods - reverse causality checks



Note: This figure represents the response of the external finance premium (EFP) to a one-standard-deviation shock to (A)IGI, for lax *vs.* strong macroprudential framework, over horizons from 1 to 12 quarters. Dotted lines correspond to confidence bands at 90%. Shaded areas indicate that the interaction term is significantly different from zero at the 5% confidence level.

Figure 1.9.21: Response of the EFP to floods - recent period



Note: This figure represents the response of the external finance premium (EFP) to a one-standard-deviation shock to (A)IGI-flood, for a lax *vs.* strong macroprudential framework, over horizons from 1 to 12 quarters. Dotted lines correspond to confidence bands at 90%. Shaded areas indicate that the interaction term is significantly different from zero at the 5% confidence level. Estimation period: 2006-2016.

Table 1.9.7: Storms: The effects of macroprudential policies while adding other shock absorbers

IGI Storm	Quarter 1	Quarter 4	Quarter 8	Quarter 12
Baseline	-0.06* (0.03)	-0.26*** (0.03)	-0.39*** (0.04)	-0.36*** (0.04)
GDP per capita	-0.06* (0.04)	-0.26*** (0.03)	-0.39*** (0.04)	-0.36*** (0.04)
Polity2	-0.06* (0.03)	-0.28*** (0.03)	-0.40*** (0.05)	-0.38*** (0.04)
Control of corruption	-0.07** (0.03)	-0.28*** (0.04)	-0.39*** (0.05)	-0.39*** (0.04)
Inflation targeting	-0.06* (0.03)	-0.26*** (0.03)	-0.38*** (0.04)	-0.36*** (0.04)
FX regime	-0.06* (0.04)	-0.26*** (0.03)	-0.38*** (0.04)	-0.38*** (0.04)
Financial markets depth	-0.03 (0.03)	-0.26*** (0.04)	-0.40*** (0.05)	-0.37*** (0.04)
Budget balance rule	-0.05* (0.03)	-0.26*** (0.04)	-0.38*** (0.04)	-0.35*** (0.04)
All	-0.01 (0.09)	-0.26*** (0.08)	-0.40*** (0.08)	-0.45*** (0.10)
AIGI Storm	Quarter 1	Quarter 4	Quarter 8	Quarter 12
Baseline	-0.09** (0.04)	-0.51*** (0.05)	-0.61*** (0.05)	-0.59*** (0.04)
GDP per capita	-0.05 (0.07)	-0.54*** (0.06)	-0.65*** (0.06)	-0.63*** (0.09)
Polity2	-0.12** (0.06)	-0.54*** (0.04)	-0.60*** (0.05)	-0.58*** (0.05)
Control of corruption	-0.11*** (0.04)	-0.50*** (0.05)	-0.58*** (0.05)	-0.57*** (0.05)
Inflation targeting	-0.09** (0.04)	-0.51*** (0.05)	-0.61*** (0.05)	-0.60*** (0.04)
FX regime	-0.09** (0.04)	-0.51*** (0.05)	-0.60*** (0.05)	-0.58*** (0.04)
Financial markets depth	-0.02 (0.07)	-0.54*** (0.09)	-0.77*** (0.08)	-0.77*** (0.11)
Budget balance rule	-0.09** (0.04)	-0.51*** (0.04)	-0.61*** (0.05)	-0.58*** (0.05)
All	0.11 (0.17)	-0.34* (0.19)	-0.59*** (0.16)	-0.80*** (0.22)
Number of observations	5436	5166	4813	4465

Note: This table reports the estimated value of the interaction term of the geophysical intensity of storms (A)IGI and the dummy variable that represents the stringency of macroprudential framework when adding other potential mitigating factors in interaction with (A)IGI. These other shock absorbers are labelled in the first column. The dependent variable is the external finance premium (EFP). All regressions include control variables (see Section 1.4.3) as well as time and country FEs. Standard errors in parentheses are corrected for heteroskedasticity and clustered at the country level. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 1.9.8: Floods: The effects of macroprudential policies while adding other shock absorbers

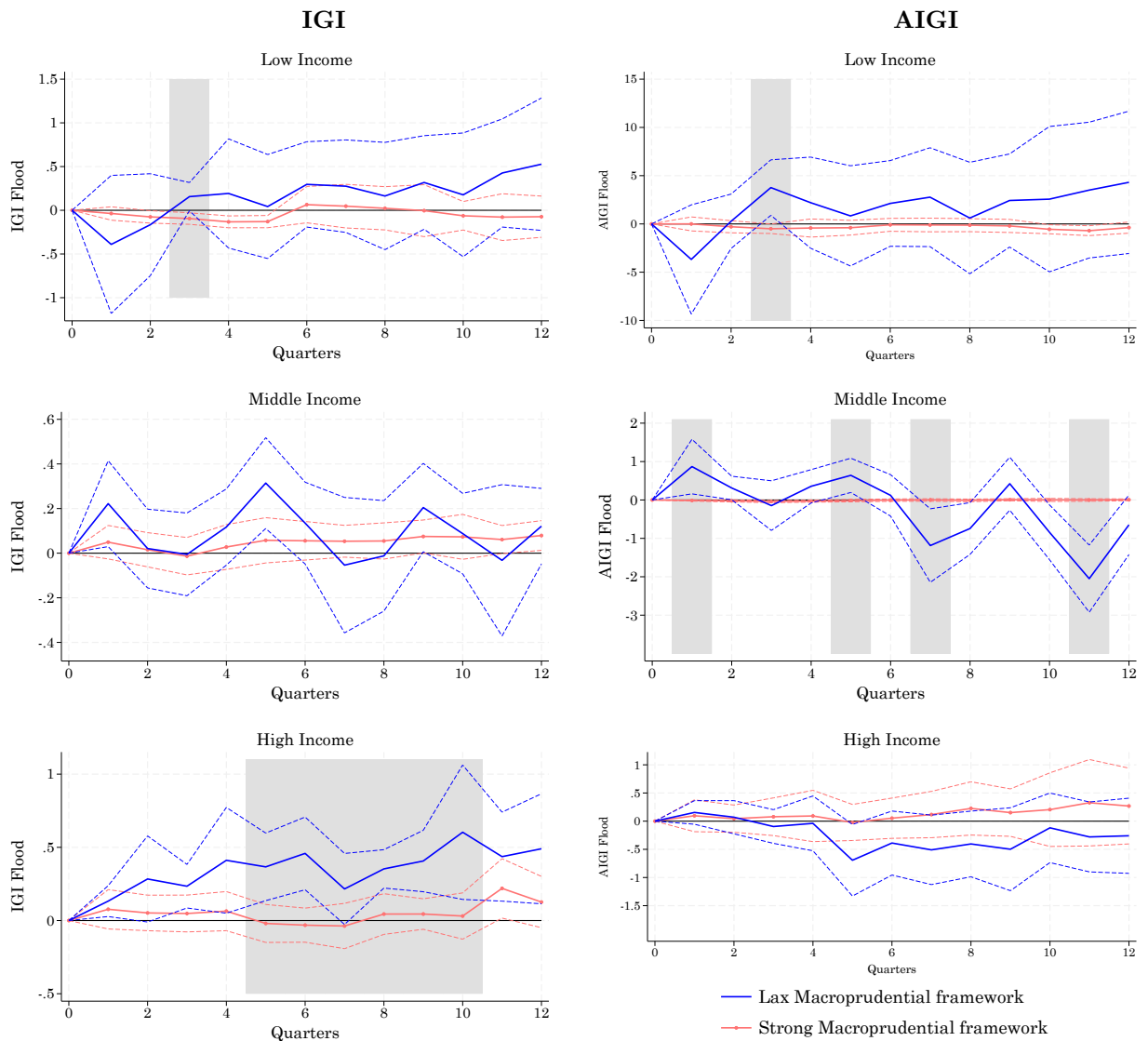
IGI Flood	Quarter 1	Quarter 4	Quarter 8	Quarter 12
Baseline	-0.22** (0.09)	-0.29** (0.14)	-0.10 (0.10)	-0.18 (0.12)
GDP per capita	-0.20** (0.08)	-0.26** (0.12)	-0.10 (0.09)	-0.18 (0.12)
Polity2	-0.19** (0.09)	-0.25* (0.13)	-0.13 (0.10)	-0.21 (0.13)
Control of corruption	-0.22*** (0.08)	-0.29*** (0.10)	-0.13 (0.08)	-0.19* (0.11)
Inflation targeting	-0.24*** (0.09)	-0.32** (0.15)	-0.12 (0.12)	-0.20 (0.14)
FX regime	-0.18** (0.09)	-0.21 (0.14)	-0.09 (0.11)	-0.16 (0.12)
Financial markets depth	-0.21** (0.09)	-0.27** (0.11)	-0.09 (0.09)	-0.16 (0.11)
Budget balance rule	-0.21** (0.09)	-0.27** (0.11)	-0.09 (0.09)	-0.16 (0.11)
All	-0.21** (0.09)	-0.29** (0.14)	-0.15 (0.11)	-0.20 (0.14)
AIGI Flood	Quarter 1	Quarter 4	Quarter 8	Quarter 12
Baseline	-0.68* (0.37)	-0.27 (0.29)	0.36 (0.31)	0.42 (0.34)
Log GDP per capita	-0.68* (0.37)	-0.30 (0.32)	0.32 (0.28)	0.47 (0.36)
Polity2	-0.72* (0.36)	-0.36 (0.31)	0.23 (0.29)	0.36 (0.33)
Control of corruption	-0.67* (0.37)	-0.32 (0.32)	0.32 (0.28)	0.48 (0.35)
Inflation targeting	-0.75** (0.34)	-0.36 (0.31)	0.29 (0.37)	0.35 (0.38)
FX regime	-0.80*** (0.29)	-0.52** (0.23)	0.13 (0.42)	0.06 (0.44)
Financial markets depth	-0.69* (0.36)	-0.21 (0.30)	0.37 (0.33)	0.35 (0.35)
Budget Balance Rule	-0.61 (0.37)	-0.19 (0.29)	0.47 (0.31)	0.54 (0.33)
All	-0.92*** (0.25)	-0.53 (0.32)	-0.17 (0.53)	0.01 (0.65)
Number of observations	5436	5166	4813	4465

Note: The table reports the estimated value of the interaction term of the geophysical intensity of floods (A)IGI and the dummy variable that represents the stringency of macroprudential framework when adding other potential mitigating factors in interaction with (A)IGI. These other shock absorbers are labelled in the first column. The dependent variable is the external finance premium (EFP). All regressions include control variables (see Section 1.4.3) as well as time and country FEs. Standard errors in parentheses are corrected for heteroskedasticity and clustered at the country level. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 1.9.9: List of excluded storms

IGI				AIGI			
Country	Date	Value	MP framework	Country	Date	Value	MP framework
Jamaica	2008 Q3	9.33	Strong	Jamaica	2012 Q4	53.69	Strong
Jamaica	2012 Q4	10.05	Strong	Trinidad & Tobago	2004 Q3	51.49	Lax
Trinidad & Tobago	2004 Q3	10.10	Lax	Lebanon	2002 Q4	49.06	Strong
Trinidad & Tobago	2005 Q3	11.62	Lax	Lebanon	2015 Q1	69.82	Strong
Cyprus	2004 Q1	12.63	Lax	Philippines	2002 Q2	100.23	Strong
Mauritius	1996 Q4	40.86	Lax	Mauritius	1996 Q4	479.55	Lax
Mauritius	1999 Q1	41.04	Lax	Mauritius	1999 Q1	479.42	Lax
Mauritius	2002 Q1	48.45	Lax	Mauritius	2002 Q1	1836.88	Lax
Mauritius	2007 Q1	49.36	Strong	Mauritius	2007 Q1	535.36	Strong

Figure 1.9.22: Response of the EFP to floods depending on country income level



Note: This figure represents the response of the external finance premium (EFP) to a one-standard-deviation shock to IGI-flood in the first column of plots and to a one-standard-deviation shock to AIGI-flood in the second column of plots, for lax *vs.* strong macroprudential framework, over horizons from 1 to 12 quarters, depending on country income level. Dotted lines correspond to confidence bands at 90%. Shaded areas indicate that the interaction term is significantly different from zero at the 5% confidence level.

Chapter 2

Chapter 2

Typhoons in China: Do bankers want their umbrellas back when it rains?

Co-written with Grégory Levieuge & Camélia Turcu

2.1 Introduction

The increased frequency and severity of natural disasters (NDs) in the wake of global warming are largely acknowledged (Hoepe, 2016; Botzen et al., 2019), and their impact on the real side of the economy is rather well-documented (Noy, 2009; Crespo Cuaresma et al., 2008; Schumacher and Strobl, 2011; Cavallo et al., 2013; McDermott et al., 2013). A significant strand of the literature agrees that this impact is particularly important in emerging and developing countries. However, the financial dimension of physical risks has been less studied, whereas financial institutions, and banks in particular, have a crucial role to play in providing post-disaster recovery lending and, more generally, in financing the development of these economies. Depending on whether they support the recovery or, on the contrary, are reluctant to lend following an unexpected shock, especially as their own solvency may be negatively affected (Noth and Schüwer, 2023; Gramlich et al., 2023), banks can mitigate or amplify the impact of natural disasters (NDs).

In this context, this paper aims to empirically study, using micro-banking data, the impact of NDs on the banking sector in China, a leading emerging economy that is highly exposed to NDs. We put a particular focus on the bank-related impact of physical risks, as the reaction of banks may be ambivalent.

On the one hand, by destroying capital and wealth, NDs cause a worsening of information asymmetries.¹ According to the financial accelerator and the bank capital channel, less-diversified banks and/or banks having clients with initially large informational asymmetries are likely to tighten credit conditions and ration credit.² In this case, banks would act as shock transmitters. On the other hand, banks having a strong local anchor through relationship lending would be willing to provide recovery lending. Indeed, a good knowledge of local firms, markets, and risks – including climate risks³ – gives advantages in screening and monitoring projects. In such a context, banks would act as shock absorbers.

From this perspective, analyzing the reaction of the Chinese banking sector to NDs is interesting in several respects. First, this provides new evidence concerning an emerging country that plays a key role in the world economy: it has the largest share of the world GDP (over 18% in 2022) and has been, since 2011, the world's undisputed top exporter. Second, the banking sector plays a crucial role in China's economy. For example, domestic credit to the private sector as a percentage of Gross Regional Product (GRP) increased by about 80% from 2008 to 2020 (source: World Bank WDI, 2021). Third, as the Chinese banking sector has been liberalized recently⁴, banks may not have yet developed avoidance strategies against NDs. Moreover, the insurance market remains underdeveloped: insurance claims have historically accounted for less than 1% of direct economic losses in major large-scale disasters in China (Ye and Mu, 2020). Therefore, the banking sector plays a crucial role in facilitating post-natural disaster recovery, rendering it an intriguing field for analysis. Last, the structure of the Chinese banking sector is original, in that it contains different types of banks with specific characteristics. In general, these banks exhibit distinct features in terms of ownership (public versus private), objectives (ranging from strategic investments in the core sector to the financing of small private local firms), and geographic diversification (spanning from nationwide to rural counties). The specificities of these different types of banks, particularly with respect to their local anchoring, are interesting to analyze and allow us to understand why banks can act as transmitters or absorbers of shocks. We will focus in particular on the difference between commercial banks and rural banks⁵, as they are the more numerous (see details below) and have different roles with regard to the Chinese banking system.

As for natural disasters, we focus on typhoons. China is confronted with high levels of disaster risk, as indicated by its ranking (67 out of 191 countries) in the 2019 INFORM Risk Index from the Climate Change Knowledge Portal (CCKP) of the World Bank. This ranking primarily stems from China's

¹See Avril et al. (2022) for details on these transmission channels.

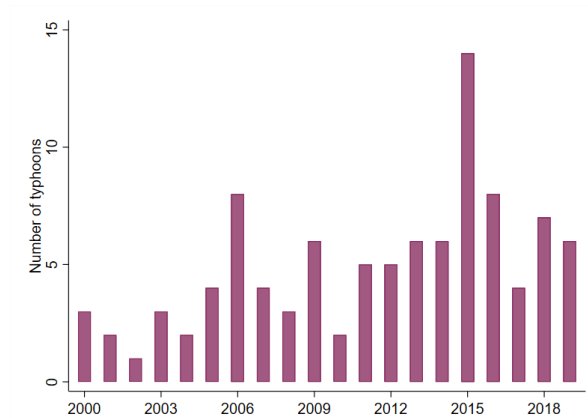
²See Kiyotaki and Moore (1997); Bernanke et al. (1999); Cerqueiro et al. (2016); Di Tella (2017) for examples of the financial accelerator mechanism and borrowers' balance sheet effects, as well as Gertler and Karadi (2011); Gertler et al. (2012); Brunnermeier and Sannikov (2014); He and Krishnamurthy (2019) for theoretical and empirical evidence of banks' balance sheet effects.

³See Xu and Xu (2023) for evidence of the importance of local natural hazard information.

⁴China joined the World Trade Organization (WTO) in 2001, whose General Agreement on Trade in Services (GATS) includes banking services. Limits on lending and deposits were removed in 2004.

⁵Nonetheless, we keep in mind that state-owned banks, although there are only 5 of them, represent an important share of the banking sector in terms of loans. We also note that there are also a few foreign banks operating in the country.

Figure 2.1.1: Number of intense typhoons in China



Note: Number of typhoons of maximum intensity (level 6) according to the Chinese National Standard for Grade of Tropical Cyclones. Source: China Meteorological Administration (CMA). Authors' calculations.

extensive exposure to tropical cyclones (typhoons) and the associated hazards (the country is ranked 6th worldwide in terms of typhoon exposure)⁶. Therefore, our analysis will give particular attention to typhoons as a specific type of natural disaster affecting the Chinese economy. Moreover, these natural disasters represent an important and growing threat in China (Park et al., 2014; Yao et al., 2021). According to Figure 2.1.1, between 2009 and 2018, there was a significantly higher occurrence of intense typhoons reaching the maximum intensity, as per the Chinese National Standard for Grade of Tropical Cyclones, compared to the period from 2000 to 2009. Deadly typhoons such as Haiyan in 2013, Meranti in 2016, and Doksuri in 2023 are only several examples. Moreover, China is even more vulnerable to typhoons as they mainly hit the country's highly urbanized east coast (Fischer et al., 2015). Therefore, despite national public management strategies, the negative impact of typhoons on Chinese GDP has increased over time (Elliott et al., 2015).

Thus, in this paper, we study the impact of major typhoons on loans, but also on non-performing loans (NPLs), liquidity ratios, and leverage ratios of different types of banks. We rely on a difference-in-difference methodology over the period from 2004 to 2019, on a sample of about 161,100 branches held by 327 banking groups and dispersed over 31 Chinese provinces. To this end, we develop an original measure of banks' exposure to the 23 most intense typhoons over the timespan from 2004 to 2019. This measure is based on localized disaggregated data regarding the geographical position of banks' branches. Moreover, by relying on the intensity of typhoons, our measure allows us to investigate the exposure and reaction of the Chinese banking system to exogenous shocks.

We find that, on average, typhoons trigger a decrease in the variation of loans that accounts for 2.8% of

⁶Furthermore, China also experiences significant exposure to floods and droughts. The country's overall disaster risk is further compounded by moderate levels of social vulnerability.

total bank assets and an increase in NPLs of 0.30 percentage points. However, it is primarily commercial banks that reduce their lending activities. Moreover, as these banks also suffer from a decrease in their liquidity ratio, balance-sheet effects could explain why they act as shock transmitters. On the contrary, rural banks do not significantly decrease their lending. Facing an increase in NPLs, at the same time, they seem to act as shock absorbers. This may be a consequence of relationship lending, as well as of a better knowledge of local economic activity and physical risks.

The contribution of this research is at the crossroads of several strands of the literature. First, we contribute to the emerging literature that investigates the impact of NDs on the banking system. It is widely acknowledged that funding needs increase in the wake of a disaster (Del Ninno et al., 2003; Berg and Schrader, 2012; Czura and Klonner, 2023). This growing demand can be met by recovery lending from banks, albeit depending on the structure of the banking system (Cortés, 2014; Schuwer et al., 2019). Chavaz (2016) suggests that recovery lending is facilitated by small local banks that take advantage of the opportunities arising from increased demand and/or have long-term relationships with their clients. Further, these loans are transferred through the secondary market to more diversified financial institutions that can better support the associated risks. Koetter et al. (2020) also find that local lenders play a key role in providing recovery lending, particularly to small local firms that are affected. Cortés and Strahan (2017) show that multi-market banks protect their core markets by reallocating capital when local demand for credit increases after an ND. This reallocation comes at the cost of regions that are unaffected and where banks do not have branches. Moreover, as credit supply may have positive externalities on local house prices, local banks may be more prone to continue lending to an area in which they have a high share of outstanding loans (Favara and Giannetti, 2017). Thus, by providing recovery lending, banks act as substitutes for insurance contracts covering disaster risks, which might typically lack comprehensive coverage for disaster risks. In this respect, it should be noted that the insurance market for natural disasters is poorly developed in emerging countries, such as China (Wang et al., 2012). However, some studies do not support the recovery lending hypothesis (Noy, 2009; Hosono et al., 2016).⁷ Therefore, our study sheds new light on the question of whether NDs dampen or stimulate credit activity. We confirm that this depends on the banking market structure: more precisely, the presence of local banks is crucial to ensure recovery lending. Our findings even highlight that having a banking structure with no rural bank branches is detrimental to post-disaster growth.

Second, by focusing on banking market structure, and by distinguishing the response of different types of banks in terms of ownership, scope, and geographical diversification, we contribute to the literature on financial intermediation. In particular, we address information asymmetries, competition, and external

⁷From a more structural point of view, Garmaise and Moskowitz (2009) and Faiella and Natoli (2018) find a negative correlation between lending and exposure to physical risk, especially in case of insurance market imperfections.

pressures. It is widely acknowledged that banks can mitigate information asymmetries through relationship lending, which allows them to exploit soft and qualitative information. In doing so, they expect to compensate for any short-term temporary losses in the future, especially those caused by increased non-performing loans due to unforeseen events. Therefore, they can alleviate the financing constraints that small firms otherwise face, due to a lack of hard and quantitative information. Hence, for firms, building close ties with a bank not only offers advantages in terms of financing availability (Petersen and Rajan, 1994; Elsas and Krahnen, 1998; Brown et al., 2021; Bolton et al., 2016), but also in terms of credit conditions (Berger and Udell, 1995), especially in the case of unexpected adverse shocks.⁸ Small local banks, in particular, are better at using this qualitative information, since soft information circulates better within a small organization (Stein, 2002; Berger et al., 2005; Agarwal and Hauswald, 2010; Canales and Nanda, 2012; Berger et al., 2017). Consequently, they are more likely to provide liquidity and interest-rate insurance to their clients. Nevertheless, as they are less diversified and benefit less from government guarantees than large banks, their liquidity support could be limited during a financial crisis (Berger et al., 2015). Moreover, competition is not neutral. Duqi et al. (2021) find that economic recovery in the wake of an ND is faster in less competitive banking markets. This finding is in line with Crawford et al. (2018), who show that the adverse effects of asymmetric information become weaker as bank market power increases. Finally, political interference and pressure can influence the lending behavior of banks (Chu and Zhang, 2022). In this paper, we confirm that banks having a local anchorage, i.e. a good knowledge of local economic and natural risks with possibly long-term customer relationships, are likely to dampen the economic impact of NDs. In contrast, financial intermediaries that do not have such informational advantages in screening and monitoring projects are more likely to exacerbate the adverse effects of such exogenous shocks. In addition, our results do not rule out a significant impact of political pressure on lending activity following a typhoon.

Third, the majority of studies on the financial consequences of NDs predominantly involve developed countries (See, e.g., Noth and Schüwer, 2023), which generally have a more mature insurance market.⁹ In emerging economies, such as China, the insurance market is less developed and the banking sector often has a distinct structure characterized by more government involvement, which in turn increases the political pressures experienced by banks. Moreover, empirical evidence suggests that emerging and developing countries are the most affected by natural disasters, making them particularly vulnerable to such events (Kellenberg and Mobarak, 2011; McDermott et al., 2013; Klomp, 2014). This, nevertheless, remains only briefly addressed in the literature. Focusing on the Chinese case fills in this gap and contributes to a better understanding of the functioning of emerging economies that extensively rely on

⁸See also the survey of Boot (2000) and the meta-analysis proposed by Kysucky and Norden (2016).

⁹One exception is Brei et al. (2019), who find that withdrawals of bank deposits are used to compensate for the decline in the supply of bank lending following hurricanes in the Eastern Caribbean islands.

the banking system to finance their growth. To the best of our knowledge, this is the first study on the impact of typhoons on Chinese banks.

Last, our findings contribute to the emerging new economic and financial geography field (Zhao and Jones-Evans, 2017; Dixon, 2012; Basker and Miranda, 2018). We take a disaggregated regional approach in analyzing the reaction of banks to localized natural disasters and we further delve into the recovery patterns of Chinese provinces in the wake of these extreme events. Our analysis takes into account the structure of the local banking system as well as the internal and external political pressure on banks within the regions.

The rest of the paper is organized as follows. Section 2.2 presents our balance sheet data and describes our measure of the exposure of Chinese banks to typhoons as well as all our control variables. Section 2.3 is dedicated to the presentation of the difference-in-difference framework that we use to gauge the reactions of Chinese banks to typhoons. Section 2.4 presents the baseline results, additional results with alternative control groups, and robustness checks. Section 2.5 explores post-typhoon local growth according to local banking sector structures. Finally, we investigate the role of political pressure on the reaction of banks to typhoons in Section 2.6. Section 2.7 concludes.

2.2 Data

This section intends to present the dataset we use in our empirical investigation. We focus on the measure of banks' exposure to typhoons, as well as on the definition and construction of the control variables.

2.2.1 Source of banks' balance sheet data and dependent variables

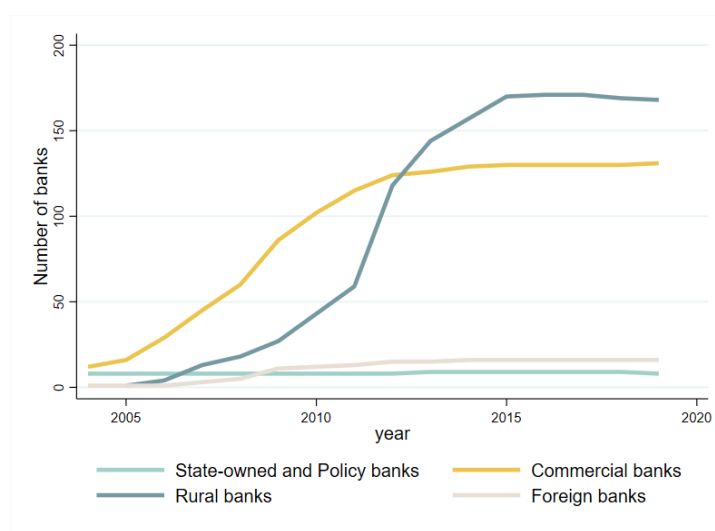
Our analysis relies on banks' balance sheet information, collected from the China Stock Market Accounting Administration (CSMAR), from 2004 to 2019. The starting date is justified by the Chinese financial system's liberalization, which has been strengthened since the beginning of the 2000s. After the creation of the China Banking Regulatory Commission (CBRC), dedicated to the supervision and regulation of the financial system, in 2004, China removed its limitations on lending rates and those related to the deposit rate.

As a consequence, Figure 2.2.1 shows that the number of commercial and rural banks has increased significantly, from almost zero in the very early 2000s to about 130 and 170, respectively, in 2019. Furthermore, they have developed many branches in different regions. Rural banks encompass rural commercial banks, rural cooperative banks, and rural credit unions. They handle funding in counties and rural areas. Thus, their business is highly concentrated in terms of geography and customers (evidence

will be provided below). Commercial banks include joint-stock commercial banks and (lower-size and less sprawling) city commercial banks. These institutions have a rather flexible ownership structure and provide services mostly to medium and small enterprises in the private sector (Tan, 2017). As these two types of banks have distinct business models, it will be interesting to compare their behavior in the wake of typhoons.

Figure 2.2.1 also shows that the number of state-owned and foreign banks has shown little to no growth since the beginning of the 2000s. However, state banks still cover 60% of loans nationwide, compared to 35% for commercial banks and 5% for rural banks.

Figure 2.2.1: The number of Chinese banks, by type of bank



Source: CSMAR, Authors' calculations.

By considering banks as they are created¹⁰, our analysis is conducted on an unbalanced panel of 327 banks, composed of 9 state-owned and policy banks, 16 foreign banks, 132 joint-stock and city commercial banks, and 171 rural banks.¹¹ Thus, our study covers almost all Chinese banks.

While investigating the reactions of these different banks to NDs, we are mainly interested in four variables stemming from banks' balance sheets. First and foremost, we examine the variation of the total amount of loans (the variation is expressed in trillion yuans). This is a key variable for detecting whether banks practice recovery lending or whether they cut credit following the deterioration of creditworthiness generated by typhoons. Second, we consider the non-performing loan (NPL) ratio, defined as the percentage of substandard loans, doubtful loans, and loss loans over the total of loans. Typically, an increase in NPLs can be the corollary of a shock-absorbing effect by banks. Third, we will also study the impact

¹⁰The sole requirement for inclusion in the sample is that banks should have a minimum existence of four years, with at least one observation available for all dependent variables.

¹¹Note that Postal Savings Bank of China, which was a state-owned institution, became a joint-stock bank during the investigation period and is included in our study.

of typhoons on banks' liquidity ratios, defined as liquid assets over short-term liabilities. Finally we also investigate their leverage ratios, computed as the ratio of total equity to total assets. For the two former dependent variables, the reason under their investigation is that the adverse effects of natural disasters on banks' liquidity (e.g., due to important withdrawals of deposits) and capital (e.g., due to a fall in retained earnings) could explain banks' reluctance or inability to offer recovery lending, as suggested by the bank capital channel. Thus, capturing these potential banks' balance sheet effects would give us a better understanding of the banks' responses in terms of lending. Last, we limit our analysis to data up to 2019 to exclude any singular effects related to the COVID-19 crisis.

2.2.2 Measuring banking groups' exposure to typhoons

In this section, we present our methodology used to quantify the exposure of each banking group to geo-localized typhoons. First, we extract information on typhoons from the Tropical Cyclone Best Track provided by the China Meteorological Administration (CMA).¹² From this dataset, we retrieve the precise location and intensity of each typhoon, every six hours. While typhoons can impact large areas of the territory (Holland et al., 2010; Yang, 2005), the radius considered as damaging is generally about 100 km around the eye, which is the calmest part of the typhoon. However, in order not to lose any information on the potential impact of typhoons, we follow Berlemann and Wenzel (2018) by considering that these events can have an impact within a radius of 160 km all along their trajectory. Second, we precisely locate branches of the 371 banks in our sample based on the information provided by the China Stock Market & Accounting Research (CSMAR) in the China Bank Research Database. This dataset provides precise information on the full names of banks' branches, their addresses, their geographic coordinates, the banks they are affiliated with, and their opening and closing dates. In doing so, our sample includes up to 161,504 bank branches in 2019.

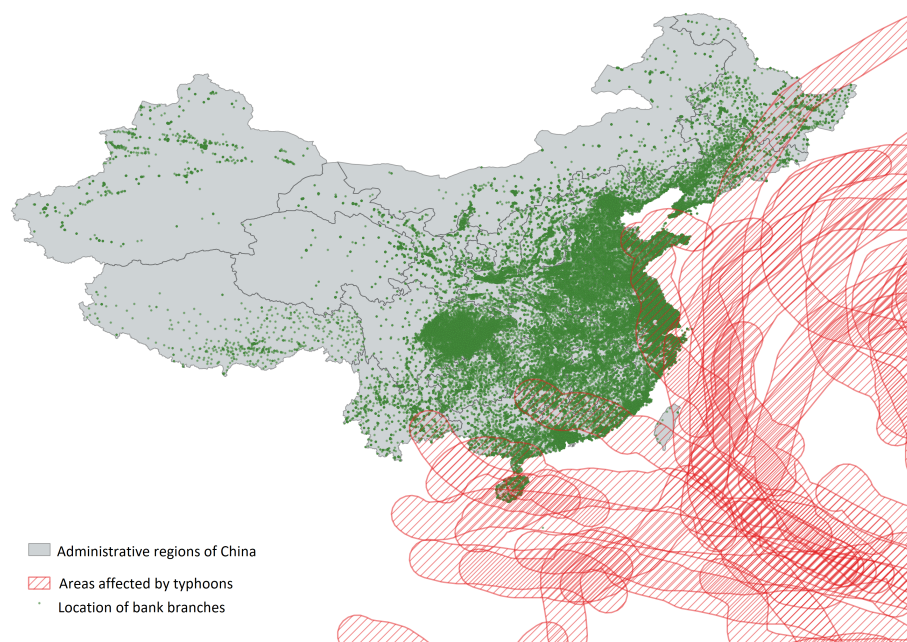
Third, we use the QGIS software and a China shapefile to combine the location of banks with the trajectories of typhoons.¹³ In doing so, we can measure to what extent each bank has been affected by typhoons, given the location of its branches. Figure 2.2.2 illustrates our approach. The green dots represent the location of branches, while the red hatched areas correspond to the trajectories of the 2019 typhoons, in a radius of 160 km. Each bank branch located in the red area can be viewed as potentially affected. Nevertheless, in practical terms, banking groups are actually affected only if the typhoon reaches a certain level of intensity and affects a sufficient number of their local branches. To address this, we impose two restrictions. To eliminate low-intensity events from the analysis, we narrow our focus only

¹²The data is obtained from tcdata.typhoon.org.cn. See Ying et al. (2014) and Lu et al. (2021) for more details.

¹³Shapefiles at all administrative levels can be downloaded at <https://data.humdata.org/dataset/cod-ab-chn?> and are provided by OCHA Regional Office for Asia and the Pacific (ROAP).

on major typhoons with an intensity level¹⁴ of at least 3. In addition, we consider a bank as affected at the consolidated level if more than 50% of its branches have been hit.¹⁵

Figure 2.2.2: Branches affected by 2019's typhoons



Finally, we measure the overall exposure of the affected banking group i to a typhoon d at time t by reporting the number of its affected branches over its total number of branches across the country, weighted by the intensity of the typhoon, such as:

$$\text{Exposure}_{i,t} = \sum_{d=1}^D \frac{\text{local branches affected}_{i,t,d}}{\text{total banking activities}_{i,t}} \times \text{typhoon intensity}_{t,d} \quad (2.1)$$

This measure is in line with Schuwer et al. (2019), who consider the share of banking business located in the affected counties, weighted by the damage incurred within the county. Our approach nevertheless has the advantage of using weights derived from an exogenous measure, i.e. the geophysical intensity of the typhoons, unlike damages that are strongly correlated to the economic, financial, and social contexts (Noy, 2009; Felbermayr and Groschl, 2014; McDermott et al., 2013).

