

How Banks Are Impacted By and Mediate the Economic Consequences of Natural Disasters and Climate Shocks: A Review*

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Abstract

Natural hazard shocks (such as natural disasters, extreme weather events, and climate shocks) have significant negative consequences for real economic activity. The banking sector can mitigate (or exacerbate) some of these consequences. This paper reviews the recent empirical literature on how banks are affected by such shocks, and how banks mediate the economic consequences to households and the real economy. After conceptualizing the theoretical transmission channels between the real economy and the banking sector, the review proceeds in two steps. First, it synthesises the existing literature on the direct effects of natural hazard shocks on bank stability, bank profitability, and credit supply. Then, the critical role of banking in economic recovery is analysed, including research on spillovers into unaffected regions through the banking system. Negative direct effects of natural hazard shocks on banks can be significant but are often transitory. Banking systems in less developed countries appear more vulnerable and are less able to maintain credit supply under adverse conditions. Banks that are better capitalised and that have incentives to support affected economies contribute to economic resilience. The review identifies several avenues for future research and highlights specific features and trade-offs relevant to policymakers interested in enabling the banking system to contribute to sustained economic development in the face of worsening physical climate risks.

Keywords: Banking, Climate Change, Economic Resilience, Financial Institutions, Financial Stability, Natural Hazards

JEL Codes: E51, G21, O10, Q54

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1 Introduction

Natural hazard shocks (such as disasters, extreme weather events, and climate shocks) pose significant threats to economic growth and employment in affected regions (Botzen, Deschenes, & Sanders, 2019; Klomp & Valckx, 2014). With progressing climate change, such events are expected to become more frequent and severe in large parts of the world (e.g., Hoeppe, 2016; Intergovernmental Panel on Climate Change, 2022). Policymakers and scientists continuously express their concerns that the physical and societal consequences of a warming climate and natural hazard shocks threaten progress in human development, as codified in the United Nations' Sustainable Development Goals (SDGs). Through the destruction of capital, the disruption of business, and the loss of human livelihoods, the goal of sustained, inclusive and sustainable economic growth and employment (SDG 8) is particularly at risk (World Economic Forum, 2023; World Meteorological Organization, 2023). Limiting the negative economic consequences of future natural hazard shocks is therefore an urgent and high-priority policy goal (Koubi, 2019; United Nations, 2015).

It is widely acknowledged that the banking sector has an important role to play in this endeavour (Carney, 2015; Ranger, Mahul, & Monasterolo, 2021; United Nations, 2023). By facilitating access to finance, banks can enhance economic resilience through critical times and contribute to sustained economic growth and employment participation across societal groups. This is particularly true for small and medium-sized enterprises (SMEs) and otherwise underserved and excluded populations, which are highly vulnerable to exogenous shocks. However, the relationship between natural hazards, banks, and real economic resilience is more complex than this. First, banks themselves can be negatively impacted and experience losses and threats to their financial health, potentially limiting the *ability* to supply recovery loans. Second, banks may differ in their *willingness* to support economic recovery based on their business models, ownership structures, and resulting objective functions (Beck, Degryse, Haas, & van Horen, 2018; Brei & Schclarek, 2015).

Against this background, this review is motivated by the question of what a banking system looks like that best enhances the resilience of the real economy to natural hazard shocks, informing policy efforts to achieve sustained economic growth and employment in the face of worsening physical climate risks. Since the resilience of the banking sector itself is a precondition for this, the study is structured around two interrelated questions: First, what are the direct effects of natural hazard shocks on the banking system, in particular on bank stability, profitability, and credit supply? Second, how does the banking system shape the resilience of the real economy to natural hazard shocks?

A burgeoning literature discusses the economic and financial consequences of climate change and natural hazard-related disasters. Previous reviews have assessed the impact of disasters on real economic development (Botzen et al., 2019; Lazzaroni & van Bergeijk, 2014), the role of insurance in the face of extreme weather events (Kousky, 2019; Lucas, Booth, & Garcia, 2021), the environmental and climate-related risk management practices of financial firms (Breitenstein, Nguyen, & Walther, 2021), the impact of disasters on international financial flows, including foreign aid (Osberghaus, 2019; Zhou, Endendijk, & Botzen, 2023), the pricing of climate risks in financial

assets and investor portfolios (Campiglio, Daumas, Monnin, & von Jagow, 2022; Giglio, Kelly, & Stroebe, 2021; Monasterolo, 2020), and the implications of the transition to a low-carbon economy for financial stability, systemic financial risk, and financial regulation (D’Orazio & Popoyan, 2019; Monasterolo, 2020; Semieniuk, Campiglio, Mercure, Volz, & Edwards, 2020).

While these studies provide insights into the real economic impacts of disasters and climate transition risks, existing literature has not made sufficient efforts to understand the complex interactions between *physical* climate and natural hazard shocks, banks, and the real economy. In the works closest to mine, Zhou et al. (2023) and Duqi (2023) provide excellent but very broad overviews. In particular, Zhou et al. (2023) cover insurance, equity markets, bond markets, international financial flows, and the banking sector, making it suitable as a first introduction to various general aspects of the literature. The textbook of Duqi (2023) provides regulatory context and discusses foundational theories, making it useful for instance for educational purposes. However, due to the scope of these studies, the analyses remain shallow and unstructured and do not systematically cover the intricacies and heterogeneities within the banking sector that are necessary to understand to guide future research and give context-sensitive policy recommendations.

Therefore, this review contributes an in-depth, systematic analysis of the empirical evidence on the bank-level impacts of natural hazard shocks, and the channels through which banks mediate the real economic consequences. The provided insights underscore the importance of tailored approaches that take into account the unique circumstances and characteristics of different economic and financial systems, highlighting nuances and potential trade-offs relevant for policy that have hitherto been ignored. Finally, it offers critical reflections on the state of the literature and identifies clear gaps that provide promising avenues for future research.

The review is organised as follows: Section 2 discusses a conceptual framework of how natural hazard shocks affect the banking sector, and how banks’ responses translate into real economic outcomes. Section 3 describes the review methodology and provides an overview of the studies included. Section 4 examines the evidence on the direct effects of natural disasters and extreme weather events on banks, in particular bank stability (4.1), profitability (4.2), and credit supply (4.3). Section 5 examines the mediating role of banks and financial intermediaries with respect to the real economic impact of natural hazard-related shocks, starting with macro-level, cross-country approaches (5.1), then turning to the regional and local level (5.2), as well as micro-financial institutions (5.3). Section 5.4 summarises studies that discuss spillover effects from affected to unaffected entities through financial intermediaries. Section 6 discusses the main findings and explores potential avenues for future research. Section 7 offers some concluding remarks.

2 Background

To inform and encourage discussions on the role of the banking sector in managing the physical risks associated with climate change, this review focuses on both weather-related (such as storms, floods, droughts, and extreme temperature events) and non-weather-related (such as earthquakes)

natural hazard shocks.

Such shocks directly affect banks through the destruction of physical capital and the disruption of business activity in banks' business areas. The prior includes both banks' own assets as well as – in quantitative terms more importantly – the assets of banks' customers. For households and firms, the destruction of capital may lead to a reduction in their wealth, their collateral, and thus their creditworthiness.¹ The interruption of business and general economic activity in the aftermath of extreme events may further entail a reduction in income, which can lead to illiquidity, solvency straits, and borrowers' inability to service existing debt. This may induce higher non-performing loans and impairment flows on banks' balance sheets, potentially decreasing bank profitability and threatening bank stability, especially if banks' capital buffers are low. As households and firms seek to finance repair and recovery and bridge liquidity gaps, they may draw down their deposits and increase their demand for credit.²

If the pre-event financial resilience and general banking sector health are high, single events may not pose systemic risks to financial systems as a whole (Ranger, Mahul, & Monasterolo, 2022). However, given the nature of climate change, more frequent, more intense, and compounded shocks may shift this assessment to a critical point (Dunz, Hrast Essenfelder, Mazzocchi, Monasterolo, & Raberto, 2023). At the same time, extreme impacts may threaten the lending capacity or even the survival of individual institutions in affected areas, which may have detrimental repercussions for local communities and local economic recovery and development. Therefore, the resilience of the banking sector itself is a precondition for its capacity to support the real economy in the face of natural hazard shocks. The literature on the finance-growth nexus suggests that the allocation of financial resources has consequences for real economic activity and that financial systems differ in how this allocation mechanism functions (Levine, 2005; Popov, 2018). By filling financing gaps resulting from natural hazard shocks, credit supply can play an important part for the real economic resilience to natural hazard shocks, too (Martin, Sunley, Gardiner, & Tyler, 2016; McDermott, Barry, & Tol, 2014).³ Theoretical contributions present opposing arguments about how banks' credit supply reacts to adverse shocks (Bos, Li, & Sanders, 2022; Brei & Schclarek, 2015; L. Nguyen & Wilson, 2020). From a practical standpoint, banks' credit supply decisions depend on their capitalization (How much buffer do they have to absorb the shock?), profitability (Do banks remain profitable and how do they perceive future profitability in affected regions?), and the specific type of bank under consideration with respect to its lending technology, business model, and organizational structure (e.g., What is the main objective function of banks in affected regions? How are lending

¹See for instance Gallagher and Hartley (2017) and Ratcliffe, Congdon, Teles, Stanczyk, and Martín (2020) on the impacts of natural hazard shocks on the financial health of households.

²Figure B.1 in the Online Supplementary Material outlines the interconnections between these shocks, real economic impacts, and the banking sector graphically.

³Economic resilience, in this context, can be understood as the "ability of an economy or a society to minimise welfare losses for a disaster of a given magnitude" (Hallegatte, 2014, p.2). In many applications, researchers further differentiate a system's resistance (its ability to withstand a shock) and recoverability (its ability to recover). The financial system constitutes a co-determinant of both (Martin et al., 2016). Other determinants of resilience include income, institutions, infrastructure, disaster management capabilities, and education levels, among others (Botzen et al., 2019; Noy & Yonson, 2018).

decisions made in the face of a shock?).

It should be noted that, while the focus of this review is on the banking sector, both insurance and governments play decisive roles in shaping economic resilience towards natural hazard shocks, too, and their behaviour (presumably) interacts with the banking system. Previous research has shown that insurance uptake accelerates the recovery process, thereby helping to minimise losses after the occurrence of climate events and disasters (Lucas et al., 2021; Melecky & Raddatz, 2015; von Peter, von Dahlen, & Saxena, 2012). In many cases, however, insurance only covers a fraction of losses, and coverage varies substantially across regions and types of natural hazard damages (Kousky, 2019). In addition, expectations of large future losses may render risks in certain regions entirely uninsurable (S. Collier, Elliott, & Lehtonen, 2021). In such cases, the government may or may not act as an insurer of last resort, providing funds to the uninsured or bridging insurance gaps. This may create new problems of its own, such as moral hazard (Andor, Osberghaus, & Simora, 2020; Raschky & Weck-Hannemann, 2007). This is important for a holistic understanding of resilience to natural hazard shocks, but since these aspects have been reviewed before, they are not within the scope of this article.⁴ Studies that explicitly assess the interplay of these three actors are lacking so far and should be a subject of future research (see Section 6).

3 Methodological approach and overview

The selection of studies for the review process follows a semi-structured approach, as is common practice in the social sciences (Hansen & Rieper, 2009). This approach combines the systematic rigour of structured reviews with the flexibility to explore emerging themes and insights, making it well-suited for the diverse and evolving literature in this field of research. To ensure the reliability and validity of the study, the review process adhered to the following structured aspects.

The review considers publicly available papers that are empirical ex-post analyses of

- the direct impact of some form of natural hazard shock on the stability, profitability, or credit supply of banks or the banking system as a whole,
- the mediating effects of banks or the banking system on the real economic consequences of natural hazard shocks.

Guided by the outlined research questions, the review is based on a comprehensive search for relevant literature in major academic electronic research databases such as Google Scholar, EBSCOhost, Web of Science, and ScienceDirect. The utilised keywords include synonyms related to natural hazard shocks (e.g., natural disaster, extreme weather event, climate disaster, climate shock, as well as specific types of events such as storms, floods, etc.), banking (e.g., banks, financial intermediation, banking system, banking structure, financial system, financial institution, bank

⁴Kousky (2019) and Lucas et al. (2021) review the role of insurance, Botzen et al. (2019) discuss the role of government in dealing with disastrous shocks, and Duqi (2023) surveys supra-national institutions and multilateral development banks.

stability, risk, solvency, credit supply, microfinance, lending), and economic activity (e.g., economic development, economic growth, economic resilience, employment), as well as combinations thereof. The relevance of articles concerning the defined criteria was assessed based on titles, abstracts and introductions. Studies not directly related to any aspect of the research questions were excluded.

All included studies were classified into the themes of the review according to their stated research goals and contents. A data extraction form was used to systematically collect information from each selected study, including the research objectives, sample scope, methodologies, event type, key financial variables and proxies, key economic outcomes, and key results.⁵ In the overview tables in sections 4 and 5, I use the main results of the papers as stated by the original authors in the abstracts and introductions to distil the main findings.⁶ In a second round of searches, backward and forward citation tracking was conducted to scan for previously omitted papers and ensure comprehensive coverage. The review includes peer-reviewed articles published since 2004, major reports from reputable organizations, and significant working papers published within the last ten years.

Table B.1 provides a list of all 76 studies identified as relevant in this process.⁷ Figure B.1 in the Online Supplementary Material presents a chronology of the included articles, showing the rapid increase in academic attention to this field. The results and main insights of the articles are synthesised and evaluated in chapters 4 and 5 respectively. Within these sections, papers are further classified according to the scope of their analysis, mirroring the recent development in our understanding of the link between natural hazard shocks, finance, and real economic outcomes, which has evolved alongside the quality and level of detail of available datasets.⁸ To complement the contextual review of the literature and provide some guidance for future researchers in the field, Section A of the Online Supplementary Material presents an overview and discussion of common data sources (Section A.1) and empirical approaches (Section A.2) used in the literature.

4 Direct effects on banks

4.1 Bank stability

The resilience of the banking sector itself is a precondition for its capacity to support the real economy in the face of natural hazard shocks. Table 4.1 provides an overview of the main findings of studies analyzing the impacts of natural hazards on bank stability.

⁵Figure B.3 shows how many studies address each theme of the review.

⁶Where this was not possible or ambiguous, I moved on to the full results sections of the papers to extract this information, and I discuss these cases accordingly in the text.

⁷Data collection ended as of 31 May 2024. To the best of my knowledge, all relevant and available studies are included in this review. For papers with a history of several published versions, the newest version was considered. Errors are my own and omissions are my responsibility. Should you find papers missed or mistakes in representing the included studies, please contact the author.

⁸In the earlier stages of the literature, researchers employed country-level datasets to draw conclusions on disaster impacts and the finance-resilience relationship, forming a consensus on the broad patterns that characterise the topic. More recently, the proliferation and improved access to micro-datasets, such as bank-level and loan-level data, have enabled researchers to evaluate the underlying theoretical mechanisms and channels of effects more closely.

Table 4.1: Effects of natural hazard shocks on bank stability.

