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 loanlevel 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 hazardrelated 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 & Gro¨schl, 2014; Felbermayr, Gro¨schl, 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 donn´ees 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.[2] 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

[2] Large re-insurance companies also provide comprehensive global disaster loss databases (e.g., MunichRe's NatCatSERVICE 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.

severity). Studies of the latter type find that while all types of events generally have negative socioeconomic consequences (Felbermayr & Gro¨schl, 2014), events differ in the nuances of how the adverse consequences unfold (Botzen, Deschenes, & Sanders, 2019). Next to weather-related incidents, such as storms, floods, extreme temperatures, and droughts, this review also includes geological hazards such as earthquakes.[3]

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).[4] 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 & Gro¨schl, 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 differencein-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.[5] 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).

[3] The number of studies using droughts and earthquakes is relatively low, though.

[4] For 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.

[5] The same holds true for choices regarding the estimation of standard errors.

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

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

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-scores[6], 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):

$$Y^{real} = \acute{}_1 D + \acute{}_2 Fin + \acute{}_3 D * Fin + \mu X + \epsilon \quad (2)$$

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

[6] Z-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).

availability of alternative forms of financing.[7] 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 hazards (Barth, Lee, Shen, & Yoon, 2021). Furthermore, the econometric literature on difference-indifferences 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.

[7] In 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).

B Additional Figures and Tables

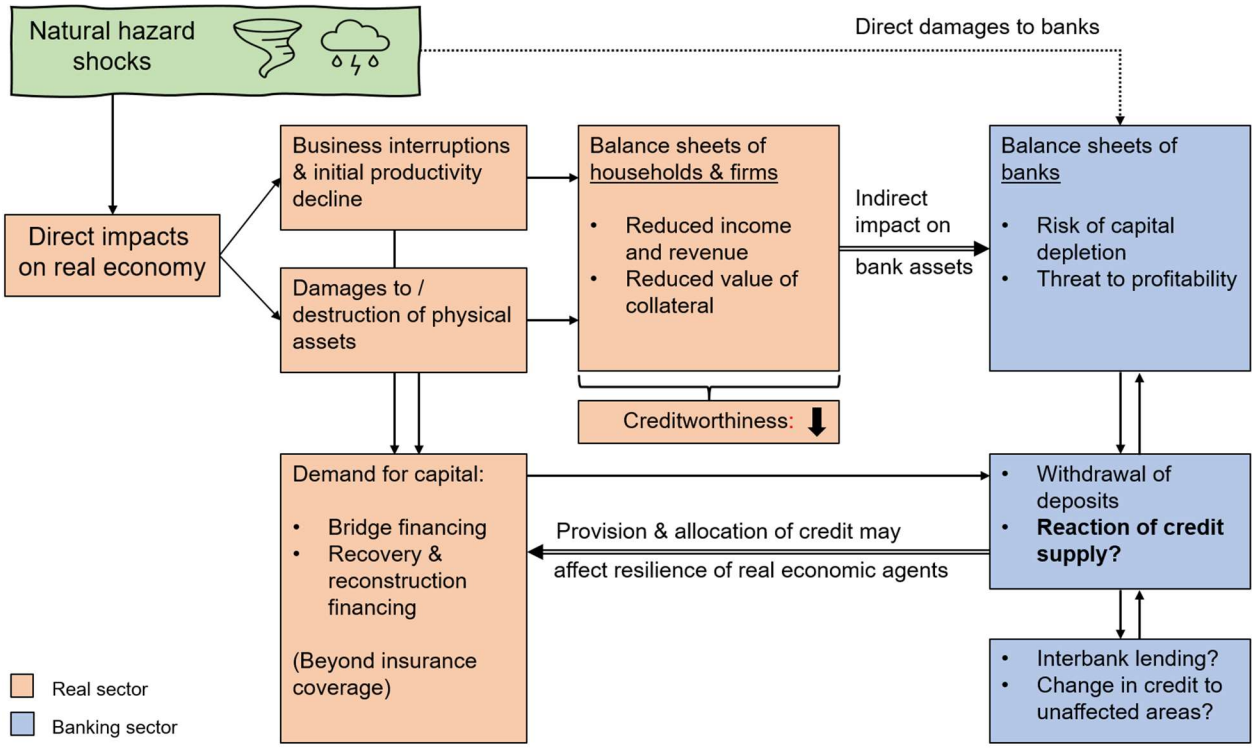

Fig. B.1: Interactions between real and financial sectors in the face of a natural hazard shock. Source: Adapted Figure based on Batten et al. (2016) and Ranger et al. (2022).