Table 2.2.1 presents some descriptive statistics for our measure of exposure. It appears that rural banks, which are less diversified (especially geographically), and have fewer branches (Table 2.8.4), are likely to be more affected than commercial banks. On the extreme opposite, state-owned and policy banks are highly diversified geographically and have numerous branches. As a result, they are never classified

¹⁴The intensity category is defined according to the Chinese National Standard for Grade of Tropical Cyclones, since 15 June 2006: categories range from 0 to 6, according to wind speed, with 6 being the highest level. Level 3 corresponds to a minimum speed of 86.4 km/h.

¹⁵For robustness checks, we will consider alternative thresholds and exclude banks that are close to being affected from the control group of unaffected banks.

as affected according to our definition of exposure (which requires that at least 50% of the branches should be affected) and our restrictions on the intensity of the considered typhoons. Note that given the two aforementioned restrictions, in theory, the minimum value of our indicator is 1.5, characterizing a banking group having just 50% of its branches being hit by a typhoon of intensity 3 at year t .

Table 2.2.1: Descriptive statistics on banks' exposure

	Mean	Sd	Min	Max
All banks (229 banks affected vs 98 never affected)	6.49	3.89	1.55	24.00
Commercial banks (73 banks affected vs 59 never affected)	5.18	2.90	1.55	18.72
Rural banks (156 banks affected vs 15 never affected)	7.08	4.13	1.61	24.00

2.2.3 Control variables

While natural disasters can affect bank lending, NPLs, liquidity, and leverage ratios, these factors depend also on the intrinsic characteristics of the banking industry and on demand-side effects. Therefore, it is crucial to consider both dimensions in our analysis.

Regarding the banking supply-side characteristics, we first consider the logarithm of the number of banks' branches as a proxy for banks' size. This information may be important, as small banks may have comparative informational advantages in alleviating financial constraints, especially under adverse economic conditions (Stein, 2002; Berger et al., 2005; Agarwal and Hauswald, 2010; Canales and Nanda, 2012; Berger et al., 2017). Moreover, we consider the geographic concentration of banks. Loutskina and Strahan (2011), show, on the one hand, that geographic diversification can lead to a decline in screening by lenders. On the other hand, lenders that are concentrated in a few markets invest more in information collection and are better positioned to price risks and ration credit less. We measure geographic concentration by computing a Herfindahl-Hirschmann Index (HHI) based on the location of banks' branches. Denoting m the total number of regions, this index is the sum of the squared shares of branches at each region level, following

$$\text{Geographic concentration}_{i,t} = \sum_{j=1}^m \left(\frac{n_{i,j,t}}{N_{i,t}} \right)^2 \equiv \sum_{j=1}^m (r_{i,j,t})^2, \quad (2.2)$$

where $n_{i,j,t}$ is the number of branches of bank i in region j , and $N_{i,t}$ is the total number of branches owned by i . Hence $r_{i,j,t}$ represents the shares of bank i 's branches located in region j . Note that this index is equal to one if all the branches of a bank are located in a single province.

Next, we consider competition in the banking market. Duqi et al. (2021), for example, find that banks

continue to lend following a natural disaster, especially in less competitive markets. Our market power indicator builds on Chong et al. (2013). For the sake of clarity, its construction is described in two steps, by defining successively (i) the regional banking concentration and (ii) the contribution of each bank to this concentration. First, we compute an HHI to measure banking concentration at the regional level. This index relies on the number of branches owned by the bank i in region j over the total number of bank branches in this region (denoted $N_{j,t}$), such as

$$\text{Banking concentration}_{j,t} = \sum_{i=1}^k \left(\frac{n_{i,j,t}}{N_{j,t}} \right)^2 \equiv \sum_{i=1}^k (s_{i,j,t})^2, \quad (2.3)$$

where k designates the total number of banks. Notice that this regional banking concentration index is equal to one if all the branches in a given region belong to a single bank. Second, we measure the contribution of each bank i to the local concentration, such as

$$\text{Local market power}_{i,j,t} = \frac{(s_{i,j,t})^2}{\sum_{i=1}^k (s_{i,j,t})^2}. \quad (2.4)$$

Note that this local market power index is equal to one if only one bank has branches in region j . Finally, given these definitions, we can gauge the global market power of bank i operating in various regions j , such as

$$\text{Market power}_{i,t} = \sum_{j=1}^m \left(\frac{(s_{i,j,t})^2}{\sum_{i=1}^k (s_{i,j,t})^2} \right) r_{i,j,t}, \quad (2.5)$$

which refers to the sum of the local market power of bank i over the m regions, weighted by the share of branches this bank owns in each region where it operates ($r_{i,j,t}$).

Regarding demand-side controls, we focus on local unemployment rates and GRP growth. These variables are initially available at the province level. To evaluate the demand conditions that each bank faces, these two variables are weighted by each bank's activities in province j over its total activities in the country (i.e., by $r_{i,j,t}$).

Descriptive statistics concerning the dependent and explanatory variables defined so far are reported in Table 2.8.1 in Appendix 2.8.1.

2.3 Empirical strategy

We use a generalized difference-in-difference (DiD) approach to assess the impact of typhoons on Chinese banks. Within this framework, we consider as "treated" the banks that have actually been exposed to a typhoon according to the definition (2.1), with an exposure indicator higher than 1.5. Banks that are not affected belong to the control group. Hence, we create a dummy variable labeled

$Treated_i$, which is equal to one if the bank i belongs to the treated group, and zero otherwise (meaning that i belongs to the control group). We also create a dummy variable denoted $Post_{i,t}$ that is equal to one during three years after a bank i has been treated, and zero otherwise. Subsequently, a treated bank can move into the control group three years after being affected by a typhoon, provided it is not hit again by another typhoon during that interval.¹⁶ The interaction between $Treated_i$ and $Post_{i,t}$ captures the difference between banks before and after being treated and the difference between being treated and not being treated.

The average treatment effect (ATE) is given by the parameter β in the following equation that is estimated:

$$Y_{i,t} = \alpha_i + \tau_t + \beta(Treated_i \times Post_{i,t}) + X_{i,t}\eta + \varepsilon_{i,t}, \quad (2.6)$$

where Y successively represents the variation of total loans, the non-performing loans ratio, the liquidity ratio, and the leverage ratio. $X_{i,t}$ contains a set of control variables related to individual banking characteristics and local demand-side features, as described in Section 2.2.3. The model also embeds individual fixed effects α_i . They aim at capturing potential time-invariant unobserved differences between the treated and non-treated banks. Specifically, a considerable number of banks in China are concentrated in the southeast of the country, which is both the most economically dynamic region and the most typhoon-prone area due to geographical and climatic conditions. In addition, we consider year-fixed effects τ_t , which are intended to capture events that may affect the entire Chinese banking system. Finally, $\varepsilon_{i,t}$ stands for standard errors, which are clustered at the bank level. Consequently, after controlling for time and bank-fixed effects, typhoons can be viewed as random and exogenous events. As a result, our estimated treatment effect can be considered as consistent, i.e. the conditional independence assumption is met.

However, the identification of a causal impact through the DiD methodology relies on the parallel trend assumption, according to which the dependent variables of treated banks would have evolved in parallel to those of untreated banks in the absence of treatment. In this respect, we conduct a preliminary examination to ascertain whether the evolution of all the variables used in the regressions is similar in the two groups. Table 2.8.3 in Appendix reports, based on Imbens and Wooldridge (2009), t-statistics for tests of normalized differences of variations. It shows that one year before a typhoon occurs, the null hypothesis of mean equality is never rejected, except for geographic concentration. Furthermore, we will test the parallel trend hypothesis using a joint test on leads significance (Cerulli and Ventura, 2019) for each estimated model. This test is well suited for time-varying treatment (i.e. with the case of many

¹⁶Since we are in a multiple-event case with exogenous timing, such as, for example, Masiero and Santarossa (2021), there is no constant pre- and post-period for the control group. Hence, the $Post_{i,t}$ dummy is specific to the banks i that are - temporary - in the treated group.

pre- and post-intervention periods). It is conducted while accounting for 3 periods before the event takes places and 3 periods after the event.

2.4 Results

In this section, we first present the baseline results of the DiD estimates. Then, we check their robustness by considering alternative control groups and definitions of the treatment.

2.4.1 Baseline results with the full sample

The columns labeled "Full sample" of Table 2.4.1 report the baseline results of the DiD estimations for banks' loans variation, non-performing loans (NPLs), liquidity ratios, and leverage ratios following intense typhoons when considering all the banks of our sample, on a yearly basis over the period from 2004 to 2019. The results suggest that being exposed to a typhoon triggers a significant decrease in the variation of loans. This would suggest that banks may act as shock amplifiers. Note that the variation of loans is expressed in trillions (10^{12}). The year-on-year loan variation is reduced by an average of 0.021 trillion yen during the three years following a typhoon compared to banks not affected. Considering that the mean of total assets is equal to 0.738 trillion, a typhoon leads to an average cut, from year to year, in lending of 2.8% of the value of total assets (i.e. 0.021 trillion yuan per year), over the three years after the disaster, for the treated banks, compared to the control group. In addition, we observe an increase in the non-performing loans ratio (at the 10% level) for treated banks, compared to the control group. This suggests that a typhoon can affect the solvency of borrowers, by mitigating production capacity and economic activity. This increase represents about 15% of the average NPL ratio in our sample. Nevertheless, being affected by a typhoon does not seem to impact banks' liquidity and solvency ratios. Brei et al. (2019) and Noth and Schüwer (2023) find a similar decline in loans and a rise in NPLs for other countries (i.e., in the Caribbean islands and the USA, respectively).

The results of the tests of parallel trend hypothesis are displayed at the bottom of Table 2. "YES" means that the null hypothesis of similar pre-treatment trajectory between treated and control banks cannot be rejected at usual confidence levels. We note that this null hypothesis cannot be rejected in any case. Therefore, differences between treated and untreated, if any, are attributable to the effects of the typhoons and not to any other unobserved causes.

Next, we focus on the specific reactions of rural and commercial banks to typhoons. Table 2.8.4 in the Appendix exhibits some important differences that justify analyzing them separately. Rural banks are generally smaller (both in terms of assets and number of branches) and more geographically concentrated (with a very low within-variability) than commercial institutions. In particular, they are more exposed to

Table 2.4.1: Baseline results - all banks

	Total loans		NPL ratio		Liquidity ratio		Leverage ratio	
	Full sample	PSM	Full sample	PSM	Full sample	PSM	Full sample	PSM
Treated \times Post	-0.021*** (0.006)	-0.010** (0.004)	0.291* (0.157)	0.186 (0.202)	0.080 (0.066)	-0.046* (0.027)	-0.003 (0.003)	-0.002 (0.003)
No. of branches (Log)	-0.003 (0.011)	0.011* (0.006)	0.565** (0.279)	0.493** (0.219)	-0.009 (0.051)	0.001 (0.038)	-0.008 (0.006)	-0.007 (0.008)
Geog. concentration	0.241*** (0.077)	-0.041 (0.038)	-3.356*** (1.018)	-4.033*** (1.071)	-0.153 (0.351)	0.220 (0.369)	0.051 (0.033)	0.049 (0.036)
Unemployment rate	0.009 (0.007)	0.015** (0.007)	-0.018 (0.217)	-0.149 (0.268)	-0.079 (0.062)	-0.076 (0.070)	-0.006 (0.004)	-0.006 (0.006)
GRP growth	-0.002 (0.063)	-0.004 (0.018)	-1.760 (1.957)	1.525 (1.683)	0.609 (0.640)	-0.199 (0.166)	-0.068** (0.032)	-0.034 (0.036)
Market power	-0.942** (0.464)	0.082* (0.047)	16.545** (7.794)	13.690* (7.695)	-1.190** (0.564)	-0.512 (0.357)	-0.014 (0.031)	-0.047 (0.057)
No. of banks	327	239	327	246	327	221	327	221
No. of obs.	2557	977	2808	1088	2394	955	2396	955
Individual FE	YES	YES	YES	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES	YES	YES
R ²	0.230	0.290	0.274	0.465	0.018	0.066	0.061	0.067
Parallel trend	YES	YES	YES	YES	YES	YES	YES	YES

Significance levels: * $p < 0.10$; ** $p < 0.05$; *** $p < 0.01$.

typhoons and have larger shares of affected branches. Furthermore, the sample split allows to work with two more homogeneous treatment and control groups. Note that political and state-owned banks cannot be studied alone. Not only are they too few in number, but their strong geographical diversification throughout China implies that they are never categorized as "treated" according to our criteria.

The results for commercial banks only are reported in the columns "Full sample" of Table 2.4.2. We can see that the commercial banks that are exposed to typhoons suffer from a decrease in their liquidity ratios and, to a lesser extent, in their leverage ratios, compared to unaffected commercial banks. These negative balance sheet effects may explain their significant decrease in lending, which reaches 0.016 trillion yuan for a bank of average size, i.e. 3.4% of the average total asset. Such pro-cyclical behavior is likely to amplify the financial effects of the initial shock, as the demand for credit tends to increase following natural disasters.

Next, the columns labeled "Full sample" in Table 2.4.3 report the results for rural banks alone. Contrary to affected commercial banks, affected rural banks do not cut lending. This can be explained by a better knowledge of local markets, local borrowers, and local risks, as well as by the long-term relationships facilitated by a local presence (Petersen and Rajan, 1994; Elsas and Krahen, 1998; Brown et al., 2021; Bolton et al., 2016). In doing so, local banks would act as shock absorbers. Moreover, because of their limited diversification, and probably because they do not cut lending, affected rural banks suffer

Table 2.4.2: Baseline results - commercial banks

	Total loans		NPL ratio		Liquidity ratio		Leverage ratio	
	Full sample	PSM	Full sample	PSM	Full sample	PSM	Full sample	PSM
Treated \times Post _t	-0.016*** (0.005)	-0.018** (0.007)	-0.001 (0.155)	0.056 (0.158)	-0.044** (0.019)	-0.046* (0.027)	-0.005* (0.003)	-0.004 (0.003)
No. of branches (Log)	0.037*** (0.013)	0.032*** (0.011)	0.718*** (0.248)	0.963** (0.369)	0.003 (0.023)	0.023 (0.039)	-0.014 (0.010)	-0.016 (0.011)
Geog. concentration	0.031 (0.037)	-0.012 (0.041)	-1.502* (0.853)	-1.816 (1.190)	0.049 (0.150)	0.051 (0.211)	0.043 (0.039)	0.061 (0.047)
Unemployment rate	0.014** (0.006)	0.009 (0.006)	-0.090 (0.211)	-0.090 (0.252)	-0.004 (0.018)	0.003 (0.020)	-0.006 (0.004)	-0.007* (0.004)
GRP growth	0.023 (0.046)	0.034 (0.039)	0.231 (1.568)	1.858 (1.342)	-0.118 (0.196)	-0.058 (0.316)	-0.061* (0.032)	-0.021 (0.035)
Market power	-0.516 (0.351)	-0.222 (0.185)	-10.050* (5.107)	-9.106* (5.274)	-0.582 (0.770)	-1.362 (0.958)	0.029 (0.161)	-0.064 (0.155)
No. of banks	132	127	132	128	132	126	132	126
No. of obs.	1243	715	1363	790	1226	714	1225	714
Individual FE	YES	YES	YES	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES	YES	YES
R ²	0.316	0.406	0.415	0.485	0.069	0.121	0.116	0.136
Parallel trend	YES	YES	YES	YES	YES	YES	YES	YES

Significance levels: * p < 0.10 ; ** p < 0.05 ; *** p < 0.01

from an increase in non-performing loans of 0.59 bp (which is twice as much as the estimates for the full sample), compared to the control group.

We can observe certain regularities when analyzing the control variables' signs and coefficients. For example, when significant, the banks' size proxied by the logarithm of the number of branches positively affects the variation of loans and the NPL ratio. The geographic concentration seems to matter especially for the NPL ratio: a higher concentration is associated with fewer non-performing loans, which aligns with the hypothesis that geographically concentrated banks have an enhanced local knowledge and this plays a crucial role in managing loan risks effectively. The regional context, specifically regarding unemployment and GRP growth, does not seem to be of primary significance concerning our balance sheet data-dependent variables. Finally, the local market power of a bank seems to increase NPL when considering all banks. This effect is reversed when focusing solely on commercial banks, where higher local market power is associated with a reduction of the NPL amount. Table 2.8.6 in Appendix 2.8.2 shows that the results remain the same in the absence of control variables.

2.4.2 Results when considering alternative control groups

Typhoons are highly localized phenomena. As shown in Figure 2.2.2, they usually occur along coasts, where most of China's economic and banking activity is concentrated. Therefore, the set of these treated

Table 2.4.3: Baseline results - rural banks

	Total loans		NPL ratio		Liquidity ratio		Leverage ratio	
	Full sample	PSM	Full sample	PSM	Full sample	PSM	Full sample	PSM
Treated \times Post _t	-0.000 (0.001)	0.005 (0.005)	0.593* (0.301)	0.996* (0.584)	0.207 (0.170)	-0.053 (0.033)	-0.002 (0.005)	0.016* (0.009)
No. of branches (Log)	-0.001 (0.001)	-0.001 (0.005)	0.503 (0.422)	0.881 (0.630)	0.018 (0.114)	0.035 (0.026)	-0.001 (0.011)	0.007 (0.018)
Geog. concentration	-0.043 (0.074)	-0.338 (0.211)	-37.253*** (11.831)	-71.268*** (17.282)	-1.462 (0.951)	-0.227 (0.436)	-0.026 (0.068)	-0.264 (0.162)
Unemployment rate	0.002 (0.002)	0.002 (0.002)	-0.010 (0.491)	-0.584 (0.714)	-0.208 (0.198)	-0.028 (0.030)	-0.001 (0.004)	-0.007 (0.010)
GRP growth	0.007 (0.013)	-0.047 (0.029)	-2.648 (5.053)	-7.066 (8.848)	3.877 (2.696)	0.290 (0.362)	-0.031 (0.053)	0.044 (0.157)
Market power	-0.004 (0.017)	0.108 (0.069)	5.635 (3.494)	8.727 (11.136)	-2.049*** (0.453)	-1.424*** (0.252)	0.009 (0.024)	-0.163* (0.086)
No. of banks	171	62	171	63	171	54	171	58
No. of obs.	1036	140	1198	164	877	144	879	144
Individual FE	YES	YES	YES	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES	YES	YES
R ²	0.070	0.557	0.138	0.486	0.026	0.587	0.150	0.194
Parallel trend	YES	-	YES	-	YES	-	YES	-

Significance levels: * p < 0.10 ; ** p < 0.05 ; *** p < 0.01

banks located in southeastern China may differ significantly from untreated banks that are located elsewhere in the country. In this case, our model might capture a pattern in treated banks' behaviors that is not (only) due to typhoon exposure. Table 2.8.5 in the Appendix shows balance statistics for each covariate, while considering all banks, as well as commercial and rural banks only. The tests confirm some differences between treated and control banks.

Hence, a possible pitfall in comparing treated and untreated banks is that they may be structurally different *a priori*. One way to deal with this potential issue is to compare banks that have common structural characteristics. This can be done by defining a control group on the basis of one-to-one nearest-neighbor propensity score matching (PSM). Having more similar groups of treated and untreated reduces unobserved heterogeneity and thus diminishes the risk of having a treatment potentially related to unobservable characteristics. In practical terms, the matching is based on all our control variables and time-fixed effects. Table 2.8.5 in the Appendix shows that the differences in covariates turn out to be rarely significant in the "matched" sample, irrespective of the type of banks. Therefore, PSM ensures independence between the fact to be treated and the control variables.

The DiD results with control groups based on a PSM approach are reported in the columns labeled "PSM" in Tables 2.4.1 to 2.4.3. First, it is worth noting that this method leads to a reduction of the sample size, since the banks for which relevant matching is not possible are ignored. In particular, the number of rural banks under review drops from 171 to 43. In this case, it is no longer feasible to conduct

parallel trend tests due to insufficient data.

In general, the results are rather similar to those obtained with the "full sample". First, they confirm a decline in the variation total loans when considering all banks and commercial banks only. The decrease in the leverage ratio is not significant anymore for commercial banks. Nevertheless, balance sheet effects cannot be ruled out as an explanation for their credit decline, given that a decrease in the liquidity ratio is confirmed.

We also address the issue of structural differences between treated and untreated banks by keeping only banks operating in typhoon-prone regions in the control group. The corresponding results are presented in Table 2.8.7 in the Appendix. They remain the same as in the baseline estimations, but without a significant increase in rural banks' NPLs.

Finally, we examine the results when removing from the control group the banks that have 25% to 50% of their branches hit by a typhoon. These banks are considered as "non-treated" in our baseline specification, even though they were affected to some extent. Table 2.8.8 in the Appendix shows that removing this grey area of control does not change the results.

2.4.3 Sensitivity to the definition of treatment

In addition to the various robustness checks conducted so far, the sensitivity analysis in this section focuses on examining more closely the definition of the treatment. Until now, a bank has been defined as "treated" for a period of three years after being actually affected by a typhoon. We now consider a bank as "treated" for a period of two or four years after being actually hit. The results are presented in Tables 2.8.9 and 2.8.10, respectively. They confirm the initial findings. Interestingly, the deterioration of borrowers' creditworthiness following disasters leads to an increase in non-performing loans for rural banks in the medium term (4-year window), but not in the short term (2-year window).

Furthermore, up until now, we have considered a bank to be affected if more than 50% of its branches were actually impacted. We modify this threshold to 40% and 60%, respectively. The corresponding results are presented in Tables 2.8.11 and 2.8.12, respectively. Once again, the results are unaffected by these changes.

Therefore, all the robustness checks, including changes in the composition and size of the sample, confirm the baseline results.

2.5 Banking sector structure and post-typhoon growth

As a continuation of our baseline results, we further assess whether the structure of the local banking sector can exert an influence on local economic recovery after a disaster. Noy (2009), Cortés (2014),

and Brown et al. (2021), among others, find that local bank lending is crucial to dampen the negative economic effects of natural disasters. Duqi et al. (2021) show that recovery depends on competition in the banking market. In this vein, and given our previous findings, we assess whether GRP growth is relatively more affected by typhoons in prefectures with only commercial banks.¹⁷

To conduct this investigation, we need to identify affected areas at the prefecture level, which goes beyond the previous step of determining whether a bank's branch was within the radius of a typhoon. Still assuming that a typhoon affects a territory on a radius of 160km, we use the QGIS software to locate impacted areas at time t . We consider a prefecture as affected when more than 75% of its territory is actually impacted. We create a dummy variable $Treated_p$ that is equal to one if the prefecture p is considered as affected, and zero otherwise. The list of the 299 prefectures of our sample, including the 175 prefectures that are treated at least once, is reported in Appendix 2.8.3.¹⁸ Further, we define $Post_{p,t}$ as a dummy variable that is equal to one during the three years after prefecture p has been treated, and zero otherwise. Last, we create $C_{p,t}$ the "only commercial" dummy variable that is equal to one in a prefecture where there are only commercial branches (and no rural branches at all). Hence, denoting $g_{p,t}$ the GRP growth of prefecture p , the regression is:

$$g_{p,t} = \alpha_p + \tau_t + \gamma_r + \beta_1 C_{p,t} + \beta_2 (Treated_p \times Post_{p,t}) + \beta_3 (Treated_p \times Post_{p,t} \times C_{p,t}) + \theta X_{p,t-1} + \varepsilon_{i,t}, \quad (2.7)$$

where α_p stands for prefecture-level fixed effects, τ_t for time-fixed effects, and γ_r for provincial fixed effects. We are especially interested in the triple interaction with the "only commercial" dummy ($C_{p,t}$): β_3 describes the additional effect of a local banking structure based solely on commercial banks on post-typhoon growth. $X_{p,t}$ designates control variables, i.e. some prefectures' characteristics that are likely to influence the post-disaster growth of GDP, such as the population, the growth of local government expenditures, and the local unemployment rate. These features are lagged one period to deal with possible reverse causality. We also control for the number of state-owned banks' branches in each prefecture p , to take into account their potential role in the post-typhoon growth.

The estimates of Eq. (2.7) are compiled in Table 2.5.1, for local economic growth from one to three years after a typhoon. Regardless of the horizon, we first note that all the covariates are significant, with the expected sign. Most importantly, we find a significant negative additional effect of having only a commercial-based structure ($Treated \times Post \times Only\ Commercial$) on GDP growth. On average, provinces without rural banks suffer from an additional decrease in GRP growth of 1.6 percentage points one year after a typhoon, compared to provinces with rural banks. Such a negative effect remains is also

¹⁷Prefectures with only state-owned branches (i.e. without commercial or rural branches at all) are excluded from this extension.

¹⁸Due to the availability of data on Gross Regional Product growth and the unemployment rate, our sample covers 299 out of the 339 Chinese prefectures.

significant 2 and 3 years after the typhoon.¹⁹ Hence, having a banking structure with no rural bank branches is detrimental to post-disaster growth.

Table 2.5.1: The impact of having only commercial banks on local post-typhoon economic growth

	1 year	2 years	3 years
Treated \times Post _t	0.704 (0.581)	0.754 (0.637)	1.724*** (0.598)
Only Commercial	-0.798 (0.715)	-0.883 (0.812)	-0.483 (0.838)
Treated \times Post _t \times Only Commercial	-1.627** (0.665)	-1.296* (0.740)	-1.927*** (0.743)
Number of state branches	0.013*** (0.002)	0.013*** (0.002)	0.013*** (0.003)
Population	0.002** (0.001)	0.002** (0.001)	0.002** (0.001)
Growth of local government expenditures	5.378*** (1.605)	5.397*** (1.610)	5.402*** (1.612)
Unemployment rate	-1.515* (0.809)	-1.537* (0.808)	-1.496* (0.805)
No. of obs.	3265	3265	3265
Individual FE	YES	YES	YES
Province FE	YES	YES	YES
Year FE	YES	YES	YES
R ²	0.526	0.526	0.526

2.6 Considering political objectives and pressure

In general, banks can be subject to political pressures that influence the allocation of credit and their performances (Iannotta et al., 2007; Shen and Lin, 2012; Carvalho, 2014; Gropp et al., 2020; Chu and Zhang, 2022). In the Chinese case, political pressure can be internal and/or external. Internal pressure is related to the public ownership of a bank. Wang et al. (2019) claim that, given their specific ownership structure, public banks pursue clearly different objectives than the other financial institutions. External pressure is possible due to certain institutional features. The political regime of China can be viewed as a form of federalism with a high level of economic decentralization but strong political centralization (Persson and Zhuravskaya, 2016). On the one hand, the management of the local economy is fully delegated to the respective local government, which has full responsibility in initiating, implementing

¹⁹Note that a positive impact of being treated is found when considering a growth rate three years after the typhoon (but not before). This could be explained by productivity gains related to reconstruction and the replacement of destroyed capital by more productive capital, financed in particular by rural banks.

and conducting reforms (Xu, 2011). On the other hand, nominations, promotions, and removals of sub-national officials are fully centralized. Importantly, the promotion system encourages regional officials to follow the policies set by the central government (Wang, 2013; Wang et al., 2019) and is based in particular on local economic performance (Maskin et al., 2000; Chen et al., 2005; Li and Zhou, 2005). This is likely to generate political pressure on banks to lend, especially in the wake of natural disasters (Kang et al., 2021).

We construct two indicators to measure the effects of political pressure. First, internal pressure is proxied by the percentage share of public ownership. We create a dummy that is equal to one if the state ownership of a bank i is higher than 19.5% of its total capital, and zero otherwise. The threshold of 19.5% corresponds to the 75% percentile of the distribution of state ownership in our sample. Second, given the institutional characteristics mentioned above, and following Qian et al. (2011), Wang et al. (2019), and Kang et al. (2021), external pressure faced by banks is supposed to depend on the relative economic performance of prefectures in which they operate.²⁰ Economic performance in each prefecture p , denoted $S_{p,t}$, is computed as the average of the performances $S_{x,p,t}$ related to economic variables x at time t . $x_{p,t}$ are the GRP growth rate, the fiscal surplus (i.e., local revenues minus local expenditures divided by local GRP), and the unemployment rate.

Like Wang et al. (2019), we assign a value $S_{x,p,t}$ between 0 and 3 to the three economic variables x , according to their values compared to the economic performance of the province P to which the prefecture p belongs.²¹ For GRP growth rate and fiscal surplus, this score is computed as

$$S_{x,p,t} = \begin{cases} 0 & \text{if } x_{p,t} \in [(V_{P,max} + \bar{V}_P)/2; V_{P,max}] \\ 1 & \text{if } x_{p,t} \in [\bar{V}_P; (V_{P,max} + \bar{V}_P)/2[\\ 2 & \text{if } x_{p,t} \in [(\bar{V}_P + V_{P,min})/2; \bar{V}_P[\\ 3 & \text{if } x_{p,t} \in [V_{P,min}; \bar{V}_P + V_{P,min})/2[\end{cases}$$

with \bar{V}_P , $V_{P,max}$ and $V_{P,min}$ being respectively the mean, maximum, and minimum values of x in the province P . The higher $S_{x,p,t}$, the lower the economic performances, and so the higher the presumed external political pressure. On the contrary, for the unemployment rate, $S_{x,p,t}$ is computed as

$$S_{x,p,t} = \begin{cases} 0 & \text{if } x_{p,t} \in [V_{P,min}; \bar{V}_P + V_{P,min})/2[\\ 1 & \text{if } x_{p,t} \in [(\bar{V}_P + V_{P,min})/2; \bar{V}_P[\\ 2 & \text{if } x_{p,t} \in [\bar{V}_P; (V_{P,max} + \bar{V}_P)/2[\\ 3 & \text{if } x_{p,t} \in [(V_{P,max} + \bar{V}_P)/2; V_{P,max}] \end{cases}$$

²⁰Note that the prefecture level (p) is the second level of administrative division. It is more granular than the regional or provincial level (j) which is considered to compute the control variables. There are 339 prefecture-level areas in China. However, we exclude Taiwan, which contains six prefectures. Therefore, we have 333 prefectures in our sample.

²¹Since competition for political promotions occurs inside provinces, we only compare prefectures belonging to the same province.

Then, the overall score of external political pressure $S_{p,t}$ for prefecture p at time t is defined as the average of the three indicators $S_{x,p,t}$. Once more, the higher the score, the stronger the external political pressure is likely to be.

Finally, we evaluate the total external political pressure that a bank i might face as a weighted average of the pressure that may affect each of its branches (located in different prefectures) as a proportion of its total activities, such as

$$S_{i,t} = \sum_{p=1}^n S_{p,t} \times r_{i,p,t} \quad (2.8)$$

where $r_{i,p,t}$ represents the shares of a bank i 's branches located in prefecture p , at time t .

This indicator of external political pressure can be resumed as follows. The higher the score, the lower the economic performance, and the stronger then external political pressure for the officials to improve the performance of their prefecture.

The impact of potential internal and external political pressure on bank loans is gauged through a triple DiD approach. The baseline model (2.6) is augmented by an interaction term ($treated \times Post \times political\ pressure$), measuring the relative impact of being hit by a typhoon conditional on the intensity of the political pressure.

The left side of Table 2.6.1 reports the results obtained while considering internal pressure. Despite a smaller sample size than for the baseline estimations²², it is confirmed that being exposed to a typhoon makes commercial banks cut lending, while it is still not the case for rural banks. However, we find that government ownership mitigates the relative decline in lending by typhoon-hit commercial banks. With low state ownership (inferior to 19.5%), commercial banks' loans variation would decrease by 17 billion yuan for an average-size commercial bank. However, this negative impact is largely counteracted by state ownership; state ownership superior to 19.5% would imply a decrease in the variation loans of 3 billion yuan instead for an average-sized commercial bank.

The right side part of Table 2.6.1 reports the triple DiD results with external pressure. Once again, it is confirmed that commercial banks affected by a typhoon reduce their lending, compared to unaffected commercial institutions. Nonetheless, as external political pressure intensifies, exposed banks diminish their credit less in comparison with untreated banks. While an average-sized commercial bank cut lending by about 13% of its total assets in the presumed absence of external political pressure (i.e. for a score equal to 0), on the contrary, same-size banks increase their lending by 2.5% if they operate in a context of extreme external political pressure (i.e. with a score equal to 3).²³

²²Certain ownership information was missing, especially for rural banks. Similarly, when computing external pressure, some economic performance data at the prefecture level were also incomplete. Lastly, banks were removed from the sample when information was missing for more than 50% of their branches.

²³For a score equal to 3, $\Delta Loans = [3 \times 0.016 - 0.036] = 0.012$. Given the mean value of total assets of commercial banks

Table 2.6.1: Influence of internal and external political pressure on the variation of total loans

	Internal pressure (state ownership)			External political pressure		
	All banks	Commercial	Rural	All banks	Commercial	Rural
Treated \times Post _t	-0.019*** (0.007)	-0.017*** (0.006)	0.000 (0.001)	-0.020** (0.009)	-0.036*** (0.012)	0.002 (0.002)
Treated \times Post _t \times State ownership	0.017** (0.007)	0.014* (0.007)	0.002 (0.004)			
Treated \times Post _t \times Political pressure				0.002 (0.004)	0.016** (0.007)	-0.002 (0.002)
State ownership	-0.016** (0.007)	-0.010 (0.007)	0.001 (0.002)			
Political pressure				-0.002 (0.004)	0.000 (0.004)	-0.001 (0.001)
No. of branches (Log)	0.006 (0.012)	0.031** (0.014)	-0.001 (0.001)	-0.002 (0.011)	0.038** (0.015)	-0.001 (0.001)
Geog. concentration	-0.123** (0.051)	-0.122*** (0.046)	-0.096 (0.096)	0.149* (0.079)	-0.005 (0.046)	0.005 (0.019)
Unemployment rate	-0.000 (0.005)	0.011* (0.006)	0.001 (0.002)	0.001 (0.007)	0.014** (0.006)	0.003* (0.002)
GRP growth	-0.033 (0.045)	-0.027 (0.060)	0.001 (0.018)	0.016 (0.058)	0.044 (0.047)	-0.005 (0.012)
Market power	-0.333* (0.191)	-0.457 (0.366)	0.005 (0.025)	-1.916*** (0.470)	-0.691 (0.453)	-0.568 (0.513)
No. of banks	288	125	155	307	127	162
No. of obs.	1729	903	757	2326	1155	950
Individual FE	YES	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES
R ²	0.042	0.168	0.063	0.278	0.325	0.080

Significance levels are: * p < 0.10 ; ** p < 0.05 ; *** p < 0.01.