Study	Sample	Event data	Stability proxy	Effect	
Cross-country evidence:					
Klomp (2014)	160 countries, 1997-2010 (y)	EM-DAT events: I/O, Damages	Distance-to-default: Z-scores	-	
Klomp (2018)	80 developing and emerging countries, 1999-2013 (y)	EM-DAT events: I/O	Composite micro-finance risk indicator	-	
Albuquerque and Rajhi (2019)	66 countries, 1995-2011 (y)	Disability Adjusted Life Years Index (Noy, 2015)	Non-performing loans, Z-scores	-	
Chang and Zhang (2020)	136 countries, 1984-2013 (y)	EM-DAT events: People affected, I/O	ICRG financial risk indicator	-	
Chen and Chang (2021)	116 countries, 1996-2017 (y)	EM-DAT events: People affected/dead	Z-scores through financial risks	-	
Chabot and Bertrand (2023)	13 European countries, 2001-2021 (y)	BD Catnat: I/O	Z-score, default probability, Bloomberg financial conditions, market volatility	-	
Chen et al. (2023)	101 countries, 1996-2017 (y)	EM-DAT events: People dead	Non-performing loans through financial risks	-	
Gramlich et al. (2023)	149 countries, 2000-2017 (y)	EM-DAT events: Damages	Equity ratio, tier-1 capital ratio	-	
Le et al. (2023)	109 countries, 2005-2019 (y)	Global Climate Risk Index: Impact Score	Z-score, liquidity risk, NPL ratio, loan loss provisions	-	
Nie et al. (2023)	184 countries, 1980-2019 (y)	EM-DAT events: I/O	NPL ratio	-	
Liu et al. (2024)	53 countries, 2007-2019 (y)	Global Climate Risk Index: Impact Score	Z-scores	-	
Developed economies: Bank-level evidence					
Schüwer et al. (2019)	United States, 2003-2007 (q)	Hurricane Katrina (2005): I/O	Risk-based capital ratios of independent banks (+), bank holding companies (n.s.)	+	n.s.
Koetter et al. (2020)	Germany, 2011-2015 (y)	Elbe floods (2013): I/O	Equity ratios (+), impaired loans, Z-scores (n.s.)	+	n.s.
Ozsoy et al. (2020)	United States, 2000-2017 (q)	Droughts: Physical intensity	Z-scores, return volatility, non-performing loans	-	

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Table 4.1: Effects of natural hazard shocks on bank stability. (Continued)

Study	Sample	Event data	Stability proxy	Effect	
Apergis (2022)	United States, 1995-2018 (y)	SHELDUS/FEMA events: Damages	Non-performing loans ratio, loan-to-deposit ratio	-	
Blickle et al. (2022)	United States, 1995-2018 (y)	SHELDUS/FEMA events: Damages	Capital ratios, Z-scores (neg. eff. in extreme, single-county cases)	n.s.	-
Bos and Li (2022)	California, US, 1994-2013 (q)	Earthquakes: I/O	Equity buffers, loan quality (long-term)	+	
Do et al. (2022)	United States, 2010-2019 (q)	SHELDUS events: I/O	Z-scores	-	
Petkov (2022)	United States, 1999-2019 (q)	Hurricanes, Floods, Severe Storms: Damages (multiple sources)	Loan defaults (Local: -, non-local: n.s.)	n.s.	-
Berger et al. (2023)	United States, 2000-2019 (q)	SHELDUS storms: Damages	Operational Losses	-	
Noth and Schüwer (2023)	United States, 1994-2012 (y)	SHELDUS events: Damages, Physical intensity: Precipitation	Z-scores, predicted probability of default, NPA ratio, foreclosure ratio	-	
Walker et al. (2023)	United States, 2000-2014 (y)	EM-DAT events: Damages	Impaired loans, equity/tier-1 capital ratio	-	
Shala and Schumacher (2024)	Germany, 2009-2015 (y)	Elbe floods (2013): I/O	Loan impairments	-	
<i>Developed economies: Borrower-/loan-level evidence</i>					
Barbaglia et al. (2023)	4 European countries, 2008-2019 (y)	Flood events: I/O	Loan defaults	-	
<i>Developing economies: Bank-level evidence</i>					
Brei et al. (2019)	Eastern Caribbean Islands, 2000-2012 (q)	Hurricanes: Damages, Physical Intensity	Z-scores (-), Non-performing loans, bank capitalization (n.s.)	n.s.	-
Bayangos et al. (2021)	Philippines, 2014-2018 (q)	Extreme precipitation	Non-performing loans	-	
Choudhary and Jain (2022)	Pakistan, 2008-2012 (q)	Floods: Damages	Loan defaults, deposit withdrawals	-	
D. T. T. Nguyen et al. (2023)	7 East-Asian countries, 1999-2014 (y)	EM-DAT events: Damages	Deposits ratio (-), liquidity, credit risk, Z-score (n.s.)	n.s.	-

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Table 4.1: Effects of natural hazard shocks on bank stability. (Continued)

Study	Sample	Event data	Stability proxy	Effect	
Brei et al. (2024)	20 Caribbean/Central American countries, 1990-2020 (y)	Hurricanes: Damages, Physical Intensity	Deposits (-), non-performing loans	n.s.	-
Huesler (2024)	British Colonial Caribbean, 1922-1927 (half-monthly)	Hurricanes: Damages, Physical Intensity	Current accounts overdrafts (-), deposits (+)	+	-
Developing economies: Province-level evidence					
Calice and Miguel (2021)	5 Latin American Countries, 2011-2020 (y), provinces	EM-DAT Droughts, Floods, Hurricanes: I/O	Non-performing loans	-	
Developing economies: Borrower-/loan-level evidence					
Aguilar-Gomez et al. (2024)	Mexico, 2010-2018 (q)	Extreme temperature events: I/O	Loan delinquencies	-	

Articles are sorted according to year of publication. Peer-reviewed studies are printed in bold. Red cells indicate negative effects, green cells indicate positive effects, yellow cells indicate no or mixed effects. Abbreviations: y = yearly, q = quarterly, m = monthly, I/O = Event incidence/occurrence, SHELDUS/FEMA = SHELDUS events with FEMA declaration, NPA = Non-performing assets, n.s. = not significant.

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Cross-country studies. Cross-country analyses allow insights into the impacts of natural hazard shocks on bank stability from a broad, macroeconomic perspective. In a seminal study, Klomp (2014) assesses the impact of large-scale disasters on the distance-to-default of the banking sectors in 160 countries. Particularly geophysical and meteorological disasters increase the likelihood of banks' defaults, while financial and economic development and the rigorousness of financial regulation and supervision dampen negative impacts. These results have since been corroborated by several more recent works, using a range of different datasets and outcome variables (Gramlich, Walker, & Zhao, 2023; Le, Tran, & Mishra, 2023; Liu, He, Men, & Sun, 2024; Nie, Regelink, & Wang, 2023). While the negative effects of natural hazards are aggravated in lower-income countries, Chabot and Bertrand (2023) provide evidence that acute physical climate shocks also pose significant risks specifically within the European financial system.

Albuquerque and Rajhi (2019) report temporary increases in the amount of non-performing loans and increases in the likelihood of bank defaults in 66 developing countries, using a method that collapses mortality, morbidity, displacements, and damages into a single measure of human life years lost. Covering a global sample of over 100 countries in three related studies, Chang and Zhang (2020), Chen and Chang (2021) and Chen et al. (2023) use composite indicators of financial risk provided by the International Country Risk Guide (ICRG), as well as Z-scores and non-performing loans, to assess the implications of natural hazard shocks at the financial-system level. They conclude that deadly natural disasters lead to dynamic, long-term increases in financial risks, partly triggered by decreases in economic activity. Klomp (2018) presents insights into the impacts of disasters on the financial fragility of microfinance institutions (MFIs) in 80 developing and emerging market economies, based on a composite measure of MFI risk. Disasters significantly increase the financial risk faced by MFIs, especially after hydro-meteorological events.

The country-level evidence suggests natural hazard shocks pose significant short-term threats to bank stability. Financial and economic development as well as regulatory rigor mitigate the negative impacts. Furthermore, natural hazard shocks can lead to long-term increases in financial risks – especially in lower-income countries – and increase the financial risk microfinance institutions face. With progressing climate change, this may increase the burden of achieving economic development in particular for the less-developed countries. While macroeconomic cross-country studies give a first indication of the impacts of natural hazard shocks on bank stability, there are several problems endemic to studies using country-level aggregates. Importantly, natural hazards typically have a very localised impact, and a lot of heterogeneity may be lost in the aggregation process (Botzen et al., 2019). Furthermore, differences in country-level financial systems as well as other determinants of disaster outcomes such as institutional quality, insurance coverage, and government responses are hard to account for, and will likely affect the resilience of the banking sector.

Developed economies. Researchers frequently use micro-level data from developed economies, in particular the United States and Germany. This data allows researchers to study disaster consequences at the bank level, and to tease out the specific channels through which banks are impacted.

Noth and Schüwer (2023) find that destructive weather-related disasters in the United States significantly weaken bank stability across several different indicators, including lower Z-scores, higher probabilities of default, increases in non-performing assets, and lower equity ratios of affected banks. Based on a sample of 907 domestic and local US banks, Do, Phan, and Nguyen (2022) similarly find deteriorating Z-scores resulting from increased deposit and equity volatility and loan loss provisions. Walker, Xu, Gramlich, and Zhao (2023) study the effects of 187 highly destructive disasters on 2,900 US banks between 2000 and 2014. They report pronounced negative effects on the equity and tier-1 capital ratios of these banks, but only for local and nationally active banks. Regional banks seem to increase their capital reserves after a disaster while no effects are found on non-performing loans in these banks. According to the authors, this may be due to limited data availability or because such loans are fully written off in the aftermath of disasters, reducing a bank's impaired loan balance, while increasing its actual loan write-offs. Berger, Curti, Lazaryan, Mihov, and Roman (2023) document that large US bank holding companies suffer more operational losses during extreme storms.

Blickle et al. (2022) conclude that after events that triggered FEMA disaster declarations, loan losses, and default risks (Z-scores) of affected banks do *not* increase significantly. Only for the most extreme events (above 90th percentile) do particular single-county banks experience negative stability effects in terms of lower capital ratios (short-lived) and Z-scores (sustained). Such effects are not apparent for larger, multi-county banks. Building directly on the results of Blickle et al. (2022) and using the same dataset, Apergis (2022) considers alternative channels through which climate-related weather shocks may affect banks' systemic financial risks. He suggests that disaster exposure has detrimental effects on US banks through significant increases in non-performing loan ratios and decreases in banks' loan-to-deposit ratios for both single-county and multi-county banks. Considering only hurricane events, Petkov (2022) finds that severe disasters are associated with loan defaults for local, but not for non-local lenders in the US.

Somewhat in contrast to these findings, Schüwer et al. (2019) find independent local banks that are not part of a bank holding company to have increased their risk-based capital ratios after Hurricane Katrina if they were highly capitalised before, while those that are part of bank holding companies or low-capitalised have not. Petkov (2022) finds an increase in capital ratios for non-local but not for local lenders, suggesting that the former prepare for spillovers of default risks to their customer base. Bos et al. (2022) show that Californian banks that had more intense earthquake experiences in the past increase their equity buffers and reduce their exposure to real estate and low-quality loans in the long run.

Two studies focus on the impacts of the Elbe River floods in Germany in 2013. The research design of Koetter et al. (2020) considers banks that were not directly located in affected regions but have relationships with firms in flooded counties. The considered banks are therefore only affected indirectly through their customers. The authors find that these banks face reductions in their liquidity buffers, which are used to absorb the shocks. Concerning risk measures, they do not find increases in credit risk (impaired loans relative to gross loans) or insolvency risk (Z-scores). In

fact, banks that were exposed to the flood through their customers seemed to have increased their equity ratios after the event relative to the control group. In contrast to Koetter et al. (2020), Shala and Schumacher (2024) study locally-oriented banks in directly affected regions using supervisory bank-level data. These banks indeed experienced heightened credit risk through transitory increases in their impairment flows. Impairments occurred mostly in corporate loans to the agricultural and manufacturing sectors, and to a lesser extent in mortgage loans to the retail sector. Banks did not seem to suffer significantly from direct losses. Leveraging loan-level data from 4 European countries (Belgium, France, Italy, Spain), Barbaglia et al. (2023) document a deterioration in loan performance in flood-affected counties.

While most of these studies focus on sudden-onset events such as storms and floods, Ozsoy et al. (2020) present a study on the impact of droughts on banks in the United States.⁹ They find that banks located in drought-affected regions experience significant deterioration in asset quality as well as higher risk levels, measured by lower Z-scores, higher volatility in returns on assets and equity, and increases in the non-performing loans ratio.

So far, there is no clear-cut consensus on the bank-stability impacts of natural hazard shocks in developed economies. Some of the controversies in the literature may be explained by differences in terms of data availability and measurement, e.g., with respect to non-performing loans and write-offs. Hidden reserves in bank balance sheets may cushion the visible impacts of shocks as well. Evidence points towards adverse, but transitory effects. Highly destructive events seem to be a particular burden for local banks whose lending activities are concentrated in affected regions. Higher pre-event capitalization provides some protection against post-event deterioration in bank health, in line with the macroeconomic evidence on stricter financial regulation. Some evidence suggests that banks further increase their capitalization after natural hazard shocks, which may represent a form of bank adaption to increasing (salience of) risks posed by natural hazards. Further research on slow-onset events, such as droughts, is needed.

Developing economies. In a study of credit supply effects of floods in Pakistan, Choudhary and Jain (2022) show that affected banks experienced a capital shock in the form of increased loan defaults, and a liquidity shock in the form of significant deposit withdrawals. This leads affected banks to restrict their credit supply. Similarly, Bayangos, Cachuela, and Prado (2021) report increases in the share of non-performing loans after extreme rainfall events in Philippine banks using branch-level banking data from supervisory reports, while Aguilar-Gomez, Gutierrez, Heres, Jaume, and Tobal (2024) utilise loan-level supervisory data from Mexico to show that anomalous days of extreme temperature, in particular heat, increase the rate of non-performing loans among Mexican firms. In the latter study, the negative effect is most pronounced in the agricultural sector and in industries dependent on local demand. D. T. T. Nguyen, Diaz-Rainey, Roberts, and Le (2023), on the other hand, find mostly insignificant effects of disaster damages on several indicators

⁹The effects of slow-onset events such as droughts are typically spread out over long periods of times, making it somewhat more difficult to define the timing and occurrence of this type of shock. This leads to less clear-cut "event" definitions. For instance, FEMA registers only one drought event for the US since the year 2000 (Ozsoy et al., 2020).

of bank stability in a sample of 7 East-Asian countries.

In an assessment of 5 Latin American countries (Argentina, Brazil, Chile, Mexico, and Peru), Calice and Miguel (2021) affirm increases in non-performing loans after droughts, floods, and storms, driven by corporate loans. Their investigations into the role of regulatory relief applied after catastrophes remain inconclusive. Brei et al. (2019) and Brei, Mohan, Perez Barahona, and Strobl (2024), on the other hand, observe liquidity shocks through substantial deposit withdrawals after hurricanes in the Caribbean. They do not find evidence of increases in non-performing loans and loan losses, nor do they observe reductions in bank capital. However, overall bank risk as measured by Z-scores appears to increase. Huesler (2024) provides a historical perspective on how the Colonial Banks in the British Caribbean in the 1920s dealt with the fallout of hurricanes.