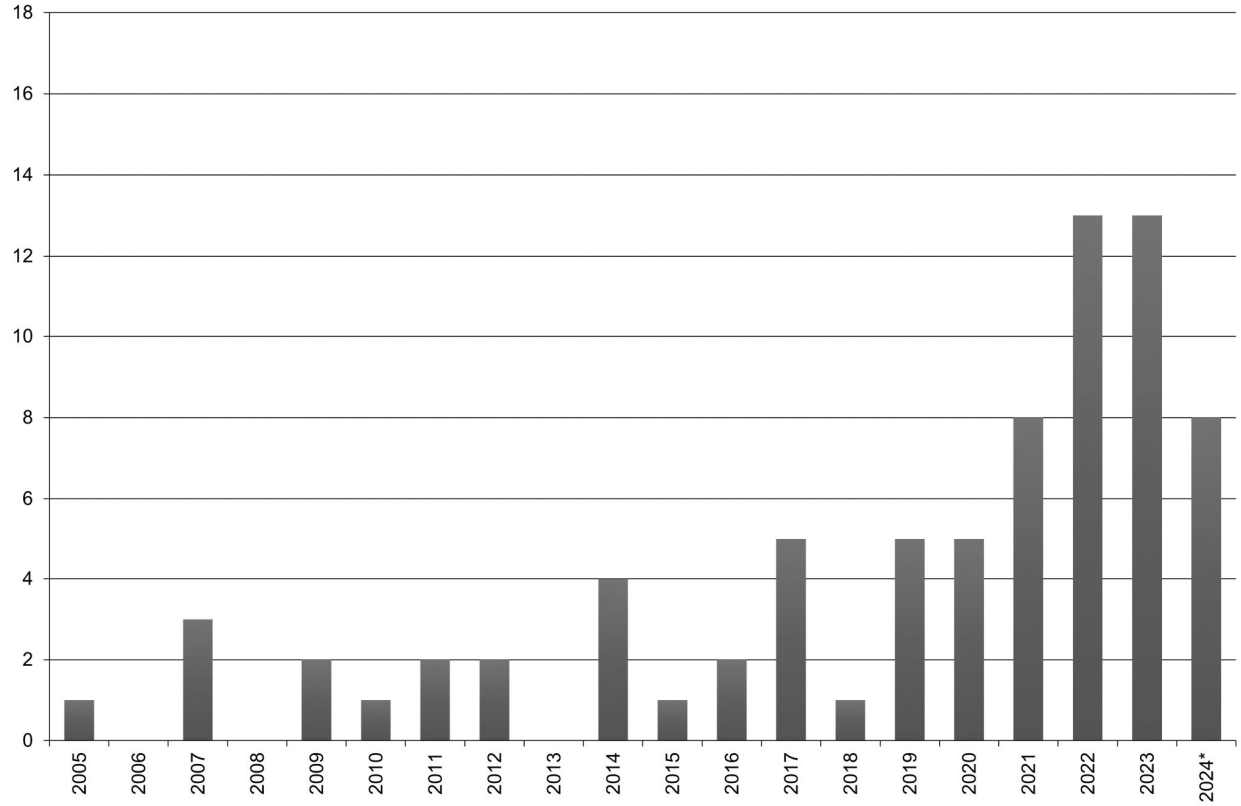

Fig. B.2: Chronology of new articles relevant to the literature, 2005-2024 (*per 31 May 2024)

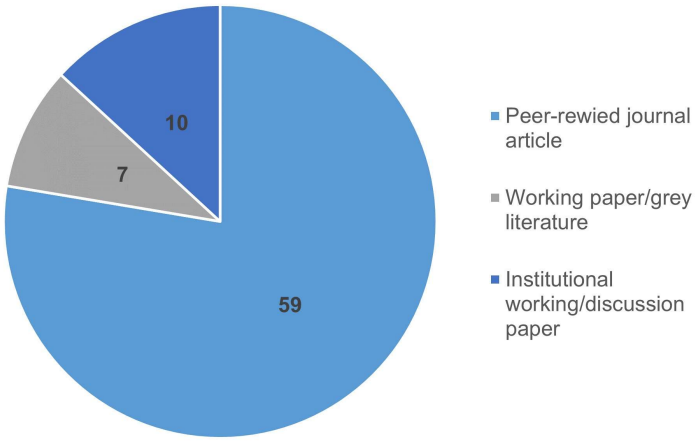

Fig. B.3: Types of articles included in the review

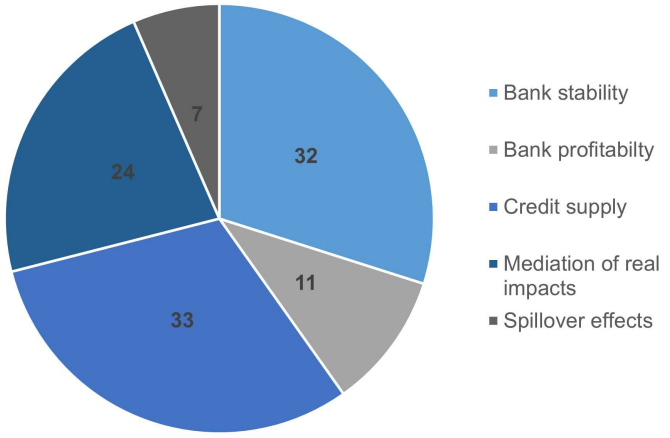

Fig. B.4: Focus of articles included in the review

Table B.1: Classification of included studies

	Study	**Journal**	**ffects on ba**			**Mediation**	**Spillover**
			Stability	Profitability	Credit supply		
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	Cort´es (2014)	*FRB of Cleveland Working Paper*			x	x	
13	Felbermayr and Gro¨schl (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)	*Bank of England Working Paper*			x		x