Therefore, the upward influence of political pressure on lending activity in the aftermath of a typhoon cannot be excluded.

2.7 Concluding remarks

To the best of our knowledge, this is the first study exploring how typhoons affect the lending activities of Chinese banks. To this end, we develop an original measure of the natural disaster (ND) exposure of 327 banks, which relies on two main elements: the precise location of more than 161,000 of their branches, and a comprehensive analysis of the trajectories and intensities of the 23 most severe typhoons that hit China from 2004 to 2019. Basing the exposure measure on typhoon intensity ensures that we assess the response of banks to a strictly exogenous shock.

is 0.471 trillion, $\Delta\text{Loans}/\text{Total assets} = 2.5\%$.

Our difference-in-difference estimates reveal that, on average, typhoons trigger a decrease in lending that accounts for 2.8 percent of total bank assets. Further analysis reveals that this decline comes from commercial banks, and can be explained by negative balance sheet effects, as these banks suffer from a significant decrease in their liquidity ratios. On the contrary, rural banks do not reduce their lending. Their stronger local anchorage with relationship lending makes them more prone to provide recovery lending. Hence, they act as shock absorbers, at the expense of an increase in their NPLs by 0.59 percentage points.

The presence of local banks remains vital in facilitating post-typhoon recovery lending and supporting subsequent regional economic growth. For a given level of exposure, provinces without rural banks suffer from an additional decrease in GRP growth of 1.6 percentage points, compared to provinces with rural banks, one year after the typhoon.

Interestingly, we also find that state ownership and external political pressure can mitigate the relative decline in lending by commercial banks that are affected by typhoons.

2.8 Appendix

2.8.1 Summary and descriptive statistics

Table 2.8.1: Summary statistics

Variable	Mean	Std. Dev.	Min.	Max.	N
Loan variation	0.05	0.18	-0.51	4.00	2397
Non-performing loan ratio	1.89	2.05	0	47.88	2808
Leverage ratio	0.08	0.05	0	0.81	2396
Liquidity ratio	0.65	0.71	0	21.32	2394
Total assets (trillion yuan)	0.74	2.73	0.0005	30.11	2396
Number of branches (Log)	4.26	1.47	0	10.61	3270
Geographic concentration	0.85	0.31	0.04	1	3270
Market power	0.01	0.07	0	0.89	3270
Unemployment rate	3.28	0.5	1.20	5.10	3270
Gross regional product growth	0.11	0.05	-0.04	0.3	3270

Table 2.8.2: Cross-correlation table

Variables	Number of branches (Log.)	Geographic concent.	Unemploy. rate	GRP growth	Local market power
Number of branches (Log.)	1.000				
Geographic concentration	-0.458	1.000			
Unemployment rate	-0.011	0.046	1.000		
GRP growth	-0.017	-0.033	0.221	1.000	
Local market power	0.475	-0.144	-0.006	0.083	1.000

Table 2.8.3: Mean differences between treated and untreated one year before a typhoon

Variable	Treated Mean (SE)	Non-treated Mean (SE)	t-test Difference (1)-(2)	Normalized difference (1)-(2)
Total loan	106.783 (11.286)	124.976 (17.524)	-18.193	-0.061
Non performing loans	36.031 (12.532)	17.514 (6.731)	18.518	0.057
Leverage ratio	4.134 (1.339)	1.604 (1.700)	2.530	0.073
Liquidity ratio	1.865 (1.293)	0.012 (1.137)	1.853	0.056
No. of branches (Log)	2.001 (0.142)	2.006 (0.341)	-0.005	-0.001
Geog. concentration	-1.747 (0.155)	-0.677 (0.144)	-1.070***	0.235
Unemployment rate	-1.531 (0.180)	-1.230 (0.310)	-0.301	-0.055
GRP growth	51.372 (46.632)	16.782 (6.571)	34.590	0.026
Market power	7.039 (1.307)	9.214 (2.417)	-2.176	-0.054

Note: ***, **, and * indicate significance at the 1, 5, and 10 percent critical level. Normalized difference larger than 0.25 indicates that the difference is significantly different from 0.

Table 2.8.4: Main characteristics of commercial and rural banks

Variables	Commercial	Rural
Geographic concentration	0.835 (0.28)	0.996 (0.04)
Percentage of affected branches	41.66 (35.22)	85.77 (28.11)
Number of typhoons	2.35 (3.07)	4.27 (2.37)
Total assets (Log)	25.62 (1.47)	23.92 (1.48)
Number of branches	208.76 (1082.30)	96.43 (210.91)
Market power	0.0064 (0.1939)	0.0145 (0.0767)
Credit concentration	8.21 (14.47)	7.23 (41.40)
Return on assets	0.90 (0.40)	1.09 (0.58)
State ownership	22.50 (23.26)	1.28 (5.99)

Note: This table reports the mean value of the mentioned variables for both commercial and rural banks, as well as their standard deviation in parentheses.

Table 2.8.5: Covariates balance

Variables	Sample	Treated	Control	Diff
All banks				
Number of branches (Log)	Full	4.0293	4.7289	-0.6996***
	Matched	4.2079	4.0639	0.1440**
Geographic concentration	Full	0.9499	0.6396	0.3103***
	Matched	0.8978	0.9013	-0.0035
Unemployment rate	Full	3.2185	3.4103	-0.1918***
	Matched	3.4652	3.4185	0.0467
GRP growth	Full	0.1093	0.1143	-0.0050***
	Matched	0.1125	0.1089	0.0036
Market power	Full	0.0055	0.0310	-0.0255***
	Matched	0.0127	0.0139	-0.0012
Commercial banks				
Number of branches (Log)	Full	4.4608	4.6593	-0.1985***
	Matched	4.5972	4.4359	0.1613**
Geographic concentration	Full	0.8783	0.7798	0.0985***
	Matched	0.8289	0.8733	-0.0444***
Unemployment rate	Full	3.2987	3.5379	-0.2392***
	Matched	3.4564	3.4886	-0.0322
GRP growth	Full	0.1097	0.1139	-0.0042
	Matched	0.1082	0.1089	-0.0007
Market power	Full	0.0058	0.0070	-0.0010
	Matched	0.0074	0.0073	0.0001
Rural banks				
Number of branches (Log)	Full	3.7635	4.5204	-0.7569***
	Matched	4.0456	3.9361	0.1095
Geographic concentration	Full	0.9979	0.9725	0.0254***
	Matched	0.9874	0.9955	-0.0080
Unemployment rate	Full	3.1659	3.3105	-0.1456***
	Matched	3.5172	3.4070	0.1102
GRP growth	Full	0.1081	0.1142	-0.0061
	Matched	0.1147	0.1100	0.0047
Market power	Full	0.0051	0.1040	-0.0989***
	Matched	0.0209	0.0271	-0.0062

Significance of the difference are: * $p < 0.10$; ** $p < 0.05$; *** $p < 0.01$

2.8.2 Additional results and robustness checks

Table 2.8.6: Baseline results without controls

	Loans			NPL ratio		
	All banks	Com. banks	Rural banks	All banks	Com. banks	Rural banks
Treated \times Post _t	-0.019*** (0.005)	-0.015*** (0.005)	-0.000 (0.001)	0.220 (0.157)	-0.046 (0.160)	0.675** (0.320)
R ²	0.188	0.288	0.067	0.218	0.390	0.121
	Liquidity ratio			Leverage ratio		
	All banks	Com. banks	Rural banks	All banks	Com. banks	Rural banks
Treated \times Post _t	0.079 (0.065)	-0.044** (0.018)	0.175 (0.154)	-0.002 (0.003)	-0.005 (0.003)	-0.002 (0.005)
R ²	0.016	0.068	0.019	0.022	0.057	0.148

Significance levels are: * p < 0.10 ; ** p < 0.05 ; *** p < 0.01. Individual and time FE are included.

Table 2.8.7: Results with a sample restricted to affected regions only

	Total loans			NPL ratio			Liquidity ratio			Leverage ratio		
	All banks	Com. banks	Rural banks	All banks	Com. banks	Rural banks	All banks	Com. banks	Rural banks	All banks	Com. banks	Rural banks
Treated \times Post _t	-0.019** (0.007)	-0.011*** (0.004)	0.001 (0.001)	0.242 (0.164)	-0.097 (0.162)	0.471 (0.306)	0.114 (0.084)	-0.048** (0.022)	0.232 (0.189)	-0.001 (0.002)	-0.001 (0.003)	-0.001 (0.003)
No. of branches (Log)	0.004 (0.020)	0.040** (0.017)	0.001 (0.003)	0.551*** (0.192)	0.428** (0.209)	2.851*** (1.068)	-0.023 (0.068)	0.007 (0.030)	0.032 (0.212)	-0.003 (0.004)	-0.005 (0.009)	0.005 (0.018)
Geog. concentration	0.224*** (0.073)	0.035 (0.044)	-0.048 (0.082)	-2.549*** (0.971)	-1.421 (0.954)	-12.522* (6.462)	-0.316 (0.360)	0.099 (0.180)	-1.544 (1.448)	0.057 (0.043)	0.062 (0.046)	-0.068 (0.067)
Unemployment rate	0.002 (0.009)	0.008 (0.007)	0.000 (0.001)	0.404* (0.234)	0.231 (0.261)	0.452 (0.454)	-0.060 (0.065)	-0.010 (0.022)	-0.265 (0.227)	-0.004 (0.004)	-0.007 (0.005)	-0.001 (0.004)
GRP growth	-0.026 (0.094)	0.095 (0.059)	0.000 (0.014)	-2.185 (2.939)	0.773 (2.255)	-2.501 (6.549)	1.299 (1.224)	-0.014 (0.410)	6.291 (4.458)	-0.055 (0.036)	-0.045 (0.046)	-0.068* (0.035)
Market power	-1.599*** (0.341)	-1.105 (0.689)	0.048*** (0.008)	26.978*** (5.586)	1.153 (8.005)	18.659*** (7.071)	-0.780 (0.815)	-1.737 (2.396)	-1.669 (1.155)	-0.054* (0.031)	-0.294 (0.246)	-0.073** (0.029)
No. of banks	238	87	143	238	87	143	238	87	143	238	87	143
No. of obs	1859	842	862	2059	911	996	1673	834	710	1674	833	711
Individual FE	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
R ²	0.265	0.390	0.182	0.270	0.366	0.094	0.024	0.119	0.030	0.115	0.116	0.200

Significance levels are: * p < 0.10 ; ** p < 0.05 ; *** p < 0.01

Table 2.8.8: Results when excluding from the control group banks that have 25% to 50% of their branches affected

	Total loans			NPL ratio			Liquidity ratio			Capital ratio		
	All banks	Com. banks	Rural banks	All banks	Com. banks	Rural banks	All banks	Com. banks	Rural banks	All banks	Com. banks	Rural banks
Treated \times Post _t	-0.020*** (0.007)	-0.011** (0.005)	-0.001 (0.001)	0.332*** (0.161)	0.084 (0.163)	0.531* (0.299)	0.085 (0.070)	-0.039*** (0.016)	0.214 (0.175)	-0.002 (0.003)	-0.004 (0.003)	-0.002 (0.005)
No. of branches (Log)	-0.010 (0.009)	0.007 (0.008)	-0.001 (0.001)	0.392* (0.228)	0.358* (0.193)	0.489 (0.414)	-0.025 (0.045)	-0.003 (0.018)	0.023 (0.117)	-0.009 (0.006)	-0.010 (0.010)	-0.002 (0.011)
Geog. concentration	0.291*** (0.107)	-0.088*** (0.025)	-0.010 (0.061)	-4.502*** (1.228)	-2.800*** (0.957)	-33.161*** (12.460)	-0.201 (0.508)	-0.030 (0.155)	-1.663 (1.052)	0.013 (0.025)	-0.010 (0.020)	-0.005 (0.067)
Unemployment rate	0.008 (0.007)	0.009 (0.006)	0.002 (0.002)	-0.066 (0.224)	-0.159 (0.217)	0.041 (0.497)	-0.088 (0.065)	-0.014 (0.017)	-0.212 (0.203)	-0.009** (0.004)	-0.009** (0.004)	-0.001 (0.004)
GRP growth	0.001 (0.065)	-0.013 (0.039)	0.010 (0.013)	-1.382 (1.947)	0.333 (1.458)	-2.249 (5.383)	0.656 (0.651)	-0.129 (0.178)	4.193 (2.853)	-0.051* (0.027)	-0.046* (0.028)	-0.041 (0.055)
Market power	-0.990** (0.480)	-0.016 (0.144)	-0.016** (0.008)	14.315* (7.868)	-4.431 (4.240)	2.953** (1.324)	-1.188** (0.578)	-0.593 (0.696)	-2.210*** (0.409)	-0.020 (0.031)	0.044 (0.168)	0.018 (0.020)
No. of banks	312	122	168	312	122	168	312	122	168	312	122	168
No. of obs.	2358	1097	1015	2608	1212	1174	2208	1087	856	2209	1086	858
Individual FE	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
R ²	0.223	0.159	0.077	0.284	0.462	0.118	0.019	0.110	0.027	0.048	0.088	0.149

Significance levels are: * p < 0.10; ** p < 0.05; *** p < 0.01.

Table 2.8.9: Results when considering that the treatment lasts 2 years

	Total loans			NPL ratio			Liquidity ratio			Leverage ratio		
	All banks	Com. banks	Rural banks	All banks	Com. banks	Rural banks	All banks	Com. banks	Rural banks	All banks	Com. banks	Rural banks
Treated \times Post _t	-0.013*** (0.005)	-0.011** (0.004)	-0.000 (0.001)	0.172 (0.121)	-0.018 (0.120)	0.277 (0.224)	0.044 (0.059)	-0.044** (0.017)	0.082 (0.147)	-0.003 (0.003)	-0.005 (0.003)	0.000 (0.003)
No. of branches (Log)	-0.003 (0.011)	0.037*** (0.013)	-0.001 (0.001)	0.556** (0.276)	0.718*** (0.248)	0.510 (0.437)	-0.011 (0.051)	0.004 (0.023)	0.067 (0.103)	-0.008 (0.006)	-0.014 (0.010)	-0.002 (0.011)
Geog. concentration	0.239*** (0.077)	0.029 (0.037)	-0.043 (0.074)	-3.327*** (1.017)	-1.498* (0.855)	-37.356*** (11.901)	-0.144 (0.348)	0.047 (0.149)	-1.452 (0.907)	0.050 (0.033)	0.043 (0.039)	-0.025 (0.067)
Unemployment rate	0.009 (0.007)	0.014** (0.006)	0.002 (0.002)	-0.013 (0.218)	-0.090 (0.211)	0.019 (0.494)	-0.078 (0.062)	-0.004 (0.018)	-0.196 (0.193)	-0.006* (0.004)	-0.006 (0.004)	-0.001 (0.004)
GRP growth	-0.007 (0.063)	0.019 (0.046)	0.008 (0.013)	-1.687 (1.949)	0.240 (1.571)	-2.934 (5.079)	0.633 (0.649)	-0.123 (0.196)	3.895 (2.789)	-0.068** (0.032)	-0.061* (0.032)	-0.030 (0.053)
Market power	-0.945** (0.464)	-0.512 (0.353)	-0.004 (0.017)	16.637** (7.806)	-10.048* (5.109)	5.943* (3.589)	-1.174** (0.565)	-0.555 (0.771)	-1.956*** (0.467)	-0.014 (0.031)	0.032 (0.163)	0.007 (0.024)
No. of banks	327	132	171	327	132	171	327	132	171	327	132	171
No. of obs	2557	1243	1036	2808	1363	1198	2394	1226	877	2396	1225	879
Individual FE	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
R ²	0.230	0.313	0.070	0.273	0.415	0.135	0.018	0.070	0.024	0.062	0.117	0.149

Significance levels are: * p < 0.10 ; ** p < 0.05 ; *** p < 0.01

Table 2.8.10: Results when considering that the treatment lasts 4 years

	Total loans			NPL ratio			Liquidity ratio			Leverage ratio		
	All banks	Com. banks	Rural banks	All banks	Com. banks	Rural banks	All banks	Com. banks	Rural banks	All banks	Com. banks	Rural banks
Treated \times Post _t	-0.024*** (0.007)	-0.018*** (0.005)	-0.000 (0.001)	0.291 (0.179)	-0.045 (0.190)	0.641* (0.333)	0.081 (0.068)	-0.053*** (0.023)	0.232 (0.190)	-0.003 (0.003)	-0.005 (0.003)	-0.002 (0.005)
No. of branches (Log)	-0.003 (0.011)	0.037*** (0.013)	-0.001 (0.001)	0.563*** (0.277)	0.717*** (0.248)	0.504 (0.419)	-0.009 (0.051)	0.003 (0.023)	0.011 (0.113)	-0.008 (0.006)	-0.014 (0.010)	-0.001 (0.011)
Geog. concentration	0.241*** (0.077)	0.031 (0.037)	-0.043 (0.074)	-3.352*** (1.017)	-1.490* (0.854)	-37.396*** (11.827)	-0.153 (0.352)	0.051 (0.150)	-1.507 (0.995)	0.050 (0.033)	0.043 (0.039)	-0.025 (0.068)
Unemployment rate	0.009 (0.007)	0.014** (0.006)	0.002 (0.002)	-0.023 (0.217)	-0.090 (0.211)	-0.034 (0.491)	-0.080 (0.063)	-0.003 (0.018)	-0.214 (0.202)	-0.006 (0.004)	-0.006 (0.004)	-0.001 (0.004)
GRP growth	-0.006 (0.063)	0.021 (0.046)	0.007 (0.013)	-1.698 (1.947)	0.253 (1.564)	-2.628 (5.044)	0.627 (0.650)	-0.123 (0.197)	3.909 (2.719)	-0.068** (0.032)	-0.062* (0.033)	-0.031 (0.054)
Market power	-0.940*** (0.464)	-0.526 (0.349)	-0.003 (0.018)	16.535*** (7.794)	-10.101*** (5.101)	5.572 (3.473)	-1.195*** (0.566)	-0.599 (0.773)	-2.078*** (0.470)	-0.014 (0.031)	0.029 (0.161)	0.010 (0.024)
No. of banks	327	132	171	327	132	171	327	132	171	327	132	171
No. of obs.	2557	1243	1036	2808	1363	1198	2394	1226	877	2396	1225,000	879
Individual FE	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
R ²	0.231	0.317	0.070	0.274	0.415	0.139	0.018	0.072	0.026	0.061	0.115	0.150

Significance levels are: * p < 0.10; ** p < 0.05; *** p < 0.01

Table 2.8.11: Results when considering banks as treated when 40% of their branches are hit

	Total loans			NPL ratio			Liquidity ratio			Capital ratio		
	All banks	Com. banks	Rural banks	All banks	Com. banks	Rural banks	All banks	Com. banks	Rural banks	All banks	Com. banks	Rural banks
Treated \times Post _t	-0.019*** (0.005)	-0.025*** (0.008)	0.000 (0.001)	0.206 (0.170)	-0.116 (0.180)	0.585* (0.304)	0.052 (0.059)	-0.048** (0.021)	0.206 (0.171)	-0.005 (0.003)	-0.007** (0.003)	-0.002 (0.005)
No. of branches (Log)	-0.004 (0.011)	0.036*** (0.013)	-0.001 (0.001)	0.561** (0.278)	0.711*** (0.247)	0.502 (0.421)	-0.010 (0.052)	0.001 (0.022)	0.013 (0.113)	-0.008 (0.006)	-0.014 (0.010)	-0.001 (0.011)
Geog. concentration	0.240*** (0.077)	0.032 (0.036)	-0.043 (0.074)	-3.352*** (1.022)	-1.472* (0.856)	-37.306*** (11.829)	-0.150 (0.352)	0.051 (0.150)	-1.487 (0.952)	0.051 (0.033)	0.044 (0.038)	-0.026 (0.068)
Unemployment rate	0.009 (0.007)	0.015** (0.006)	0.002 (0.002)	-0.017 (0.218)	-0.091 (0.211)	-0.015 (0.491)	-0.079 (0.062)	-0.004 (0.018)	-0.210 (0.200)	-0.006 (0.004)	-0.006 (0.004)	-0.001 (0.004)
GRP growth	-0.002 (0.062)	0.029 (0.046)	0.008 (0.013)	-1.730 (1.955)	0.311 (1.555)	-2.703 (5.055)	0.621 (0.640)	-0.117 (0.197)	3.855 (2.678)	-0.067** (0.032)	-0.060* (0.032)	-0.031 (0.053)
Market power	-0.943** (0.465)	-0.507 (0.350)	-0.004 (0.017)	16.608** (7.813)	-10.080** (5.070)	5.617 (3.486)	-1.179** (0.564)	-0.581 (0.773)	-2.058*** (0.460)	-0.013 (0.031)	0.027 (0.160)	0.010 (0.024)
No. of banks	327	132	171	327	132	171	327	132	171	327	132	171
No. of obs.	2557	1243	1036	2808	1363	1198	2394	1226	877	2396	1225	879
Individual FE	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
R ²	0.230	0.327	0.070	0.273	0.416	0.138	0.018	0.072	0.026	0.063	0.119	0.150

Significance levels are: * p < 0.10 ; ** p < 0.05 ; *** p < 0.01

Table 2.8.12: Results when considering banks as treated when 60% of their branches are hit

	Total loans			NPL ratio			Liquidity ratio			Capital ratio		
	All banks	Com. banks	Rural banks	All banks	Com. banks	Rural banks	All banks	Com. banks	Rural banks	All banks	Com. banks	Rural banks
Treated \times Post _t	-0.022*** (0.007)	-0.019*** (0.008)	-0.001 (0.001)	0.293* (0.136)	-0.004 (0.146)	0.614*** (0.304)	0.087 (0.064)	-0.032* (0.016)	0.210 (0.169)	-0.003 (0.003)	-0.005 (0.003)	-0.002 (0.005)
No. of branches (Log)	-0.004 (0.011)	0.037*** (0.013)	-0.001 (0.001)	0.568*** (0.279)	0.718*** (0.248)	0.503 (0.421)	-0.008 (0.051)	0.002 (0.022)	0.016 (0.114)	-0.008 (0.006)	-0.014 (0.010)	-0.001 (0.011)
Geog. concentration	0.242*** (0.077)	0.033 (0.037)	-0.044 (0.074)	-3.385*** (1.023)	-1.500* (0.854)	-37.403*** (11.832)	-0.162 (0.353)	0.048 (0.150)	-1.461 (0.951)	0.051 (0.033)	0.043 (0.039)	-0.026 (0.068)
Unemployment rate	0.009 (0.007)	0.015** (0.006)	0.002 (0.002)	-0.024 (0.217)	-0.090 (0.210)	-0.003 (0.491)	-0.082 (0.063)	-0.002 (0.018)	-0.208 (0.198)	-0.006 (0.004)	-0.006 (0.004)	-0.001 (0.004)
GRP growth	0.003 (0.062)	0.032 (0.041)	0.007 (0.013)	-1.808 (1.965)	0.234 (1.557)	-2.672 (5.045)	0.594 (0.633)	-0.118 (0.194)	3.876 (2.693)	-0.067** (0.032)	-0.060* (0.032)	-0.031 (0.054)
Market power	-0.941** (0.463)	-0.502 (0.358)	-0.003 (0.018)	16.529** (7.793)	-10.048* (5.113)	5.607 (3.477)	-1.199** (0.564)	-0.535 (0.764)	-2.050*** (0.451)	-0.014 (0.031)	0.034 (0.163)	0.010 (0.024)
No. of banks	327	132	171	327	132	171	327	132	171	327	132	171
No. of obs.	2557	1243	1036	2808	1363	1198	2394	1226	877	2396	1225	879
Individual FE	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
R ²	0.231	0.320	0.070	0.274	0.415	0.139	0.018	0.065	0.026	0.061	0.115	0.150

Significance levels are: * p < 0.10; ** p < 0.05; *** p < 0.01

2.8.3 List of the Chinese prefectures by regions

In this appendix, we present the Chinese regions and their prefectures included in our analysis. Prefectures are designated as "prefectures, prefecture-level cities", "autonomous prefectures", and "leagues". Those that have been actually affected by at least one typhoon are in bold characters.

- Anhui Province: **Anqing**, **Bengbu**, **Bozhou**, **Chizhu**, **Chuzhou**, **Fuyang**, **Hefei**, **Huaibei**, **Huainan**, **Huangshan**, **Lu'an**, **Maanshan**, Suzhou, **Tongling**, **Wuhu**, **Xuancheng**
- Fujian Province: **Fuzhou**, **Longyan**, **Nanping**, **Ningde**, **Putian**, **Quanzhou**, **Sanming**, **Xiamen**, **Zhangzhou**
- Gansu Province: Dingxi, Jiayuguan, Jinchang, Jiuquan, Lan'Zhou, Longnan, Pingliang, Qingyang, Silver, Tianshui, Wuwei, Zhangye
- Guangdong Province : **Chaozhou**, **Dongguan**, **Foshan**, **Guangzhou**, **Heyuan**, **Huizhou**, **Jiangmen**, **Jieyang**, **Maoming**, **Meizhou**, **Qingyuan**, **Shaoguan**, **Shenzhen**, **Yangjiang**, **Yunfu**, **Zhanjiang**, **Zhaoqing**, **Zhongshan**, **Zhuhai**, **Shantou**
- Guangxi Zhuang Autonomous Region: **Baise**, **Beihai**, **Chongzuo**, **Fangchenggang**, **Guigang**, **Guilin**, **Hechi**, **Hezhou**, **Laibin**, **Liuzhou**, **NanNing**, **Qinzhou**, **Wuzhou**, Yulin
- Guizhou Province: **Anshun**, Bijie, **Guiyang**, Liupanshui, **Tongren**, Zunyi
- Hainan: **Haikou**, **Sanya**
- Hebei Province: Baoding, **Cangzhou**, **Chengde**, Handan, Hengshui, **Langfang**, **Qinhuangdao**, Shijiazhuang, **Tangshan**, Xingtai, Zhangjiakou
- Heilongjiang Province: Daqing, Daxinganling, **Harbin**, **Hegang**, Heihe, **Jiamusi**, Jixi, **Mudanjiang**, Qiqihar, Qitaihe, **Shuangyashan**, **Suihua**, Yichun
- Henan Province: Anyang, Hebi, Jiaozuo, **Kaifeng**, **Luohe**, Luoyang, **Nanyang**, Pingdingshan, **Puyang**, Sanmenxia, **Shangqiu**, **Xinxiang**, **Xinyang**, **Xuchang**, **Zhengzhou**, **Zhoukou**, **Zhumadian**
- Hubei Province: **Ezhou**, **Huanggang**, **Huangshi**, **Jingmen**, **Jingzhou**, Shiyan, **Suizhou**, **Wuhan**, **Xiangyang**, **Xianning**, **Xiaogan**, Yichang
- Hunan Province: **Changde**, **Changsha**, **Chenzhou**, **Hengyang**, **Huaihua**, **Loudi**, **Shaoyang**, **Xiangtan**, **Yiyang**, **Yongzhou**, **Yueyang**, Zhangjiajie, **Zhuzhou**
- Inner Mongolia Autonomous Region: Alxa League, Baotou, Bayannur, Chifeng, Hohhot, Hulunbeir, Ordos, Tongliao, Wuhai, Wulanchabu, Xilin Gol League, Xing'an League

- Jiangsu Province: **Changzhou, Huaian, Lianyungang, Nanjing, Nantong, Suqian, Suzhou**, Taizhou, **Wuxi, Xuzhou, Yancheng, Yangzhou, Zhenjiang**
- Jiangxi Province: **Fuzhou, Ganzhou, Ji'an, Jingdezhen, Jiujiang, Nanchang, Pingxiang, Shangrao, Xinyu, Yichun, Yingtian**
- Jilin Province: **Baicheng, Baishan**, Changchun, **Jilin, Liaoyuan**, Siping, **Songyuan, Tonghua**, Yanbian Korean Autonomous Prefecture
- Liaoning Province: **Anshan, Benxi, Chaoyang, Dalian, Dandong, Fushun**, Fuxin, Huludao, Jinzhou, Liaoyang, Panjin, Shenyang, Tieling, **Yingkou**
- Ningxia Hui Autonomous Region: Guyuan, Shizuishan, Wuzhong, Yinchuan, Zhongwei
- Qinghai Province: Haidong, Xining
- Shaanxi Province: Ankang, Baoji, Hanzhong, Shangluo, Tongchuan, Weinan, Xi'an, Xianyang, Yan'an, **Yulin**
- Shandong Province: **Binzhou, Yantai, Dezhou, Dongying, Heze, Jinan, Jining, Liaocheng, Linyi, Qingdao, Rizhao, Tai'an, Weifang, Weihai, Zaozhuang, Zibo**
- Shanxi Province: Changzhi, Datong, Jincheng, Jinzhong, Linfen, Luliang, Shuozhou, Taiyuan, Xinzhou, Yangquan, Yuncheng
- Sichuan Province: Aba Tibetan and Qiang Autonomous Prefecture, Bazhong, Chengdu, Dazhou, Deyang, Ganzi Tibetan Autonomous Prefecture, Guang'an, Guangyuan, Leshan, Liangshan Yi Autonomous Prefecture, Luzhou, Meishan, Mianyang, Nanchong, Neijiang, Panzhihua, Suining, Ya'an, Yibin, Zigong, Ziyang
- Tibet Autonomous Region: Lhasa
- Xinjiang Uygur Autonomous Region: Changji Hui Autonomous Prefecture, Hami, Karamay, Turpan, Urumqi
- Yunnan Province: Baoshan, Chuxiong Yi Autonomous Prefecture, Dali Bai Autonomous Prefecture, Dehong Dai and Jingpo Autonomous Prefecture, **Honghe Hani and Yi Autonomous Prefecture**, Kunming, Lijiang, **Lincang, Pu'er**, Qujing, **Xishuangbanna Dai Autonomous Prefecture**, Yuxi, Zhaotong
- Zhejiang Province: **Hangzhou, Huzhou, Jiaxing, Jinhua, Lishui, Ningbo, Quzhou, Shaoxing, Taizhou, Wenzhou, Zhoushan**

Chapter 3

Chapter 3

Is the physical risk priced by the Eurozone bond market ?

3.1 Introduction

According to the World Meteorological Organization, in the last half-century, there has been a global rise in the occurrence of climate-related disasters, resulting in increased overall economic and financial damages. In the European Union, it has been estimated that these events have caused a staggering economic loss of 487,005 billion euros, as stated by the European Environment Agency. These past events have thus inflicted significant economic losses in Europe, but the outlook for the future is even bleaker due to the anticipated increase in both the severity and frequency of such disasters. The G20 Risk Atlas, with a specific focus on the European Union, underscores the significant influence of emission trajectories on the magnitude of damages arising from physical risks. In scenarios where temperature increases are relatively moderate, losses are projected to be approximately of €30-40 billion by the end of the century. In contrast, if emissions follow a high trajectory, the losses could soar to over €70 billion by the end of the century.

In this context, the physical risk emerges as a substantial concern not only for the overall economy but also for the financial sector. Physical risks, by causing significant business disruptions and destruction (Fankhauser and Tol, 2005), have the potential to introduce considerable challenges for companies. Furthermore, these risks can alter firms' expected profitability, potentially leading to revisions in equity prices (Carvalho et al., 2020). Additionally, the inherent uncertainty associated with various potential scenarios of accelerated climate change makes pricing climate change risks a complex task. A mispricing of these forward-looking risks could pose a significant threat to future stability and potentially lead to

substantial losses for investors (Kruttl et al., 2019). Consequently, investors need to hedge against these risks.

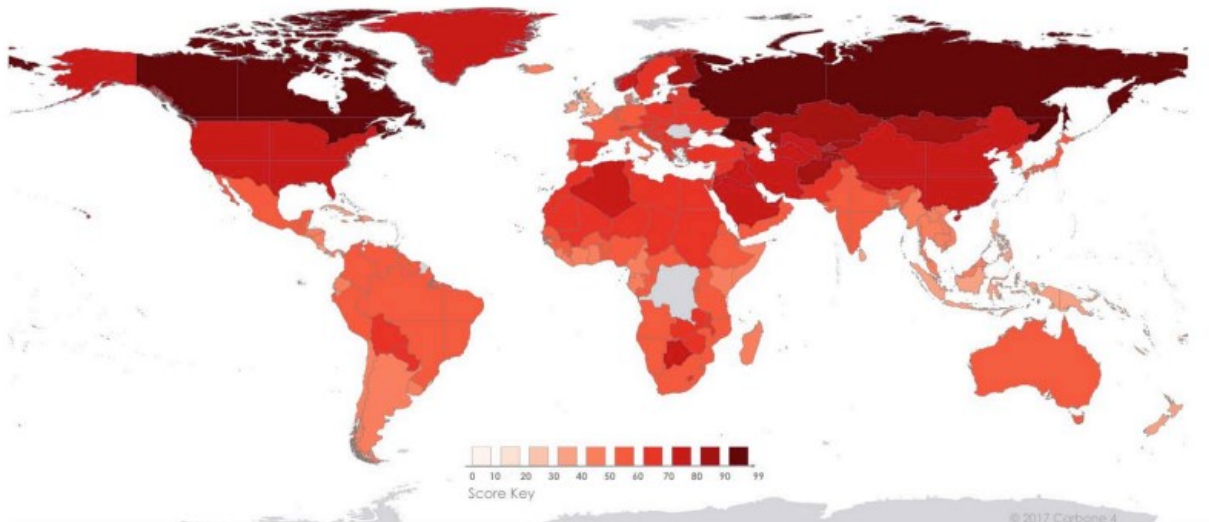
Against this background, this paper aims to delve into the assessment of forward-looking physical risk pricing within the euro area bond market. Furthermore, our analysis seeks to ascertain whether the occurrence of natural disasters within the region has any discernible impact on bond pricing and, if so, whether such changes in pricing persist over time.

We know that investors' decisions are rooted in their beliefs. These beliefs are, to a significant extent, shaped by past experiences. Consequently, it is quite plausible that a prior experience has led to investors becoming more aware, causing them to reevaluate a risk they had previously perceived as distant or even non-existent.