Natural hazard shocks pose significant threats to banks in developing countries, working through loan defaults and overall bank risk. Given the scarcity of studies focusing on this group of countries, more evidence is required and should focus on regulatory and policy levers that can help enhance the resilience of the banking sector in the developing world. It should further be taken into account that many developing countries are located in regions that face the highest physical risks from climate change (Intergovernmental Panel on Climate Change, 2022).

4.2 Bank profitability

The existing studies investigating the impact of natural hazards on bank profitability primarily look at banks in specific countries or homogeneous country groups. Table 4.2 gives an overview of the main findings, which are evaluated in the following.

Developed economies. Noth and Schüwer (2023) find property damages from weather-related disasters significantly impede the profitability of affected banks in the US upon impact, before it recovers after some years. The results of Walker et al. (2023) and Do et al. (2022) confirm this notion for broader sets of hazards and different bank samples. Do et al. (2022) suggest that in particular strong corporate governance, sufficient loss buffers, and strong loan portfolios are factors that help US banks recover their profitability quickly.

The results of Shala and Schumacher (2024), focusing on the 2013 Elbe River floods in Eastern Germany, demonstrate that the profitability of regional banks located in affected regions is impaired, as measured by return on assets and net interest income. Focusing on regional banks located *outside* the affected regions but with directly affected customers, Koetter et al. (2020) do not find significant impacts on the profitability of regional banks, concluding that these banks are neither badly hurt nor do they extract rents from disaster-struck customers to boost profits.

In a different approach, Barth, Sun, and Zhang (2019) examine the responses of deposit and loan rates after natural disasters. While banks raise both, the latter increase by more, resulting in larger net interest margins overall and increases in the return on assets of affected banks, especially among small banks. While these results contrast the previous evidence, the economic magnitude of the positive effects is small. Similarly, Blickle et al. (2022) find that relatively large, multi-county

Table 4.2: Effects of natural hazard shocks on bank profitability.

Study	Sample	Event data	Profitability proxy	Effect	
Developed Economies: Bank-level evidence					
Barth et al. (2019)	United States, 2000-2017 (q)	SHELDUS events: Damages	Net interest margin, return on assets	+	
Koetter et al. (2020)	Germany,2011-2015 (y)	Elbe floods (2013): I/O	Net interest margin	n.s.	
Blickle et al. (2022)	United States, 1995-2018 (y)	SHELDUS/FEMA events: Damages	Net income (+), return on assets (n.s.)	+	n.s.
Do et al. (2022)	United States, 2010-2019 (q)	SHELDUS events: I/O	Loan spreads, return on assets	-	
Noth and Schüwer (2023)	United States, 1994-2012 (y)	SHELDUS events: Damages	Return on assets	-	
Walker et al. (2023)	United States, 2000-2014 (y)	EM-DAT events: Damages	Net-income-to-assets/equity, return on assets	-	
Shala and Schumacher (2024)	Germany, 2009-2015 (y)	Elbe floods (2013): I/O	Return on assets, net interest income	-	
Developing Economies: Bank-level evidence					
Brei et al. (2019)	Eastern Caribbean Islands, 2000-2012 (q)	Hurricanes: Damages, Physical Intensity	Return on equity	n.s.	
Bayangos et al. (2021)	Philippines, 2014 (q)	Extreme precipitation: Physical intensity	Net profit growth, return on assets	-	
D. T. T. Nguyen et al. (2023)	7 East-Asian countries, 1999-2014 (y)	EM-DAT events: Damages	Return on assets	n.s.	
Brei et al. (2024)	20 Caribbean/Central American countries, 1990-2020 (y)	Hurricanes: Damages, Physical Intensity	Return on equity (short-term: n.s., long-term: -)	n.s.	-

Within clusters, articles are sorted according to the year of publication. Peer-reviewed studies are printed in bold. Red cells indicate negative effects, green cells indicate positive effects, yellow cells indicate no or mixed effects. Abbreviations: y = yearly, q = quarterly, m = monthly, I/O = Event incidence/occurrence, SHELDUS/FEMA = SHELDUS events with FEMA declaration, n.s. = not significant.

banks (and local banks in high-damage cases above the 90th percentile) experience small increases in net income though not in return on assets after FEMA-declared weather disasters, implying that both income and asset volumes increase. The authors argue that increased loan demand and the utilization of local knowledge about disaster risks and consequent reallocation of lending flows are likely to explain these results, while large inflows of aid are not.¹⁰

Developing economies. The literature on bank profitability effects of natural hazards for developing economies is particularly thin. Brei et al. (2019) as well as D. T. T. Nguyen et al. (2023) report statistically at most marginally significant but economically insignificant effects of natural hazard shocks on banks in the Eastern Caribbean and East Asia, respectively. Bayangos et al. (2021) report significant but transitory negative effects on the profitability of Philippine banks after extreme rainfall events, while Brei et al. (2024) find loan losses for Caribbean banks that are long-lasting, but for some banks only materialising after several years.

4.3 Effects on credit supply

While credit demand unambiguously increases after a natural hazard shock (e.g., Berg & Schrader, 2012; S. Collier et al., 2021; Ivanov, Macchiavelli, & Santos, 2022), a discussion of the effects on credit supply requires some elaboration. Table 4.3 summarises the baseline results of the diverse group of studies that address this question.

Cross-country studies. Covering 147 high-, middle- and low-income countries, Keerthiratne and Tol (2017) find companies and households, on average, increase their debt levels after the occurrence of natural disasters, but caution that the impact of disasters on credit per capita is both country- and time-specific with respect to the pre-event levels of economic and financial development, private saving, and insurance penetration.¹¹ Providing plausibly causal evidence for the impacts of extreme disasters, Horvath (2021) finds that, in developing countries, catastrophes reduce the level of financial development. These effects are sizeable, statistically significant, and long-lasting, with the credit-to-GDP ratio remaining about 30% below its counterfactual path a decade after the shock. B. Collier and Babich (2019) also study a sample of developing and emerging economies, but focus on the lending activities of community lenders. These lenders reduce their lending to households and micro, small, and medium enterprises (MSMEs). They attribute this to the capital constraints faced by lenders who have to replace lost equity after the event. International capital flows do not seem to compensate for the lack of local sources of finance in developing countries, as reported by David (2011). While the occurrence of disasters boosts the

¹⁰In support of this view, the works of Brown, Gustafson, and Ivanov (2021) or Das, Majilla, and Saurav (2023) suggest that banks indeed charge borrowers for liquidity provision after extreme weather events with higher interest rates, shorter loan maturities, and stricter loan provisions, although these authors do not explicitly investigate the net effects on bank income and profitability.

¹¹This caution is insofar warranted as a simple fixed-effect estimator may face difficulties in providing identification for their chosen sample of very heterogeneous countries, and the wide array of disasters under study (Cavallo, Galiani, Noy, & Pantano, 2013; Horvath, 2021)

Table 4.3: Effects of natural hazard shocks on credit supply.

Study	Sample	Event data	Credit supply proxy	Effect
<i>Cross-country evidence</i>				
David (2011)	78 developing countries, 1970-2005 (y)	EM-DAT events: I/O	International bank lending flows	-
Keerthiratne and Tol (2017)	147 countries, 1979-2011 (y)	EM-DAT events: People affected	Private credit per capita	+
Collier and Babich (2019)	78 developing countries, 1995-2013 (y)	EM-DAT events: People affected	MFI loans	-
Horvath (2021)	10 developing countries, 1960-2013 (y)	EM-DAT events: People killed (Top 1%)	Credit-to-GDP ratio	-
<i>Developed Economies: Bank-/county-level evidence</i>				
Cortés (2014)	United States, 1997-2010 (q)	SHELDUS events: I/O, Damages	Total loan growth of local banks	+
Chavaz (2016)	United States, 2003-2008 (y)	Hurricanes: I/O	New mortgage originations	+
Cortés and Strahan (2017)	United States, 2001-2010 (m)	SHELDUS/FEMA events: I/O, Damages	Mortgage originations	+
Schüwer et al. (2019)	United States, 2003-2007 (q)	Hurricane Katrina (2005): I/O	New originations of corporate loans	+
Koetter et al. (2020)	Germany, 2011-2015 (y)	Elbe Floods (2013): I/O	Customer loans (+), mortgages (n.s.)	+
Duqi et al. (2021)	United States, 1995-2017 (q)	SHELDUS hurricanes: I/O	SBA loans (+), C&I loans (n.s.), consumer loans (n.s.), mortgages (n.s.)	+ n.s.
Qi et al. (2021)	United States, 2007-2017 (m)	Earthquakes: Physical intensity	Fintech lending: number of loan applications, ratio accepted	+
K. Allen et al. (2022)	United States, 2010-2017 (q)	SHELDUS events: Damages	Total loan growth of community banks	+
L. Allen et al. (2022)	United States, 2010-2017 (y)	FEMA events: I/O	Mortgage supply of FinTech and traditional banks	+
Blickle et al. (2022)	United States, 1995-2018 (y)	SHELDUS/FEMA events: Damages	Total loans and subsets: multi-county banks (+), single-county banks (n. s.)	+ n.s.
Bos and Li (2022)	California, US, 1994-2013 (q)	Earthquakes: I/O	Real estate loan ratio (long-run)	-

Continued on next page

Table 4.3: Effects of natural hazard shocks on credit supply. (Continued)

Study	Sample	Event data	Credit supply proxy	Effect	
Bos et al. (2022)	United States, 2001-2013 (q)	EM-DAT events: I/O	Total loans and subsets	+	
Petkov (2022)	United States, 1999-2019 (q)	Hurricanes, Floods, Severe Storms: Damages	Total loans: local lenders (-), non-local lenders (+)	+	-
Rajan and Ramcharan (2023)	United States, 1929-1960 (y)	”1950s” droughts	Total loans of local banks	+	
Dlugosz et al. (2024)	United States, 1999-2013 (q)	SHELDUS/FEMA events: I/O	Mortgage lending growth	+	
Peters (2024)	United States, 2003-2020 (q)	SHELDUS events: Damages	Small business lending: Community banks (n.s.), non-community banks (-)	n.s.	-
Developed Economies: Borrower-/loan-level evidence					
Garmaise and Moskowitz (2009)	United States, 1992-1999 (y)	Northridge earthquake (1994): I/O	Commercial real estate loan transactions	-	
Gallagher and Hartley (2017)	New Orleans, LA, US, 2003-2008 (q)	Hurricane Katrina (2005): I/O	Number of new credit accounts	-	
Brown et al. (2021)	United States, 2012-2016 (y)	Severe winter weather: Physical intensity	Credit line use and size	+	
Ivanov et al. (2022)	United States, 1992-2014 (y)	SHELDUS events: Damages	Total commitment and utilised amount of syndicated corporate loans	+	
Barbaglia et al. (2023)	4 European countries, 2008-2019 (y)	Flood events: I/O	Volume of newly originated, securitised loans	+	
Developing Economies: Bank-/county-level evidence					
Brei et al. (2019)	Eastern Caribbean Islands, 2000-2012 (q)	Hurricanes: Damages, Physical Intensity	Total / household loans	-	
L. Nguyen and Wilson (2020)	Thailand, 2004-2005 (m)	Tsunami (2004): I/O	Total loan growth	-	
Bayangos et al. (2021)	Philippines, 2014-2018 (q)	Extreme precipitation: Physical intensity	Total loan growth	-	
Celil et al. (2022)	China, 2007-2017 (y)	EM-DAT events: I/O	Total loan growth of regional banks	+	

Continued on next page

Table 4.3: Effects of natural hazard shocks on credit supply. (Continued)

Study	Sample	Event data	Credit supply proxy	Effect
Brei et al. (2024)	20 Caribbean/Central American countries, 1990-2020 (y)	Hurricanes: Damages, Physical Intensity	Bank lending to private sector	-
<i>Developing Economies: Borrower-/loan-level evidence</i>				
Berg and Schrader (2012)	Ecuador, 2002-2007 (m)	Volcanic activity: I/O, Physical intensity	MFI credit approvals	-
Choudhary and Jain (2022)	Pakistan, 2008-2012 (q)	Floods: Damages	Consumer and corporate loans	-
Das et al. (2023)	India, 2000-2012 (y)	EM-DAT events: Damages, Negative rainfall shock: I/O	Total loans (-), interest rates (+)	-

Within clusters, articles are sorted according to the year of publication. Peer-reviewed studies are printed in bold. Red cells indicate negative effects, green cells indicate positive effects, yellow cells indicate no or mixed effects. Abbreviations: y = yearly, q = quarterly, m = monthly, I/O = Event incidence/occurrence, SHELDUS/FEMA = SHELDUS events with FEMA declaration, MFI = Microfinance institution, SBA = Small Business Administration, C&I = Commercial and Industrial, n.s. = not significant.

inflow of remittances, bank lending flows to affected countries contract, and equity flows tend not to change significantly.

Table 4.3 reveals further heterogeneity when considering the subnational evidence for the different country groups. Credit supply overall seems to react positively to natural hazards in developed economies, such as the United States and Germany, and negatively in most developing economies, including Ecuador, Peru, Pakistan, Thailand, and the Philippines. In other words, credit supply is more resilient in economies that are characterised by higher levels of economic and financial development, reflecting the patterns of macroeconomic responses to natural shocks (Noy, 2009). Given the complex web of transmission channels of shocks between the financial sector and the real economy, including the presence of feedback loops, the resilience of the two is highly interdependent. This means that if higher-income countries have higher levels of insurance, savings, and better institutions and infrastructure, a disaster of a given intensity will be easier dealt with, limiting the consequences for the real economy and in this way the indirect impacts on banks, allowing banks to continue lending through the shock, which further enhances the recovery process.

Developed Economies. The studies dedicated to developed economies use various measures and channels to assess banks' behaviour in supplying credit after natural hazard-related shocks. The notion of increased credit supply is supported by county-, bank-, and borrower-level evidence, as becomes apparent in Table 4.3. Almost all of these studies focus on commercial banks, thereby covering mortgage, firm, and syndicated corporate loans. Overall, the effects of natural hazards on credit supply are much more robustly studied when it comes to corporate credit and mortgage supply compared to private consumer credit.

Out of the US-centered studies, some report negative effects on credit supply. This includes the two studies of bank-level effects that focus particularly on earthquakes (Bos et al., 2022; Garmaise & Moskowitz, 2009) and a household-level study of the effects of the 2005 Hurricane Katrina (Gallagher & Hartley, 2017). Garmaise and Moskowitz (2009) study the effect of the 1994 Northridge earthquake on commercial real estate lending in California, while Bos et al. (2022) consider the long-term effects on banks using a comprehensive sample of Californian earthquakes spanning multiple decades. Qi et al. (2021) and L. Allen et al. (2022) suggest that FinTech lending may act as a complement to bank lending after natural hazard shocks, especially in more severely affected regions and regions with a sparser presence of traditional banks.¹² Gallagher and Hartley (2017) take a specific view on private household finance. Their result of tightened credit supply for flooded households after Hurricane Katrina is based on data on the number of new credit accounts.

Notably, Duqi et al. (2021) suggest that increases in credit supply in US counties after hurricanes are driven by banks' inter-mediation of disaster loans on behalf of the Small Business Administration (SBA) rather than their own lending, especially in the consumer and the commercial and industrial

¹²Baltas, Fiordelisi, and Mare (2021) suggest that also alternative forms of finance, such as private equity, crowd-funding, and venture capital, can be a means of satisfying increased funding demands in the aftermath of disasters. Using data from private companies in the United States between 2010 and 2019, these authors find that firms affected by extreme events increased the amount raised through alternative funding in the 3 months after a shock.

segments. These increases in lending should therefore also be neutral to local market structure and conditions.