Table B.1 continued from previous page

18	Hosono et al. (2016)	International Economic Review					x
19	Calis et al. (2017)	Journal of International Development				x	
20	Cort´es and Strahan (2017)	Journal of Financial Economics			x		x
21	Gallagher and Hartley (2017)	American Economic Journal: Economic Policy			x		
22	Keerthiratne and Tol (2017)	Economics of Disasters and Climate Change			x		
23	Lensink et al. (2017)	The Review of Income and Wealth				x	
	Study	**Journal**	**ffects on ba**			**Mediation**	**Spillover**
			Stability	Profitability	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)	*Not peer-reviewed*		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	Schu¨wer et al. (2019)	Review of Finance	x		x	x	
30	Chang and Zhang (2020)	*Bulletin of Monetary Economics and Banking*	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)	*Not peer-reviewed*	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		

Table B.1 continued from previous page

36	Brown et al. (2021)	Journal of Finance			x		
37	Calice and Miguel (2021)	*World Bank Policy Research Working Paper*	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)	*Not peer-reviewed*			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)	*FRB of New York Staff Report*	x	x	x		
47	Bos and Li (2022)	*Not peer-reviewed*	x		x		

Table B.1 continued from previous page

	Study	Journal	ffects on ba			Mediation	Spillover
			Stability	Profitability	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)	*BGFRS International Finance Discussion Paper*					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)	*Not peer-reviewed*	x		x	x	
55	Rehbein and Ongena (2022)	Journal of Financial and Quantitative Analysis					x
56	Barbaglia et al. (2023)	*JRC Working Paper*	x		x		
57	Berger et al. (2023)	*FRB of Philadelphia Working Paper*	x				
58	Chabot and Bertrand (2023)	Journal of Financial Stability	x				
59	Chen et al. (2023)	Economic Systems	x				
60	Das et al. (2023)	*Not peer-reviewed*			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)	*World Bank Policy Research Working Paper*	x				

Table B.1 continued from previous page

65	Noth and Schu¨wer (2023)	Journal of Environmental Economics and Management	x	x			
66	Peters et al. (2023)	Climatic Change				x	
67	Rajan and Ramcharan (2023)	*NBER Working Paper*			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)	*Journal of Financial Stability*					x

Table B.1 continued from previous page

	Study	Journal	ffects on ba			Mediation	Spillover
			Stability	Profitability	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)	Cliometrica	x				
74	Liu et al. (2024)	International Review of Financial Analysis	x				
75	Peters et al. (2024)	*Not peer-reviewed*			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); Schu¨wer 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 Schu¨wer (2023); Ozsoy et al. (2020)
	Probability of default	Chabot and Bertrand (2023); Noth and Schu¨wer (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 Schu¨wer (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 Schu¨wer (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); Cort´es (2014); Cort´es and Strahan (2017); Dlugosz et al. (2024); Gallagher and Hartley (2017); L. Nguyen and Wilson (2020); Peters et al. (2024); Schu¨wer 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 Gr¨oschl (2014); McDermott et al. (2014); Melecky and Raddatz (2015); Noy (2009); Zhang and Managi (2020)
	(Sector-specific) Value added	Sseruyange and Klomp (2021)
	GDP/Income growth	Celil et al. (2022); Duqi et al. (2021); Peters et al. (2023); Schu¨wer et al. (2019)
	Employment growth	Cort´es (2014); Peters et al. (2024, 2023); Petkov (2022); Qi et al. (2021); Schu¨wer et al. (2019)

Regional/ sub-national level	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 Gr¨oschl (2014); Noy (2009)
		Edwards (2007) index	Noy (2009)
		Foreign exchange reserves	Noy (2009)
Micro level	Lender characteristics	Local lender deposits/lending	Celil et al. (2022); Cort´es (2014); Peters et al. (2024); Petkov (2022); Rajan and Ramcharan (2023)
		Independent bank share	Schu¨wer et al. (2019)
		Bank capitalization	Schu¨wer et al. (2019)
		State-owned bank share	Celil et al. (2022); Peters et al. (2023)
	Banking market structure	Bank competition (Lerner Index)	Duqi et al. (2021)
		Pre-event debt levels/leverage	Peters et al. (2023)
	Microfinance	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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