To do this, we examine the monthly bond market spread, using the European Central Bank's (ECB) yield curve as a benchmark. This yield curve is based on European triple-A-rated bonds. In our analysis, we account for all the conventional factors influencing bond spreads and incorporate a metric to gauge the forward-looking physical risk exposure of the issuing firms. The firm-level exposure to various forward-looking physical risk is quantified through a unified score system developed by Carbone4, called Climate Risk Impact Screening (CRIS). There is 7 sub-scores available representing different hazards. The overall score is a mean of those sub-scores. The computation of the exposure scores take into consideration all the various segments and operational regions of a company to provide a comprehensive assessment of its exposure. It is important to note that these scores are derived from the Intergovernmental Panel on Climate Change (IPCC) scenarios, then the scenarios will differ in term of horizons and intensity. The exposure scores computed by CRIS will be contingent on the selected IPCC scenario. To illustrate Figure 3.1.1 depicts the geographical distribution of the score associated to increasing temperature for a long-term horizon and a high-emission scenario. In the paper, we will evaluate both the high-emissions and medium-emissions scenarios. Moreover, we opt to focus on forward-looking risk due to the medium-term maturity of bonds. It is of prime importance for investors to anticipate the future. While past experiences can provide some insights, the physical risk is on an upward trajectory and is expected to persist in this direction. To effectively hedge against these risks, medium-term investors must gain an understanding of future developments in the coming years.

Our global findings indicate that, with the exception of rising heat waves, physical risk is currently not incorporated into pricing on the euro area market. Furthermore, by using the EM-DAT database to assess the total damages resulting from natural disasters, we find that there is an observable rise in the spread, after significant natural disaster damages. Moreover, our findings indicate that the observed outcomes are not induced by domestic disasters (occurring in countries where the firms have their headquarters), but rather by disasters within the euro area. This suggests that it is not solely the actual occurrence

Figure 3.1.1: CRIS ratings capturing increases in annual mean temperature, run for a long-term horizon and a high-emission scenario



Note: Countries with no data are in grey. Source: CRIS - Carbone4.

of the risk that has an impact, but rather its perception that plays a significant role. Nonetheless, our investigation reveals that this increase is short-lived, consistently dissipating within one year.

The contribution of this research stands at the crossroads of several strands of existing literature. First, we contribute to the literature on climate risk pricing within the bond market (Seltzer et al., 2022; Amiraslani et al., 2023; Safiullah et al., 2021; Stellner et al., 2015). It is worth noting that this literature predominantly focuses on evaluating transition risk. Few contributions deal with the pricing of physical risk, and even fewer delve into its implications for the bond market. In this regard, the closest paper to ours is Ginglinger and Moreau (2019), which uses the same database on forward-looking physical risk (CRIS) on an U.S. firms sample from 2010 to 2019. While their primary focus is on the impact of physical risk on capital structure, a segment of their research focuses on the role of bond financing. Notably, they find an increase in interest rates in the bond markets for highly-exposed firms following the Paris Agreement. Given that there is limited existing research on the subject, our study first contribution is to offer new insights into the pricing of physical risk, a dimension that holds longer-term significance for investors.

A majority of research in this field has primarily focused on the U.S. market. Nevertheless, it is crucial to highlight the role played by the European bond market as well. Indeed, at the end of 2021, the euro area represented around 12% of the world non-financial corporations bond market.¹ Our second contribution is to initiate this study on the Eurozone corporate bond market. As pointed out by Darmouni and Papoutsis (2022), the Eurozone initially leaned toward a bank-centered system, but since 2000, the

¹See Tresor-Economics note No. 313 of September 2022

bond market has outpaced the banking sector's growth. This shift is attributed to reduced access to bank loans after the Global Financial Crisis and stricter regulations. The authors also note a surge in smaller, higher-risk issuers in recent years. Given this transformation, it's crucial to study the evolving euro area bond market. Our third and final contribution pertains to the body of literature that examines the revision of beliefs. As exemplified in studies such as Letta et al. (2022), market prices adapt to the non-linear effects of unusual weather. In this paper, our objective is to offer new evidence regarding how past events play a role in shaping awareness and, consequently, how they influence risk premiums (Chen et al., 2012). We demonstrate that after natural disasters occur, there is a rise in the risk premium, thus supporting the theory of belief revision.

The remainder of this paper is structured as follows: In Section 3.2, we provide an overview of the literature and outline our hypotheses. Section 3.3 is dedicated to presenting our data and offering some descriptive statistics. Section 3.4 delves into our examination of the influence of forward-looking physical risk on the euro area bond market. In Section 3.5, we explore the market's response following natural disasters. Our robustness analysis is presented in Section 3.7.5. Subsequently, in Section 3.5.2, we scrutinize the proximity of the risk. Finally, Section 3.6 provides our concluding remarks.

3.2 Literature review and hypothesis development

The majority of studies examining how climate risk is assessed in the bond market primarily concentrate on transition risk. This can be explained by the anticipated costs associated with the transition to a more environmentally sustainable economy, including regulatory risk stemming from changes in regulations and reputational risk arising from shifts in investor perceptions and beliefs. Seltzer et al. (2022) find a link between poor environmental performance of companies and the amplification of yield spreads alongside a reduction in credit ratings, particularly for companies functioning in areas with strict environmental regulation. In the same vein, Amiraslani et al. (2023) find that during the 2008 financial crisis, the secondary market bond spreads of high Environmental and Social (E&S) firms did not rise as much as the spread of low E&S firms. Moreover, Safiullah et al. (2021) found that emissions have a significant negative effect on credit ratings and that the effect of direct emissions is more pronounced. Nonetheless, it's important to emphasize that these studies specifically deal with on the U.S. market. In contrast, Stellner et al. (2015) find no consistent evidence that high Corporate Social Performance (CSP) reduces credit risks in the euro area.

On the contrary, there is a limited body of literature that delves into the pricing of physical risks (i.e. natural disasters) in the bond market. This can be explained by the fact that these climate risk seems less of a concern for investors. The issue of climate change is examined in a comprehensive survey

conducted by Stroebel and Wurgler (2021) involving various actors of the financial domain. The findings indicate that respondents commonly regard regulatory risks as the more immediate climate concern, whereas physical climate risks are viewed as longer-term risks, extending over the next three decades.

However, a part of the literature has demonstrated that physical risk poses a significant threat to companies' profitability, financing, and investment. Thus, Kling et al. (2021) identified that companies with greater exposure to climate risks experience elevated financing expenses and encounter more pronounced financial limitations. Similarly, Huynh et al. (2020) reveal that droughts lead to higher funding costs for businesses. The study carried out by Hosono et al. (2016) reveal a decline in the capital investment ratio of firms subsequent to the Hanshin-Awaji earthquake. Additionally, Basker and Miranda (2018) found a decrease in the survival rate of smaller and less productive companies following the aftermath of Hurricane Katrina.

These studies provide insights into the adverse impact of natural disasters on firms' operations, subsequently elevating the risks they encounter. However, the evidence regarding the pricing of these risks are mixed. For instance, Correa et al. (2020) demonstrate that borrowers indirectly affected by natural disasters tend to experience higher spreads on their loans subsequent to such events. This effect becomes more pronounced during periods of heightened media attention on climate change and in the case of the most severe disasters. Similarly, Huynh and Xia (2021) shows that firms investing in improving their environmental performance face lower costs for their debt financing and better respond when physical risk materialized. In contrast, Manela and Moreira (2017) conclude that natural disasters do not serve as robust predictors for market returns. Furthermore, Hong et al. (2019) find inefficiencies in stock markets related to the pricing of information concerning drought trends, particularly within the food industry sector.

Few studies have examined the valuation of natural disaster risks on the bond market. Furthermore, those that have tend to focus on the municipal bond market. Painter (2020) emphasize the importance of beliefs about the forward-looking climate risk in the U.S. municipalities bond market. Investors factor take into account uncertainty when evaluating municipal bonds issued in counties with elevated climate change risk, irrespective of whether those counties will ultimately experience the effects of climate change. This conclusion, however, is particularly relevant to long-term municipal bonds. Additionally, Goldsmith-Pinkham et al. (2022) identify a substantial impact of sea level rise risk on default risk for municipal bonds, with this effect being found across both short and long-term maturities, albeit more pronounced in the long term.

Regarding physical risk, it is important to note that channels at stake are not reputational nor regulatory. Regarding physical risks, the primary mechanism at play involves the risk of deteriorating the balance sheet and devaluing assets. Indeed, bonds' pricing should react to the potential threat

of natural disasters shocks, which can introduce uncertainty for companies in terms of profitability, funding expenses, credit reimbursement and operational costs. With regard to the literature, the first research question we investigate is the following: are firms exposed to high forward-looking risk of natural disasters bear higher risk premia in their bonds ? In this line, we exclusively focus on the forward-looking risk of natural disasters, based on medium-term scenarios. Nevertheless, past encounters with similar risks can shape behaviors in relation to this particular risk. Bourdeau-Brien and Kryzanowski (2020) demonstrate through their empirical findings that natural disasters induce a notable and meaningful rise in risk aversion at the local level. This effect can potentially enhance the perceived importance of risk management initiatives and infrastructural investments. Furthermore, the theoretical framework of Chen et al. (2012) demonstrates that the premium for physical risk is expected to be minimal during normal periods. Nonetheless, after a catastrophic event, this risk premium will experience a significant surge. This is due to the fact that the natural disasters' impact on consumption and wealth alters the outlook of optimistic investors, leading them to align their beliefs regarding disasters with those of pessimistic counterparts. The findings of Kruttli et al. (2019) are consistent with the aforementioned model. Specifically, their research identifies instances of under-reaction in stock returns to the volatility generated by hurricanes. Although hurricanes did not lead to increased expected returns for affected companies across the entire dataset, following Hurricane Sandy, hit firms did experience positive expected returns in the wake of this event. Subsequently, it becomes clear that the perception of risk is influenced to a certain extent by the experience of it. Indeed, significant past events can mold perceptions of potential future risks. These insights provide the foundation raising a follow-up research question. The occurrence of a natural disaster should update the beliefs, making the risk associated more imminent. Hence, we investigate whether in the wake of natural disasters events there is a rise in the risk premia for euro area bonds.

3.3 Data

3.3.1 Construction of the sample, measure of risk and control variables

We focus in our study on the Eurozone. First, we employ Thomson Reuters Eikon to identify non-financial companies situated within the euro area that have issued bonds denominated in euros. While a majority of studies concentrate on the US bond market, we opt to delve into the euro area market in order to bring novel insights into the valuation of climate risk. Subsequently, we proceed with the task of integrating these companies into the Climate Risk Impact Screening (CRIS) database provided by Carbon4. This database provides details regarding the potential physical risks attributed to forthcoming climate changes for companies. Employing the ISIN code, we establish a correspondence with the CRIS

database, resulting in a dataset of 223 companies that have issued a total of 1,564 bonds.

Our dependent variable is computed as the monthly yield spread at the level of individual bonds, enabling us to gauge the associated risk with each bond. The spread is determined in the following manner: on a monthly basis, we take the mid yield of a bond i from Thomson Reuters Eikon and subtract the yield corresponding to the same remaining maturity from the yield curve constructed by the European Central Bank (ECB). This yield curve is established using a Svensson model and encompasses all issuers with a triple-A rating, which is regarded as risk-free. The ECB's yield curve starts at a maturity of 10 months and extends up to 30 years.² Additionally, we apply a 1% winsorization to the spread to prevent our outcomes from being influenced by outliers. Subsequently, we retain only those bonds for which we possess yield-related information, resulting in a subset of 1,000 bonds originating from 190 distinct firms.

Next, we narrow our focus to exclusively include bonds that hold ratings from one of the prominent rating agencies (S&P, Fitch, Moody's). Lastly, we eliminate certain bond types, namely convertible, exchangeable, puttable, floating, zero-coupon, perpetual, preferred, structured, and asset-backed securities as it is common in the literature. Ultimately, after applying filters and accounting for the availability of control variables, our dataset comprises an unbalanced panel of 666 bonds stemming from 115 euro area companies, spanning the time frame from 2014 to 2022 and covering 8 countries.

Concerning the control variables, we follow the literature (Stellner et al., 2015; Seltzer et al., 2022; Amiraslani et al., 2023) by incorporating both bond-level and firm-level characteristics (see Section 3.7.2 for details on the variables construction).

At the bond level, we incorporate variables such as the logarithm of the issued amount, time to maturity, callable indicator, coupon rate, Roll illiquidity, and credit ratings. These control variables come from Thomson Reuters Eikon. Ratings are transformed into numerical values, with 1 corresponding to the lowest grade (D) for S&P and Fitch, and (C) for Moody's, while 22 corresponds to the highest grade (AAA) for S&P and Fitch, and (Aaa) for Moody's.³ In cases where a bond receives ratings from multiple agencies, we retain the highest grade, representing the best rating. Concerning the monthly absolute Roll measure of illiquidity ($\hat{\lambda}$) the objective is to reproduce a theoretical bid-ask spread based on daily close price (see Section 3.7.2 for the complete formula).

At the firm level, we incorporate the logarithm of total assets, leverage, debt service capability, cash to assets, operating profit margin, tangibility, annual returns and the CAPEX ratio. We also add the monthly volatility of returns calculated on a rolling window of one year. Additionally, a carbon premia can arise when looking at the risk associated to a bond (Safiullah et al., 2021). Hence, we control for the

²For bonds that maturities are lower than 10 months, we employ the 10-months ECB yield as the reference yield, while for maturities exceeding 30 years, the 30-year yield is used.

³See Table 3.7.1 for details.

carbon risk by adding as control the carbon intensity of firm.

Finally, as we work on a sample of multiple euro area countries, we opt to account for the coping capacity in term of natural disasters in the country where the firm's headquarters are situated. This consideration is prompted by the understanding that these factors could significantly influence bond pricing in terms of how the anticipated effects are perceived.

3.3.2 Climate Risk Impact Screening (CRIS)

CRIS (Carbon Risk Integration System), is a database created by Carbon4.⁴ This database computes indicators related to potential physical risks arising from anticipated climate changes. With regard to evaluating climate risk at the firm level, the calculations rely on climate projections tailored to particular geographical areas and vulnerabilities specific to various sectors. Each climate risk rating is determined by combining location-specific climate hazards with sector-specific vulnerabilities.

The indicators are derived from the scenarios presented in Assessment Report 5 of the Intergovernmental Panel on Climate Change (IPCC), encompassing three scenarios of emission levels (low, medium, and high) and for two horizons (2050 and 2100). Given that we analyse bonds with a moderately near-term maturity (average year to maturity of about 8 years), we concentrate on the 2050 horizon and specifically focus on the high-emission scenario.⁵ However, as mentioned in the work of Ginglinger and Moreau (2019), it is important to bear in mind that climate risk will progressively manifest in the years ahead.

The ratings are computed using a bottom-up approach, encompassing a numerical range from 0 to 99. For instance, in the case of a company engaged in diverse sectoral activities across various countries, the assessment is initially carried out for each sector within each country, before being aggregated at the company-wide level.⁶ The identification of a firm's activities is established through its financial statements. In the situation, where a firm operates across multiple business segments (encompassing various sectors and countries), the risk rating for each hazard is determined by calculating the weighted mean of all the risk ratings computed for each of the firm's business segments for that particular hazard. The weights are determined by the proportional contribution of the firm's revenue or fixed assets (in case of capital-intensive segments) within each segment. For each hazard, the risk rating attributed to a specific sector within a specific country is a composite of the country's hazard rating and the sector's vulnerability rating. To illustrate the computation of the score see Appendix 3.7.1, where we provide CRIS example for a fictional firm.

The database provides seven distinct sub-scores tailored to various types of climate hazards: increase

⁴You will find more details on the Carbon4 organism and the database here.

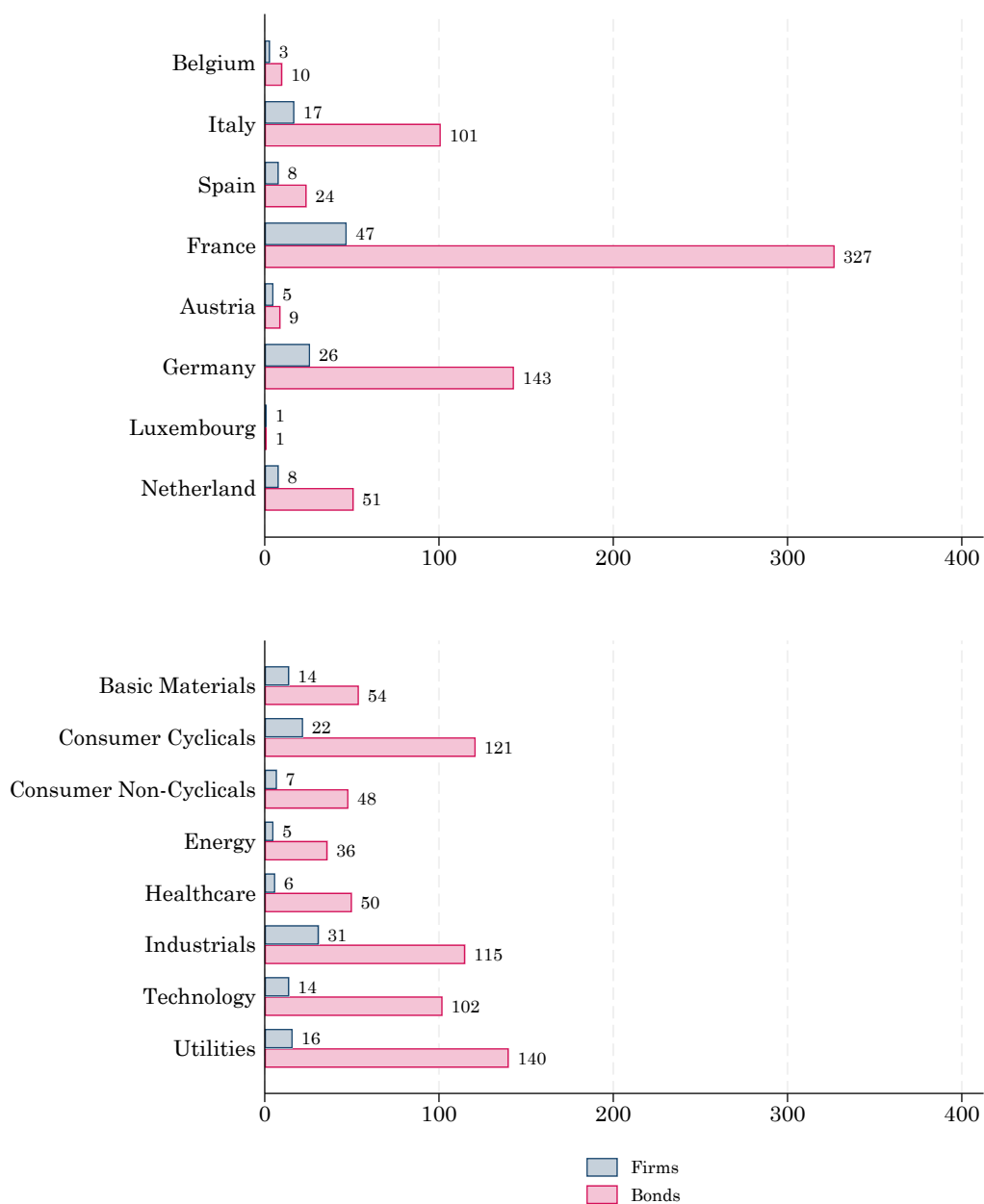
⁵You will find the results using the medium-emission scenario in Section 3.5.4.

⁶CRIS considers data from 210 countries and 60 sectors.

in average temperature, increase in heatwaves, amplification of droughts, alterations in rainfall patterns, augmentation in heavy rainfall, rise in sea levels, and intensification of storms. Additionally, an aggregate score is available, which is computed as the weighted geometric mean derived from all the risk ratings calculated for each of the seven aforementioned hazards.

3.3.3 Descriptive statistics

Figure 3.3.1: Geographic and sectoral composition of the sample



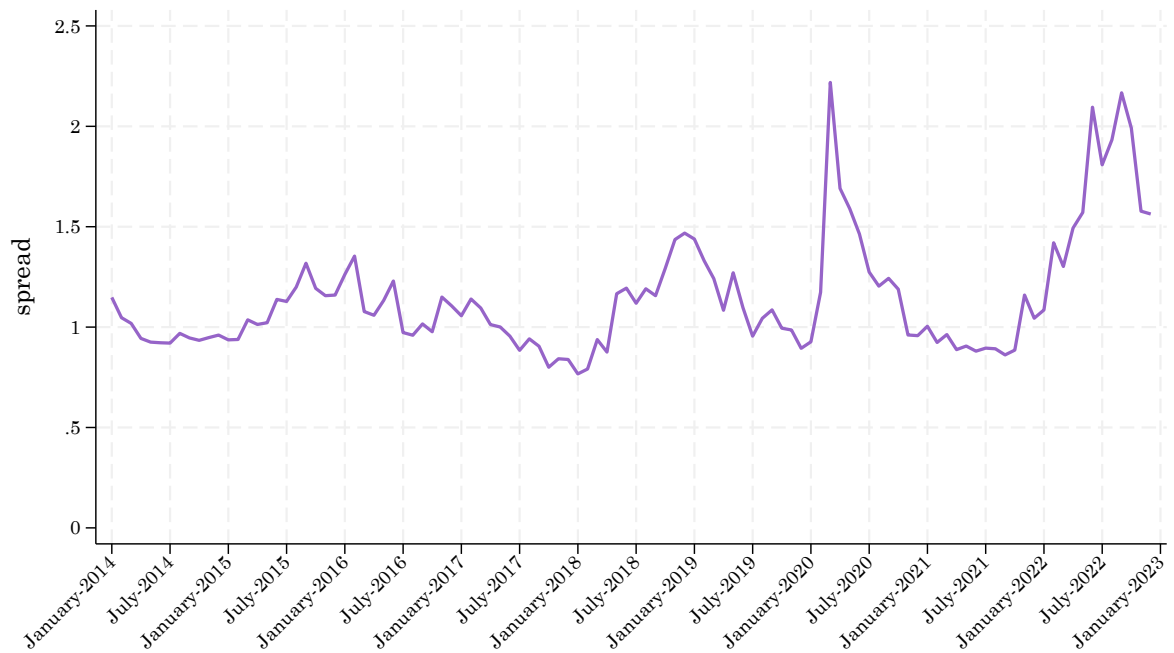
Note: The bars represent the number of firms (blue) or bonds (bond).

Our analysis is based on the euro area. As shown by Figure 3.3.1 we have collected bonds from 8 countries due to the availability of the data. Nonetheless, to analyse changes in awareness we use as natural disasters all the event happening in the 20 countries that are part of the Eurozone. However, as shown by Figure 3.3.1 we have collected bonds from 8 countries due to the availability of the data. Our sample contains a greater number of firms from France and Germany, which are responsible for issuing the majority of bonds in our dataset, approximately 70.5%. This is due to the fact that France and Germany represent a large share of the European corporate bond market (European Commission, 2017). When examining the sectoral distribution, our sample is more evenly distributed. Despite the prevalence of certain sectors, both in terms of firms and bonds—namely Utilities, Consumer Cyclicals, Industrials, and Technology—the overall sectoral distribution seems to be more balanced.

The summary statistics for all our variables can be found in Table 3.7.2. However, our current focus will be directed towards a more detailed examination of both our dependent variable and the variable of interest.

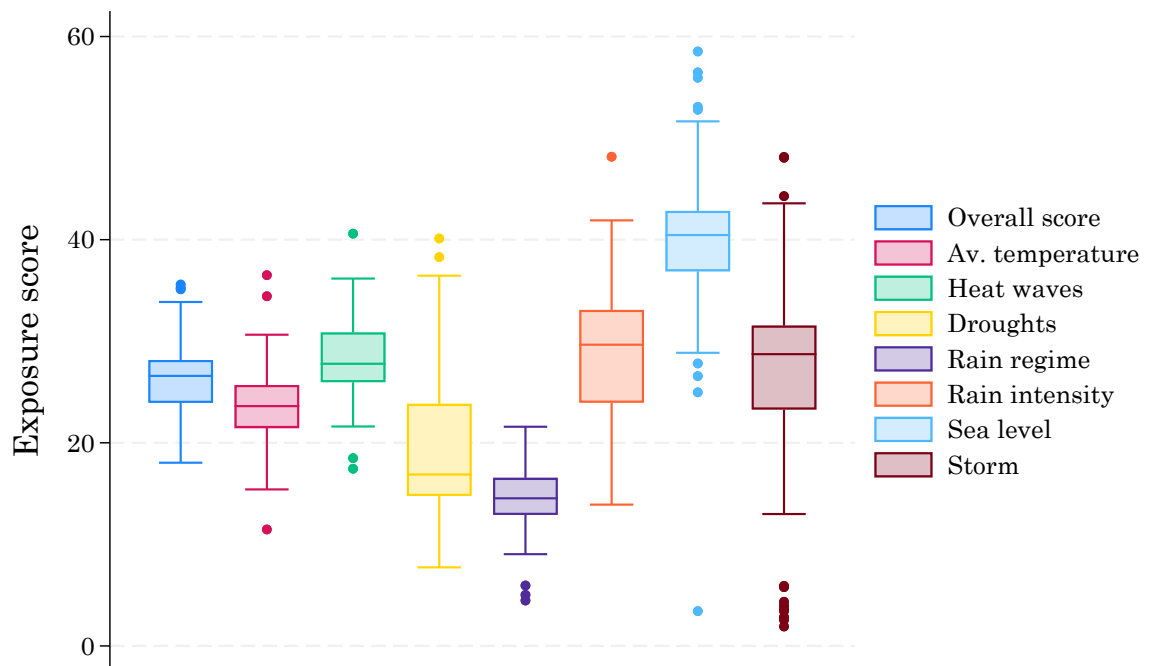
Examining Figure 3.3.2, it appears that the average spread across our sample seems to center around 100 basis points (1%), except towards the end of our observed period. Indeed, the substantial spike in spread at the outset of 2020 corresponds to the period of the Covid-19 pandemic, and this spike is mitigated following the introduction of the Pandemic Emergency Purchase Programme (PEPP) jointly with Government-guaranteed loan (GPL) and the use of macroprudential instruments. Additionally, the notable increase starting in 2022 coincides with the European Central Bank's decision to raise interest rates. One of the advantages of working at the euro area level is the homogeneity of risks. This mitigates our concerns about a different exposition to other shocks.

Figure 3.3.2: Average spread evolution



Note: The line represent the average spread in our sample, by month.

Figure 3.3.3: Distribution of exposure scores



Note: In this box plot, the points represent the outliers. Starting from the top, the first line is the upper adjacent value, the second is the upper quartile, the third is the median, the fourth is the lower quartile and the fifth the lower adjacent value.

Finally, Figure 3.3.3 depict the distribution of natural disasters exposure scores across natural disasters hazards. Within the CRIS database, it is possible to access information on various types of exposures, encompassing both *acute risks* (heat waves, droughts, and storms) as well as *chronic risks* (average temperature, rainfall regime, rain intensity, and sea level). We discern that within this plot the most elevated risk within our dataset is associated with sea level exposure. Moreover, among the categories considered, the distributions for drought, rain intensity, and storms exhibit the highest levels of dispersion. However, when we narrow our focus to the high-risk segment (top quartile), it becomes apparent that the most significant risks are linked to heat waves, rain intensity, and storms. On the other hand, it seems that concerns related to rain patterns and droughts are less prominent within our sample. The distribution of the overall score appears relatively concentrated, with an upper quartile score of around 28.5, a median score of 26.7, and a lower quartile of 24.

This analysis highlights that exposure heterogeneity is more pronounced when examining sub-scores as opposed to the overall score.

3.4 The pricing of forward-looking natural disaster risk on the euro area bond market

The first step of our analyse in to investigate how forward-looking risks of natural disasters are priced on the euro area bond market. They can be priced or not, according to the importance given by the investors.

Our identification strategy for this first hypothesis is based on a panel model that allow us to control for all the traditional determinants of bonds spread. Our focus is on the interpretation and the significance of the relation between the forward-looking exposure of the firm and its bonds spread. Then, we estimate the following model using monthly spread data:

$$Y_{i,t} = \beta_1 ExposureScore_j + \beta_2 W_{i,t} + \beta_3 X_{j,t-1} + \beta_4 Z_{c,t-1} + FE + \varepsilon_{i,t}, \quad (3.1)$$

where $Y_{i,t}$ is our dependent variable, the monthly spread for a corporate bond i at time t . $ExposureScore_j$ is our variable of interest, the forward looking exposure score to natural disasters for a company j that have emitted the bond.⁷ We will consider 8 exposure scores. $W_{i,t}$ represent a set of bond-specific characteristics that can influence the spread behavior.⁸ As bond-level characteristics we use: logarithm of the amount issued, year to maturity, callable status of the bond, coupon rate, credit rating and absolute

⁷Note that we use in the main table this measure as a continuous variable, but we will explore the potential nonlinearities by converting it into a dummy that will take the value of 1 for the top-quartile (i.e. the most exposed firms).

⁸Note that the controls variables can be time-varying or not

Roll measure of illiquidity. $X_{j,t-1}$ represent a set of firm-specific characteristics at $t - 1$. We include at a firm level: logarithm of total assets, leverage, debt service capability, cash to assets, operating profit margin, tangibility, annual returns, volatility of returns, CAPEX ratio and the carbon intensity.⁹ Finally, $Z_{c,t-1}$ represents a country specific time-varying characteristic in $t-1$, the lack of coping capacity.

All our specifications include both time and industry fixed effects (columns (1), (3), (5) and (7)), and in some of them we add country fixed effects (columns (2), (4), (6) and (8)). Our standard error are clustered at the firm level to control for cross-sectional dependence.

Our results are presented in Table 3.4.1 and Table 3.4.2.

Our interest lies in the relation between the exposure and the bond spread. We estimate 8 models with different exposure measures. First, we consider the overall score. Then, we investigate individually the 7 sub-score constituting the main score. Column (1) and (2) in Table 3.4.1 do not provide any indication of a significant pricing related to the overall risk of future natural disasters. Ginglinger and Moreau (2019) found a significant effect of the overall risk after the Paris Agreement on the cost of bonds, only for high risk firms. However, even when transforming the exposure score into a more restrictive definition for high-risk and low-risk firms we find no significant pricing of the overall risk (column (1) in Table 3.7.3). This could be due to the fact that we work in a more narrow geographic area (i.e. the euro area). With the Paris Agreement, there is an universal acknowledgment of environmental concerns. To be sure that the pricing is not appearing only after this significant event, we re-estimate our model starting in November 2016, as detailed in Section 3.5.3.

However, intriguing patterns emerge while examining the dis-aggregated indicators. Only a subset of the forward-looking disaster risks are accurately priced into the bond costs. Indeed, we notice that only the risks of heat waves and droughts (columns (5) to (7) in Table 3.4.1) have a significant and positive impact on the rise of the spread. However, the impact of drought risk disappear when taking into account country fixed effect that are essential to encompass geographical features (column (8) in Table 3.4.1). Interestingly, the risks associated with rain intensity and storms (columns (3) and (7) in Table 3.4.2) are priced significantly in the opposite sign, yet these effects also vanish when country fixed effects are introduced (columns (4) and (8) in Table 3.4.2). In this particular specification, the sole effect that stands out as robust is the heat waves exposure. To provide a more insightful interpretation, our findings indicate that an elevation of one standard deviation in heat wave exposure (3.53) leads to a 92 basis points rise in the spread. Considering that the mean spread within our sample is 1.22, this effect corresponds to a 75% increase relative to the average spread.

In order to examine the possibility of non-linearities in the relation between the spread and exposure

⁹Following the literature, we winsorized the spread and the following controls : illiquidity, logarithm of total assets, leverage, debt service capability, operating profit margin, tangibility, annual returns, volatility of returns, CAPEX ratio and carbon intensity.