On the whole, banks in developed economies react to natural hazard shocks by increasing their credit supply. The origination of real estate loans after earthquakes seems to be an important exception, which may be explained by the concentrated direct effect of such events on property values and learning effects for affected banks. Further patterns of heterogeneity are discussed in the dedicated section below.

Developing Economies. Studies on developing economies cover a wide range of different countries and regions. Considering the Americas, Berg and Schrader (2012) utilise data from microfinance institutions (MFIs) in Ecuador to study their behaviour in response to natural hazard-related shocks, while Brei et al. (2019) collect bank-level data from the Eastern Caribbean Central Bank (ECCB). For Asia, Choudhary and Jain (2022) and Das et al. (2023) have access to comprehensive loan-level data for Pakistan and India respectively, L. Nguyen and Wilson (2020) use data on bank loans at the province level for Thailand, and Bayangos et al. (2021) use data at the bank-branch level to study extreme rainfall events on the Philippines. All of these studies consistently find a contraction in credit supply in the aftermath of natural hazard shocks. The study of Celil, Oh, and Selvam (2022) deviates from this pattern in that it reports increases in credit supply by local state-owned banks in the prefectures of China. These banks do not follow market incentives but government directives, causing them to increase credit in the face of an adverse shock.

Consistent with the cross-country evidence and the fact that bank stability and profitability are more adversely affected in developing countries (see sections 4.1 and 4.2), credit supply dries up in the face of natural hazard shocks. China seems to be an exception to this rule, suggesting that banks backed up by a state with the capacity to mobilise funds and a directed objective for recovery present a means of keeping the credit supply flowing.

Heterogeneity. At the sub-national level, the literature identifies several sources of heterogeneity in the responses of credit supply that hold across the different groups of countries. First, the strength of bank-borrower relationships seems to increase credit availability for affected borrowers, regardless of the economic or financial development context (e.g., K. Allen, Whitley, & Winters, 2022; Berg & Schrader, 2012; Choudhary & Jain, 2022; Koetter et al., 2020). Relatedly, the geographical orientation of banks is considered in several studies. On the one hand, being local (and thus heavily connected to affected borrowers) increases the exposure and vulnerability of these banks, given that their own assets and their primary customers are concentrated in the affected areas, and they may face more capital constraints. On the other hand, due to their connection to the local market, these banks may have a more pronounced interest in providing recovery funds to support their customer base. In the aftermath of a natural hazard-related shock, when collateral is impaired and the (short-term) economic outlook may be uncertain, local banks have informational advantages resulting in relatively lower screening and monitoring costs (Agarwal & Hauswald, 2010; Berger, Miller, Petersen, Rajan, & Stein, 2005; Schüwer et al., 2019). This suggests that, in the ab-

sence of state-owned banks (Brei & Schclarek, 2015; Celil et al., 2022), relationship lending may be an important mechanism to retain access to credit, conditional on the ability of lenders to continue lending.

For instance, Cortés (2014), Koetter et al. (2020), K. Allen et al. (2022), and Peters (2024) specifically focus on local and regional lenders who have their core business areas in specific regions in the US and Germany, respectively. Their findings support the notion that such lenders increase credit supply in the aftermath of natural hazard shocks. Schüwer et al. (2019) consider the role of independent banks which are not part of a bank holding company and have a local focus. They find that particularly highly capitalised independent banks increase their new lending. The aspect of bank capitalization is also picked up by B. Collier and Babich (2019), whose findings suggest that financial intermediaries with low pre-event capital ratios reduce their lending to households and micro, small, and medium-sized enterprises in developing countries significantly more than better-capitalised ones.

Petkov (2022), in contrast, suggests that un-diversified local lenders reduce lending, as a consequence of higher losses in their loan portfolios. Diversified non-local banks, on the other hand, whose stability is not directly affected, do increase lending after a disaster, although it is not clear where this credit is headed. Against the background of mortgage reductions to New Orleans residents after Hurricane Katrina, the results of Gallagher and Hartley (2017) suggest that local banks decreased their credit supply to a lesser extent than non-local banks, consistent with the findings of Peters (2024).

Chavaz (2016) emphasises the aspect of bank diversification, concluding that local banks lend more in the aftermath of a shock, but use securitization to transfer the associated risks to agents in the secondary market. Duqi et al. (2021) suggest that banks intermediate SBA disaster loans which include a government guarantee in case of borrower defaults after severe hurricanes. Consistent with this, recent evidence by Ouazad and Kahn (2022) further suggests that US lenders are relatively more likely to approve mortgages (on the intensive margin) that can be securitised and passed on to government-sponsored enterprises (GSEs) in the aftermath of disasters, consistent with lenders learning about and adapting to local hazard risks by using GSEs as a means of re-insurance.

5 Banks as mediators of real economic impacts

The empirical literature on the economic impacts of natural hazard-related shocks has established that natural hazard shocks have significant negative consequences, subject to qualifications concerning the level of economic development in affected regions, hazard type, impact duration, and event severity (e.g., Botzen et al., 2019; Klomp & Valecx, 2014). In addition to direct damages, impacts comprise the short- and long-term losses in economic output and consumption that result from changes in economic activity as a consequence of the actual shock (Hallegatte, 2014; Kousky, 2014). If indeed, as suggested in section 2, the availability of funds matters for the recovery in the aftermath of a natural hazard shock, the central question is which structural setup of the banking

sector induces an allocation of financial resources that best enables economic resilience.

5.1 Macro-level financial development and cross-country studies

Macro-level cross-country studies of the finance-resilience relationship mostly focus on indirect costs of natural hazard shocks, as measured by reductions in GDP growth (see Table 5.1). These studies further consider two channels through which finance is expected to mediate disaster outcomes. One is the level of financial development and depth, and another is the degree of financial openness. More advanced financial development increases an affected country's ability to borrow domestically, which should help overcome the immanent liquidity constraints associated with the income shock and allow for adequate investments in the recovery phase (McDermott et al., 2014; Melecky & Raddatz, 2015). Higher openness enhances the absorptive capacity of an economy through the availability of foreign funds and investments (Felbermayr & Gröschl, 2014). The two are highly correlated and presumably endogenous.

Studying a global set of disaster events from EM-DAT, the seminal study of Noy (2009) considers both the development and the openness of financial systems as determinants of the indirect costs of disasters. The author approximates financial development or depth with the capitalization of the domestic stock market and the level of domestic credit (in % of GDP) before the event. His results suggest that stock markets do not play a role in minimizing the macroeconomic consequences of disasters, while domestic credit does. Concerning financial openness, Noy (2009) considers the role of *de jure* capital account openness (using measures of Chinn and Ito (2006) and Edwards (2007)) as well as pre-event levels of hard-currency reserves. He finds that countries with *less* open capital accounts but more foreign exchange reserves experience lower indirect costs from disasters.

In contrast to this, Felbermayr and Gröschl (2014) present evidence for positive effects of *more* open capital accounts. Using exogenous measures of the physical intensity of events (rather than damages caused) as explanatory variables and the Chinn-Ito index of financial openness, the authors find that disaster years at the 95th percentile of the physical intensity distribution reduce GDP per capita by 2.12, 1.43 and 0.50 percentage points for countries with low, intermediate, and high levels of financial openness, respectively. Felbermayr and Gröschl (2014) use financial openness as their only measure of financial development, without controlling for the domestic level of financial development and ex-ante foreign reserves. Omitted variable bias may thus be a concern.

Both McDermott et al. (2014) and Melecky and Raddatz (2015) affirm the findings of Noy (2009) on financial development. McDermott et al. (2014) offer a simple two-period model of the investment effects of disasters, comparing credit-constrained and unconstrained economies. They highlight the potential role of credit market development for growth dynamics after a capital-destroying shock. Testing the implications of the model on a global sample of countries, the authors conclude that access to finance (measured as the level of private credit over GDP) constitutes a relevant channel for the economic effects of disasters. Particularly countries with lower levels of financial development experience persistent negative growth effects from disasters for up to five years after an event. Melecky and Raddatz (2015), employing panel vector autoregressive

Table 5.1: How banks mediate the economic consequences of natural hazard shocks: Cross-country evidence.

Study	Sample	Event data	Real outcome	Financial proxies
Toya and Skidmore (2007)	151 countries, 1960-2003 (y)	EM-DAT events	<i>Direct costs:</i> Deaths, Damage/GDP	<i>Development:</i> M3/GDP (–)
Noy (2009)	109 countries, 1970-2003 (y)	EM-DAT events: I/O, People dead/ affected, Damages	<i>Indirect costs:</i> GDP growth	<i>Development:</i> Stock market capitalization (ns), domestic credit (+) <i>Openness:</i> Chinn-Ito index (–), Edwards (2007) index (ns), foreign exchange reserves (+)
Felbermayr and Gröschl (2014)	108 countries, 1979-2010 (y)	GAME events: Physical intensity	<i>Indirect costs:</i> GDP growth	<i>Openness:</i> Chinn-Ito index (+)
McDermott et al. (2014)	178 countries, 1979-2007 (y)	EM-DAT events: People affected	<i>Indirect costs:</i> GDP growth	<i>Development:</i> Private credit/GDP (+)
Melecky and Raddatz (2015)	77 high- and middle-income countries, 1975-2008 (y)	EM-DAT events: I/O	<i>Indirect costs:</i> GDP, (govt. deficits)	<i>Development:</i> Private credit/GDP (+), insurance penetration (+)
Zhang and Managi (2020)	Pacific small island states, 1976-2014 (y)	EM-DAT events: I/O	<i>Indirect costs:</i> GDP p.c. growth	<i>Development:</i> Domestic credit/GDP (+)

Articles are sorted according to year of publication. Peer-reviewed studies are printed in bold. (–) indicates negative mediation effects on real outcomes, (+) indicates positive mediation effects on real outcomes, (n.s.) indicates no significant mediation effects on real outcomes. Abbreviations: y = yearly, q = quarterly, m = monthly, I/O = Event incidence/occurrence.

models on samples of high- and middle-income countries, underline the beneficial role of both credit market development and insurance penetration, as both contribute to mitigating negative economic consequences. Moreover, these authors show that countries with higher financial development expand their budget deficits further in response to such shocks, while greater insurance penetration does not lead to fiscal expansion. Financial development thus enables countries to use government expenditure to provide assistance and reconstruction investments.

More recently, Zhang and Managi (2020) have investigated the role of financial development in the disaster resilience of the Pacific small island states. Consistent with the previous studies, they find financial development helps mitigate the impacts of natural hazard-related disasters in this region. Further, the authors suggest internal financing opportunities contribute more to preserving economic development than external financing sources, meaning that domestic financial development plays a more important role in resilience than financial openness.

Complementing these indirect cost studies, Toya and Skidmore (2007) focuses on the direct costs of natural disasters, i.e. the number of fatalities and damages as a share of GDP. Based on a comparably rudimentary approach, their results suggest countries with more complete financial systems, as measured by the broad monetary aggregate M3 over GDP, experience fewer deaths from natural disasters, especially in developing countries. The level of damages does not seem to be correlated with their measure of financial depth.

The existing cross-country studies on the relationship between finance and resilience have found

both financial development and openness to play a role in mitigating the real economic consequences of natural hazard shocks. Financial development helps countries access domestic credit and overcome liquidity constraints, while financial openness can provide access to foreign funds and investments. Domestic credit seems relatively more important than foreign credit at the macro level, reflecting the notion that a closer relationship with the affected economy matters, for instance by easing information frictions.¹³

This strand of research suffers from several shortcomings. First, the literature is mostly limited to using the size of financial markets and institutions as proxies for financial development. Other financial system characteristics may also explain the results. Čihák, Demirgüç-Kunt, Feyen, and Levine (2013), for instance, highlight the efficiency and stability of financial institutions, as well as the overall access to financial services in a country as aspects of financial development that matter for real economic outcomes. These factors likely correlate with financial development and openness. Second, analog to the relationship between finance and growth in "normal" times (Arcand, Berkes, & Panizza, 2015; Law & Singh, 2014), the relationship between finance and resilience may be non-linear. Economies can be credit-constrained if there is no access to credit, or because they are too highly indebted to be considered creditworthy after a collateral-destroying shock. This would imply an inverted U-shaped rather than a linear relationship. The existing studies do not incorporate this. A third potential advancement would be to distinguish more systematically between indicators of financial development that reflect debt, and indicators that reflect reserves, buffers, and equity investment. The underlying question would be which kind of financial development enhances a country's ability to respond more flexibly to a significant exogenous shock. Lastly, causal identification at the macro level remains difficult, due to unobservable, non-financial confounders that may (partly) be captured by the financial variables. Examples may be institutional quality, the propensity to save, or attitudes towards risk-taking that also matter for economic resilience. Subnational studies may alleviate these identification concerns.

5.2 Micro-level financial intermediation and local economic impacts

A key feature of studies that zoom in on local economic impacts of natural hazards is their focus on local banking market conditions, which include the geographical orientation of banks, their business model, their level of diversification and capitalization, as well as the level of competition. What matters here, rather than the observed type of the institution as such, is the way credit allocation decisions are made in the face of a shock, i.e., the ability and willingness of banks to extend credit during a crisis. Based on the premise that credit availability helps mitigate the welfare losses from a natural hazard shock (McDermott et al., 2014), curtailing credit may be individually rational for a bank, but irrational from a societal perspective. The societal benefits investigated in these studies range from local income and employment (e.g., Duqi et al., 2021; Schüwer et al., 2019), to regional R&D activities (Das et al., 2023) and population dynamics (Rajan & Ramcharan, 2023). Table 5.2 provides an overview of recent studies in this strand of research.

¹³Similar patterns at the subnational level are the subject of discussion in the following section.

Table 5.2: How banks mediate the economic consequences of natural hazard shocks: Regional and subnational evidence.

Study	Sample	Event data	Real outcome	Financial proxies
Cortés (2014)	United States, 1997-2010 (q), bank/county	SHELDUS events: I/O, Damages	Employment growth	<i>Lender characteristics:</i> Local lender deposits (+)
Schüwer et al. (2019)	United States, 2003-2007 (q), bank/county	Hurricane Katrina (2005): I/O	Personal income, employment	<i>Lender characteristics:</i> independent banks (+), risk-based capital ratios (+)
Duqi et al. (2021)	United States, 1995-2017 (q), county	SHELDUS hurricanes: I/O	Income growth, establishment growth	<i>Banking market structure:</i> Lerner indices of county-level bank competition (-)
Qi et al. (2021)	United States, 2007-2017 (m), 3-digit zip code	Earthquakes: Physical Intensity	Unemployment rate	<i>Lender characteristics:</i> Fintech Lending (+)
Celil et al. (2022)	China, 2007-2017 (y), prefecture	EM-DAT events: I/O	Night lights, GDP growth	<i>Lender characteristics:</i> Local bank lending (+) State ownership (+)
Petkov (2022)	United States, 1999-2019 (q), industry/county	Hurricanes, Floods, Severe Storms: Damages	Employment growth	<i>Lender characteristics:</i> Local lender deposits (-)
Das et al. (2023)	India, 2000-2012 (y), firm/grid cells	EM-DAT events, Negative rainfall shocks: I/O	Interest expenses, debt, R&D activity, night lights	<i>Loan terms:</i> Interest rate shocks (-)
Peters et al. (2023)	China, 2004-2014 (y), prefecture	GAME-LIGHTS storms, floods: Physical intensity	GDP growth	<i>Banking market structure:</i> Pre-event indebtedness (-), <i>Lender characteristics:</i> large state-owned banks (+)
Rajan and Ramcharan (2023)	United States, 1929-1960 (y), county	"1950s" droughts: I/O	Population, firm survival, irrigation investment	<i>Banking market structure:</i> Credit availability (+)
Peters (2024)	United States, 2003-2020 (q), county	SHELDUS events: Damages	Employment growth	<i>Lender characteristics:</i> Local lender deposits (+)

Articles are sorted according to year of publication. Peer-reviewed studies are printed in bold. (-) indicates negative mediation effects on real outcome, (+) indicates positive mediation effects on real outcomes, (n.s.) indicates no significant mediation effects on real outcomes. Abbreviations: y = yearly, q = quarterly, m = monthly, I/O = Event incidence/occurrence.