Table 3.4.1: Natural disasters exposure and bond spreads - 1/2

	Overall score		Av. temperature		Heat waves		Droughts	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Exposure score	-0.012 (0.014)	-0.000 (0.013)	0.020 (0.016)	0.009 (0.016)	0.038*** (0.014)	0.026* (0.014)	0.016** (0.007)	0.010 (0.007)
Log of amount issue	-0.016 (0.028)	-0.029 (0.026)	-0.021 (0.027)	-0.030 (0.025)	-0.016 (0.026)	-0.026 (0.024)	-0.010 (0.027)	-0.024 (0.025)
Year to maturity	0.021*** (0.004)	0.021*** (0.004)	0.021*** (0.004)	0.021*** (0.004)	0.021*** (0.004)	0.021*** (0.004)	0.021*** (0.004)	0.021*** (0.004)
Callable	0.130** (0.065)	0.219*** (0.057)	0.129** (0.064)	0.215*** (0.057)	0.133** (0.063)	0.205*** (0.054)	0.133** (0.067)	0.219*** (0.057)
Coupon rate	0.076*** (0.023)	0.080*** (0.024)	0.075*** (0.024)	0.079*** (0.025)	0.072*** (0.024)	0.077*** (0.024)	0.072*** (0.023)	0.079*** (0.024)
Ratings	-0.216*** (0.028)	-0.206*** (0.028)	-0.220*** (0.028)	-0.209*** (0.028)	-0.224*** (0.029)	-0.217*** (0.029)	-0.226*** (0.029)	-0.212*** (0.029)
Illiquidity measure	0.507*** (0.090)	0.492*** (0.086)	0.505*** (0.090)	0.491*** (0.086)	0.498*** (0.088)	0.487*** (0.084)	0.499*** (0.089)	0.488*** (0.086)
Logarithm total assets	0.014 (0.040)	0.067* (0.039)	0.015 (0.042)	0.068* (0.038)	0.014 (0.042)	0.064* (0.038)	0.029 (0.043)	0.074* (0.039)
Leverage	0.062** (0.029)	0.070** (0.029)	0.073*** (0.028)	0.075** (0.030)	0.081*** (0.029)	0.080** (0.031)	0.073** (0.029)	0.072** (0.030)
Debt service capability	0.005 (0.003)	0.003 (0.003)	0.003 (0.003)	0.003 (0.003)	0.004 (0.003)	0.003 (0.003)	0.005* (0.003)	0.004 (0.003)
Cash to assets	-0.003 (0.002)	-0.002 (0.002)	-0.003 (0.002)	-0.002 (0.002)	-0.004* (0.002)	-0.002 (0.002)	-0.004* (0.002)	-0.002 (0.002)
Operating profit margin	-0.004 (0.004)	-0.005 (0.003)	-0.005 (0.004)	-0.006 (0.003)	-0.005 (0.004)	-0.005 (0.003)	-0.005 (0.004)	-0.005 (0.003)
Tangibility	0.048 (0.267)	-0.036 (0.283)	0.073 (0.253)	-0.025 (0.283)	0.014 (0.242)	-0.083 (0.274)	-0.016 (0.251)	-0.083 (0.268)
Annual returns	-0.981*** (0.371)	-1.016*** (0.366)	-0.918** (0.377)	-1.004*** (0.367)	-0.901** (0.360)	-0.982*** (0.359)	-0.883** (0.368)	-0.979*** (0.363)
Volatility of returns	2.875*** (0.591)	2.702*** (0.569)	2.682*** (0.571)	2.652*** (0.560)	2.618*** (0.586)	2.577*** (0.580)	2.721*** (0.561)	2.648*** (0.561)
CAPEX ratio	0.007 (0.005)	0.006 (0.005)	0.009* (0.005)	0.007 (0.005)	0.004 (0.005)	0.005 (0.005)	0.005 (0.005)	0.005 (0.005)
Carbon intensity	0.540 (0.997)	0.656 (0.790)	0.117 (0.920)	0.525 (0.755)	0.645 (0.746)	0.741 (0.737)	0.229 (0.914)	0.580 (0.776)
Lack of coping capacity	0.400*** (0.124)	-0.254 (0.211)	0.389*** (0.127)	-0.251 (0.212)	0.204 (0.135)	-0.235 (0.209)	0.267** (0.126)	-0.249 (0.210)
Time FE	✓	✓	✓	✓	✓	✓	✓	✓
Sector FE	✓	✓	✓	✓	✓	✓	✓	✓
Country FE		✓		✓		✓		✓
N	30998	30998	30998	30998	30998	30998	30998	30998
Number firms	115	115	115	115	115	115	115	115
Number bonds	666	666	666	666	666	666	666	666
R ²	0.697	0.713	0.699	0.713	0.704	0.715	0.700	0.714

Significance levels are: * p < 0.10 ; ** p < 0.05 ; *** p < 0.01

3.4. THE PRICING OF FORWARD-LOOKING NATURAL DISASTER RISK

Table 3.4.2: Natural disasters exposure and bond spreads - 2/2

	Rain Regime		Rain Intensity		Sea level		Storm	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Exposure score	-0.025 (0.020)	-0.022 (0.021)	-0.014** (0.007)	-0.011 (0.008)	-0.009 (0.005)	-0.006 (0.006)	-0.009* (0.005)	0.000 (0.006)
Log of amount issue	-0.021 (0.028)	-0.032 (0.027)	-0.016 (0.027)	-0.027 (0.025)	-0.012 (0.029)	-0.026 (0.027)	-0.013 (0.027)	-0.030 (0.026)
Year to maturity	0.021*** (0.004)	0.021*** (0.004)	0.021*** (0.004)	0.021*** (0.004)	0.021*** (0.004)	0.021*** (0.004)	0.021*** (0.004)	0.022*** (0.004)
Callable	0.125* (0.064)	0.220*** (0.056)	0.127* (0.064)	0.216*** (0.056)	0.137** (0.067)	0.223*** (0.057)	0.147** (0.063)	0.219*** (0.057)
Coupon rate	0.074*** (0.023)	0.082*** (0.024)	0.072*** (0.023)	0.079*** (0.024)	0.078*** (0.024)	0.082*** (0.025)	0.078*** (0.024)	0.080*** (0.024)
Ratings	-0.226*** (0.026)	-0.207*** (0.026)	-0.214*** (0.027)	-0.203*** (0.027)	-0.218*** (0.027)	-0.204*** (0.027)	-0.208*** (0.028)	-0.206*** (0.027)
Illiquidity measure	0.508*** (0.090)	0.495*** (0.086)	0.509*** (0.089)	0.494*** (0.086)	0.503*** (0.089)	0.491*** (0.086)	0.502*** (0.090)	0.492*** (0.086)
Logarithm total assets	0.030 (0.040)	0.071* (0.036)	0.011 (0.038)	0.060 (0.036)	0.011 (0.041)	0.060 (0.040)	0.024 (0.040)	0.067* (0.038)
Leverage	0.055** (0.027)	0.059** (0.029)	0.059** (0.027)	0.064** (0.029)	0.069** (0.029)	0.071** (0.030)	0.063** (0.028)	0.070** (0.030)
Debt service capability	0.005* (0.003)	0.004 (0.003)	0.005* (0.003)	0.004 (0.003)	0.005 (0.003)	0.003 (0.003)	0.004 (0.003)	0.003 (0.003)
Cash to assets	-0.003 (0.002)	-0.002 (0.002)	-0.003* (0.002)	-0.002 (0.002)	-0.003 (0.002)	-0.002 (0.002)	-0.003 (0.002)	-0.002 (0.002)
Operating profit margin	-0.004 (0.004)	-0.005 (0.003)	-0.005 (0.003)	-0.005 (0.003)	-0.003 (0.003)	-0.005 (0.003)	-0.005 (0.004)	-0.005 (0.003)
Tangibility	-0.025 (0.257)	-0.085 (0.267)	0.005 (0.264)	-0.079 (0.276)	0.077 (0.263)	-0.010 (0.281)	-0.013 (0.272)	-0.035 (0.285)
Annual returns	-0.988*** (0.367)	-1.058*** (0.358)	-1.038*** (0.359)	-1.095*** (0.349)	-0.969** (0.371)	-1.033*** (0.363)	-0.990*** (0.372)	-1.014*** (0.364)
Volatility of returns	2.752*** (0.531)	2.681*** (0.530)	2.947*** (0.554)	2.810*** (0.525)	2.840*** (0.558)	2.755*** (0.554)	2.921*** (0.591)	2.696*** (0.555)
CAPEX ratio	0.007 (0.005)	0.006 (0.005)	0.006 (0.005)	0.005 (0.005)	0.006 (0.005)	0.005 (0.005)	0.006 (0.005)	0.007 (0.005)
Carbon intensity	0.599 (1.013)	1.036 (0.755)	0.907 (0.896)	1.087 (0.764)	0.334 (1.002)	0.749 (0.768)	1.058 (0.919)	0.634 (0.816)
Lack of coping capacity	0.434*** (0.123)	-0.244 (0.214)	0.369*** (0.120)	-0.266 (0.209)	0.396*** (0.122)	-0.255 (0.208)	0.283** (0.120)	-0.254 (0.210)
Time FE	✓	✓	✓	✓	✓	✓	✓	✓
Sector FE	✓	✓	✓	✓	✓	✓	✓	✓
Country FE		✓		✓		✓		✓
N	30998	30998	30998	30998	30998	30998	30998	30998
Number firms	115	115	115	115	115	115	115	115
Number bonds	666	666	666	666	666	666	666	666
R ²	0.700	0.715	0.700	0.714	0.699	0.713	0.700	0.713

Significance levels are: * p < 0.10 ; ** p < 0.05 ; *** p < 0.01

scores, we convert the exposure scores into dummy variables. These dummies will be equal to 1 when the firms fall within the top quartile of the distribution for each score. Results are presented in Table 3.7.3, we found that the results concerning the pricing of the heat waves risks are robust using the dummy. However, the positive pricing of droughts as well as the negative pricing of the rain intensity and storm exposure in the absence of country fixed-effect disappear. Moreover, we found a pricing of the average temperature only in the absence of country fixed-effect.

We notice that the control variables that are significant in our model have the expected signs, which can also explain the high R^2 we obtain. An increase in the time to maturity leads to higher spread, called the term risk. The risk increase with the duration due to the fact that more events might compromise the interest and principal payments (King and Khang, 2005). The callable feature of the bond is also important to take into account (Duffee, 1998). The positive and significant nature of being callable can be attributed to its heightened sensitivity to uncertainties concerning changes in interest rates. The effect of coupon rate is explained by tax-related effect (Krylova, 2016). The rationale behind the increased premium for a higher coupon rate lies in the fact that a lower coupon rate can lead to savings in tax expenses. The relationship between credit ratings and their impact remains highly consistent. The ratings assigned by agencies are meant to evaluate the level of risk associated with the issuer. Therefore, it is logical to infer that a higher rating (indicating a lower risk) would lead to a decrease in the premium. Concerning the measure of illiquidity, as shown in several paper, higher liquidity results in a lower spread (Acharya and Pedersen, 2005; De Jong and Driessen, 2012; Lin et al., 2011). On the contrary, higher illiquidity results in an higher spread. More leveraged firms have higher chances of default which can explain their higher spreads (Merton, 1974). We also find that higher annual returns lead to lower spreads. Returns can translate the healthiness of a company and also take into account cycles in the firm's environment. However, higher volatility of returns generate an increase of the premia as a result of higher uncertainty (Campbell and Taksler, 2003). We do not uncover any indications supporting the presence of a carbon premium within our dataset. It is important to note that there is currently no unanimous consensus in the academic literature regarding the existence of a carbon premium. Certain studies have identified a notable influence on returns (Bolton and Kacperczyk, 2021), while others have found no substantial effects (Görge et al., 2020). Lastly, with regard to the ability to handle natural disasters at the country level, we observe that this variable exhibits the expected effect when country fixed-effects are not considered. Specifically, when the issuing firm operates in a country with a greater deficiency in coping capacity, the risk associated with the bond tends to rise. However, this relationship becomes insignificant upon introducing country-specific effects, indicating that this aspect is likely to be incorporated within those fixed effects due to its limited temporal fluctuation.

Overall, our findings suggest limited pricing of forward-looking exposure risks over the analyzed

period. Consequently, it becomes clear that the consideration of physical risk is not a priority as it is not adequately priced within the euro area bond market, except in the case of heat waves exposure. This observation gives rise to our follow-up investigation: investors may only factor in this risk if they perceive it to be imminent. As a result, it is plausible to postulate that significant events involving natural disasters could influence the pricing of companies with high future exposure to these events.

3.5 The impact of natural disasters experience

In this section, our goal is to assess whether the occurrence of natural disasters in the Eurozone triggers a shift in investor beliefs and elevates their awareness of forthcoming physical risks. We then delve into whether this increase in awareness is a result of domestic disasters or extends more broadly across the euro area.

3.5.1 Changes in physical risk awareness

As stated previously, our follow-up hypothesis concern the update of beliefs that might affect the discount rate and create revisions in the pricing of bonds. As shown by Chen et al. (2012), disasters risk premium should be low during normal times. However, following a disaster event, the risk premium will increase substantially because the disaster affects the consumption and wealth of these optimistic investors, causing their beliefs about disasters to converge toward those of pessimists. Moreover, Malmendier and Nagel (2011) argued that macroeconomic shocks can have long-term repercussions on beliefs. Hence, we can wonder if it would be the case for natural disaster events. To test this, we add an interactive term to our previous model that is computed as the sum of previous damages caused by natural disasters in the euro area. We use different time-window for computing prior damages to see if the repricing effects hold in the long run.

We can argue that damages are usually prone to an endogeneity issue (Felbermayr and Groschl, 2014). Nevertheless, in this particular instance, concerns can be eased. First, the issue stems from disparities in reporting, which might vary significantly among countries with different level of income. Given our focus on the euro area, the potential differences become less worrisome. Second, we work on the reaction of investors: the objective here is not to have a proxy of the physical intensity of the disasters but rather a measure of visibility for investors. We want to measure how investor perceive the event.

Subsequently, in order to assess the impact of past disasters on bonds pricing within the euro area, we calculate the accumulated damages over the preceding time frames (3 months, 6 months, 1 year), rescaled by the Eurozone GDP. We consider multiple time horizons, recognizing that investor reactions may not be sustained over extended periods. This is especially relevant if investors exhibit short-sighted

tendencies, as their re-pricing behavior might not persist even following an important event. We estimate the following model:

$$Y_{i,t} = \beta_1 ExposureScore_j + \beta_2 ExposureScore_j \times \sum_{h=0}^m DamagesEA_t + \beta_3 W_{i,t} + \beta_4 X_{j,t-1} + \beta_5 Z_{c,t-1} + FE + \varepsilon_{i,t} \quad (3.2)$$

where $Y_{i,t}$ is our dependent variable, the monthly spread for a corporate bond i at time t . $ExposureScore_j$ is the forward looking exposure score to natural disasters for a company j that has emitted the bond. We will consider the score as a continuous variable as well as a dummy variable as previously in two sets of regressions to take into account potential non linearities. The bond-specific characteristics ($W_{i,t}$), the firm-specific characteristics ($X_{j,t-1}$) and the country-specific characteristic ($Z_{c,t-1}$) are the same as in the previous model. Here again, standard errors are clustered at the firm level. Our interest variable here is the interaction between the exposure and the cumulative previous damages (β_2). The cumulative damages are computed using the EM-DAT database from the the Centre for Research on the Epidemiology of Disasters (CRED). We select the 20 countries that are today part of the euro area and keep the following disasters: extreme temperature, drought, flood, wildfire and storm. For the overall exposure score we create a monthly variable that is the sum over the following months (3, 6 or 12) of the damages generated by all these disasters and we re-scale by the GDP of the area. Regarding the 7 sub-scores, we matched each of them with the corresponding disasters (refer to Table 3.5.1). Regrettably, due to the lower frequency of certain events and the absence of particular disasters, we are only able to perform this assessment for 4 of the sub-scores.

Table 3.5.1: Matched exposure score with corresponding disasters in the euro area

Exposure score	Corresponding disasters	Number of events ^a	Mean of damages ^b
Overall score	extreme temperature, drought, flood, wildfire, storm	188	2126.62
Average temperature	extreme temperature	32	6048.16
Rain intensity	flood	64	2734.02
Sea Level	flood	64	2734.02
Storm	storm	70	799.78

Note: ^a We only take into account events that have generated some damages. ^b The average damages per period where at least one disaster occurred. Damages are expressed in millions dollars adjusted by the consumer price index.

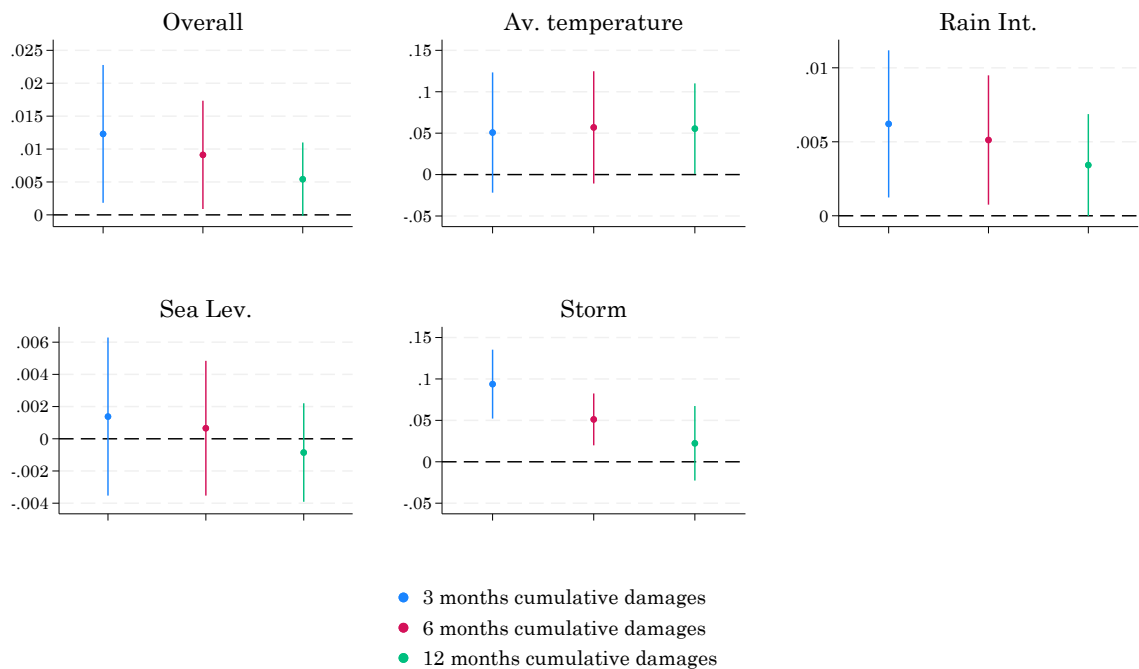
Within our dataset, we have documented the presence of 188 natural disaster events recorded in the euro area. The mean financial losses per month, when at least one disaster takes place, amount to \$2126.62 million. The most common occurrences are storms, with floods coming in a close second. On average, the most financially impactful disasters are those related to extreme temperatures.

The interaction term (β_3) is presented in Figure 3.5.1 when we consider the exposure as a continuous

variable and in Figure 3.5.2 when we transform the score in a dummy based on the top-quartile to define highly exposed firms.

Figure 3.5.1, suggests the presence of a pattern. When examining the overall exposure as well as rain intensity and storm exposure, the interaction coefficient (β_3) is significant. However, it has a noticeable decreasing trend in significance as we extend the timeframe for evaluating the impact of cumulative damages. This pattern indicates that market pricing incorporates the associated risks notably in the 3 to 6 months following specific natural disaster events that caused damages. However, when assessing the 12-months period leading up to the damages, the significance of the interaction coefficient vanishes. It is worth noting that the coefficient's magnitude declines with times.

Figure 3.5.1: Impact of former natural disasters on the spread according to the level of forward-looking exposure (continuous)



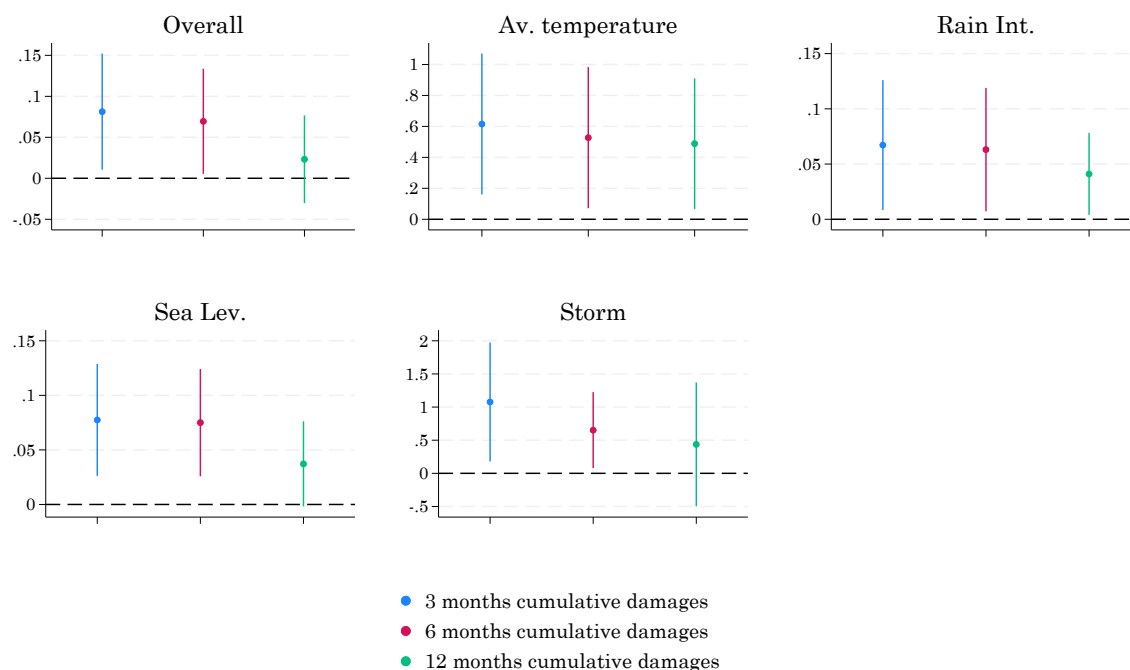
Note: This figure represent the interaction (β_3) between the exposure and the cumulative damages for the previous months (3 in blue, 6 in red and 12 in green). The coefficient are represented by the points and the line correspond to the confidence interval at 90%.

Additionally, we see than when considering the exposure as a continuous variable, there is no significant effect for the interaction between former damages and the average temperature exposure as well as the sea level exposure. The table corresponding to Figure 3.5.1 is available in Appendix (Table 3.7.4). To illustrate the impact for the overall score, for an average exposed firm in term of overall risk (26.5), an increase in one standard deviation in the 3 months prior cumulative damages (0.33) will result in an increase of the spread of 102 basis points¹⁰, which represent 8.36% of the average spread. The same

¹⁰ $0.102 = 0.33 \times (-0.009 + 26.5 \times 0.012)$

increase in the 6 months prior cumulative damages will result in an increase of the spread of about 76 basis points, which represent 6.23% of the average spread.

Figure 3.5.2: Impact of former natural disasters on the spread according to the level of forward-looking exposure (quartile)



Note: This figure represents the interaction (β_3) between the exposure and the cumulative damages for the previous months (3 in blue, 6 in red and 12 in green). The coefficients are represented by the points and the lines correspond to the confidence interval at 90%.

Focusing now on Figure 3.5.2 where the exposure is considered as a dummy variable based on the top-quartile, we note that the same pattern characterizes all of the sub-indicators (see Table 3.7.5). Indeed, in this configuration, for the average temperature and the sea level exposure we also have a significant and positive interaction with the prior damages associated. Subsequently, when introducing nonlinearities into the relationship and adopting a more stringent definition of exposure, we discover that all risks exhibit pricing adjustments following natural disaster events. However, this pricing effect is temporary, vanishing when we take into account the cumulative damages occurring over the one-year period preceding. Furthermore, when we extend the timeframe for assessing cumulative damages, the magnitude of the interaction shows a diminishing trend. To illustrate the effect concerning average temperature exposure, for a company classified as being highly-exposed to this risk (falling within the top quartile), an increase of one standard deviation in the damages related to extreme temperatures in the preceding 3 months (0.45) results in an expansion of approximately 0.330 basis points in the spread. This expansion corresponds to 27% of the average spread.

Overall, it can be observed across all climate hazard risks that there exists a pricing response to the

physical exposure of businesses following a natural disaster event resulting in damages. Nevertheless, investors appear to have a short memory, as the majority of the risk pricing vanishes for nearly all types of disasters when examining the accumulated damages spanning a one-year timeframe.

3.5.2 Proximity of the risk: domestic vs Eurozone

We go further into the analyse of the repricing effect by exploring whether it is exclusively happening after nearby events. It is conceivable that investor repricing takes place solely when an event directly impacts the country where the firm has its headquarter. Alternatively, we could anticipate that significant events occurring within the euro area, even if they do not directly affect the firm's home country, could lead to revisions in beliefs.

To examine this hypothesis, we divided the previous damages variable into two categories: domestic damages and damages occurring in the rest of the euro area. Then our model is now composed of two interactive variables. We interact first the exposure score with a the prior damages that happen in the euro area deducting the damages in the home country of the firm if any (β_2). We add an interaction between the exposure score and the prior damages in the home country if any (β_3). Then, we estimate the following model:

$$\begin{aligned}
 Y_{i,t} = & \beta_1 ExposureScore_j + \beta_2 ExposureScore_j \times \sum_{h=0}^m DamagesEAexcl_{i,t} \\
 & + \beta_3 ExposureScore_j \times \sum_{h=0}^m DamagesCountry_{i,t} + \beta_4 W_{i,t} + \beta_5 X_{j,t-1} + \beta_6 Z_{c,t-1} + FE + \varepsilon_{i,t}
 \end{aligned} \tag{3.3}$$

The dependant and the control variables remain the same and we still cluster standard errors at a firm level.

If the repricing of highly exposed firms is not only due to nearby risk we expect that the interaction between exposure score and the damages in the rest of euro area (β_2) will remain significant when adding a second interaction with domestic damages (β_3).

For this part of the analyse our attention will be directed towards the exposure score used as a binary variable. Since we have identified distinct nonlinear patterns in the impact based on the definition of exposure, employing the exposure score as a continuous variable might lead to misleading interpretations¹¹.

Looking at the results Table 3.5.2, we notice that non-realized risks (damages in the euro area) noticeably increase the bond risk for highly exposed firms, except for rain intensity exposure associated with flood damages. Interestingly, direct risks (damages in the firm's home country) appear to have an

¹¹You can still see the results when using exposure as a continuous variable in the Appendix Table 3.7.6. In the case of continuous exposure. The anticipated effect was observed exclusively in the context of storms, indicating that the repricing is influenced not only by national risks.

insignificant impact on raising the risk for highly exposed firms in almost all cases. These observations could potentially be clarified by the notion that rain intensity constitutes a highly localized risk. Consequently, even when a significant event takes place, its effects might not be widely applicable, leading to the observed results.

Table 3.5.2: The impact of home country natural disaster damages vs euro area damages according to the level of exposure (categorical)

	Overall	Av. Temp.	Rain Int.	Sea Lev.	Storm
Exposure score dummy	-0.008 (0.069)	0.117 (0.114)	-0.050 (0.057)	-0.124* (0.070)	0.059 (0.084)
— × cumulative damages 3m. euro area	0.088* (0.045)	0.730* (0.383)	0.053 (0.047)	0.091** (0.037)	0.915* (0.538)
— × cumulative damages 3m. Country	0.029 (0.042)	0.154 (0.127)	0.036 (0.027)	-0.025 (0.025)	0.221 (0.316)
Exposure score dummy	-0.015 (0.071)	0.110 (0.115)	-0.055 (0.057)	-0.129* (0.070)	0.060 (0.084)
— × cumulative damages 6m. euro area	0.078* (0.042)	0.710* (0.387)	0.048 (0.045)	0.089** (0.037)	0.457 (0.368)
— × cumulative damages 6m. Country	0.016 (0.037)	0.119 (0.119)	0.038 (0.028)	-0.025 (0.024)	0.055 (0.399)
Exposure score dummy	-0.019 (0.069)	0.096 (0.115)	-0.061 (0.056)	-0.133* (0.070)	0.056 (0.100)
— × cumulative damages 12m. euro area	0.010 (0.040)	0.655* (0.377)	0.014 (0.034)	0.040 (0.030)	-0.020 (0.552)
— × cumulative damages 12m. Country	0.040 (0.044)	0.118 (0.111)	0.047* (0.026)	0.003 (0.038)	0.331 (0.394)
Controls variables	YES	YES	YES	YES	YES
Time FE	✓	✓	✓	✓	✓
Sector FE	✓	✓	✓	✓	✓
Country FE	✓	✓	✓	✓	✓
N	30998	30998	30998	30998	30998
Number firms	115	115	115	115	115
Number bonds	666	666	666	666	666
R ²	0.717	0.719	0.717	0.719	0.717

Significance levels are: * p < 0.10 ; ** p < 0.05 ; *** p < 0.01

Furthermore, it is notable that the requirement for risk to be fully realized does not seem necessary, as damages incurred in other countries of the euro area are adequate to induce repricing effects. Moreover, the risk might not need to be truly realized as the damages caused in other country are sufficient to create a repricing. Nevertheless, this phenomenon appears to lack sustainability in the long run, leading us to deduce that investors tend to adopt a short-term perspective when it comes to this type of risk.

3.5.3 After Paris Agreement

As stated by numerous paper (Ehlers et al., 2022; Carbone et al., 2021; Ginglinger and Moreau, 2019), the Paris Agreement has a pivotal role in the reevaluation of climate-related risks. Our paper does not primarily seek to quantify the precise impact of the Paris Agreement on the enhancement of risk pricing. Instead, our objective is to ascertain the presence of effective pricing mechanisms. Consequently, within this section, we examine the robustness of our findings within the context of the post-Paris Agreement, from November 2016 to December 2022. In Table 3.7.7, we propose a investigation on the pricing of physical risks post Paris-Agreement. The evidence of robust significant pricing remains elusive. Comparable outcomes emerge when examining pricing as a discrete variable categorized by quartiles, as depicted in Table 3.7.8. Notably, only the valuation of heat waves exposure appears to be robust.

We additionally examine whether in this setting natural events prompt a short-term reevaluation of more exposed companies if we focus solely on the period following the Paris Agreement. Observing Table 3.7.9, we notice that when considering the exposure to forward-looking physical risk as a continuous measure the results the outcomes retain their overall significance. Specifically, rain intensity and storm exposure exhibit continued statistical significance when considering cumulative damages over 3 and 6 months. However, it is noteworthy that the coefficients exhibit a higher magnitude. An increase of one standard deviation in the cumulative damages over the preceding 3 months (0.33) results in an amplified spread of 0.111 basis points for an averagely exposed firm concerning overall vulnerability, as opposed to the previous value of 0.102 basis points during the entire period. Furthermore, it's worth mentioning that the impact of 1-year cumulative prior damages is significant for overall vulnerability and rain intensity in the context of the post Paris-Agreement period, a phenomenon not observed when considering the all period. When considering the exposure as a categorical variable (see Table 3.7.10), we notice the same pattern of significance. Nevertheless, it is noteworthy that the impact magnitudes, with the exception of firms highly susceptible to average temperature rise risk, exhibit greater values during the post Paris-Agreement period.

Based on the insights gained from this robustness assessment, it can be deduced that the Paris Agreement did not substantially alter the European valuation of forward-looking physical risk. However, in terms of the reevaluation subsequent to natural disaster events, the impacts appear to exhibit a more pronounced magnitude.

3.5.4 Change in the exposure scenario and area considered for disasters measurement

As previously discussed in Section 3.3.2, the exposure calculations for firms are derived from the IPCC scenarios. In light of this, we proceed to investigate the stability of our findings by examining whether the results hold when employing the medium emissions scenario instead of the high emissions scenario. Examining Table 3.7.11 and 3.7.12, whether we analyze exposure as a continuous or categorical variable, we observe a pattern where only heat wave exposure consistently impacts the euro area bond market prices. Then, we assess the consistency of our second hypothesis regarding pricing adjustments following damages resulting from natural disasters in the euro area, using the intermediate scenario. Beginning with a focus on continuous exposure (Table 3.7.13), we observe that the outcomes for the cumulative periods of 3 and 6 months exhibit notable similarity in terms of both significance and magnitude across both scenarios. Nevertheless, when shifting attention to the 12-month period of cumulative damages, the interaction retains its significance for overall exposure and rain intensity exposure – a pattern not previously observed. Turning our attention to categorical exposure (Table 3.7.14), we find consistence in outcomes between the two scenarios, with one exception: the average temperature exposure loses its statistical significance. This outcome can be attributed to the fact that temperature rise is the physical event most closely tied to the emissions scenario.

Another avenue to explore in terms of robustness is the geographical area deemed influential for investors in the euro area bond market. Up until this point, our analysis has centered on damages incurred by disasters impacting the euro area (comprising 20 countries). However, in order to assess the durability of our findings, we opt to test our conclusions using damages caused by natural disasters within the broader context of the European Union (comprising 27 countries). Results are presented in Table 3.7.15 and Table 3.7.16. Remarkably, the results exhibit substantial consistency in both significance and extent when employing these two distinct geographical scopes for the natural disasters under consideration. The only small difference concern the interaction between the categorical storm exposure and the 6 months prior cumulative damages that lose its significance when considering the European Union.

Overall, our findings demonstrate a high degree of robustness when using a less severe scenario and expanding the geographical scope of natural disaster events under consideration.

3.5.5 Placebo natural disasters

The last avenue we decide to explore involve determining whether the repricing that follows significant natural disasters is genuinely attributable to these events. To assess this, we opted to perform placebo tests. In these tests, we randomly reallocate the events and their associated damages. Specifically,

within the timeframe of 2014-2022, we introduce random alterations to the total monthly damages in the euro area. Subsequently, we proceed to compute cumulative sums over periods of 3, 6, and 12 months. Table 3.7.17 outlines the outcomes of the placebo tests performed with continuous exposure variables. We show that a significant portion of the time, our targeted interaction lacks significance or displays a noteworthy negative trend. These same trends persist when categorical exposure variables are employed, as demonstrated in Table 3.7.18. This deviation from our earlier findings underscores the conclusion that the substantial spread increase witnessed after events is not consistently replicated when events are randomly reassigned.

3.6 Conclusion

In this study, we conduct an empirical examination of how the Euro-zone bond market values firms' forward-looking physical risk. We use the CRIS database to gauge exposure to physical risk, utilizing both the sub-scores categorized by the type of physical risk and the overall score. Bond risk is assessed in terms of spread using as risk-free yield the ECB yield curve on triple-A rated bonds. We employ a panel model that incorporates the conventional factors influencing bond spreads to specifically isolating the influence of future physical risk on the spread. Analyzing a dataset comprising 666 bonds, our findings do not strongly support the notion of a consistently accurate pricing of forward-looking physical risk during the period spanning from 2014 to 2022. The sole exception is the exposure to heat waves, which appears to be appropriately valued within the overall dataset. A one-standard deviation increase in heat wave exposure results in a 75% increase in the average spread. These findings are robust even after re-estimation following the Paris Agreement and when employing a different emissions scenario to calculate firms' exposure to physical risks.

Subsequently, we investigate whether the occurrence of natural disasters in the euro area affects the pricing of forward-looking physical risk. To gauge the visibility of these events, we use the monthly damages resulting from natural disasters in the region as a proxy. Globally, our findings indicate that the spread increases for highly exposed firms following significant events. However, it's important to note that this adequate pricing effect is short-term and dissipates after one year. Notably, these conclusions do not hold as strongly for average temperature and sea level exposures when employing continuous exposure as a measure.

We demonstrate additionally that the influence of natural disaster events on bond pricing is not attributable to domestic damages but rather to more significant shocks at the Eurozone level. These shocks can affect perceptions even when the risk is not realized in the country where the firm is headquartered.

These outcomes, nonetheless, remain for the most part consistent when we conduct estimations solely

after the Paris Agreement, apply a medium emissions scenario, and calculate natural disasters damages across the broader European Union (not limited to the Eurozone). Lastly, we validate the robustness of our findings by performing placebo estimations on the disaster variable. We randomly allocate these disasters across the time period to ensure that our results are not merely coincidental.

In sum, our assessment leads us to the conclusion that the pricing of physical risk is not currently a persistent element in firms' risk considerations. The increase of the awareness that followed significant events is of short-term nature. Nevertheless, given the rising frequency of large-scale natural disasters, this mispricing could potentially lead to significant destabilization in financial markets over time, as adjustments will become costlier.

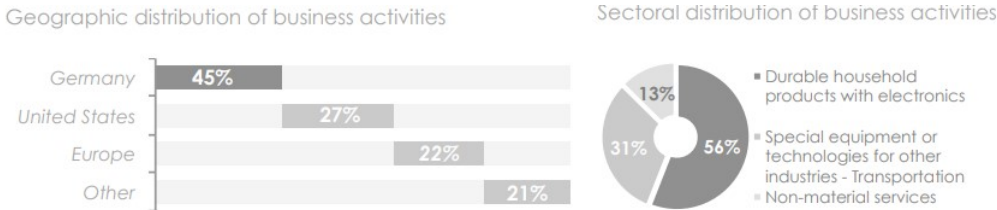
3.7 Appendix

3.7.1 CRIS fictional firm example

To illustrate the construction of exposure scores we take the example provided in the CRIS guidebook of a fictional German multinational automotive corporation called LaVoitureDE.

The first step to compute the score is to identify the segment of operation of the firm. In this example the company operate mainly in the automotive industry (classified as industrial producing durable products with electronics within the CRIS classification). Then, according to the segment of operation vulnerability are identified. LaVoitureDE is more vulnerable to heavy rainfall, storms, and sea level rise.

The second step to compute the score is based on the geolocation of activities. See the example below:



The company is mainly located in Europe. The locations are exposed to some intense hazard projections, but much less than some of its locations in Mexico and China, where detailed risk analysis should be run. LaVoitureDE is assessed with a moderate risk rating (37) at a mid-term time horizon and for a medium emission scenario. The company faces a level of risk comparable to its sector, based on a sample of 25 companies.



Figure 33 - Global risk rating and sectoral comparison for mid-term and medium-emission scenario

Temp rise	Heat waves	Droughts	Rainfall patterns	Heavy rainfall	Sea level rise	Storms
24	28	32	15	40	47	50
Lower Risk	Moderate Risk	Medium Risk	High Risk	Very High Risk		

3.7.2 Definition of variables

- **Monthly spread for a corporate bond.** Mid-yield of a bond minus the yield of the same maturity from the yield curve constructed by the European Central Bank (ECB) using Svensson model on all triple-A rating. Source: Datastream Refinitiv Eikon, European Central Bank Data Portal.
- **Cumulative damages.** The cumulative damages are constructed as the sum of prior damages over the period considered (3, 6 or 12 months). Damages are constitutes of all damages and economic losses directly or indirectly related to the disaster. The information may include the breakdown figures by sectors: Social, Infrastructure, Production, Environment and other (when available). Source: EM-DAT from CRED, UCLouvain.
- **Logarithm of the amount issued.** The total amount to be raised by the issue of the Bond, in logarithm. Source: Datastream Refinitiv Eikon.
- **Year to maturity.** Using the maturity date, we compute the year to maturity as the maturity year minus the year of the current date. Source: Datastream Refinitiv Eikon.
- **Callable.** A binary variable that indicate if the bond is callable. Callable bonds are bonds whose contract allows the issuer to redeem them before the maturity date. Source: Datastream Refinitiv Eikon.
- **Coupon rate.** The coupon rate is the annual income an investor can expect to receive while holding a particular bond. It is fixed when the bond is issued and is calculated by dividing the sum of the annual coupon payments by the par value. Source: Datastream Refinitiv Eikon.
- **Credit rating.** Ratings aims at asses the level of creditworthiness of a bond, if missing we take the rating of the company. We use the information of the 3 majors rating agencies: S&P, Fitch and Moody's. We transform them into numerical values, with 1 corresponding to the lowest grade while 22 corresponds to the highest grade. Source: Datastream Refinitiv Eikon.
- **Absolute Roll measure of illiquidity.** Roll's measure estimates liquidity from correlations in price change. We computed using the following formula:

$$\hat{\lambda}_t = 2\sqrt{|-Cov(\Delta P_{t,j}, \Delta P_{t,j+1})|} \quad (3.4)$$

with $Cov(\Delta P_t, \Delta P_{t+1})$ the auto-covariance of price changes, we consider for each bond 20 training day j per month t . We take the absolute value following Christopoulos (2021) to preserve a maximum of our data. Source: Datastream Refinitiv Eikon.

Table 3.7.1: Ratings correspondance table

Rating score	S&P	Fitch	Moody's
22	AAA	AAA	Aaa
21	AA+	AA+	Aa1
20	AA	AA	Aa2
19	AA-	AA-	Aa3
18	A+	A+	A1
17	A	A	A2
16	A-	A-	A3
15	BBB+	BBB+	Baa1
14	BBB	BBB	Baa2
13	BBB-	BBB-	Baa3
12	BB+	BB+	Ba1
11	BB	BB	Ba2
10	BB-	BB-	Ba3
9	B+	B+	B1
8	B	B	B2
7	B-	B-	B3
6	CCC+	CCC+	Caa1
5	CCC	CCC	Caa2
4	CCC-	CCC-	Caa3
3	CC	CC	Ca
2	C	C	-
1	D	D	C

- **Logarithm of total assets.** Total assets embody the valuation of all possessions owned by a company, a calculation achieved by summing up owner's equity and liabilities, in logarithm. Source: Datastream Refinitiv Eikon (WorldScope).
- **Leverage.** Leverage is calculated as the percentage of total debt to total equity. It reflects a company's capital arrangement, indicating the extent of debt within the blend of its debt and equity components. Source: Datastream Refinitiv Eikon.
- **Debt service capability.** Debt service capability is calculated by dividing Earnings Before Interest and Taxes (EBIT) by Interest Expense. This metric gauges the extent to which a company's earnings cover its interest obligations. Source: Datastream Refinitiv Eikon (WorldScope).
- **Cash to asset.** Cash to assets is computed as the amount of cash and equivalents divided by the current total assets. This ratio is a ratio of liquidity. Source: Datastream Refinitiv Eikon (WorldScope).
- **Operating profit margin** The operating profit margin is a ratio of profitability computed as the operating income over the net sales. Source: Datastream Refinitiv Eikon (WorldScope).
- **Tangibility.** This ratio signifies the proportion of tangible assets within the total assets. A higher ratio signifies a greater presence of tangible assets (or fixed assets) within the entirety of an entity's

assets, while a lower ratio indicates the opposite. Source: Datastream Refinitiv Eikon (WorldScope).

- **Annual returns** We compute the annual returns of a firm by deducing the logarithm of price from the previous year to the logarithm of price of the current one. Source: Datastream Refinitiv Eikon.
- **Volatility of returns** Volatility is a statistical metric characterized by the annualized standard deviation of logarithmic price fluctuations. It quantifies the extent of variation across time. We computed monthly volatility using a moving window spanning one year. Source: Datastream Refinitiv Eikon.
- **CAPEX ratio.** The capex ratio is determined by dividing capital expenditures by net sales. This metric gauges the extent of a company's investments directed towards its future growth. Source: Datastream Refinitiv Eikon (WorldScope).
- **Carbon intensity.** To compute the carbon intensity we use the total emissions divided by the total revenue of the company. This carbon intensity allow us to gauge the amount of emissions for one unit or revenue. Datastream Refinitiv Eikon (Asset4 and WorldScope).
- **Lack of coping capacity.** It's a score going from 0 to 10, it relates to the ability of a country to cope with disasters in terms of formal, organized activities and the effort of the country's government as well as the existing infrastructure which contribute to the reduction of disaster risk. Source: IMF - Climate-driven INFORM Risk.

3.7.3 Descriptive statistics

Table 3.7.2: Summary statistics

Variable	Mean	Std. Dev.	Min.	Max.	N
Spread	1.22	0.86	0.37	5.52	30998
Log. of issued amount	20.04	0.83	16.12	21.64	30998
Year to maturity	8.17	6.93	0	97	30998
Callable	0.61	0.49	0	1	30998
Coupon Rate	2.05	1.41	0	8.5	30998
Rating	14.58	1.85	2	20	30998
Illiquidity	0.26	0.26	0.01	1.59	30998
Log. of total assets	17.53	1.04	15.01	19.53	30998
Leverage	1.39	1.08	0.2	6.67	30998
Debt capability	8.42	10.45	-11.94	53.83	30998
Cash to assets	36.19	14.9	6.12	81.95	30998
Operating profit margin	11.28	11.44	-19.58	53.94	30998
Tangibility	0.27	0.17	0.01	0.77	30998
Annual returns	0	0.09	-0.13	0.3	30998
Volatility of returns	0.28	0.11	0	1.1	30998
CAPEX ratio	9.76	9.49	0.78	53.04	30998
Carbon intensity	0.03	0.04	0	0.2	30998

3.7.4 Complementary tables

Table 3.7.3: Baseline results with exposure dummy based on quartile

	Overall score		Av. temperature		Heat waves		Droughts	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Exposure score dummy	0.023 (0.074)	0.095 (0.078)	0.211* (0.124)	0.124 (0.123)	0.396*** (0.113)	0.298** (0.127)	0.203 (0.155)	0.182 (0.166)
R ²	0.697	0.714	0.701	0.714	0.709	0.719	0.699	0.714
	Rain Regime		Rain Intensity		Sea level		Storm	
	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
Exposure score dummy	-0.013 (0.117)	-0.050 (0.106)	-0.088 (0.071)	-0.058 (0.063)	-0.074 (0.081)	-0.053 (0.075)	-0.002 (0.093)	0.083 (0.091)
R ²	0.696	0.713	0.698	0.713	0.697	0.713	0.696	0.713
Controls variables	YES	YES	YES	YES	YES	YES	YES	YES
Time FE	✓	✓	✓	✓	✓	✓	✓	✓
Sector FE	✓	✓	✓	✓	✓	✓	✓	✓
Country FE		✓		✓		✓		✓
N	30998	30998	30998	30998	30998	30998	30998	30998
Number firms	115	115	115	115	115	115	115	115
Number bonds	666	666	666	666	666	666	666	666

Significance levels are: * p < 0.10 ; ** p < 0.05 ; *** p < 0.01.

Table 3.7.4: Impact of natural disasters damages according to the level of exposure (continuous)

	Overall	Av. Temp.	Rain Int.	Sea Lev.	Storm
Exposure score	-0.009 (0.012)	0.004 (0.015)	-0.011 (0.007)	-0.008 (0.006)	-0.004 (0.005)
— × cumulative damages 3m.	0.012* (0.006)	0.051 (0.044)	0.006** (0.003)	0.001 (0.003)	0.094*** (0.025)
R ²	0.717	0.716	0.718	0.717	0.717
Exposure score	-0.009 (0.012)	0.003 (0.015)	-0.011 (0.007)	-0.007 (0.006)	-0.004 (0.005)
— × cumulative damages 6m.	0.009* (0.005)	0.057 (0.041)	0.005* (0.003)	0.001 (0.003)	0.051** (0.019)
R ²	0.717	0.716	0.718	0.717	0.717
Exposure score	-0.010 (0.012)	0.002 (0.015)	-0.011 (0.007)	-0.007 (0.006)	-0.004 (0.070)
— × cumulative damages 12m.	0.005 (0.003)	0.055* (0.033)	0.003 (0.002)	-0.001 (0.002)	0.022 (0.027)
R ²	0.717	0.717	0.718	0.717	0.716
Controls variables	YES	YES	YES	YES	YES
Time FE	✓	✓	✓	✓	✓
Sector FE	✓	✓	✓	✓	✓
Country FE	✓	✓	✓	✓	✓
N	30998	30998	30998	30998	30998
Number firms	115	115	115	115	115
Number bonds	666	666	666	666	666
R ²	0.717	0.717	0.718	0.717	0.716

Significance levels are: * p < 0.10 ; ** p < 0.05 ; *** p < 0.01

Table 3.7.5: Impact of natural disasters damages according to the level of exposure (dummy)

	Overall	Av. Temp.	Rain Int.	Sea Lev.	Storm
Exposure score dummy	-0.006 (0.069)	0.119 (0.114)	-0.050 (0.057)	-0.126* (0.069)	0.058 (0.083)
— × cumulative damages 3m.	0.081* (0.043)	0.615** (0.274)	0.067* (0.035)	0.080** (0.031)	1.076* (0.541)
R ²	0.716	0.718	0.717	0.718	0.717
Exposure score dummy	-0.014 (0.070)	0.115 (0.115)	-0.055 (0.057)	-0.132* (0.070)	0.054 (0.083)
— × cumulative damages 6m.	0.070* (0.039)	0.527* (0.275)	0.063* (0.030)	0.075** (0.029)	0.652* (0.345)
R ²	0.717	0.718	0.717	0.718	0.717
Exposure score dummy	-0.009 (0.069)	0.105 (0.115)	-0.058 (0.055)	-0.134* (0.070)	0.046 (0.098)
— × cumulative damages 12m.	0.023 (0.032)	0.488* (0.255)	0.041* (0.022)	0.037 (0.024)	0.437 (0.563)
R ²	0.716	0.718	0.717	0.718	0.717
Controls variables	YES	YES	YES	YES	YES
Time FE	✓	✓	✓	✓	✓
Sector FE	✓	✓	✓	✓	✓
Country FE	✓	✓	✓	✓	✓
N	30998	30998	30998	30998	30998
Number firms	115	115	115	115	115
Number bonds	666	666	666	666	666
R ²	0.716	0.718	0.717	0.718	0.717

Significance levels are: * p < 0.10 ; ** p < 0.05 ; *** p < 0.01

Table 3.7.6: The impact of home country natural disaster damages vs euro area damages according to the level of exposure (continuous)

	Overall	Av. Temp.	Rain Int.	Sea Lev.	Storm
Exposure score	-0.009 (0.012)	0.004 (0.015)	-0.011 (0.007)	-0.007 (0.006)	-0.003 (0.005)
— × cumulative damages 3m. euro area	0.011 (0.007)	-0.011 (0.056)	0.006 (0.004)	0.001 (0.003)	0.113*** (0.032)
— × cumulative damages 3m. Country	0.006 (0.004)	0.034** (0.014)	0.003 (0.003)	-0.000 (0.002)	-0.019* (0.010)
R ²	0.717	0.717	0.718	0.717	0.717
Exposure score	-0.010 (0.012)	0.003 (0.015)	-0.011 (0.007)	-0.007 (0.006)	-0.003 (0.005)
— × cumulative damages 6m. euro area	0.007 (0.005)	0.001 (0.053)	0.004 (0.003)	0.001 (0.003)	0.066** (0.026)
— × cumulative damages 6m. Country	0.006 (0.004)	0.034** (0.014)	0.003 (0.003)	-0.002 (0.002)	-0.027** (0.012)
R ²	0.717	0.717	0.718	0.717	0.717
Exposure score	-0.011 (0.013)	0.002 (0.015)	-0.012* (0.007)	-0.007 (0.006)	-0.002 (0.006)
— × cumulative damages 12m. euro area	0.002 (0.004)	-0.001 (0.043)	0.002 (0.003)	-0.001 (0.002)	0.020 (0.029)
— × cumulative damages 12m. Country	0.007* (0.004)	0.034*** (0.013)	0.004 (0.002)	-0.001 (0.003)	-0.023** (0.011)
R ²	0.717	0.718	0.718	0.717	0.717
Controls variables	YES	YES	YES	YES	YES
Time FE	✓	✓	✓	✓	✓
Sector FE	✓	✓	✓	✓	✓
Country FE	✓	✓	✓	✓	✓
N	30998	30998	30998	30998	30998
Number firms	115	115	115	115	115
Number bonds	666	666	666	666	666
R ²	0.717	0.719	0.717	0.719	0.717

Significance levels are: * p < 0.10 ; ** p < 0.05 ; *** p < 0.01

3.7.5 Robustness checks

Table 3.7.7: Baseline results after Paris-Agreement (continuous exposure)

	Overall score		Av.temperature		Heat waves		Droughts	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Exposure score	-0.010 (0.014)	0.002 (0.014)	0.025 (0.017)	0.014 (0.017)	0.039*** (0.015)	0.025 (0.015)	0.014** (0.007)	0.008 (0.008)
R ²	0.708	0.723	0.710	0.724	0.715	0.725	0.710	0.724
	Rain Regime		Rain Intensity		Sea level		Storm	
	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
Exposure score	-0.020 (0.021)	-0.017 (0.021)	-0.012* (0.007)	-0.009 (0.008)	-0.009 (0.006)	-0.005 (0.006)	-0.009* (0.005)	0.002 (0.006)
R ²	0.709	0.724	0.710	0.724	0.709	0.724	0.710	0.723
Controls variables	YES	YES	YES	YES	YES	YES	YES	YES
Time FE	✓	✓	✓	✓	✓	✓	✓	✓
Sector FE	✓	✓	✓	✓	✓	✓	✓	✓
Country FE		✓		✓		✓		✓
N	27689	27689	27689	27689	27689	27689	27689	27689
Number firms	115	115	115	115	115	115	115	115
Number bonds	665	665	665	665	665	665	665	665

Significance levels are: * p < 0.10 ; ** p < 0.05 ; *** p < 0.01.

Table 3.7.8: Baseline results after Paris-Agreement (categorical exposure)

	Overall score		Av.temperature		Heat waves		Droughts	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Exposure score	0.041 (0.081)	0.125 (0.079)	0.247* (0.129)	0.159 (0.126)	0.383*** (0.115)	0.279** (0.131)	0.179 (0.156)	0.153 (0.169)
R ²	0.708	0.725	0.714	0.725	0.719	0.728	0.709	0.724
	Rain Regime		Rain Intensity		Sea level		Storm	
	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
Exposure score	0.001 (0.123)	-0.038 (0.110)	-0.082 (0.076)	-0.052 (0.067)	-0.052 (0.086)	-0.028 (0.078)	0.010 (0.094)	0.099 (0.093)
R ²	0.707	0.723	0.708	0.723	0.708	0.723	0.707	0.724
Controls variables	YES	YES	YES	YES	YES	YES	YES	YES
Time FE	✓	✓	✓	✓	✓	✓	✓	✓
Sector FE	✓	✓	✓	✓	✓	✓	✓	✓
Country FE		✓		✓		✓		✓
N	27689	27689	27689	27689	27689	27689	27689	27689
Number firms	115	115	115	115	115	115	115	115
Number bonds	665	665	665	665	665	665	665	665

Significance levels are: * p < 0.10 ; ** p < 0.05 ; *** p < 0.01.

Table 3.7.9: After Paris Agreement - impact of natural disasters damages (continuous exposure)

	Overall	Av. Temp.	Rain Int.	Sea Lev.	Storm
Exposure score	-0.007 (0.013)	0.008 (0.015)	-0.009 (0.007)	-0.007 (0.006)	-0.003 (0.006)
— × cumulative damages 3m.	0.013** (0.006)	0.045 (0.041)	0.006** (0.003)	0.001 (0.003)	0.104*** (0.025)
R^2	0.728	0.728	0.729	0.729	0.728
Exposure score	-0.008 (0.013)	0.007 (0.015)	-0.009 (0.007)	-0.007 (0.006)	-0.003 (0.006)
— × cumulative damages 6m.	0.010** (0.005)	0.051 (0.039)	0.005* (0.003)	0.001 (0.002)	0.058*** (0.018)
R^2	0.728	0.728	0.729	0.729	0.728
Exposure score	-0.009 (0.013)	0.006 (0.015)	-0.009 (0.007)	-0.006 (0.006)	-0.004 (0.007)
— × cumulative damages 12m.	0.006* (0.003)	0.049 (0.031)	0.003* (0.002)	-0.001 (0.002)	0.045 (0.039)
R^2	0.728	0.728	0.729	0.729	0.728
Controls variables	YES	YES	YES	YES	YES
Time FE	✓	✓	✓	✓	✓
Sector FE	✓	✓	✓	✓	✓
Country FE	✓	✓	✓	✓	✓
N	27689	27689	27689	27689	27689
Number firms	115	115	115	115	115
Number bonds	665	665	665	665	665

Significance levels are: * p < 0.10 ; ** p < 0.05 ; *** p < 0.01

Table 3.7.10: After Paris Agreement - impact of natural disasters damages (categorical exposure)

	Overall	Av. Temp.	Rain Int.	Sea Lev.	Storm
Exposure score dummy	0.010 (0.069)	0.156 (0.117)	-0.038 (0.060)	-0.101 (0.071)	0.068 (0.085)
— × cumulative damages 3m.	0.084** (0.040)	0.569** (0.262)	0.070** (0.035)	0.076** (0.030)	1.079* (0.562)
R^2	0.728	0.730	0.728	0.729	0.729
Exposure score dummy	0.003 (0.069)	0.152 (0.117)	-0.043 (0.060)	-0.108 (0.072)	0.066 (0.085)
— × cumulative damages 6m.	0.071* (0.037)	0.486* (0.270)	0.065* (0.034)	0.074** (0.029)	0.616* (0.324)
R^2	0.728	0.728	0.729	0.729	0.728
Exposure score dummy	0.006 (0.068)	0.142 (0.117)	-0.049 (0.058)	-0.109 (0.071)	0.042 (0.109)
— × cumulative damages 12m.	0.029 (0.030)	0.437* (0.253)	0.045** (0.022)	0.035 (0.023)	0.687 (0.828)
R^2	0.728	0.728	0.729	0.729	0.728
Controls variables	YES	YES	YES	YES	YES
Time FE	✓	✓	✓	✓	✓
Sector FE	✓	✓	✓	✓	✓
Country FE	✓	✓	✓	✓	✓
N	27689	27689	27689	27689	27689
Number firms	115	115	115	115	115
Number bonds	665	665	665	665	665

Significance levels are: * p < 0.10 ; ** p < 0.05 ; *** p < 0.01

Table 3.7.11: Baseline results with medium scenario (continuous exposure)

	Overall score		Av.temperature		Heat waves		Droughts	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Exposure score	-0.010 (0.014)	0.002 (0.014)	0.023 (0.018)	0.007 (0.018)	0.033** (0.015)	0.024* (0.014)	0.017** (0.007)	0.011 (0.007)
R ²	0.697	0.713	0.698	0.713	0.702	0.715	0.700	0.714
	Rain Regime		Rain Intensity		Sea level		Storm	
	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
Exposure score	-0.028 (0.029)	-0.021 (0.029)	-0.011 (0.007)	-0.009 (0.007)	-0.009 (0.006)	-0.005 (0.006)	-0.009* (0.005)	0.000 (0.006)
R ²	0.700	0.714	0.698	0.714	0.699	0.713	0.700	0.713
Controls variables	YES	YES	YES	YES	YES	YES	YES	YES
Time FE	✓	✓	✓	✓	✓	✓	✓	✓
Sector FE	✓	✓	✓	✓	✓	✓	✓	✓
Country FE		✓		✓		✓		✓
N	30998	30998	30998	30998	30998	30998	30998	30998
Number firms	115	115	115	115	115	115	115	115
Number bonds	666	666	666	666	666	666	666	666

Significance levels are: * p < 0.10 ; ** p < 0.05 ; *** p < 0.01.

Table 3.7.12: Baseline results with medium scenario (categorical exposure)

	Overall score		Av.temperature		Heat waves		Droughts	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Exposure score dummy	0.037 (0.074)	0.101 (0.080)	0.126 (0.138)	-0.052 (0.137)	0.406*** (0.121)	0.328** (0.129)	0.179 (0.150)	0.157 (0.156)
R ²	0.697	0.714	0.698	0.713	0.709	0.720	0.698	0.714
	Rain Regime		Rain Intensity		Sea level		Storm	
	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
Exposure score dummy	-0.154 (0.105)	-0.212** (0.099)	-0.121* (0.062)	-0.090 (0.056)	-0.074 (0.081)	-0.053 (0.075)	-0.002 (0.093)	0.083 (0.091)
R ²	0.700	0.718	0.699	0.714	0.697	0.713	0.696	0.713
Controls variables	YES	YES	YES	YES	YES	YES	YES	YES
Time FE	✓	✓	✓	✓	✓	✓	✓	✓
Sector FE	✓	✓	✓	✓	✓	✓	✓	✓
Country FE		✓		✓		✓		✓
N	30998	30998	30998	30998	30998	30998	30998	30998
Number firms	115	115	115	115	115	115	115	115
Number bonds	666	666	666	666	666	666	666	666

Significance levels are: * p < 0.10 ; ** p < 0.05 ; *** p < 0.01.

Table 3.7.13: Medium scenario - impact of natural disasters damages (continuous exposure)

	Overall	Av. Temp.	Rain Int.	Sea Lev.	Storm
Exposure score	-0.008 (0.013)	0.001 (0.017)	-0.010 (0.007)	-0.007 (0.006)	-0.004 (0.005)
— × cumulative damages 3m.	0.013** (0.006)	0.056 (0.050)	0.006** (0.003)	0.002 (0.003)	0.094*** (0.025)
R^2	0.717	0.716	0.718	0.717	0.717
Exposure score	-0.009 (0.013)	0.000 (0.017)	-0.011 (0.007)	-0.007 (0.006)	-0.004 (0.005)
— × cumulative damages 6m.	0.010* (0.005)	0.067 (0.046)	0.005** (0.002)	0.001 (0.003)	0.051*** (0.019)
R^2	0.717	0.716	0.718	0.717	0.717
Exposure score	-0.009 (0.013)	-0.001 (0.017)	-0.011 (0.007)	-0.007 (0.006)	-0.004 (0.006)
— × cumulative damages 12m.	0.006* (0.004)	0.063* (0.038)	0.004* (0.002)	-0.001 (0.002)	0.022 (0.027)
R^2	0.717	0.717	0.718	0.717	0.716
Controls variables	YES	YES	YES	YES	YES
Time FE	✓	✓	✓	✓	✓
Sector FE	✓	✓	✓	✓	✓
Country FE	✓	✓	✓	✓	✓
N	30998	30998	30998	30998	30998

Significance levels are: * $p < 0.10$; ** $p < 0.05$; *** $p < 0.01$

Table 3.7.14: Medium scenario - impact of natural disasters damages (categorical exposure)

	Overall	Av. Temp.	Rain Int.	Sea Lev.	Storm
Exposure score dummy	-0.005 (0.070)	-0.026 (0.131)	-0.074 (0.049)	-0.126* (0.069)	0.058 (0.083)
— × cumulative damages 3m.	0.102** (0.042)	0.457 (0.290)	0.083** (0.034)	0.077** (0.031)	1.076** (0.541)
R^2	0.717	0.716	0.717	0.718	0.717
Exposure score dummy	-0.014 (0.071)	-0.029 (0.132)	-0.080 (0.049)	-0.132* (0.070)	0.054 (0.083)
— × cumulative damages 6m.	0.086** (0.038)	0.371 (0.294)	0.077** (0.032)	0.075** (0.030)	0.652* (0.345)
R^2	0.717	0.716	0.717	0.718	0.717
Exposure score dummy	-0.007 (0.071)	-0.036 (0.133)	-0.082* (0.047)	-0.134* (0.070)	0.046 (0.098)
— × cumulative damages 12m.	0.027 (0.032)	0.318 (0.273)	0.042* (0.022)	0.037 (0.024)	0.437 (0.563)
R^2	0.716	0.716	0.717	0.718	0.717
Controls variables	YES	YES	YES	YES	YES
Time FE	✓	✓	✓	✓	✓
Sector FE	✓	✓	✓	✓	✓
Country FE	✓	✓	✓	✓	✓

Significance levels are: * $p < 0.10$; ** $p < 0.05$; *** $p < 0.01$

Table 3.7.15: European Union damages - impact of natural disasters damages (continuous exposure)

	Overall	Av. Temp.	Rain Int.	Sea Lev.	Storm
Exposure score	-0.009 (0.012)	0.004 (0.015)	-0.011 (0.007)	-0.008 (0.006)	-0.004 (0.005)
— × cumulative damages 3m.	0.014* (0.007)	0.060 (0.051)	0.007** (0.004)	0.002 (0.003)	0.120*** (0.035)
R^2	0.717	0.716	0.718	0.717	0.717
Exposure score	-0.009 (0.012)	0.003 (0.015)	-0.011 (0.007)	-0.007 (0.006)	-0.004 (0.005)
— × cumulative damages 6m.	0.011* (0.006)	0.067 (0.048)	0.006* (0.003)	0.001 (0.003)	0.073** (0.028)
R^2	0.717	0.716	0.718	0.717	0.717
Exposure score	-0.010 (0.012)	0.002 (0.015)	-0.011 (0.007)	-0.007 (0.006)	-0.004 (0.006)
— × cumulative damages 12m.	0.006 (0.004)	0.065* (0.039)	0.004 (0.002)	-0.001 (0.002)	0.037 (0.033)
R^2	0.717	0.717	0.718	0.717	0.716
Controls variables	YES	YES	YES	YES	YES
Time FE	✓	✓	✓	✓	✓
Sector FE	✓	✓	✓	✓	✓
Country FE	✓	✓	✓	✓	✓

Significance levels are: * $p < 0.10$; ** $p < 0.05$; *** $p < 0.01$

Table 3.7.16: European Union damages - impact of natural disasters damages (categorical exposure)

	Overall	Av. Temp.	Rain Int.	Sea Lev.	Storm
Exposure score	-0.006 (0.069)	0.119 (0.114)	-0.050 (0.057)	-0.126* (0.069)	0.056 (0.084)
— × cumulative damages 3m.	0.095* (0.050)	0.722** (0.322)	0.079* (0.042)	0.091** (0.036)	1.230* (0.740)
R^2	0.716	0.718	0.717	0.718	0.717
Exposure score	-0.014 (0.070)	0.115 (0.115)	-0.055 (0.057)	-0.132* (0.070)	0.050 (0.085)
— × cumulative damages 6m.	0.081* (0.045)	0.619* (0.322)	0.074* (0.039)	0.088** (0.035)	0.835 (0.513)
R^2	0.717	0.718	0.717	0.718	0.717
Exposure score	-0.009 (0.069)	0.105 (0.115)	-0.059 (0.055)	-0.134* (0.070)	0.039 (0.100)
— × cumulative damages 12m.	0.028 (0.037)	0.573* (0.299)	0.048* (0.026)	0.043 (0.028)	0.563 (0.655)
R^2	0.716	0.718	0.717	0.718	0.717
Controls variables	YES	YES	YES	YES	YES
Time FE	✓	✓	✓	✓	✓
Sector FE	✓	✓	✓	✓	✓
Country FE	✓	✓	✓	✓	✓

Significance levels are: * $p < 0.10$; ** $p < 0.05$; *** $p < 0.01$

Table 3.7.17: Placebos - impact of natural disasters damages (continuous exposure)

	Overall	Av. Temp.	Rain Int.	Sea Lev.	Storm
Exposure score	-0.005 (0.012)	0.004 (0.015)	-0.009 (0.007)	-0.007 (0.005)	-0.002 (0.005)
— × cumulative damages 3m.	-0.015* (0.008)	0.048 (0.042)	-0.009** (0.004)	-0.003 (0.004)	-0.044*** (0.014)
R^2	0.717	0.716	0.718	0.717	0.716
Exposure score	-0.004 (0.012)	0.004 (0.015)	-0.008 (0.007)	-0.007 (0.006)	-0.002 (0.005)
— × cumulative damages 6m.	-0.014** (0.007)	0.053 (0.037)	-0.009** (0.004)	-0.002 (0.003)	-0.012 (0.014)
R^2	0.717	0.716	0.718	0.717	0.716
Exposure score	-0.003 (0.012)	0.004 (0.015)	-0.007 (0.007)	-0.007 (0.006)	-0.002 (0.006)
— × cumulative damages 12m.	-0.010** (0.004)	0.048 (0.029)	-0.008*** (0.002)	-0.001 (0.002)	-0.008 (0.017)
R^2	0.717	0.716	0.719	0.717	0.716
Controls variables	YES	YES	YES	YES	YES
Time FE	✓	✓	✓	✓	✓
Sector FE	✓	✓	✓	✓	✓
Country FE	✓	✓	✓	✓	✓
N	30998	30998	30998	30998	30998
Number firms	115	115	115	115	115
Number bonds	666	666	666	666	666

Significance levels are: * $p < 0.10$; ** $p < 0.05$; *** $p < 0.01$

Table 3.7.18: Placebos - impact of natural disasters damages (categorical exposure)

	Overall	Av. Temp.	Rain Int.	Sea Lev.	Storm
Exposure score	0.014 (0.068)	0.124 (0.115)	-0.036 (0.057)	-0.114 (0.069)	0.077 (0.086)
— × cumulative damages 3m.	-0.096*** (0.034)	0.255 (0.267)	-0.091** (0.035)	-0.053 (0.036)	-0.417 (0.408)
R^2	0.716	0.718	0.717	0.718	0.717
Exposure score	0.022 (0.068)	0.123 (0.115)	-0.027 (0.057)	-0.111 (0.069)	0.079 (0.088)
— × cumulative damages 6m.	-0.085** (0.035)	0.200 (0.252)	-0.091** (0.040)	-0.041 (0.039)	-0.314 (0.483)
R^2	0.717	0.718	0.717	0.718	0.717
Exposure score	0.022 (0.070)	0.125 (0.116)	-0.014 (0.058)	-0.111 (0.071)	0.081 (0.088)
— × cumulative damages 12m.	-0.043 (0.029)	0.014 (0.265)	-0.087** (0.034)	-0.021 (0.030)	-0.195 (0.478)
R^2	0.716	0.718	0.717	0.718	0.717
Controls variables	YES	YES	YES	YES	YES
Time FE	✓	✓	✓	✓	✓
Sector FE	✓	✓	✓	✓	✓
Country FE	✓	✓	✓	✓	✓
N	30998	30998	30998	30998	30998
Number firms	115	115	115	115	115
Number bonds	666	666	666	666	666

Significance levels are: * $p < 0.10$; ** $p < 0.05$; *** $p < 0.01$

General Conclusion

General conclusion

The current acceleration climate change causes an increase in both the frequency and intensity of natural disasters. Given the escalating damages they entail, it is a risk that need to be analyzed. Despite investors placing transition risk closer at hand (Stroebele and Wurgler, 2021), recent significant natural disasters paint a different picture.

The comprehensive examination of the actual consequences of natural disasters has been extensively studied, yet ongoing debates persist due to the substantial heterogeneity in the impacts observed. Despite policies directed towards mitigating climate change, it appears that these efforts may still fall short. Conversely, the financial system, a primary avenue for gathering investments and funds, has not received adequate attention within the context of climate change. Nevertheless, the financial sphere is exposed to climate-related risks. Those risks could ultimately lead to significant destabilising effects within financial markets and potentially result in severe crises. Further, financial crises can have profound repercussions on the real economy, as shown by the 2008 financial crisis. The financial industry also bears a responsibility in mitigating these risks. This can be achieved through actions such as providing funds after physical risk realization and implementing preventative measures like reallocating investments towards abatement technologies or greener firms, appropriately pricing risk, and incorporating climate risk considerations into credit ratings.