Both Cortés (2014) and Peters (2024) use natural hazard-related disasters as exogenous shocks to US counties to identify the impact of local financial conditions on employment growth. Considering *truly local* lenders based on their deposit market shares, these studies find local finance helps maintain local employment growth. Studying the specific case of the 2005 Hurricane Katrina, Schüwer et al. (2019) provide evidence that affected counties with larger shares of independent banks and higher average bank capital ratios show a better recovery. This is in line with the more generally established finding that relationship lenders, who rely on soft information, build higher capital buffers by charging higher intermediation spreads in normal times, but support their customers through favourable recovery lending terms during and after crises (Beck et al., 2018; Bolton, Freixas, Gambacorta, & Mistrulli, 2016).

In contrast, Petkov (2022) finds that non-diversified local lenders exacerbate employment contractions and decrease resilience in the face of high-impact hurricanes. He argues this is because local lenders experience more severe portfolio losses due to their high geographical concentration, which limits their credit supply in return. This study accounts for local weather risk, discusses

the potential endogeneity of local banking structure and disaster risk, and uses industry-specific county-level data on employment outcomes.¹⁴

Also focusing on the United States, Duqi et al. (2021) highlight the role of banking market competition in post-disaster recovery. Banks that are facing less competition provide more real estate credit after hurricanes. Quantitatively, they associate a 10 percentage point reduction (1/3 SD) in the Lerner index with 0.32 percentage point higher output growth after the shock, with this effect being stronger for small, profitable, and highly capitalised banks.

Lastly, Qi et al. (2021) find positive effects of FinTech credit on job retention after earthquakes in US counties. Importantly, the authors report the role of FinTech lending is smaller in counties with more intensive banking networks, less banking competition, and a higher share of local banks, thus complementing the findings of Duqi et al. (2021), Cortés (2014), and Schüwer et al. (2019).

With Celil et al. (2022) and Peters et al. (2023), two studies investigate the role of local finance in natural hazard impacts at the prefecture level in China. Using EM-DAT disasters and defining the subset of (partially) state-owned city-commercial banks as local lenders, Celil et al. (2022) find post-disaster growth to be stronger in cities in which state-owned city-commercial banks expand credit more in reaction to a shock. The authors attribute this to the extent of state control over these banks, in particular local governments.

In contrast to Celil et al. (2022), Peters et al. (2023) use exogenous data on the physical intensity of extreme weather events, and consider the local level of pre-event indebtedness and the presence of the large "Big 4" state-owned commercial banks. Their findings suggest that high pre-event debt decreases the resilience of cities in the face of storms and extreme precipitation events. Given the high levels of debt resulting from the credit-fueled growth of Chinese cities in recent decades, these findings suggest that (too) high leverage carries a negative externality for resilience. This is in some ways contradicting previous studies that suggest positive effects of enhanced financial development at the country level, but it re-emphasises the need to investigate potential non-linearities in that relationship (as discussed in section 5.1). Further, Peters et al. (2023) find that a higher local market shares of the "Big 4" state-owned commercial banks coincides with higher resilience, consistent with Celil et al. (2022). State ownership of banks in China has benefits for natural hazard resilience. Peters et al. (2023) point out the deep pockets and means of diversification of these large "state-owned" banks that allow them to keep lending in the face of a shock.

The analysis of regional and subnational studies provides an interesting set of insights and takeaways. Recent studies of local lender characteristics and resilience have started to address the question of which local financial structure enhances economic resilience. So far, the results on the role of local lenders are mixed, and further evidence is necessary to unpack the underlying mechanisms. From a broader perspective, a trade-off between efficiency and resilience seems to exist, implying that banking structures often considered more efficient in normal times (higher banking competition, privatization, transaction-oriented banking) may be debilitating in times of

¹⁴The relevance of accounting for previous or historical exposure to extreme events has already been demonstrated by Hsiang and Jina (2014) in a study of the long-run economic effects of cyclones.

crisis. It remains crucial to extend our knowledge of factors that enable individual banks and financial systems to enhance real economic resilience. Higher bank capitalization certainly is one such factor. Accordingly, excessive pre-event leverage tends to be hurtful in the face of shocks. For the specific case of China, the benefits of state ownership in recovery financing are striking.

5.3 Microfinance

Microfinance describes the provision of financial services, such as loans, savings, and insurance, to otherwise excluded customers, for instance, poor and low-income households and businesses. Designed to help these individuals access the financial resources they need to build self-sustained livelihoods, it also presents a potential recovery tool after natural hazard shocks. Access to financial services can help disaster-affected communities rebuild and recover by providing a source of capital and a means of saving and protecting assets where traditional banking services struggle. In recognition of the fact that disasters often have particularly devastating impacts on poorer countries and population groups, this area deserves special attention (Klomp & Valckx, 2014; Wallemacq & House, 2018).

Many studies discuss the relevance and possible mechanisms and channels of microfinance for resilience theoretically (e.g., Dowla, 2018; Kumar & Newport, 2005; Marincioni, Appiotti, Pusceddu, & Byrne, 2013). The existing empirical literature is listed in Table 5.3. Survey-based case studies of specific events show that membership in or access to credit from microfinance institutions improves post-disaster outcomes, e.g. the secondary school attainment of children after the 1998 hurricane Mitch in Honduras (Gitter & Barham, 2007), household consumption after the 1998 and 2004 floods in Bangladesh (Khandker, 2007; Shoji, 2010) and the 2013 cyclone Phailing in India (Calis, Gangopadhyay, Ghosh, Lensink, & Meesters, 2017), as well as income and employment after the 2004 tsunami in Sri Lanka (Becchetti & Castriota, 2011) and after drought, wildfire, and flood events in Mexico (Lensink, Servin, & van den Berg, 2017).¹⁵ Shoji (2010) adds that microfinance institutions that offer contingent repayment provisions are able to better serve their clients during natural disasters, as these provisions provide a safety net for borrowers who may be struggling to repay their loans due to the impact of the disaster.

Taking a macroeconomic perspective, Sseruyange and Klomp (2021) complement the existing evidence using a comprehensive sample of more than 80 developing economies. Starting from the observation that disasters primarily affect agricultural output in these countries, they conclude that access to MFI lending facilities helps keep the indirect economic losses small. The mitigating effect of microfinance further hinges on MFI characteristics, such as their business model, age, size, and their profitability.

Overall, microfinance can be an important tool for developing economies to deal with natural hazard shocks. It is important to note, however, that the effectiveness of microfinance depends on many factors, such as the specific terms of the MFI services, the severity of the disaster, and the capacity of the microfinance institution to implement recovery lending provisions effectively.

¹⁵Further, also Pantoja (2002) provides several anecdotal reports on microfinance responses to disasters.

Table 5.3: How microfinance mediates the economic consequences of natural hazard shocks.

Study	Sample	Event data	Real outcome	Financial proxies
Gitter and Barham (2007)	Honduras, 1994-2001 (y), household survey	Hurricane Mitch (1998): Damages	Secondary school attainment of children	Access to credit (+)
Khandker (2007)	Bangladesh, 1991-1999 (y), household survey	1998 Floods: I/O	Household consumption and asset holding	Household borrowing (+)
Shoji (2010)	Bangladesh, 2004-2005 (y), household survey	2004 Floods: Damages	Probability of meal omission	Contingent repayment of microfinance loans (+)
Becchetti and Castriota (2011)	Sri Lanka, 2004-2007 (m), borrower survey	2004 Tsunami: I/O	Real income and weekly worked hours	Post-disaster loan to income ratio (+)
Parvin and Shaw (2012)	Bangladesh, 2008 (cs), household survey	Cyclones and river erosion: I/O	Disaster preparedness, response, and recovery	(Duration of) MFI membership (+)
Calis et al. (2017)	India, 2012-2014 (m), household survey	Cyclone Phailing (2013): I/O	Consumption expenses	MFI membership (+)
Lensink et al. (2017)	Mexico, 2004-2007 (y), household survey	Droughts, fires, floods: I/O	Income, income variability, probability of becoming poor	MFI membership (+)
Sseruyange and Klomp (2021)	80 developing countries, 1995-2010 (y)	GAME events: I/O, Physical intensity	Sector-specific value-added per capita output	MFI accessibility indicator (+)

Articles are sorted according to year of publication. Peer-reviewed studies are printed in bold. (–) indicates negative mediation effects on real outcome, (+) indicates positive mediation effects on real outcomes, (n.s.) indicates no significant mediation effects on real outcomes. Abbreviations: y = yearly, q = quarterly, m = monthly, cs = cross-sectional, I/O = Event incidence/occurrence.

Further research should tease out the conditions under which the effectiveness of microfinance can be levered as a tool for resilience-building in the face of climate change.

5.4 Spillover effects through the banking sector

Aside from direct effects on banks and the real economy, indirect impacts of disasters and extreme events can also spill over to neighboring or otherwise connected regions and entities (Botzen et al., 2019; Felbermayr, Gröschl, Sanders, Schippers, & Steinwachs, 2022). Banks and financial networks are one link through which impacts may be transmitted to regions, firms, or households not directly affected themselves. For such spillovers, it does not matter whether the direct effect of a natural hazard shock on banks is interpreted as a supply or a demand shock. The demand shock perspective posits that the increase in credit demand in affected regions leads banks to either cut their lending in other regions (Rehbein & Ongena, 2022) or to refinance themselves via secondary markets (Bos et al., 2022; Chavaz, 2016; Cortés & Strahan, 2017). The supply shock perspective implies that banks cut their lending across the board, due to the adverse impacts of the shock (Rehbein & Ongena, 2022). In either case, the implications for credit availability in unaffected regions would be negative. On the other hand, financial intermediaries may learn about hazard risk in affected regions and decide to relocate their business to other, less risky regions. This could lead to increases in supply or more competition in these markets (Barth, Hu, Sickles, Sun, & Yu, 2024; Correa, He,

Table 5.4: Spillover effects of natural hazard shocks through the banking sector.

Study	Sample	Event data	Spillover effects on	Effects mediated by
Chavaz (2016)	United States, 2003-2008 (y)	2005 Hurricane season: I/O	Credit supply	
Hosono et al. (2016)	Japan, 1995-1997 (y)	1995 Kobe Earthquake: I/O	Firm investment, credit supply (intensity of banking relationship)	
Cortés and Strahan (2017)	United States, 2001-2010 (m)	SHELDUS/FEMA events: I/O, Damages	Credit supply, Deposit rates	Own branch presence, market power, protection of core market
Correa et al. (2022)	United States, 1996-2019 (m)	SHELDUS/FEMA hurricanes, floods, wildfires: I/O, Damages	Loan spreads	Borrowers' creditworthiness, time-varying attention
Ivanov et al. (2022)	United States, 1992-2014 (y)	SHELDUS events: Damages	Credit supply	Bank capitalisation, strategic importance of market
Rehbein and Ongena (2022)	Germany, 2009-2014 (y)	Elbe Floods (2013): I/O	Credit supply, firm employment, tangible assets	Bank capitalisation
Barth et al. (2024)	United States, 2008-2017 (q)	SHELDUS/FEMA events: I/O	Deposit rates	Social connectedness, geographic distance

Articles are sorted according to year of publication. Abbreviations: y = yearly, q = quarterly, m = monthly, I/O = Event incidence/occurrence.

Herpfer, & Lel, 2022). The literature evaluating these questions is surveyed in the following section and presented in Table 5.4.

Chavaz (2016), Hosono et al. (2016), Cortés and Strahan (2017), Ivanov et al. (2022), and Rehbein and Ongena (2022) demonstrate that banks directly affected by natural hazard shocks reduce their lending in unaffected regions. Zooming in on these studies, Chavaz (2016) identifies two margins of adjustment that banks employ when adjusting their lending in response to a credit demand shock. First, banks increase the share of accepted credit applications in affected areas after the shock but decrease it in unaffected areas. Second, banks sell more of this new lending into secondary markets. In other terms, banks re-balance their lending towards affected regions while avoiding the associated risks. Focusing on firms after the 1995 Kobe earthquake, Hosono et al. (2016) find that being connected to banks located inside the disaster area had real effects on firms that were unaffected by the event. These indirectly affected firms show significantly lower investment ratios than comparable firms whose banks were not affected by the earthquake. In addition, these firms reported a decreasing relevance of affected banks as their main lenders in the aftermath of the event, implying that these banks reduced their credit supply to these firms.

Subsequent papers further consider the role of heterogeneity at the bank level and factors that mediate the spillovers. Cortés and Strahan (2017), for instance, find that banks cut lending most in connected markets in which they possess little or no market power. They interpret this result as banks shielding their core markets while abandoning markets where they are less established.

Two studies point toward the role of bank capitalization in the transmission of natural hazard

shocks through banks. Based on a sample of large US banks and SHELDUS disasters between 1992 and 2014, Ivanov et al. (2022) provide evidence of a reallocation of credit supply away from unaffected regions. This is driven by banks with lower regulatory capital, consistent with a supply shock interpretation and a negative "network effect". Similar to Cortés and Strahan (2017), they find that banks strategically divert from regions that are less important for their syndicated lending business. Rehbein and Ongena (2022) focus on the 2013 Elbe River floods and affected regions in Germany. They, too, find that under-capitalised banks reduced their credit supply to unaffected regions after the flood, leading to a 2.4% reduction in the borrowing of unaffected firms. As a consequence, unaffected firms with a connection to affected banks reduced their employment by 2.4% and their tangible assets by 5.1%, confirming the notion that low bank capital carries a negative externality. Furthermore, disaster-affected banks shift lending away from unaffected firms more if these firms are located in regions that are relatively more exposed to disasters, suggesting that banks adapt to climate risk.

Addressing aspects of adaptation, Correa et al. (2022) disentangle spillover effects that are due to directly disaster-related bank-internal shifts in credit allocation from spillovers that are due to updates in the lenders' expectations about the future severity of climate-related events. These authors suggest banks update their beliefs about climate change after highly visible disasters and increase the rates on loans to at-risk yet momentarily unaffected borrowers. As attention ceases over time, the effect dissipates.

The empirical evidence on spillovers of hazard shocks through banks and financial intermediaries concludes that affected banks tend to reduce their lending in unaffected regions. This can have real economic consequences. Firms that are connected to affected banks show lower investment, employment, and profitability. Again, bank capitalization is important, in that higher capitalization mitigates the extent of these spillovers. Furthermore, banks tend to protect their core markets and long-term relationships strategically.

6 Discussion and recommendations for future research

Future research should take the interplay of insurance, government, and banking into focus. While these sectors have been considered in isolation (Duqi, 2023; Kousky, 2019; Zhou et al., 2023), an integrated assessment should identify interdependencies that help strengthen resilience. For instance, the availability of reinsurance or the possibility to emit disaster bonds may affect the ability of different types of banks to mediate shocks in different ways. Thinking of small, independent banks exposed to such shocks (as in the US, for instance), pooling risks across similar banks in different regions may strengthen their stability and credit supply in the face of shocks, similar to the ways small banks that are part of banking groups use intra-group markets in, for instance, the German banking system (Koetter et al., 2020).

Furthermore, severe disasters typically trigger governments to dispense aid to affected households. Here, we do not yet know much about how this aid interacts with the behaviour of the

banking sector. On the one hand, banks may be important for the effectiveness of aid if they play a role in how such programs are dispensed and allocated. On the other hand, government intervention may crowd out banks' recovery lending, or – possibly worse – create perverse incentives for banks to provide *too much* credit in high-risk regions (Garbarino & Guin, 2021; Ouazad & Kahn, 2022), exacerbating existing problems. Importantly, it is also not conclusively identified where the economic costs of natural hazard shocks are ultimately absorbed. Studying the interplay of banks, public institutions, and insurance promises deeper insights into how the real and financial consequences of such shocks unfold.

In conjunction with this, bank-level regulation and central bank supervision can contribute to a strengthening of the resilience-enhancing capacity of the banking sector and ensure that government intervention creates the right incentives. Based on this review, it seems imperative to further monitor and evaluate the development of financial risks created by natural hazard shocks. Ensuring adequate bank capitalization presents itself as one instrument to preserve bank stability, credit supply, and thereby economic resilience in the face of a shock while reducing negative spillover to unaffected regions through the banking sector. However, more work is needed to integrate physical risk aspects in the current climate financial regulatory frameworks. Recent proposals for "climate stress tests" mandate large banks to assess not only their exposure to transition but also physical risks (Duqi, 2023; Monasterolo, 2020), which is a first step in the right direction. Still, "most institutions have a blind spot for physical risks" (European Central Bank, 2021, p. 3). Researchers, regulators and policy-makers also need to consider heterogeneity across financial institutions and think about concrete measures to ensure the resilience of small and local banks, which play a central role in the face of local natural hazard shocks.

The question of how to address the trade-offs between efficiency and resilience, which become apparent throughout the review, demands attention from both researchers and policy-makers. A central, yet difficult quest will be to define the optimal balance between resilience and efficiency – from a theoretical perspective as well as in practice. To inform this process, academic research needs to identify more clearly under which circumstances (e.g., with respect to local environmental circumstances, bank business models, and local economic conditions) which types of banks contribute most to local resilience.

This stream of research should further acknowledge that different types of banks cater to different types of borrowers, which may imply further heterogeneity of disaster outcomes. For instance, poorer and disadvantaged population groups, as well as small- and medium-sized enterprises (SMEs) are typically more vulnerable to natural hazard shocks (B. Collier, Haughwout, Kunreuther, & Michel-Kerjan, 2020; Davlasheridze & Geylani, 2017). Yet, little is known about how the banking sector moderates inequality in disaster regions. As climate change progresses, this may aggravate issues of inequality, exclusion, and poverty and further impede the SDGs. From a societal perspective, financial intermediaries that serve these customer groups may thus be particularly important for policymakers to consider when discussing climate-related financial risk management and regulation. The ongoing trends toward market concentration and a "monoculture" of big, centralised,

transaction-oriented banks may come at a social cost if credit decisions are made purely on the basis of credit scores, which deteriorate in response to natural hazard shocks (Ratcliffe et al., 2020). Relatedly, the formation of "banking deserts" (see e.g., Deming & Weiler, 2023; Langford, Thomas, & Feldman, 2023)) raises concerns about the ability of regions to respond and recover from natural hazard shocks due to the lack of access to any financial services.

In this context, and in a way relating to all previous points, adaptation of banks to both short-term and long-term threats posed by natural hazards and climate change is another central topic for future research. The review presents some indication that banks may increase their capitalization after experiencing natural hazard shocks, reflecting learning about changing physical risks. Banks with higher exposure to natural hazard shocks may also adapt their business models, resulting in lower income and balance sheet effects for a given physical intensity of a shock. For instance, some early evidence suggests that banks may respond to elevated disaster risks by increasing their loan loss provisions (Dal Maso, Kanagaretnam, Lobo, & Mazzi, 2022) or by tightening credit standards (Duanmu, Li, Lin, & Tahsin, 2021; Huang, Kerstein, Wang, & Wu, 2022), while other studies do not find indications for adaptation in bank lending (Garbarino & Guin, 2021). This strand of research should move forward by assessing how these behavioural responses affect the resilience of banks and their associated borrowers. Other than that, the literature remains vague about how banks utilise local knowledge about hazard risks and how this may contribute to regional economic resilience. Increases in the frequency and severity of damages of natural hazard shocks in certain regions may also drive (certain types of) banks out of affected markets if the local banking structure is indeed endogenous to environmental conditions. This may further accelerate the previously discussed banking desertification and intensify concerns about economic inequality. Linking this to existing research about "managed retreat" in the face of climate change may present new avenues for future research (Hino, Field, & Mach, 2017; Miao & Davlasheridze, 2022) and important insight for policy decisions.

Some studies consider the role of alternative forms of financing in regions with fewer banks, but much more can be done to understand how in particular advancements in financial technologies can improve economic resilience. This applies expressly also to the climate resilience of developing economies, for which the opportunities and challenges associated with increasing digital financial inclusion may make a difference in how we achieve climate resilience and sustainable development goals (Demirgüç-Kunt, Klapper, Singer, Ansar, & Hess, 2020; El-Zoghbi, Chehade, McConaghy, & Soursourian, 2017).

Finally, the impacts of hard-to-measure slow-onset events such as droughts as well as compounding shocks require additional attention. Regarding the former, early but limited evidence reviewed in this paper suggests that such events, which may be particularly relevant in the face of climate change (Hong, Li, & Xu, 2019), have adverse consequences on the banking sector. However, the consequences for banking and the finance-resilience nexus likely differ from sudden-onset events such as floods and storms. Regarding the latter, virtually all of the studies reviewed in this paper consider stand-alone, one-off shocks. Recent experiences show that shocks like pandemics or

armed conflicts disrupt economies at unexpected times, and multiple disasters may occur simultaneously. Looking ahead, risks related to losses in biodiversity also bear the potential to disrupt economic systems (Dasgupta, 2021). Compounding shocks are thus a real threat to both financial and economic resilience. Some first evidence suggests that the real economic impacts of shocks are amplified non-linearly when they coincide (Brei et al., 2019; Dunz et al., 2023; Ranger et al., 2021). Not only may this change the direct effects of shocks on the banking system but also the way in which shocks are mediated to the real economy. Thorough investigations into how compounding shocks affect bank outcomes, macro-financial stability, and the finance-resilience relationship are therefore much-needed.

7 Conclusion

Natural hazard shocks have detrimental consequences for economic growth and labour market conditions in affected regions. In the face of global warming, this poses significant threats to the timely achievement of the SDGs, making action to increase the resilience of our economic and financial systems a first-order policy objective. This paper aims to enhance our understanding of how banking can help build economic resilience towards these threats. It highlights the interdependencies between financial and economic resilience and identifies important nuances and system-specific features that are important for future research as well as policies that adequately address the needs of different contexts. The paper is structured around two central questions: First, what are the direct effects of natural hazard shocks on the banking sector, in particular bank stability, profitability, and credit supply? Second, how does the banking sector shape the resilience of the real economy toward natural hazard shocks? Figure 7.1 synthesises the main insights of this review, structured into the framework introduced in section 2.

Natural hazard shocks can threaten both bank-level stability and profitability. Countries with more developed economic and financial systems and strong regulatory institutions are consistently more resilient to adverse bank-level impacts. In developed economies, adverse effects are therefore typically transitory and single events have not posed crucial threats to system-level stability in the past. In developing economies, for which evidence so far remains relatively scarce, severe shocks may cause long-term increases in financial risks and impair the stability of both traditional banks and microfinance institutions. Local institutions with concentrated lending activities in regions affected by highly destructive events bear the highest burden. Higher pre-event capitalization is robustly shown to offer protection against the deterioration of bank health, in accordance with macroeconomic evidence supporting rigorous financial regulations.

In developed economies, credit supply tends to match post-event spikes in credit demand. The results for developing economies are a cause for concern, as impaired stability and profitability result in a limited ability to maintain credit supply. Local banks in affected regions in developed economies appear to play an important role. Relationship lending as practised by such banks is a means to smooth credit supply to the local economy during a crisis. However, low diversification

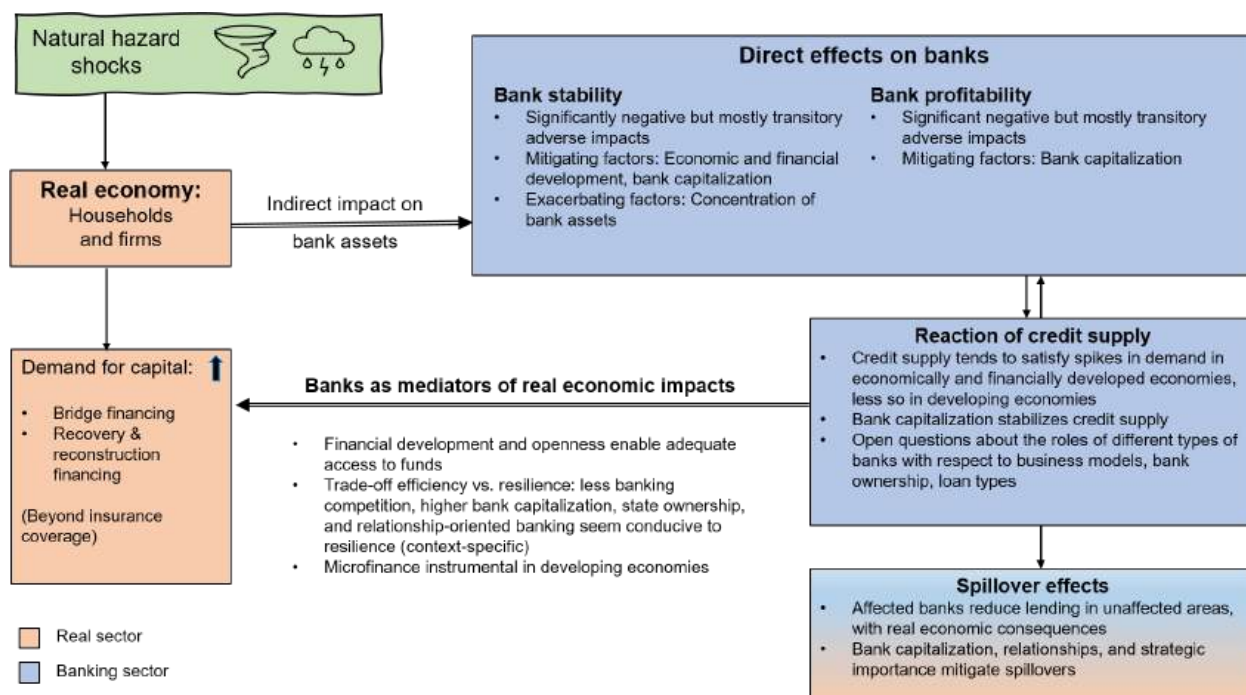


Fig. 7.1: Main insights of the reviewed literature.

increases the exposure of such lenders to localised shocks, potentially impairing their ability to maintain credit supply in the face of extremely damaging or cumulative shocks. Further research is necessary to study the conditions for and implications of these opposing effects. In the case of China, state-owned banks are used to provide liquidity in adversely affected regions.

The responses of banks to natural hazard shocks have real economic consequences. Country-level evidence indicates that domestic financial development is generally conducive to economic resilience, at least up to a point. Studies at the sub-national level suggest non-linear impacts of finance on resilience. The results further indicate a trade-off between static efficiency and resilience. What is considered efficient in normal times (high competition, privatization, transaction-oriented banking) has been found to hinder resilience. Further research is needed to identify heterogeneity across different banks with different business models, lending technologies, and ownership structures in this regard. Microfinance institutions are often viewed as a crucial resource for households and small businesses in developing economies to cope with unexpected financial setbacks. However, their effectiveness hinges on their capacity to implement recovery lending under adverse conditions. Finding ways to enable these lenders to do so will be a critical component in achieving sustainable development in the face of climate change. Lastly, banks are a channel through which local natural hazard shocks can spill over to connected regions, negatively affecting firm investment and employment. These spillovers are mitigated by bank capitalization and the strategic importance of regions for banks. Furthermore, evidence suggests that banks adjust their risk assessment after weather-related shocks.

To better inform the public, academic and policy discussions on economic resilience to natural

hazard shocks, many challenging questions still need to be addressed. For instance, it is critical to better understand the interactions between insurance, government, and banking in the face of climate change and physical climate risk. Similarly, it is important to highlight the adaptation within the banking sector and its interaction with the heterogeneity of disaster outcomes across space, time, and socio-economic circumstances should be brought into the spotlight. This is especially crucial as the potential for compounding shocks increases, threatening the attainability of sustained economic growth and productive employment in the face of natural hazard shocks.

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Lending in the Rain? A Review of the Impacts of Natural Hazard Shocks on Banks and the Finance-Resilience Nexus

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Online Appendix

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A Appendix: Data and Methods

This section is intended to provide some additional guidance for researchers interested in the topic of this review. It discusses common data sources and empirical methods employed to study the impacts of natural hazard shocks on banks and their mediating role for real economic resilience in more detail than in the main body of the review.

A.1 Data sources

Financial data. Bank stability, profitability, and credit supply may be measured and operationalised in different ways, depending on data availability and the scope of the studies at hand. Macroeconomic, cross-country studies rely on regional or country-level aggregates of bank credit or lending flows to approximate the effects of exogenous shocks on aggregate credit supply as well as aggregated measures of bank stability and profitability. Such data sets are typically retrieved from national statistical and regional statistical offices, or from central banks and financial regulators. While these datasets allow for broader comparisons of impacts across regions and events in order to see the bigger picture, they naturally mask some of the underlying heterogeneities lost in the aggregation process.

The most common source of data used to analyze credit supply effects as well as effects on the profitability and solvency of financial intermediaries is bank-level balance sheet data provided in quarterly reports or annual statements. This data can be directly available in a standardised format through a centralised and public provision by regulatory or administrative institutions, or it may be available through private providers who collect and harmonise public reports and balance sheet data directly from the respective banks.

The most granular data utilised by studies on banks' credit supply specifically stems from loan-level contracts between affected households and firms and their financial intermediaries. While this micro-level data allows for in-depth analyses of underlying mechanisms, it is usually difficult to obtain. This data is often only accessible via central banks or through the financial intermediaries themselves. In some instances, loan-level data may also be available through private providers, but only for certain types of loans, e.g., loans that exceed certain thresholds in volumes or involve partners of a certain size (e.g., Ivanov et al., 2022). The primary sources for this data are regulatory filings, bank reports, and journalist contributions. These constraints in data availability limit the scope and external validity of the results of loan-level studies.