This thesis contributes to the growing but limited body of literature concerning the influence of physical risk on financial stability and the strategies for addressing its potential adverse effects. We examine how physical risk affects various level of the financial sector and analyze how different actors can respond to mitigate these impacts.

In Chapter 1 of the thesis, we adopt a macroeconomic perspective to explore the potential benefits of macro-prudential instruments. Employing local projections with interaction variables, we analyze how natural disasters affect financial stress at the macroeconomic level, measured by the external financial premium. Our focus is on understanding the macroeconomic financial instabilities that can emerge following storms and floods. Then, we evaluate the potential advantages of implementing robust macro-prudential policies. Our dataset assesses the severity of natural disasters using meteorological intensity data, mit-

igating issues related to endogeneity when compared to damage-based data. We gauge the stringency of prudential regulations using the iMaPP database, which measures the extent of macroprudential policy implementation. Our findings, based on a panel of 88 countries spanning from 1996 to 2016, reveal substantial differences in the dynamics of external finance premiums depending of the stringency of the macroprudential framework. In countries with lax prudential regulation, lending rates increase in the aftermath of storms. On the contrary, lending rates do not increase when macroprudential regulation is stringent promoting a sounder financial system.

While the results are less conclusive for floods, it remains that in the light of the results found for storms a strong macroprudential framework improve countries' ability to better cope with the impact of some natural disasters. Consequently, macroprudential measures can serve as a safeguard against the escalating climate-related financial risks and help reduce the likelihood of a more severe economic and financial catastrophe.

Given the increasing occurrence of climate-related events, particularly in emerging markets, it is essential to gain insights into their repercussions on banks, which play a pivotal role in the economy. In Chapter 2, we focus on the post-crisis reponse of banks. More precisely, we investigate how typhoons impact Chinese banks. The Chinese banking system is interesting to be studied given its recent liberalization and the presence of different types of banks (e.g. rural, commercial). Typhoons have the potential to disrupt lending activities and economic prospects. Rural banks may mitigate these effects through their local expertise and longstanding client relationships, whereas commercial banks have a broader area of operations making it harder to deal with information asymmetries. Using a difference-in-difference approach, we analyze 327 Chinese banks over the period 2004-2019. We find that, on average, typhoons lead to a 2.8 percent decrease in lending, mainly due to commercial banks. In contrast, rural banks act as shock absorbers. As a consequence, the absence of rural banks in some Chinese prefectures is found to be detrimental to local post-typhoon economic growth. Moreover, it seems that state ownership and external pressure help mitigate lending declines in affected commercial banks. State ownership and external political pressures are identified as factors that help alleviate the decline in lending experienced by commercial banks affected by typhoons. These findings highlight the significant impact of typhoons on bank stability, with variations based on bank type. Given the increasing frequency and intensity of climate-related disasters, understanding bank vulnerabilities is crucial for effective reconstruction efforts.

The third chapter focuses on the euro area bond market. Our objective is to explore whether premiums related to physical risk are priced into bond spreads. Our dataset comprises 666 bonds issued by 115 European companies between 2014 and 2022. We calculate monthly yield spreads using the European Central Bank's yield curve for triple-A rated bonds as the risk-free reference and evaluate risk exposure using the Carbon Risk Integration System database, which provides scores based on IPCC scenarios. Our

analysis reveals limited pricing of forward-looking exposure risks in the Euro area bond market, while heat waves are a notable exception. Further, we explore how significant natural disaster events affect companies with substantial future exposure. We compute cumulative damages over specific horizons and examine their interaction with exposure scores. We find a pricing response for highly exposed firms following natural disasters. However, this pricing reaction tends to be short-lived, as it vanishes after one year. In sum, our study highlights the inadequacy of pricing physical risk in the Eurozone bond market, which poses a long-term threat to financial stability as the frequency of large-scale natural disasters continues to rise, making necessary adjustments increasingly costly.

In terms of policy recommendations, this thesis emphasizes several crucial points regarding the proactive and reactive roles the financial sector could adopt to address the impact of climate-related risks. Firstly, we demonstrate that taking preventive measures can enhance the ability to respond effectively after an adverse event. Specifically, our research highlights the effectiveness of implementing a stringent macroprudential framework at the national level to contain the repercussions of natural disasters (although its objectives is to limit financial vulnerabilities and promote crisis prevention). In this line, the adoption of specialized green macroprudential tools may further enhance this effectiveness. That is a dimension that we will consider for further extensions. Our findings also underscore the importance of local banks in the recovery process. Facilitating banks' ability to bear the costs of recovery and promoting transparency regarding their impacts could yield long-term benefits. To enhance risk assessment, we advocate for the widespread adoption of climate stress-tests at the individual bank level. Thus, it could help banks to adequately prepare and set aside some provisions for reconstruction purposes. Furthermore, there is room to adopt ex-ante policies that specifically target the reduction of climate-related risks. One approach involves reallocating investments towards companies with lower exposure to risk and a stronger commitment to environmental sustainability. This strategic shift has the potential to encourage long-term eco-friendly practices and ultimately reduce overall emissions. To successfully implement such policies, it is essential to establish an effective pricing mechanism that accurately reflects the risks associated with climate change. As shown in the last chapter it is not the case for the Eurozone bond market. There is room for improvement in this regard. Therefore, it is imperative to make concerted efforts to comprehensively assess and appropriately value the underlying climate risk while also providing incentives to companies that have already taken steps towards sustainability.

This thesis unveils opportunities for various extensions and additional investigations. Firstly, there is an ongoing debate regarding the extent of involvement that monetary policy should have in addressing these issues, with differing viewpoints among central bankers. However, it is worth noting that natural disasters have been shown to have disruptive effects on inflation (Heinen et al., 2019; Beirne et al., 2021; Mukherjee and Ouattara, 2021). This implies that these issues ultimately fall within the scope of central

banks' mandates. Consequently, there is a compelling need for further comprehensive research to delve into the mechanisms and timing of monetary policy interventions in response to extreme climate-related risks. A second avenue that could be explored involves investigating the possibility of contagion risk among banks. As discussed in Chapter 2 and corroborated by several papers in the literature (Schuwer et al., 2019; Koetter et al., 2020), banks are highly exposed to physical risk. This naturally leads to the follow-up questions: can these individual risks spread throughout the banking system, giving rise to systemic risk? If so, is it feasible to mitigate such risks through micro-prudential regulations applied at the individual bank level? Thirdly, it is crucial to investigate the underwriting risk within the insurance sector, as previously highlighted in the introduction. Insurance companies might face significant challenges if the current trend of climate change intensification persists: they may not be able to bear all the associated costs. One noteworthy concern in this respect is the limited availability of insurance-related data. Nevertheless, it is imperative to thoroughly assess this risk, and concerted efforts should be directed towards improving the availability of insurance data for in-depth analysis of the potential financial burdens they may face. Fourthly, as highlighted in the introduction, numerous institutional reports stress the significance of redirecting resources towards the shift to a low-carbon economy. Companies with high exposure to physical risks may find themselves at risk of resource shortages resulting from these challenges. This situation might necessitate a choice between resource allocation to mitigate physical risks and investment in transitioning toward low-carbon process. In that case, the responses to both risks could be closely intertwined, warranting further examination. Lastly, we can also examine the impact of the escalating frequency of natural disasters on sovereign risk. The necessity for immediate emergency funding, as well as the potential need for government bailouts in the aftermath of such events, could significantly increase government expenditures. When coupled with the adjustments in banks' balance sheets, it can lead to the emergence of a "doom loop" (Brunnermeier et al., 2016; Farhi and Tirole, 2018). This results in reduced confidence in the solvency of domestic banks and an increased perception that government bailouts will be required. Consequently, this exacerbates sovereign distress. Such mechanisms, which pose substantial financial systemic risks, were observed during the COVID-19 pandemic (Bolton et al., 2021). It would be a compelling exercise to investigate whether the "doom loop" manifests itself in the context of shocks caused by natural disasters.

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Résumé français

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Catastrophes naturelles et instabilité financière

Le 1er novembre 1755, le monde a été témoin du catastrophique tremblement de terre de Lisbonne, qui a été qualifié de première catastrophe moderne par Dynes (2003). Cet événement de renom a laissé une empreinte durable dans la conscience collective, principalement en raison des énormes pertes humaines et économiques qu'il a causées. Avec une population de 275 000 habitants, Lisbonne a connu la perte de 100 000 vies, ce qui représente un taux de mortalité de 36 %. De plus, cette catastrophe a déclenché des débats animés parmi les philosophes de l'époque, ce qui lui confère une importance historique encore plus grande.

Dans les semaines qui ont suivi, Voltaire a tenté de trouver un sens à la souffrance engendrée dans un poème, suggérant qu'elle pourrait servir un dessein supérieur. Il laisse entendre que l'univers pourrait contenir des éléments de mal inhérent et que certaines souffrances injustes pourraient être attribuées à une source divine : *"La Nature est silencieuse, en vain nous l'interrogeons. Un jour, tout ira bien, c'est notre espoir ; tout va bien aujourd'hui, c'est une illusion."* (Poème sur la catastrophe de Lisbonne, 1755).

Cependant, Rousseau était en désaccord avec l'idée que la catastrophe avait une explication divine. Il a exprimé ses opinions dans une lettre, *"Lettre sur la Providence (1759)"*, en réponse à Voltaire. Rousseau soutient que la source de la catastrophe n'était pas la volonté divine de Dieu, mais plutôt le résultat des choix et des actions humaines : *"Convenez, par exemple, que la nature n'avait point rassemblé là vingt mille maisons de six à sept étages, et que si les habitants de cette grande ville eussent été dispersés plus également et plus légèrement logés, le dégât eût été beaucoup moindre et peut-être nul."* La perspective novatrice de Rousseau était notable pour sa reconnaissance précoce d'une corrélation entre les événements physiques et les actions de l'humanité. En établissant ce lien, il a involontairement jeté les bases de ce qui évoluerait plus tard en la théorie de l'Anthropocène. Cette théorie souligne que les activités humaines ont eu un impact profond et durable sur les processus géologiques et naturels, englobant des éléments tels que la déforestation, le changement climatique et l'extinction des espèces.

Rousseau a soulevé des questions qui continuent à résonner dans les discussions contemporaines sur les

catastrophes naturelles. Tout d'abord, il a introduit le concept de vulnérabilité, comme le souligne Dynes (2003) : *"Comprendre la signification de la catastrophe de Lisbonne dépendait... de la compréhension de la structure sociale et de la culture de la communauté dans laquelle le tremblement de terre s'est produit."* À l'époque, Rousseau a reconnu que le contexte économique et social jouait un rôle crucial, dont l'impact varierait considérablement parmi les populations touchées. Deuxièmement, Dynes (2003) évoque le rôle que les sociétés ont eu à jouer en termes d'efforts de récupération, faisant de cet événement la première catastrophe naturelle moderne : *"Le tremblement de terre a été la première catastrophe où le gouvernement a accepté la responsabilité de mobiliser la réponse d'urgence et de développer et mettre en œuvre un effort collectif de reconstruction."* Ses observations demeurent pertinentes dans les débats contemporains.

Suite à cet événement, différents types de catastrophes naturelles ont continué à se produire au fil des ans partout dans le monde. Cela inclut des événements tels que les inondations en Chine en 1931, le cyclone Bholá en 1970, le séisme de Kobe en 1995, le tsunami de l'océan Indien en 2004, la tempête Katrina en 2005, les incendies en Australie en 2020, le séisme en Haïti en 2021, les inondations au Pakistan en 2022, le séisme en Afghanistan en 2022, et plus récemment, le séisme au Maroc et les inondations en Libye en septembre 2023.

Le risque physique : un risque anthropique

Réchauffement climatique

Le changement climatique englobe des modifications prolongées des modèles climatiques mondiaux ou locaux, impliquant spécifiquement des variations de température et de précipitations. Ces changements peuvent résulter de processus naturels ou d'activités humaines. De nombreuses preuves scientifiques soulignent le phénomène du réchauffement climatique. Les recherches de Jones et Mann (2004) mettent en évidence le fait que le XXe siècle se distingue comme une période marquée par les fluctuations de température les plus significatives observées au cours des deux mille dernières années. Le premier Groupe d'experts intergouvernemental sur l'évolution du climat (IPCC, 2001) souligne l'idée que les changements observés seraient hautement improbables sans l'influence humaine. Des études ultérieures ont renforcé les preuves montrant la contribution substantielle des émissions de dioxyde de carbone au réchauffement climatique (Houghton, 2005; Florides et Christodoulides, 2009). La connexion entre le réchauffement climatique et l'impact humain est solidement établie, validant le concept de l'ère de l'Anthropocène

Changement climatique et fréquence des catastrophes naturelles

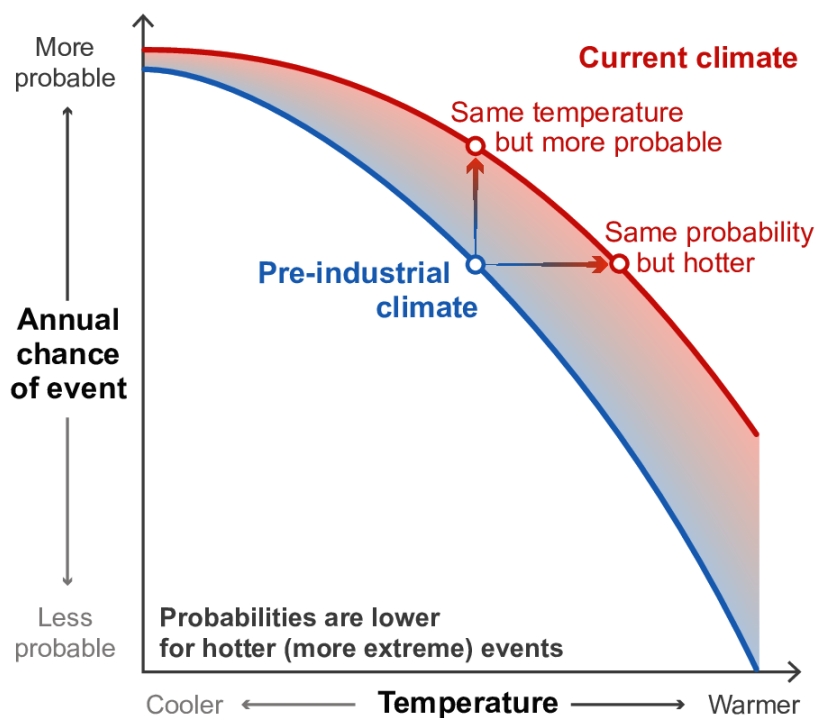
Cependant, il a fallu un certain temps pour établir le lien entre la fréquence et l'intensité des événements extrêmes et leur relation avec l'influence humaine. Dans son article publié dans la revue *Nature*, Allen (2003) suggère que certains facteurs externes contribuant au changement climatique, tels que les émissions de gaz à effet de serre, ont peut-être contribué à accroître le risque d'événements extrêmes, en utilisant comme exemple une inondation extrême au Royaume-Uni. En se basant sur cette observation, plusieurs études ont montré que de nombreux événements extrêmes vont au-delà des prédictions antérieures (Schär et Jendritzky, 2004). Progressivement, des preuves ont émergé concernant l'influence des activités humaines sur la survenue d'événements extrêmes (Stott et al., 2004; Stone et Allen, 2005; Perkins-Kirkpatrick et al., 2022). Stott et al. (2004) estime qu'il existe une forte probabilité que l'influence humaine ait doublé les chances de survenue de la canicule européenne de 2003. Schaller et al. (2016) a conclu que le changement climatique avait augmenté de 43 % les chances des inondations au Royaume-Uni en 2014.

À la suite d'une série de découvertes scientifiques, le GIEC, dans son rapport spécial sur les événements extrêmes (IPCC, 2012), a reconnu le lien entre le changement climatique et la survenue de catastrophes naturelles. Il déclare que *"Un climat changeant provoque des modifications dans la fréquence, l'intensité, la portée géographique, la durée et la chronologie des événements météorologiques et climatiques extrêmes, conduisant potentiellement à des occurrences sans précédent."* Comme le montre la Figure 3.7.1, les conditions climatiques actuelles ont déplacé la courbe vers la droite de manière non parallèle. En prenant l'exemple de la température moyenne, nous observons une augmentation significative de la probabilité d'événements annuels par rapport au climat préindustriel.

Étant donné l'état de l'art actuel, certaines initiatives telles que le projet *World Weather Attribution* ont vu le jour, visant à centraliser les efforts internationaux et à communiquer pour accélérer notre capacité à évaluer l'impact du changement climatique sur la survenue d'événements météorologiques extrêmes. Établir un tel lien est important car il nous permettra d'anticiper l'augmentation du nombre de ces événements. Cette compréhension, à son tour, nous permettra de mieux nous préparer et de faciliter la prise de mesures proactives.

Après avoir confirmé que les risques physiques sont une caractéristique inhérente de l'ère de l'Anthropocène, nous pouvons maintenant prendre en considération leur fréquence et leur intensité croissantes, étroitement liées au changement climatique. Comme illustré dans la Figure 3.7.2 de l'Organisation météorologique mondiale (OMM), le nombre de catastrophes naturelles signalées a considérablement augmenté entre 2000 et 2019. D'un côté, on observe une notable diminution du nombre de décès. D'un autre côté, il y a eu une forte augmentation des pertes économiques. Le rapport du GIEC IPCC (2012) sur les risques

FIGURE 3.7.1 : Relation entre l'augmentation de la température et la probabilité annuelle d'événement



Source : IPCC (2021)

physiques a émis des projections concernant la probabilité d'événements au XXI^e siècle.

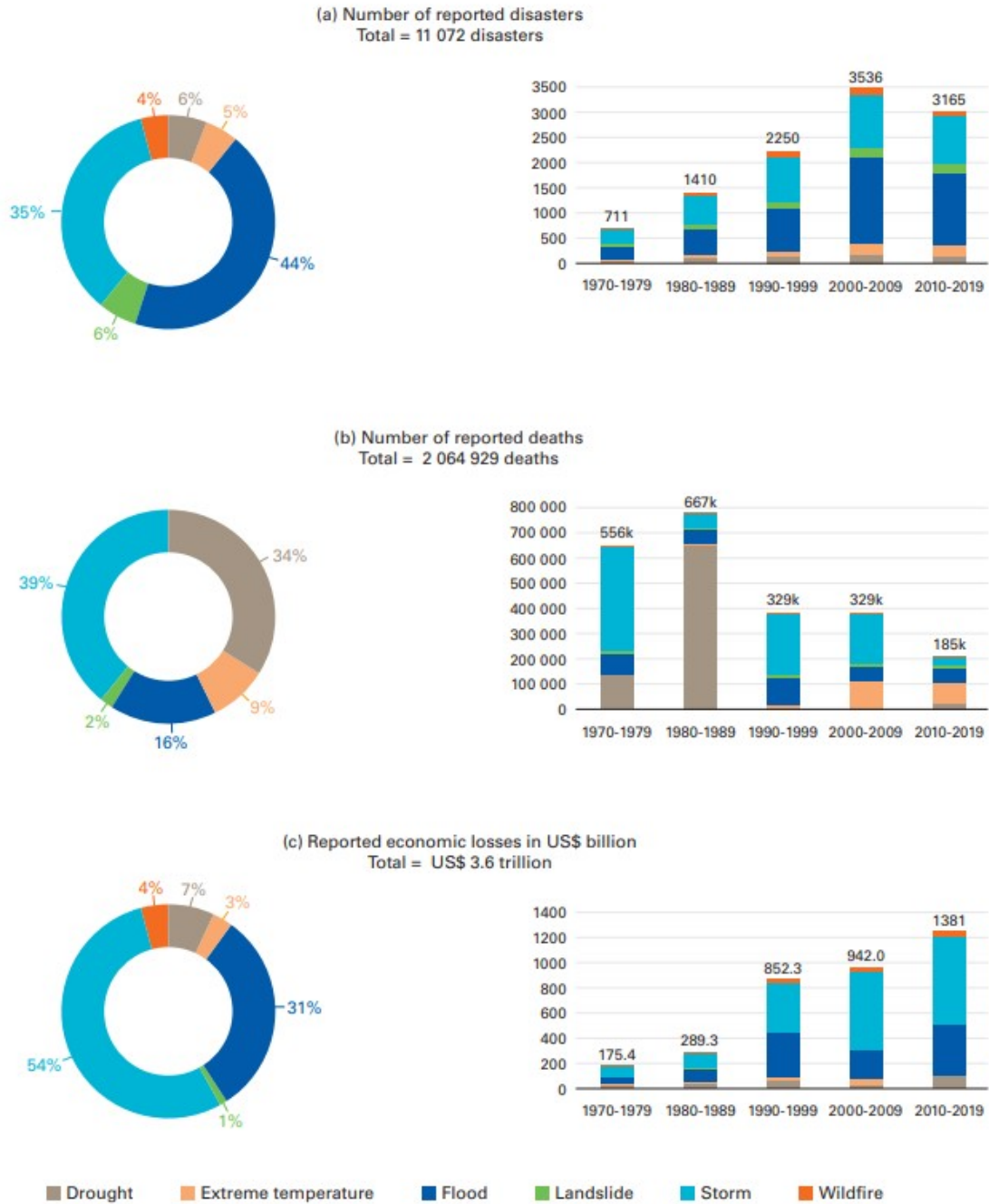
Le rapport prévoit une augmentation de la fréquence des fortes précipitations et des changements dans les extrêmes de température, entraînant des événements extrêmes tels que des inondations et des vagues de chaleur. Il existe un niveau modéré de confiance dans l'intensification des sécheresses au XXI^e siècle. Cependant, les conclusions concernant les vents extrêmes sont moins solides, principalement parce qu'il existe peu de modèles disponibles pour de tels événements. En ce qui concerne l'augmentation des pertes économiques dues aux événements liés au climat, le rapport met en avant une hétérogénéité spatiale significative. Plus précisément, il souligne que les pertes économiques, qu'elles soient assurées ou non, sont plus prononcées dans les pays développés. Cependant, en ce qui concerne les taux de mortalité et les pertes économiques en pourcentage du produit intérieur brut (PIB), les pays en développement connaissent des taux plus élevés.

Mesure et définitions

Risque, exposition, vulnérabilité

Selon la définition du GIEC (IPCC, 2012), nous définissons le risque physique comme la réunion de

FIGURE 3.7.2 : Évolution du nombre d'événements, des décès et des dommages



Source : MMO - *Atlas of Mortality and Economic Losses from Weather, Climate and Water Extremes (1970-2019)*

trois composantes : le risque, la vulnérabilité et l'exposition. Le risque concerne la possibilité de survenue d'un événement physique, qu'il soit d'origine naturelle ou humaine, capable d'entraîner diverses conséquences néfastes telles que des décès, des blessures, des dommages matériels et des perturbations.

Il représente une menace d'effets indésirables plutôt que l'événement physique lui-même. L'exposition fait référence à la présence de personnes, de moyens de subsistance, de services environnementaux, d'infrastructures ou d'actifs dans des zones qui peuvent être négativement influencées par des événements physiques, entraînant ainsi des dommages potentiels. Dans des conditions d'exposition, l'ampleur des conséquences néfastes dépend de l'interaction entre l'événement physique et les conditions socialement construites, connues sous le nom de vulnérabilité. La vulnérabilité est plus largement définie comme la propension à subir des effets indésirables. Elle représente des caractéristiques ou des circonstances inhérentes qui influencent la capacité à gérer et à se remettre des conséquences négatives des événements physiques. La vulnérabilité est façonnée par un éventail de facteurs et de processus historiques, sociaux, économiques, politiques, culturels, institutionnels, liés aux ressources naturelles et environnementales.

De plus, le risque physique peut être divisé en deux types de risques : aigus et chroniques. Le Conseil de stabilité financière au sein du G20 a créé la Task Force on Climate-related Financial Disclosures (TCFD) afin de fournir une compréhension complète des risques liés au climat. Dans le rapport TCFD (2017), une distinction est établie entre les risques physiques aigus et chroniques. Les risques physiques aigus sont définis comme étant liés à des événements, englobant une intensification des événements météorologiques extrêmes tels que les cyclones, les ouragans, les inondations, les sécheresses, les vagues de chaleur et les incendies. En revanche, les risques physiques chroniques font référence à des changements à plus long terme dans les schémas climatiques, susceptibles d'entraîner une montée du niveau de la mer, des vagues de chaleur persistantes et des modifications des précipitations. Le Réseau pour le verdissement du système financier (NGFS) fait également une distinction entre ces deux types de risques physiques, en particulier en ce qui concerne les dommages infligés. Les impacts aigus résultant d'événements météorologiques extrêmes peuvent entraîner des perturbations dans la chaîne de production et des dommages matériels. Alors qu'ils étaient historiquement considérés comme temporaires, la situation évolue avec l'avancée du réchauffement climatique. Ces événements peuvent accroître les risques pour les assureurs et réduire la valeur des actifs. En revanche, les impacts chroniques, principalement liés à l'augmentation des températures, à la montée du niveau de la mer et aux modifications des précipitations, ont le potentiel d'affecter la main-d'œuvre, le capital et la productivité agricole. Faire face à ces changements nécessitera des investissements importants et des efforts d'adaptation de la part des entreprises, des ménages et des gouvernements (NGFS, 2020).

Données historiques et données basées sur des scénarios

Pour évaluer et comprendre l'impact du risque physique, nous pouvons nous appuyer sur des données historiques et des données basées sur des scénarios. En ce qui concerne le risque physique, une part significative de la littérature se concentre sur les événements passés pour analyser leurs répercussions.

Cette approche est cruciale pour tirer des enseignements pratiques en matière d'évaluation du risque climatique physique. Examiner les conséquences passées des catastrophes naturelles est essentiel pour comprendre comment réagir à l'avenir. De plus, cela sert d'outil pour évaluer les facteurs contribuant à la vulnérabilité. En ce qui concerne les sources de données, il existe plusieurs bases de données complètes disponibles. EM-DAT du Centre de recherche sur l'épidémiologie des catastrophes (CRED) est la plus largement reconnue, étant une base de données publique mondiale qui fournit des informations sur la localisation et les dommages des catastrophes. De plus, il est possible de baser les analyses sur des bases de données géophysiques dérivées de données satellitaires et de stations météorologiques. Par exemple, l'Administration nationale des océans et de l'atmosphère (NOAA) propose de nombreuses bases de données qui permettent une géolocalisation précise des perturbations météorologiques. Ces bases de données géophysiques sont particulièrement précieuses car elles fournissent des mesures externes de l'intensité. Cela permet de séparer la composante du risque des autres facteurs qui peuvent être plus étroitement liés aux résultats économiques (Felbermayr et Groschl, 2014).

Les données basées sur des scénarios jouent un rôle critique en raison de l'incertitude considérable liée aux risques climatiques futurs. Ces scénarios permettent d'explorer une gamme de résultats possibles et d'évaluer comment différents facteurs peuvent interagir et évoluer au fil du temps. Ils sont essentiels pour anticiper, se préparer et élaborer des stratégies efficaces de gestion des risques climatiques et d'adaptation (Dessai et al., 2005). Un nombre croissant d'entreprises et d'institutions financières reconnaissent maintenant l'importance d'intégrer le risque physique dans l'analyse de scénarios. Ils reconnaissent la nécessité de stratégies de résilience pour faire face aux impacts du changement climatique (BIS, 2021). Ces scénarios revêtent une importance particulière du point de vue des investisseurs, principalement parce que les investissements ont tendance à avoir un horizon à moyen ou long terme (TCFD, 2017).

Le risque de transition

Alors que cette thèse se concentre sur les risques physiques, il est important de reconnaître la présence des risques de transition en tant que composante additionnelle des risques liés au climat. Ces risques englobent les défis associés à la transition vers une économie à faibles émissions de carbone. Le rapport du TCFD (2017) distingue quatre moteurs de risques de transition : (1) Les risques liés aux politiques résultant des changements dans la réglementation. Ces changements peuvent augmenter les coûts opérationnels des entreprises, car elles doivent se conformer à de nouvelles normes, nécessitant des investissements dans la technologie ou les ressources. De plus, les entreprises peuvent être contraintes de retirer prématurément des actifs si ces derniers ne satisfont plus les critères mis à jour. En fin de compte, ces changements peuvent entraîner une réduction de la demande ; (2) Les risques technologiques accrois-

sant l'incertitude liée au développement, à l'adoption et à la mise en œuvre de solutions technologiques pour résoudre les problèmes liés au climat. Ce risque peut entraîner le retrait d'actifs, une diminution de la demande, une augmentation des dépenses de R&D, des réductions des investissements en capital et des coûts de mise en œuvre élevés ; (3) Les risques de marché résultant des changements dans les dynamiques du marché qui peuvent entraîner une réévaluation des prix et une baisse de la demande ; (4) Les risques de réputation faisant référence aux dommages potentiels que l'image d'une entreprise peut subir si elle est perçue comme ayant une faible responsabilité environnementale. Ce risque peut avoir un impact négatif sur ses relations avec les investisseurs et ainsi réduire ses revenus.

Selon les conclusions de Bua et al. (2022), les primes de risque climatique sur le marché européen, englobant à la fois les risques de transition et les risques physiques, ont augmenté depuis la mise en œuvre des Accords de Paris. L'enquête menée par Stroebel et Wurgler (2021) auprès des investisseurs indique que les risques physiques semblent susciter moins d'inquiétude immédiate par rapport aux risques de transition, mais devraient devenir un point central d'attention au cours des 30 prochaines années. Néanmoins, comme démontré précédemment, les risques physiques ne sont pas aussi lointains qu'ils peuvent sembler l'être, et leur impact s'accroît, en particulier en ce qui concerne les dommages causés. Dans cette thèse, nous démontrerons que ces risques ont déjà exercé des impacts notables sur les aspects réels et financiers de l'économie et continueront de le faire s'ils ne sont pas efficacement traités. De plus, le marché mondial de l'assurance sera confronté à des contraintes pour couvrir l'ensemble de ces risques et atténuer la crise climatique. En effet, il ne peut pas offrir une réassurance illimitée. À titre d'exemple, Munich Re estime que la catastrophe naturelle la plus coûteuse de l'histoire demeure le passage de l'ouragan Katrina en Louisiane en 2005. Cet événement est évalué comme ayant entraîné un coût destructeur d'environ 150 milliards de dollars, dont l'industrie de l'assurance a couvert 62 milliards de dollars. Compte tenu du fait que les pertes assurées sont celles qui déclenchent les conséquences les plus graves, comme l'a souligné Von Peter et al. (2012), des instruments alternatifs doivent être mis en place. Ainsi, pour comprendre comment gérer et atténuer efficacement le risque physique, il est essentiel de procéder à une évaluation approfondie du risque lui-même et des canaux par lesquels il est transmis.

Les canaux de transmission du risque physique vers l'économie réelle

Impact global sur la croissance économique

Les catastrophes naturelles sont généralement perçues comme nuisibles à la croissance car elles per-

turbent les activités économiques normales, entraînent d'importantes pertes financières et détournent des ressources des investissements productifs. Dans le corpus existant de la littérature, les conclusions empiriques sur la relation entre les catastrophes naturelles et le produit intérieur brut (PIB) ne sont pas universellement concluantes. Certaines études ont découvert qu'à l'échelle mondiale, l'impact des catastrophes naturelles est effectivement négatif entraînant un ralentissement de la croissance économique (Raddatz, 2009; Strobl, 2011; Felbermayr et Groschl, 2014), en particulier à court terme (Noy, 2009). D'un autre côté, certaines études ont donné des résultats plus ambigus. Par exemple, Cavallo et al. (2013) ont découvert que seules les catastrophes exceptionnellement importantes ont un impact négatif sur la production économique. De plus, il existe des études qui ont identifié un effet de "destruction créatrice" schumpétérien associé aux catastrophes naturelles. Cet effet, qui opère à court terme, implique que certains secteurs et activités économiques connaissent un essor en raison de la nécessité de rétablissement et de reconstruction à la suite de la catastrophe (Skidmore et Toya, 2002; Ramcharan, 2007; Noy et Vu, 2010).

Canaux de transmission

Comme le montre le développement des modèles d'évaluation intégrée (IAM), qui explorent diverses disciplines académiques pour modéliser l'interaction entre l'économie et le changement climatique, il existe de nombreux canaux par lesquels les risques liés au climat peuvent impacter l'économie (Nordhaus, 1993; Nordhaus et Yang, 1996). Dans cette thèse, nous mettrons particulièrement l'accent sur la transmission des risques physiques.

Premièrement, la puissance destructrice des catastrophes naturelles peut exercer un impact considérable sur le processus de production. Ces événements ont la capacité de causer des dommages matériels, de détruire des équipements et des infrastructures publiques. Une telle destruction induit des perturbations au sein des chaînes d'approvisionnement, dont les interruptions ont un effet en cascade (Altay et Ramirez, 2010; Haraguchi et Lall, 2015). Le deuxième canal à prendre en considération est l'impact sur la productivité. Les catastrophes naturelles endommagent le capital des entreprises, comme le suggère Kahn (2005). Cependant, cet impact est débattu. Certaines études, comme Acevedo et al. (2020) et McDermott (2012), ont indiqué que le capital et la main-d'œuvre peuvent connaître une réduction de la productivité à la suite d'événements extrêmes. À l'inverse, Leiter et al. (2009) présentent une perspective différente. Ils soutiennent que, à court terme, les régions touchées par des inondations peuvent connaître une augmentation des actifs totaux et de l'emploi, suggérant un effet potentiellement positif sur la productivité et la croissance. Troisièmement, l'impact sur la rentabilité des entreprises donne également des résultats mitigés. Par exemple, Noth et Rehbein (2019) ont découvert un effet positif découlant des inondations de

2013 en Allemagne, se traduisant par une augmentation du chiffre d'affaires et des réserves de trésorerie pour les entreprises. En revanche, Hsu et al. (2018) indiquent que les entreprises possédant des usines situées dans des zones exposées aux catastrophes naturelles ont tendance à connaître une rentabilité plus faible. Enfin, une autre dimension pour comprendre la relation entre les catastrophes naturelles et la croissance économique est l'investissement. Les conclusions de la littérature sur ce point sont en accord. Il devient évident que les catastrophes naturelles importantes ont tendance à réduire les investissements directs étrangers (IDE) dans les régions touchées (Escaleras et Register, 2011; Friedt et Toner-Rodgers, 2022; Gu et Hale, 2023). De plus, Hosono et al. (2016) ont observé un impact négatif sur l'investissement privé. Dans l'ensemble, il est clair que les catastrophes naturelles peuvent influencer la croissance économique par le biais de plusieurs canaux, bien que ces canaux n'opèrent pas systématiquement dans la même direction.