Lastly, surveys at the individual, household, or firm level are frequented where the aforementioned types of data are not available. This applies in many cases to studies with a focus on developing economies and microfinance institutions.

Extreme event and disaster data. Data on extreme weather events and natural hazard-related disasters can be categorised along several dimensions: Data source, types of events considered, and approaches to measuring the frequency and intensity of events. One commonly used

dataset is the spatially and temporally comprehensive international Emergency Events Database (EM-DAT) of the Centre for Research on the Epidemiology of Disasters (CRED), which provides information on the global occurrence and direct humanitarian and economic losses from disasters from 1900 onwards. To be included in the database, an event has to have led to either 10 or more people dead, 100 people or more affected, a declaration of a state of emergency, or a call for international assistance by the affected country (Guha-Sapir, Below, & Hoyois, 2022).

Other comprehensive sources for data on natural hazards are provided by the ifo Institute, namely the Geological and Meteorological Events (GAME) and the gridded Meteorological Events and Night Light Emission (GAME-LIGHTS) databases (Felbermayr & Gröschl, 2014; Felbermayr, Gröschl, Sanders, Schippers, & Steinwachs, 2022). While the former provides information on the physical intensities of both geological and meteorological events at the country level between 1979 and 2010, the latter has information on meteorological events between 1992 and 2013 at a resolution of 0.5° x 0.5° grid cells.

More recently, several studies with a global orientation have been published that make use of the BD Catnat (Base de données catastrophes natural) Global Database, provided by the private risk management consulting firm Ubyrisk (e.g., Chabot & Bertrand, 2023), and the Global Climate Risk Index, which is compiled by the sustainable development NGO Germanwatch (e.g., Le et al., 2023; Liu et al., 2024).

Studies with a specific sub-national focus on the United States commonly retrieve data from the Spatial Hazard Events and Losses Database for the United States (SHELDUS). SHELDUS reports information on the direct humanitarian and economic losses caused by events at the county level starting in 1960 (CEMHS, 2023). Until 1995, SHELDUS includes events that caused at least \$50,000 in crop or property losses or at least one fatality. Since 1996, the loss threshold is abolished, so that the database includes all events that caused any damage or led to any fatalities (Gall, Borden, & Cutter, 2009).

Case-based studies with a relatively narrow focus (i.e., specific cities or single events) may also draw on administrative data and official reports provided by government agencies, such as environmental services or disaster management institutes, as well as damage reports from insurance companies.¹ These data sources can comprise fine-gridded data on physical intensities and/or highly disaggregated information on humanitarian and economic losses.

Regarding the types of events covered by the included studies, several distinctions can be made. While case-based studies cover only one specific event, broader studies may cover multiple events of a specific type (e.g., hurricanes between 1990 and 2020), or they may cover multiple events of different types (e.g., all events above a certain threshold of humanitarian, economic, or physical severity). Studies of the latter type find that while all types of events generally have negative socioeconomic consequences (Felbermayr & Gröschl, 2014), events differ in the nuances of how the adverse consequences unfold (Botzen, Deschenes, & Sanders, 2019). Next to weather-related

¹Large re-insurance companies also provide comprehensive global disaster loss databases (e.g., MunichRe's Nat-CatSERVICE database or SwissRe's SIGMA database), but these are typically not freely available to the public and none of the reviewed papers make use of these sources.

incidents, such as storms, floods, extreme temperatures, and droughts, this review also includes geological hazards such as earthquakes.²

An important difference across studies, that arises partly from the choice of the utilised database and partly from the investigated research question, is the way the concrete hazard variables are operationalised. Approaches based on EM-DAT and SHELDUS databases usually use the number/share of people affected or the amount of damage (relative to GDP) as the treatment variable when studying the impacts of events on an economic outcome, for instance, GDP per capita growth. Some studies also simply consider the occurrence or incidence of events above a certain threshold of losses as explanatory variables.

Such approaches have been criticised on the grounds that the probability of considering an event a disaster may depend on the socioeconomic characteristics of the affected entities as well as the purpose and audience of the data-collecting institution, resulting in potential biases (Gall et al., 2009).³ More recent studies use measures of the actual physical intensity of events in a given locality, which are presumably exogenous to economic outcomes and therefore promise a cleaner identification of effects (Felbermayr & Gröschl, 2014).

A.2 Empirical approaches

The vast majority of studies on the effects of natural hazard shocks build on panel data and associated methods. The most popular approaches are variations of panel fixed-effect and difference-in-difference estimation procedures. Few studies employ vector autoregressive (VAR), panel VAR methods (Albuquerque & Rajhi, 2019; David, 2011; Melecky & Raddatz, 2015; Zhang & Managi, 2020), or some form of binary response models (Berg & Schrader, 2012; Garmaise & Moskowitz, 2009; Shoji, 2010). On closer examination, there are subtle differences in the exact implementation also within the methodological approaches. For studies using panel fixed-effects methods, the source of the fixed effects varies greatly (time, bank/lender, branch, borrower, region, loan, household, industry-year, region-year), depending on the setup of the respective study and estimation approach.⁴ Moreover, the fixed-effects models may be set up as dynamic panels, i.e., including lags of dependent variables. Such studies typically employ system-generalised method of moments (GMM) estimators to deal with endogeneity concerns arising from dynamic panel setups (e.g., Keerthiratne & Tol, 2017).

To study the relationship between natural hazard shocks and banks' balance sheet positions or credit supply behavior, researchers typically estimate models of the form represented (in stylised fashion) in equation (1). The dependent variable Y^{bank} is a measure of bank stability, profitability, or credit supply, while D represents the natural hazard shock (measured as discussed in section

²The number of studies using droughts and earthquakes is relatively low, though.

³For instance, both the monetary damages inflicted by disasters as well as the coverage of insurance tend to be higher in richer locations, making both the measured disaster intensity and the probability of inclusion into a database (selection) correlated with the level of income. Empirically, this would likely lead to upward-biased estimates of the effects of disasters on economic growth. Some studies try to circumvent this issue by choosing only highly-destructive disasters.

⁴The same holds true for choices regarding the estimation of standard errors.

A.1). X is a vector of control variables:

$$Y^{bank} = \beta D + \gamma X + \epsilon \quad (1)$$

Researchers have utilised a diverse set of variables to analyze the direct impacts of natural hazard shocks on banks. Measures that reflect bank stability in a broad sense can be grouped into three categories: The first group focuses on bank capitalization, including lenders' (risk-based) capital ratios, equity ratios, capital adequacy, and equity volatility. The second group focuses on default risk as measured by Z-scores⁵, or predicted probabilities of default. As a third group, many studies consider changes in non-performing loan ratios to capture credit risks in the aftermath of events. Additionally, some studies also feature measures of liquidity risks. Taking a macroeconomic perspective, Klomp (2014) estimates the effects of disasters on the probability of the occurrence of banking crises. Studies investigating the impact on bank profitability measure the latter through interest margins, returns on assets/equity, or net income growth, while credit supply is mostly represented by bank lending volume or growth (aggregated or for specific loan types), or the probability of receiving new or additional loans. Table B.2 provides a comprehensive overview of all analyzed studies by commonly utilised measures.

Studies investigating the question of how financial intermediaries may mediate the real economic impacts of natural hazard events rely frequently on fixed-effects panel models with interaction terms as well as triple difference-in-difference specifications. Presented here in a simplified form, many models estimate a version of the stylised equation (2):

$$Y^{real} = \beta_1 D + \beta_2 Fin + \beta_3 D * Fin + \gamma X + \epsilon \quad (2)$$

These studies consider the real impacts of natural hazard shocks D on measures of economic activity or disaster costs Y^{real} , e.g., humanitarian and economic losses, measures of income and productivity growth, employment growth, establishment growth, or household consumption. To estimate the mediating effects of banks, the financial and banking variables of interest are included in an interaction term with the treatment variable, i.e., $D * Fin$. Variables that capture the banking sector characteristics include measures of financial development, credit supply and bank lending growth, heterogeneity in the local presence and activity of certain types of banks, as well as the availability of alternative forms of financing.⁶ Tables B.3 and B.4 link the most important measures to the respective studies.

A common trend in this literature is the increasing prevalence of difference-in-differences methods as the state-of-the-art. However, even within the same method, research discretion at various stages of the process may lead to diverging conclusions regarding the impacts of natural haz-

⁵Z-scores measure banks' distance from insolvency and are typically constructed as the (natural logarithm of) the sum of a bank's return on assets and its equity-to-asset ratios, standardised by the standard deviation of the return on assets. A higher z-score indicates that a bank is more sTable (Laeven & Levine, 2009).

⁶In some studies, Y^{bank} is the same as Fin , which means that these studies first investigate the reaction of banks to the shock, and then how heterogeneity in this reaction affects the real economic outcomes (or the other way around).

ards (Barth, Lee, Shen, & Yoon, 2021). Furthermore, the econometric literature on difference-in-differences itself has evolved rapidly in recent years, and the momentum continues to be high (Roth, Sant’Anna, Bilinski, & Poe, 2023). New econometric insights suggest, for example, that two-way fixed effects and staggered difference-in-difference models with multiple periods and variation in treatment timing – models that are used frequently in the reviewed studies – might need more careful estimation strategies to estimate clean causal effects than researchers previously thought (Baker, Larcker, & Wang, 2022). Thus, taking these new insights into the robustness and potential biases of these estimators into account could be another step forward for future research on the topics of this review.

B Additional Figures and Tables

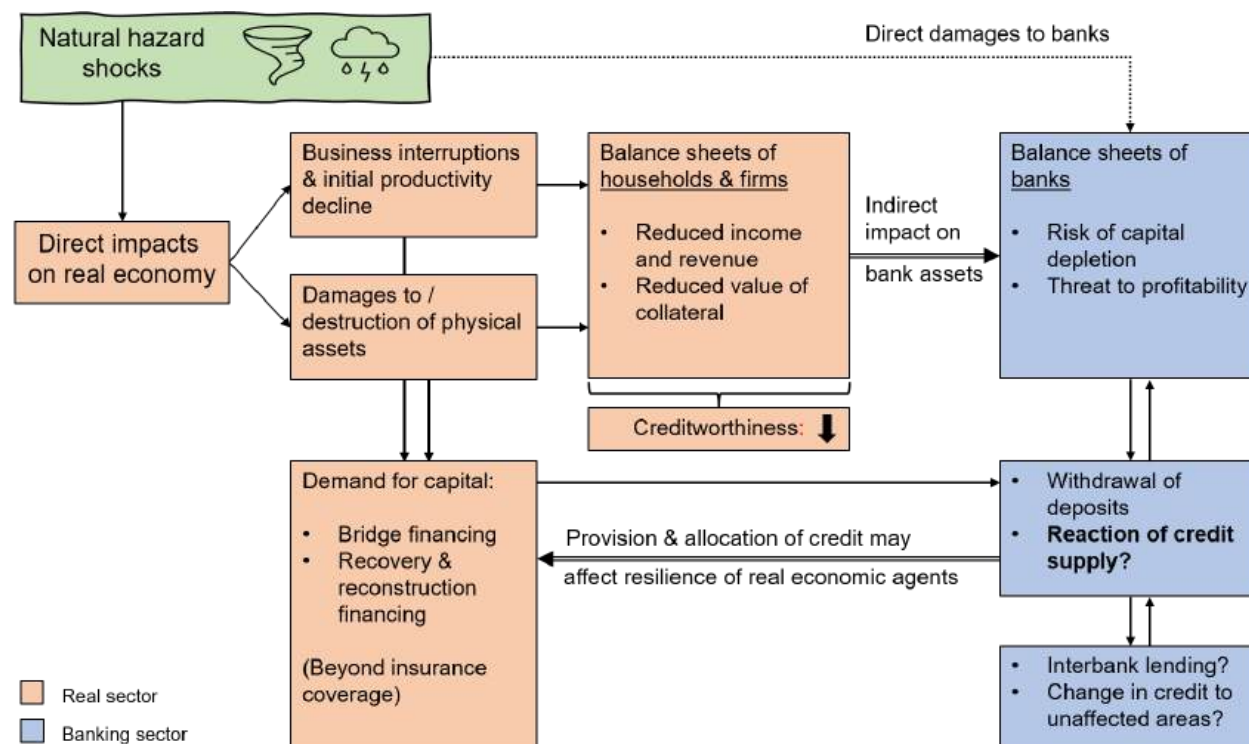


Fig. B.1: Interactions between real and financial sectors in the face of a natural hazard shock. Source: Adapted Figure based on Batten et al. (2016) and Ranger et al. (2022).

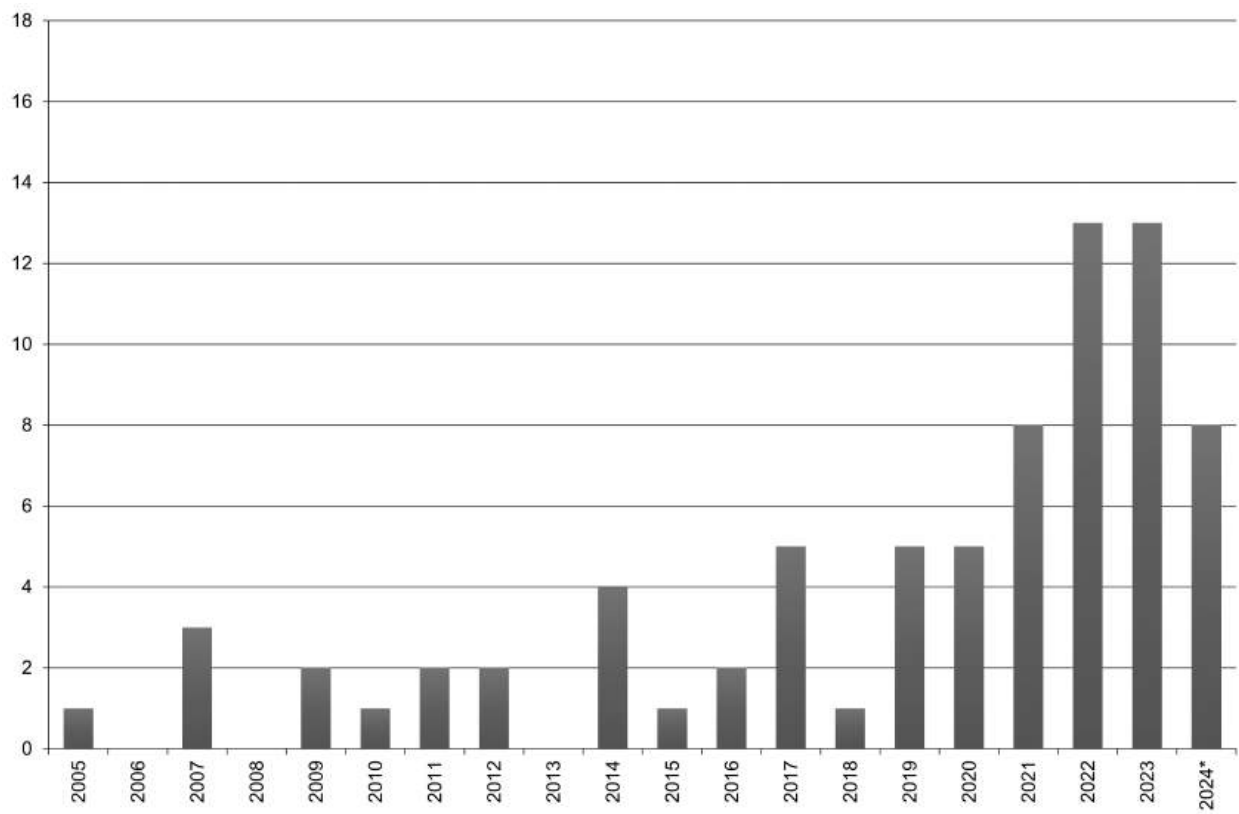


Fig. B.2: Chronology of new articles relevant to the literature, 2005-2024 (*per 31 May 2024)