Hétérogénéité des impacts

De nombreuses études établissent des seuils spécifiques en affirmant que seules les grandes catastrophes naturelles ont un impact (Raschky, 2008; Fratzscher et al., 2020). Cette pratique repose sur le consensus général selon lequel les événements à plus grande échelle ont un potentiel plus important de perturbation, comme l'ont noté Hallegatte et Przyluski (2010). Notamment, Cavallo et al. (2013) discernent spécifiquement que seules les grandes catastrophes ont un impact négatif sur la production, à la fois à court terme et à long terme. La relation entre la taille de la catastrophe et ses impacts est non linéaire. Un autre facteur clé affectant la variation des impacts des catastrophes est le type de catastrophe en lui-même. De nombreuses études ont montré que la nature de la catastrophe conduit à des résultats significativement différents (Felbermayr et Groschl, 2014; Altay et Ramirez, 2010). La dernière source notable d'hétérogénéité provient des facteurs de vulnérabilité définis dans la section 3. En effet, le contexte économique et social au sein de différentes zones joue un rôle déterminant dans les impacts résultants des catastrophes naturelles. Par exemple, les niveaux de revenus ont été identifiés comme un déterminant de l'ampleur des impacts ; les économies en développement et de plus petite taille connaissant souvent des conséquences négatives plus importantes que leurs homologues développées et plus grandes (Noy, 2009). Certaines études approfondissent cet aspect en examinant les vulnérabilités à un niveau plus granulaire, telles que les vulnérabilités sectorielles spécifiques (Loayza et al., 2012). De plus, de nombreux facteurs, notamment les niveaux d'éducation, l'ouverture au commerce, la profondeur du système financier et la qualité des institutions, peuvent également jouer des rôles cruciaux dans la formation de résultats hétérogènes (Toya et Skidmore, 2007).

Comme souligné dans cette section, il existe un corpus substantiel de la littérature dédié à l'examen des effets des catastrophes naturelles sur l'économie réelle, explorant les canaux de transmission et analysant les sources d'hétérogénéité. Néanmoins, l'impact des risques physiques sur les systèmes financiers est resté relativement inexploré et souvent négligé par les cadres réglementaires. Cependant, il est clairement établi que la réalisation des risques financiers peut résonner dans l'économie réelle, comme le démontrent les récents épisodes de crise. Par conséquent, il est impératif que ces risques fassent l'objet d'une étude approfondie afin de promouvoir la stabilité financière et la résilience des secteurs financiers face à eux.

Impact des risques liés au climat sur le secteur financier

En 2015, le gouverneur de la Banque d'Angleterre, Mark Carney, a émis une mise en garde à l'égard du système financier concernant son exposition aux risques liés au climat, qu'ils soient directs ou indirects, englobant les risques physiques et les risques liés à la transition (Carney, 2015)

Différentes sources de risques

Le NGFS (2020) met en évidence 5 risques environnementaux critiques ayant des implications significatives pour le secteur financier. Le premier risque examiné est le risque opérationnel, étroitement lié aux perturbations des opérations de production et à la réduction de la rentabilité à la suite de catastrophes naturelles. Nous avons développé ce risque dans la section précédente en raison de son impact sur l'économie réelle. Néanmoins, il peut également avoir des répercussions au sein du secteur financier, pouvant potentiellement entraîner une augmentation du risque de défaillance. En effet, les entreprises peuvent sembler plus risquées pour les investisseurs après des événements de catastrophes naturelles. Le deuxième risque est le risque de crédit (voir Figure 1.9.1 dans le chapitre 1 pour plus de détails sur les canaux). Le risque de crédit implique une probabilité accrue de défaut de crédit et/ou une diminution de la valeur des garanties. Par exemple, Bernstein et al. (2019) montrent que l'exposition à l'élévation du niveau de la mer peut entraîner une réduction de la valeur des maisons qui pourraient servir de garantie. De plus, Fankhauser et Tol (2005) confirment que la capacité de service de la dette diminue après la destruction des actifs physiques. Par conséquent, une augmentation de la proportion de prêts non performants survient fréquemment après un événement de catastrophe naturelle (Klomp, 2014). Cette escalade du risque de crédit s'applique non seulement au niveau des entreprises et des ménages, mais aussi au niveau macroéconomique, contribuant à un risque accru de défaut de la dette souveraine (Klomp, 2017; Lamperti et al., 2019). Le troisième risque qui se dégage est le risque de souscription auquel les compagnies d'assurance sont confrontées en raison d'une augmentation des pertes assurées. Les catastrophes natu-

relles peuvent perturber considérablement les opérations des compagnies d'assurance, comme le démontre Benali et Feki (2017), remettant potentiellement en question leur capacité à maintenir une couverture continue. De plus, bien que la couverture d'assurance puisse augmenter, elle aide principalement à la réponse post-catastrophe plutôt qu'à la diminution du risque en amont (Kousky, 2019). Cela souligne l'idée que l'assurance est davantage une mesure ex-post qu'une mesure ex-ante, mettant en avant son rôle dans la gestion des conséquences des catastrophes plutôt que dans leur prévention. Le quatrième risque concerne le risque de marché lié à la dynamique de réévaluation. Le modèle de Gourio (2012) illustre qu'un risque accru de catastrophe tend à réduire les attentes de revenus, ce qui se traduit par des primes de risque plus élevées. Cette adaptation de la perception du risque déclenche ensuite des effets de réévaluation sur le marché boursier. De plus, des mécanismes de réévaluations similaires entrent en jeu sur le marché obligataire en raison de la réaffectation de portefeuilles (Dafermos et al., 2018). Le cinquième et dernier risque est le risque de liquidité, découlant de la nécessité de fonds pour soutenir les efforts de reconstruction post-catastrophe, ce qui peut entraîner une forte demande de liquidité. Allen (2003) soutient cette théorie et montre une augmentation des retraits après les catastrophes naturelles. Cette demande accrue de retraits peut, à son tour, poser des défis pour les banques et augmenter le risque de liquidité (Nie et al., 2023).

La présence combinée de ces risques pose une question fondamentale concernant les risques liés au climat en tant que source potentielle de risque systémique. Tel que défini par Kaufman et Scott (2003), « *Le risque systémique fait référence au risque ou à la probabilité de défaillances dans l'ensemble d'un système, par opposition à des défaillances dans des parties ou des composantes individuelles.* ». La crise financière mondiale est un exemple saisissant de la matérialisation du risque systémique. Bernanke (2018) l'explique comme une perturbation causée par un choc dans les asymétries d'information, rendant l'évaluation du risque plus complexe. Comme le montre cette section, les catastrophes naturelles introduisent une multitude d'incertitudes qui peuvent considérablement aggraver les asymétries d'information. Bolton et al. (2021) affirment que les catastrophes naturelles, par leur nature même, représentent une source de risque systémique difficile à couvrir en raison de l'incertitude inhérente et de la capacité limitée à partager les risques entre les acteurs financiers.

Le secteur financier : un moyen de soutenir l'atténuation des impacts ?

Comme démontré dans la section précédente, le secteur financier est exposé aux risques physiques, mais il détient également le potentiel de fournir à la fois des solutions préventives et réactives. Selon le rapport de UNISDR (2015) sur la réduction des risques de catastrophe, on a estimé que les coûts mondiaux annuels des dommages suite aux catastrophes s'élèvent à environ 250 à 300 milliards de dol-

lars américains. Ces dommages substantiels soulignent la nécessité urgente d'agir. Comme l'a souligné Hammett et Mixter (2017), le secteur financier peut contribuer à atténuer les impacts des risques liés au climat. Cette implication peut englober à la fois des mesures préventives (ex-ante) et des mesures de réponse (ex-post).

D'une part, le secteur financier a le potentiel de jouer un rôle significatif dans l'aide aux efforts de reconstruction après une catastrophe naturelle. Les principaux défis à cet égard tournent autour de la garantie de la disponibilité de fonds adéquats et de la rapidité de la réponse. De nombreuses études démontrent que, suite à des catastrophes naturelles, les entreprises exposées à l'événement ont tendance à avoir des chances de survie réduites (LeSage et al., 2011; Basker et Miranda, 2018). Par conséquent, le système financier pourrait potentiellement contribuer à faciliter le processus, mais il pourrait rencontrer d'importants défis liés aux asymétries d'information. De ce fait, certaines banques pourraient réduire leur offre de crédit en raison de chocs de financement, d'un ratio élevé de prêts non performants et de retraits substantiels (Faiella et Natoli, 2018; Brei et al., 2019). La structure du système bancaire pourra également influencer la réaction des banques. La littérature existante s'accorde largement à dire que les banques locales possèdent un avantage concurrentiel en ce qui concerne le crédit aux petites entreprises (Berger et al., 2015). Cet avantage devient particulièrement prononcé à la suite de catastrophes naturelles. Cela s'explique par le fait que les prêteurs locaux peuvent bénéficier de réductions des asymétries d'information et établir des relations à long terme (Chavaz, 2016; Koetter et al., 2020).

D'autre part, le secteur financier pourrait également mettre en place des mesures préventives pour atténuer les effets néfastes des risques physiques. Nous pouvons classer ces mesures préventives en trois types. Tout d'abord, il peut jouer un rôle significatif dans la réallocation des investissements. Le risque d'actifs bloqués devrait servir de catalyseur pour rediriger les investissements vers des entreprises à plus faibles émissions.¹² De plus, cette transition peut permettre la diminution de la fréquence des risques physiques. Par conséquent, il est essentiel d'établir des incitations qui favorisent de tels investissements.

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Deuxièmement, afin de prévenir la réévaluation drastique susceptible d'entraîner des déstabilisations significatives, les marchés financiers devraient évaluer et tarifer avec précision le risque physique. Les études existantes n'ont pas identifié de preuve de tarification adéquate pour l'exposition au risque physique sur le marché des obligations d'entreprises non financières (Hong et al., 2019; Huynh et al., 2020).¹⁴

¹² Afin de limiter le réchauffement climatique à 1,5°C, un investissement annuel d'environ 2,4 billions de dollars à l'échelle mondiale serait nécessaire, spécifiquement pour la transformation du système énergétique. Ceci contraste avec le niveau actuel d'investissement d'environ 1,75 billion de dollars (IEA, 2018; IPCC, 2018)

¹³ Une autre observation importante concerne la disparité des investissements "verts" entre les secteurs. Comme le souligne FTSE Russell (2022), il semble que plus de 75% de la capitalisation boursière du marché "vert" soit concentrée dans des secteurs tels que la technologie, les biens et services industriels, l'automobile et les pièces détachées, les services publics et la construction et les matériaux.

¹⁴ Sachant que le marché des obligations des entreprises a connu une croissance substantielle. Entre 2008 et 2018, le marché international des obligations des entreprises non financières a affiché un taux de croissance de 2% (Abraham et al., 2020), en comparaison une croissance de 0,5% a été observée sur le marché du crédit.

Cette absence de tarification est également valable pour les marchés boursiers, sans preuve discernable de primes de risque associées à l'exposition au risque physique (Faccini et al., 2021; Gostlow, 2021). Des efforts considérables sont nécessaires pour intégrer correctement le risque physique dans les primes de risque sur les marchés financiers.

La dernière mesure préventive que le secteur financier peut mettre en œuvre concerne l'intégration des risques liés au climat dans les notations de crédit. Il est largement reconnu que les notations de crédit jouent un rôle crucial dans la détermination de la valeur des actifs financiers. Comme le souligne Ciummo et al. (2022), la divulgation de l'influence des risques liés au changement climatique sur les notations de crédit revêt une importance capitale. Certaines recherches ont montré que le risque lié au changement climatique est déjà pris en compte dans les notations de crédit souverain (Cevik et Jalles, 2020). Cependant, à l'échelle mondiale, les agences de notation réagissent souvent après qu'un événement se soit produit pour ajuster l'évaluation du risque de crédit (Mathiesen, 2018).

Mesures et politiques d'adaptation

Politiques d'adaptation pour l'économie réelle

De nombreuses politiques ont été mises en œuvre pour atténuer l'impact des risques liés au climat sur l'économie réelle ; les politiques environnementales et les politiques fiscales étant les catégories les plus importantes. Ces politiques sont principalement axées sur la réduction des émissions plutôt que sur l'atténuation du risque physique. D'une part, dans le cadre des politiques environnementales, nous pouvons mettre en avant l'importance des accords volontaires. L'un des accords les plus remarquables a été le Protocole de Kyoto, établi lors de la COP3 en 1997. Ce protocole a encouragé les nations industrialisées et les économies en transition à réduire et à diminuer leurs émissions de gaz à effet de serre (GES) conformément à des objectifs individuels prédéterminés. Ce protocole a été suivi par les Accords de Paris en 2015, qui vise à limiter l'augmentation des températures mondiales en deçà de +2°C. De plus, il existe des approches de "commande et de contrôle" qui impliquent des normes et des réglementations, comme le *Clean Air Act (CAA)*. Les politiques environnementales englobent une série d'initiatives liées à la labellisation et à la certification de produits ou de pratiques respectueuses de l'environnement, un processus couramment appelé l'éco-étiquetage. D'autre part, les politiques fiscales jouent un rôle central dans la génération de fonds publics pour faciliter les investissements dans diverses initiatives de durabilité. Cela peut inclure l'énergie durable, les technologies propres et les capacités d'adaptation, entre autres. Les principaux composants de ces politiques fiscales comprennent les taxes environnementales, les

réformes budgétaires, les incitations fiscales et l'augmentation des recettes publiques. Un exemple en est le Système d'échange de quotas d'émission de l'Union Européenne (EU ETS) ; un marché du carbone en Europe où les entreprises se voient attribuer des quotas d'émissions et peuvent échanger des allocations. L'importance de telles mesures a été soulignée par la création du Réseau des politiques fiscales vertes en 2014. Néanmoins, selon Calel et Dechezleprêtre (2016), le marché de l'EU ETS ne semble pas favoriser de manière significative le développement de technologies plus respectueuses de l'environnement.

Ces mesures, lorsqu'elles sont combinées, contribuent à l'avancement des objectifs climatiques et à la facilitation d'une transition vers une économie plus durable. Bien que ces transitions puissent, à leur tour, réduire la fréquence des catastrophes naturelles, il est évident que les politiques environnementales mettent principalement l'accent sur le risque de transition dans l'économie réelle, plutôt que sur le risque physique.

La situation est exacerbée lorsque l'on considère que, en plus de l'économie réelle, le secteur financier rencontre également des difficultés pour intégrer efficacement les risques liés au climat. Outre des impacts tangibles sur l'économie réelle, les risques physiques donnent également lieu à des risques financiers, comme expliqué dans la section 3. Étonnamment, ces risques financiers n'ont pas suscité autant d'attention, induisant un manque de mesures politiques pour les traiter de manière adéquate. Reconnaître les implications financières des risques physiques est une étape cruciale pour renforcer la résilience et la durabilité de nos systèmes économiques et financiers. Cette reconnaissance contribuera à élaborer des politiques d'adaptation financière adéquates.

Absence de cadre d'adaptation et de réglementation

Comme mentionné précédemment, des réglementations ont été établies pour atténuer l'impact des risques climatiques sur l'économie réelle. Cependant, lorsque nous nous tournons vers le secteur financier, il devient évident que des réglementations contraignantes ne sont pas encore en place.

Nous pouvons observer l'émergence d'instruments financiers verts tels que des produits d'épargne verts, des prêts verts et des obligations vertes. Cependant, leur part de marché demeure considérablement limitée en comparaison avec les produits financiers classiques. De plus, ces instruments abordent principalement le risque de transition, avec peu d'attention accordée au risque physique. Il est important de noter qu'il existe une absence notable de réglementations complètes, à l'exception d'initiatives comme les Principes des obligations vertes non contraignants.

En ce qui concerne les institutions financières et les banques, elles réalisent de plus en plus de tests de résistance climatique, qui ont pour but d'évaluer la résilience et la stabilité financière des entités dans divers scénarios liés au climat, y compris les risques physiques. Cet exercice permet de quantifier leur

exposition et leurs vulnérabilités, ce qui peut encourager l'adoption de meilleures pratiques dans les cadres réglementaires. Cependant, comme l'a souligné Battiston et al. (2017), le moment de la mise en place du cadre politique est crucial. Un cadre politique précoce et stable facilite des ajustements plus fluides des valeurs d'actifs et peut entraîner des gagnants potentiels et des perdants. En revanche, un cadre politique tardif et abrupt pourrait avoir des conséquences systémiques défavorables. Au sein des réglementations bancaires mondiales de Bâle III, conçues pour renforcer la stabilité et la sécurité du système bancaire, il n'existe aucune disposition concernant des instruments pouvant atténuer les risques financiers liés au climat. Dans une foire aux questions (FAQ) de décembre 2022 sur le climat, la Banque des règlements internationaux (BIS) souligne que les banques devraient évaluer comment intégrer les risques financiers liés au climat dans leur compréhension et la mise en œuvre du cadre de Bâle actuel. De plus, les banques sont encouragées à améliorer en permanence leur expertise et leurs capacités en ce qui concerne les risques financiers liés au climat. Il n'existe toujours pas de lignes directrices officiellement établies, même si certaines études ont tenté de suggérer des cadres pour intégrer les considérations climatiques dans le pilier III de Bâle (Berenguer et al., 2020). L'absence de lignes directrices officielles entrave l'efficacité des politiques prudentielles visant à atténuer l'impact des risques liés au climat. Nieto (2019) met en avant la valeur potentielle de l'exploration de politiques prudentielles comme moyen d'internaliser les externalités négatives associées aux risques climatiques, tant pour les banques que pour leurs autorités de surveillance.

La dernière discussion importante porte sur le rôle de la politique monétaire, car les banques centrales sont de plus en plus sollicitées pour faire face aux risques liés au climat qui pourraient compromettre la stabilité financière. Lors de son discours au Paris Europlace International Financial Forum le 12 juillet 2022, François Villeroy de Galhau, le gouverneur de la Banque de France, a déclaré : *"Le mandat central des banques centrales dans le monde entier est la stabilité des prix, et le changement climatique affecte déjà le niveau des prix et l'activité."* Cependant, tous les banquiers centraux ne sont pas d'accord lorsqu'il s'agit d'intégrer le changement climatique dans leurs mandats. Dans une déclaration de janvier 2023 lors de la conférence RiskBank, J. Powell a déclaré : *"Nous ne sommes pas, et ne serons pas, des décideurs en matière de climat."* De plus, certaines études indiquent que les politiques monétaires pourraient ne pas être entièrement neutres dans leurs effets sur les entreprises "brunes" et "vertes". Les résultats de la recherche suggèrent que la politique monétaire pourrait avoir un impact plus marqué sur les entreprises "brunes" (Benchora et al., 2023).

Problématiques et contributions

Nous comprenons maintenant les implications significatives des risques physiques pour le secteur financier. La menace croissante des catastrophes naturelles en raison de leur fréquence et de leur gravité

accrues dans le contexte du changement climatique constitue un défi pour la stabilité financière. Ces chocs spécifiques ont été démontrés comme ayant des effets déstabilisants sur l'économie réelle. Cependant, il existe encore un manque de preuves concernant leur impact sur le secteur financier. Les crises financières récentes, y compris la crise financière de 2008, soulignent le fait que les marchés financiers peuvent déclencher des chocs avec des conséquences substantielles pour l'économie réelle. Établir un cadre complet qui identifie précisément les différentes sources de risque et leurs magnitudes respectives sur différents marchés est d'une importance primordiale pour fournir la réponse réglementaire adéquate. Dans cette thèse, nous explorerons comment différents niveaux du secteur financier peuvent être influencés par ces chocs. Nous commencerons par une perspective macroéconomique, puis passerons par le système bancaire, pour conclure par un examen de la tarification sur le marché obligataire.

De plus, en tenant compte des conséquences du risque physique et en mettant en œuvre des réponses politiques appropriées, nous pouvons non seulement faciliter les mesures de réponse, mais aussi atténuer de manière proactive ces risques. De telles économies de ressources peuvent permettre des investissements plus efficaces dans la transition vers une économie verte et la réduction de l'escalade des catastrophes naturelles. En conséquence, cela contribue à briser le cycle des impacts néfastes du changement climatique.

La principale contribution de cette thèse consiste à évaluer les effets perturbateurs potentiels des catastrophes naturelles, en mettant particulièrement l'accent sur les mesures potentielles, à la fois réactives (ex-post) et proactives (ex-ante). Le premier chapitre de cette thèse se concentre sur l'impact des catastrophes naturelles sur la prime de financement externe des pays. De plus, nous examinons l'impact atténuant potentiel que les politiques macroprudentielles pourraient avoir dans ce contexte. Nous continuons avec un deuxième chapitre axé sur les réactions post-catastrophe des banques. Nous analysons l'impact des typhons sur les activités de prêt des banques en Chine et le rôle que ces banques peuvent jouer post-catastrophe au niveau local. Enfin, le dernier chapitre vise à identifier la tarification adéquate du risque physique à venir. Nous examinons la prime d'exposition au risque physique sur le marché obligataire de la zone euro et nous explorons l'influence potentielle des catastrophes naturelles passées.

Chapitre 1 : Catastrophes Naturelles et Stress Financier : Les réglementations macroprudentielles peuvent-elles maîtriser les Cygnes Verts ?

Malgré une littérature croissante sur le changement climatique, les effets des risques climatiques physiques sur les systèmes financiers restent largement inexplorés. Dans ce contexte, nous visons à examiner empiriquement si les catastrophes naturelles (CN) provoquent des tensions financières, et si la présence

d'un ensemble rigoureux de mesures macroprudentielles peut atténuer cet effet négatif. Nous soutenons qu'un cadre macroprudentiel strict qui améliore la résilience des emprunteurs et des prêteurs peut atténuer l'impact financier des événements climatiques. Nous nous concentrons sur deux types d'événements climatiques fréquents et dommageables : les tempêtes et les inondations.

Nous utilisons des projections locales (LPs) avec des variables d'interaction pour évaluer l'impact macroéconomique des catastrophes naturelles (CN), en termes de stress financier, conditionnellement à la rigueur des mesures macroprudentielles nationales. Le stress financier est approximé par la prime de financement externe, c'est-à-dire l'écart entre le taux de prêt bancaire et le taux monétaire (sans risque). Nous construisons une base de données originale sur les catastrophes naturelles où les CN sont évaluées en fonction de leur intensité météorologique, recueillie auprès de différentes sources (stations météorologiques et les satellites). Ainsi, nous sommes en mesure de créer des mesures objectives de la gravité des CN, bien adaptées à une analyse empirique causale, contrairement aux données basées sur les dommages, qui sont plus sujettes à des problèmes d'endogénéité. Notre mesure de la rigueur macroprudentielle, calculée à partir d'informations de la base de données sur les politiques macroprudentielles (iMaPP), rend compte du nombre d'instruments effectivement activés sur la période (traduisant l'ampleur de la politique macroprudentielle).

Les projections locales estimées sur des horizons allant de 1 à 12 trimestres, pour un panel de 88 pays sur la période de 1996 à 2016, indiquent que la dynamique des écarts de taux d'intérêt diffère considérablement entre les pays ayant une réglementation prudentielle faible et élevée. La prime de financement externe augmente à la suite des tempêtes dans les pays où la réglementation prudentielle est peu contraignante. En revanche, les pays dotés d'un cadre prudentiel solide peuvent bénéficier d'une prime d'agence plus faible, grâce à la solvabilité des prêteurs et des emprunteurs, ce qui facilite éventuellement le remplacement du capital par des technologies plus productives. Cependant, dans le cas des inondations, les impacts macroéconomiques sont moins clairs. Nos résultats sont robustes à différentes spécifications économétriques et à des mesures alternatives de la réglementation prudentielle.

Nous concluons que les tempêtes ont un impact significatif sur les conditions de financement au niveau des pays. Nous constatons également qu'une réglementation macroprudentielle solide améliore la capacité des pays à faire face à cet impact financier. Par conséquent, les mesures macroprudentielles peuvent offrir une protection contre les risques financiers liés au climat croissants et contribuer à économiser des ressources pour la transition vers une économie à faibles émissions de carbone.

Chapitre 2 : Typhons en Chine : Les banquiers veulent-ils récupérer leurs parapluies quand il pleut ?

Ce chapitre explore comment les typhons, des événements fréquents en Chine, affectent le comportement des banques chinoises. Malgré un intérêt croissant pour ces questions liées au climat, il reste encore beaucoup à analyser, en particulier au sujet des marchés émergents. Les banques sont cruciales pour financer les entreprises et les ménages, et des effets préjudiciables sur leurs performances peuvent entraîner des conséquences néfastes pour l'économie réelle. La plupart des études portant sur ce sujet se concentrent sur les États-Unis ou sur les pays développés disposant d'un marché de l'assurance, tandis que certaines études montrent que les impacts des catastrophes naturelles sont plus étendus dans les économies en développement.

Le système bancaire chinois possède certaines caractéristiques intéressantes et uniques. Tout d'abord, il a récemment été libéralisé. Par exemple, les limites des taux de prêt et de dépôt ont été supprimées en 2004. De plus, le système bancaire chinois est principalement composé de trois types de banques ayant des objectifs spécifiques (banques d'État, banques commerciales et banques rurales). Ces spécificités nous permettent d'identifier plus précisément la réaction des banques en fonction de leurs principales caractéristiques.

L'objectif principal des banques est d'analyser et de surveiller les clients pour lutter contre les asymétries d'information. D'une part, une diminution des prêts bancaires après des événements extrêmes pourrait résulter d'une détérioration des asymétries d'information, d'une diminution de la valeur des garanties et de perspectives économiques défavorables. D'autre part, grâce à une connaissance plus approfondie, les banques pourraient ne pas réduire leurs prêts et pourraient même accorder des prêts en ces périodes post-catastrophe.

Nous utilisons une régression de double-différences (DID) avec des effets fixes temporels et individuels pour évaluer l'impact des typhons sur la réaction des banques. Dans notre stratégie d'identification, le "groupe traité" est constitué des banques qui ont été touchées par des typhons importants. Nous établissons une mesure annuelle de l'exposition des banques aux typhons en fonction du pourcentage d'agences touchées et de la gravité de l'événement.

Nos estimations de double-différences basées sur un échantillon de 327 banques entre 2004 et 2019 révèlent que, en moyenne, les typhons déclenchent une diminution des prêts représentant 2,8% du total des actifs bancaires. Nous montrons que cette baisse provient des banques commerciales. En revanche, les banques rurales agissent comme des amortisseurs de choc. Cela peut être la conséquence de relations de prêt à long terme et d'une meilleure connaissance des risques économiques et climatiques locaux. De plus, l'absence de banques rurales dans les préfectures chinoises s'avère préjudiciable à la croissance locale

après un typhon. Nous constatons également que la propriété gouvernementale et la pression politique externe atténuent le déclin relatif des prêts des banques commerciales touchées par les typhons.

Nous concluons que les typhons ont un impact significatif sur la stabilité bancaire. Nous constatons également que ces effets diffèrent en fonction des caractéristiques des banques. Ainsi, sachant que ce type de catastrophes naturelles liées à la météo augmentera en termes de fréquence et d'intensité, nous soulignons que les banques courent un risque alors qu'elles sont un acteur crucial pour la reconstruction, en particulier celles qui ont une proximité locale.

Chapitre 3 : Le risque physique est-il tarifié sur le marché des obligations de la zone euro ?

Ce chapitre vise à étudier si l'exposition au risque physique génère une prime de risque sur le marché des obligations de la zone euro, et si les événements passés de catastrophes naturelles ont également un impact. Alors que de nombreuses études se concentrent sur l'évaluation du risque climatique sur le marché des obligations, elles mettent souvent l'accent sur le risque de transition. En revanche, il existe relativement peu de littérature qui se penche sur l'évaluation des risques physiques sur le marché des obligations. Néanmoins, certaines recherches ont montré que les risques physiques peuvent avoir un impact significatif sur la rentabilité, le financement et les investissements des entreprises. Par conséquent, une tarification inexacte de ce risque pourrait potentiellement entraîner des perturbations importantes sur les marchés financiers.

Notre recherche s'appuie sur un ensemble de données de 666 obligations émises par 115 entreprises européennes de 2014 à 2022. En utilisant la courbe des rendements de la Banque Centrale Européenne pour les obligations notées AAA comme référence de rendement sans risque, nous calculons la prime de rendement mensuelle pour chaque obligation individuelle comme variable dépendante. Cela nous a permis d'évaluer le risque associé à chaque obligation. Pour évaluer l'exposition aux risques physiques anticipés, nous utilisons la base de données du système d'intégration des risques liés au carbone fournie (CRIS) par Carbon4. Cette base de données calcule des scores d'exposition pour chaque entreprise, basés sur les scénarios du GIEC. La base de données propose sept sous-scores distincts, chacun conçu pour aborder différentes catégories de risques physiques, ainsi qu'un score global agrégé.

Tout d'abord, nous examinons la tarification des risques anticipés de catastrophes naturelles sur le marché des obligations de la zone euro. Notre analyse repose sur un modèle de panel, qui nous permet de tenir compte de tous les facteurs conventionnels influençant les spreads obligataires, ainsi que des effets fixes pour le temps, le secteur et le pays. En résumé, nos résultats indiquent qu'il n'y a pas eu de tarification significative des risques d'exposition anticipée au cours de la période examinée. Cela souligne

que l'intégration du risque physique n'est pas une préoccupation majeure, car elle n'est pas suffisamment reflétée dans la dynamique de tarification du marché des obligations de la zone euro, à l'exception de l'exposition aux vagues de chaleur.

Ensuite, dans le cadre d'une enquête complémentaire, nous examinons si les catastrophes naturelles peuvent avoir un impact sur la tarification des obligations des entreprises fortement exposées à de tels événements. Nous calculons les dommages cumulés sur des périodes antérieures spécifiques (3 mois, 6 mois, 1 an) et les croisons avec les mesures d'exposition. Pour l'ensemble des risques liés aux catastrophes climatiques, nous constatons qu'il y a une réaction de prime pour les entreprises fortement exposées à la suite d'une catastrophe naturelle causant des dommages. Cependant, il semble que les investisseurs aient tendance à adopter une perspective à court terme, car la majeure partie de la tarification des risques diminue pour presque tous les types de catastrophes lorsque l'on considère les dommages cumulés sur une période d'un an.

Nous concluons que la tarification du risque physique n'est pas adéquate sur le marché des obligations de la zone euro. La prise de conscience croissante qui émerge à la suite d'événements significatifs a tendance à être de courte durée. Néanmoins, compte tenu de la fréquence croissante des catastrophes naturelles à grande échelle, cette mauvaise tarification pourrait potentiellement entraîner des perturbations significatives sur les marchés financiers à long terme, car les ajustements nécessaires deviendront plus coûteux.

En résumé, cette thèse met en évidence l'influence du risque physique sur les conditions de crédit, les prêts bancaires et les obligations. Cependant, les risques financiers liés au climat n'ont pas reçu une attention adéquate de la part des institutions. Nous démontrons toutefois que des réglementations, telles que les mesures macroprudentielles, pourraient apporter une assistance, mais le paysage réglementaire actuel demeure incertain. Il existe une demande mondiale pressante pour des réglementations plus solides et transparentes à cet égard.

Pauline AVRIL

Natural disasters and financial stability

Résumé :

Cette thèse analyse l'impact des risques physiques dus au changement climatique sur la stabilité financière. Elle examine plus spécifiquement les répercussions des catastrophes naturelles sur les primes de financement externes, les primes de risques et les prêts bancaires. De plus, différentes stratégies pour atténuer l'impact potentiel négatif des catastrophes naturelles sur le secteur financier sont analysées. Étant donné la fréquence et la gravité croissantes de ces événements, il est crucial de comprendre ces impacts pour promouvoir des systèmes financiers résilients et ainsi économiser des ressources précieuses pour le financement de la transition vers une économie à faible émission de carbone. Le premier chapitre étudie l'impact des catastrophes naturelles sur la stabilité financière à un niveau macroéconomique. Dans ce chapitre il est constaté que les mesures macroprudentielles d'un pays déterminent l'ajustement de la prime de financement externe, l'absence de régulation macroprudentielle entraîne une augmentation de la prime à la suite de la matérialisation d'une tempête. Le second chapitre analyse le comportement des banques chinoises à la suite de typhons. Nos résultats suggèrent que les petites banques rurales bien ancrées localement sont plus à même d'assurer la continuité du crédit, contrairement aux banques commerciales qui auraient tendance à restreindre l'accès au crédit. Enfin, le troisième chapitre explore la tarification du risque physique sur le marché obligataire de la zone euro. Les résultats indiquent que dans des circonstances normales, le marché obligataire ne tient pas pleinement compte des risques physiques. Cependant, après des catastrophes naturelles majeures, ce risque est intégré dans la tarification, bien que pour une durée limitée.

Mots clés : Risque Climatique, Risque Physique, Catastrophes Naturelles, Stabilité Financière, Stress Financier, Système Bancaire, Marché Obligataire, Politique Macroprudentielle, Prêts de Relance, Revalorisation, Projections Locales, Double-Différence, Économétrie des Données de Panel.

Abstract :

This thesis examines the impact of physical risks associated with climate change on financial stability. It examines specifically the repercussions of natural disasters on external financing premiums, risk premiums, and bank loans. Additionally, different strategies to mitigate the potential negative impact of natural disasters on the financial sector are analyzed. Given the rising frequency and severity of such events, understanding these impacts is crucial for fostering resilient financial systems and saving resources for transitioning towards a low-carbon economy. The first chapter investigates the impact of natural disasters on financial stability at a macroeconomic level. In this chapter, it is observed that country's macroprudential measures determine the adjustment of external finance premiums, with a lack of macroprudential regulation leading to an increase in premiums following the occurrence of a storm. The second chapter analyzes the behavior of Chinese banks following typhoons. Our findings suggest that small, locally anchored rural banks are more prone to ensure credit continuity, unlike commercial banks that tend to restrict access to credit. Finally, the third chapter explores the pricing of physical risk in the Eurozone bond market. The results indicate that under normal circumstances, the bond market does not fully account for physical risks. However, after major natural disasters, this risk is integrated into pricing, albeit for a limited duration.

Keywords : Climatic Risk, Physical Risk, Natural Disasters, Financial Stability, Financial Stress, Banking System, Bond Market, Macroprudential Policy, Recovery Lending, Repricing, Local Projections, Difference-in-Difference, Econometrics of Panel Data.