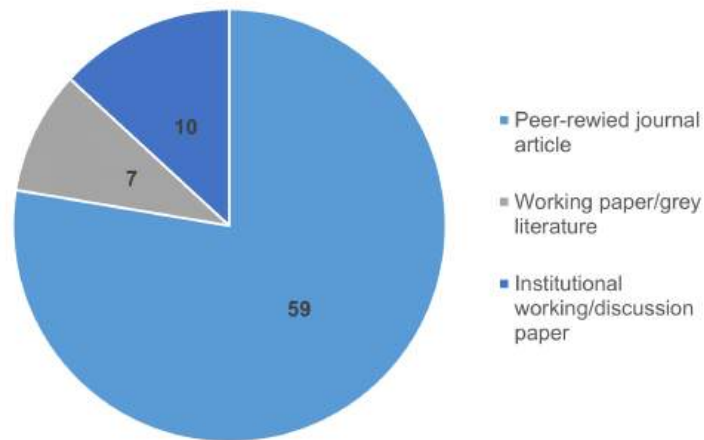


Fig. B.3: Types of articles included in the review

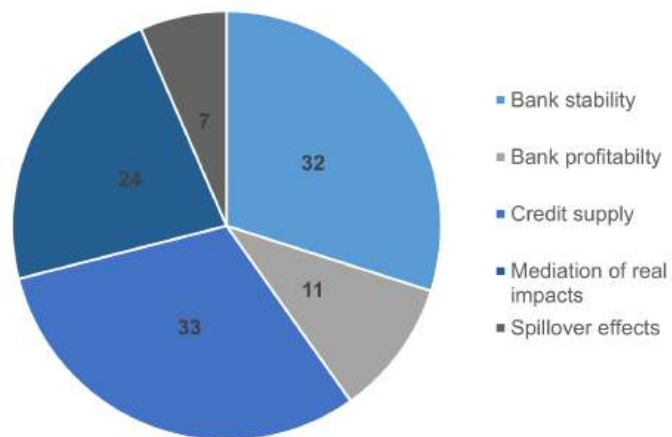


Fig. B.4: Focus of articles included in the review

Table B.1: Classification of included studies

	Study	Journal	Direct effects on banks Stability Profit-ability Credit supply	Medi- ation	Spill- over
1	Kumar and Newport (2005)	Disaster Prevention and Management		x	
2	Gitter and Barham (2007)	World Development		x	
3	Khandker (2007)	Agricultural Economics		x	
4	Toya and Skidmore (2007)	Economics Letters		x	
5	Garmaise and Moskowitz (2009)	Journal of Finance			x
6	Noy (2009)	Journal of Development Economics		x	
7	Shoji (2010)	The Journal of Development Studies		x	
8	Becchetti and Castriota (2011)	World Development		x	
9	David (2011)	Global Economy Journal			x
10	Berg and Schrader (2012)	Journal of Financial Intermediation			x
11	Parvin and Shaw (2012)	Disasters		x	
12	Cortés (2014)	<i>FRB of Cleveland Working Paper</i>		x	
13	Felbermayr and Gröschl (2014)	Journal of Development Economics		x	
14	Klomp (2014)	Journal of Financial Stability	x		
15	McDermott et al. (2014)	Oxford Economic Papers		x	
16	Melecky and Raddatz (2015)	World Bank Economic Review		x	
17	Chavaz (2016)	<i>Bank of England Working Paper</i>			x
18	Hosono et al. (2016)	International Economic Review			x
19	Calis et al. (2017)	Journal of International Development		x	
20	Cortés and Strahan (2017)	Journal of Financial Economics			x
21	Gallagher and Hartley (2017)	American Economic Journal: Economic Policy			
22	Keerthiratne and Tol (2017)	Economics of Disasters and Climate Change			
23	Lensink et al. (2017)	The Review of Income and Wealth		x	

Table B.1 continued from previous page

	Study	Journal	Direct effects on banks			Medi- ation	Spill- over
			Stability	Profit- ability	Credit supply		
24	Klomp (2018)	International Journal of Disaster Risk Reduction	x				
25	Albuquerque and Rajhi (2019)	Research in International Business and Finance	x				
26	Barth et al. (2019)	<i>Not peer-reviewed</i>		x			
27	Brei et al. (2019)	The Quarterly Review of Economics and Finance	x	x	x		
28	Collier and Babich (2019)	The Journal of Risk and Insurance			x		
29	Schüwer et al. (2019)	Review of Finance	x		x	x	
30	Chang and Zhang (2020)	<i>Bulletin of Monetary Economics and Banking</i>	x				
31	Koetter et al. (2020)	Journal of Financial Intermediation	x	x	x		
32	L. Nguyen and Wilson (2020)	The European Journal of Finance			x		
33	Ozsoy et al. (2020)	<i>Not peer-reviewed</i>	x				
34	Zhang and Managi (2020)	Economic Analysis and Policy				x	
35	Bayangos et al. (2021)	Latin American Journal of Central Banking	x	x	x		
36	Brown et al. (2021)	Journal of Finance			x		
37	Calice and Miguel (2021)	<i>World Bank Policy Research Working Paper</i>	x				
38	Chen and Chang (2021)	Natural Hazards	x				
39	Duqi et al. (2021)	Journal of Corporate Finance			x		
40	Horvath (2021)	Journal of Financial Stability			x		
41	Qi et al. (2021)	<i>Not peer-reviewed</i>			x	x	
42	Sseruyange and Klomp (2021)	Sustainability				x	
43	K. Allen et al. (2022)	Journal of Financial Stability			x		
44	L. Allen et al. (2022)	Journal of Financial and Quantitative Analysis			x		
45	Apergis (2022)	Applied Economics Letters	x				
46	Blickle et al. (2022)	<i>FRB of New York Staff Report</i>	x	x	x		
47	Bos and Li (2022)	<i>Not peer-reviewed</i>	x		x		

Table B.1 continued from previous page

	Study	Journal	Direct effects on banks			Medi- ation	Spill- over
			Stability	Profit- ability	Credit supply		
48	Bos et al. (2022)	Economic Modelling			x		
49	Celil et al. (2022)	Journal of Empirical Finance			x	x	
50	Choudhary and Jain (2022)	Journal of Financial Intermediation	x		x		
51	Correa et al. (2022)	<i>BGFRS International Finance Discussion Paper</i>					x
52	Do et al. (2022)	The European Journal of Finance	x	x			
53	Ivanov et al. (2022)	Financial Management			x		x
54	Petkov (2022)	<i>Not peer-reviewed</i>	x		x	x	
55	Rehbein and Ongena (2022)	Journal of Financial and Quantitative Analysis					x
56	Barbaglia et al. (2023)	<i>JRC Working Paper</i>	x		x		
57	Berger et al. (2023)	<i>FRB of Philadelphia Working Paper</i>	x				
58	Chabot and Bertrand (2023)	Journal of Financial Stability	x				
59	Chen et al. (2023)	Economic Systems	x				
60	Das et al. (2023)	<i>Not peer-reviewed</i>			x	x	
61	Gramlich et al. (2023)	International Journal of Central Banking	x				
62	Le et al. (2023)	Journal of Multinational Financial Management	x				
63	D. T. T. Nguyen et al. (2023)	Applied Economics	x	x			
64	Nie et al. (2023)	<i>World Bank Policy Research Working Paper</i>	x				
65	Noth and Schüwer (2023)	Journal of Environmental Economics and Manage- ment	x	x			
66	Peters et al. (2023)	Climatic Change				x	
67	Rajan and Ramcharan (2023)	<i>NBER Working Paper</i>			x	x	
68	Walker et al. (2023)	International Journal of Managerial Finance	x	x			
69	Aguilar-Gomez et al. (2024)	Journal of Development Economics	x				
70	Barth et al. (2024)	<i>Journal of Financial Stability</i>					x

Table B.1 continued from previous page

	Study	Journal	Direct effects on banks			Medi- ation	Spill- over
			Stability	Profit- ability	Credit supply		
71	Brei et al. (2024)	Journal of International Money and Finance	x	x	x		
72	Dlugosz et al. (2024)	Management Science			x		
73	Huesler (2024)	Clometrica	x				
74	Liu et al. (2024)	International Review of Financial Analysis	x				
75	Peters et al. (2024)	<i>Not peer-reviewed</i>			x	x	
76	Shala and Schumacher (2024)	Journal of Climate Finance	x	x			

Articles are sorted according to year of publication. Not independently peer-reviewed papers (grey literature and institutional working papers) in italics. Abbreviations: BGFRS = Board of Governors of the Federal Reserve System, FRB = Federal Reserve Bank, JRC = Joint Research Center of the European Commission, NBER = National Bureau of Economic Research, SAFE = Sustainable Architecture for Finance in Europe (Leibniz Institute for Financial Research).

Table B.2: Variables employed by studies investigating the direct impacts of natural hazard shocks on banks (return to section A.2)

Outcome	Variable	Studies
Bank stability	Equity (ratio)	Bos and Li (2022); Koetter et al. (2020); Walker et al. (2023)
	(Risk-based) Capital ratio / adequacy	Blickle et al. (2022); Brei et al. (2019); Gramlich et al. (2023); Koetter et al. (2020); Schüwer et al. (2019); Walker et al. (2023)
	Z-scores	Blickle et al. (2022); Brei et al. (2019); Chabot and Bertrand (2023); Chen and Chang (2021); Do et al. (2022); Klomp (2014); Koetter et al. (2020); Le et al. (2023); Liu et al. (2024); D. T. T. Nguyen et al. (2023); Noth and Schüwer (2023); Ozsoy et al. (2020)
	Probability of default	Chabot and Bertrand (2023); Noth and Schüwer (2023)
	Non-performing loans (ratio)	Aguilar-Gomez et al. (2024); Apergis (2022); Barbaglia et al. (2023); Bayangos et al. (2021); Brei et al. (2024, 2019); Calice and Miguel (2021); Chen et al. (2023); Choudhary and Jain (2022); Koetter et al. (2020); Le et al. (2023); Nie et al. (2023); Noth and Schüwer (2023); Ozsoy et al. (2020); Petkov (2022); Shala and Schumacher (2024); Walker et al. (2023)
	Liquidity risk measures	Brei et al. (2019); Koetter et al. (2020); Le et al. (2023); D. T. T. Nguyen et al. (2023)
	Deposits (ratio)	Apergis (2022); Brei et al. (2024); Choudhary and Jain (2022); Huesler (2024); D. T. T. Nguyen et al. (2023)
Bank profitability	Interest margin/loan spread	Barth et al. (2019); Do et al. (2022); Koetter et al. (2020); Shala and Schumacher (2024)
	Returns on assets/equity	Barth et al. (2019); Bayangos et al. (2021); Blickle et al. (2022); Brei et al. (2019); Do et al. (2022); Noth and Schüwer (2023); Shala and Schumacher (2024); Walker et al. (2023)
	Net profit growth	Bayangos et al. (2021)
	Net income ratio	Blickle et al. (2022); Walker et al. (2023)
Credit supply	(Aggregate, Log) Bank lending	Blickle et al. (2022); Bos and Li (2022); Bos et al. (2022); Brei et al. (2024, 2019); Choudhary and Jain (2022); Collier and Babich (2019); Das et al. (2023); Duqi et al. (2021); Horvath (2021); Ivanov et al. (2022); Keerthiratne and Tol (2017); Koetter et al. (2020); Petkov (2022); Rajan and Ramcharan (2023)
	Loan growth	K. Allen et al. (2022); Barbaglia et al. (2023); Bayangos et al. (2021); Celil et al. (2022); Chavaz (2016); Cortés (2014); Cortés and Strahan (2017); Dlugosz et al. (2024); Gallagher and Hartley (2017); L. Nguyen and Wilson (2020); Peters et al. (2024); Schüwer et al. (2019)
	Probability of loan origination	Berg and Schrader (2012); Garmaise and Moskowitz (2009); Qi et al. (2021)
	Credit line use and volume	Brown et al. (2021)

Table B.3: Variables employed by studies investigating the mediating role of finance to measure real economic outcomes (return to section A.2)

Outcome	Variable	Studies
Country level	Economic losses	Toya and Skidmore (2007)
	GDP/Income growth	Felbermayr and Gröschl (2014); McDermott et al. (2014); Melecky and Radatz (2015); Noy (2009); Zhang and Managi (2020)
	(Sector-specific)	Sseruyange and Klomp (2021)
	Value added	
Regional/ sub-national level	GDP/Income growth	Celil et al. (2022); Duqi et al. (2021); Peters et al. (2023); Schüwer et al. (2019)
	Employment growth	Cortés (2014); Peters et al. (2024, 2023); Petkov (2022); Qi et al. (2021); Schüwer et al. (2019)
	Firm growth/ survival	Duqi et al. (2021); Rajan and Ramcharan (2023)
	Firm investment/ R&D	Das et al. (2023); Hosono et al. (2016)
	Night lights	Celil et al. (2022); Das et al. (2023)
Household/ borrower level	School attainment	Gitter and Barham (2007)
	Consumption	Calis et al. (2017); Khandker (2007); Parvin and Shaw (2012); Shoji (2010)
	Income/employment	Becchetti and Castriota (2011); Lensink et al. (2017); Parvin and Shaw (2012)

Table B.4: Variables employed by studies investigating the mediating role of finance to measure relevant financial/banking characteristics (return to section A.2)

Level	Mediator	Variable	Studies
Macro level	Financial development	M3/GDP	Toya and Skidmore (2007)
		Private/domestic Credit/GDP	McDermott et al. (2014); Melecky and Raddatz (2015); Noy (2009); Zhang and Managi (2020)
		Stock market capitalization	Noy (2009)
	Financial openness	Chinn-Ito Index	Felbermayr and Gröschl (2014); Noy (2009)
		Edwards (2007) index	Noy (2009)
Micro level	Lender characteristics	Foreign exchange reserves	Noy (2009)
		Local lender deposits/lending	Celil et al. (2022); Cortés (2014); Peters et al. (2024); Petkov (2022); Rajan and Ramcharan (2023)
		Independent bank share	Schüwer et al. (2019)
		Bank capitalization	Schüwer et al. (2019)
	Banking market structure	State-owned bank share	Celil et al. (2022); Peters et al. (2023)
		Bank competition (Lerner Index)	Duqi et al. (2021)
	Microfinance	Pre-event debt levels/leverage	Peters et al. (2023)
		MFI membership	Calis et al. (2017); Lensink et al. (2017); Parvin and Shaw (2012)
		Access to credit/borrowing/MFI	Becchetti and Castriota (2011); Gitter and Barham (2007); Khandker (2007); Sseruyange and Klomp (2021)
		Contingent repayment provision	Shoji (2010)

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