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A Review of the Financial Sector Impacts of Risks Associated with Climate Change

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natural disasters, climate change, banking, insurance, financial markets, financial sector

Abstract

This article reviews the literature on the financial sector impacts of natural disasters and physical climate change risks, covering banking, insurance, stock markets, bond markets, and international financial flows. Most studies have applied statistical approaches to historical data from developed countries to identify these impacts, while some have also used theoretical and computational modeling to assess future risks under climate change scenarios. The findings show that natural disasters and climate change risks generally lower insurer profitability and risk-sharing capacity, bank stability and credit supply, returns and stability of stock and bond markets, foreign direct investment inflows, and international lending. Factors such as income levels, rigorous financial regulations, capital abundance, market diversification, and adaptation strategies mitigate the negative effects. Natural disasters increase remittance inflows and financial assistance to low- and middle-income countries. We recommend future research on forward-looking computational modeling to assess the future financial sector impacts of climate change, while accounting for adaptation actions and their drivers. Future research should also consider hazard correlations and the interactions between

financial industries and regions to more comprehensively assess the economic effects of natural disasters in general and for vulnerable countries in particular.

1. INTRODUCTION

Economic losses from natural disasters have been rising in recent decades and are expected to escalate further due to growth in economic exposure and climate change (Botzen et al. 2019). Mitigating these effects partly depends on how well the financial sector can facilitate adaptation, response, and recovery (Keerthiratne & Tol 2017, Klomp 2014, Noy 2009, Ritchie et al. 2022). First, the financial sector promotes economic growth by channeling scarce capital and savings toward favorable investment projects (Demetriades & Law 2006, Levine 1997, Pagano 1993). Second, financial markets facilitate the trading, hedging, diversification, and pooling of risks (Levine 1997, Pagano 1993). Third, the financial sector helps finance post-disaster recovery and reconstruction (Hallegatte 2014).

However, natural disasters and climate change risks may threaten financial stability and hinder economic development (ECB 2020, 2021; FSB 2020; Grippa et al. 2019). Direct damage of physical assets may increase default risk and volatilities in asset prices, and it may reduce investment returns. Part of the damage is covered by the insurance sector, which already faces rising natural disaster risks (Botzen 2021). Uncertainties in the financial system may discourage investments, reduce risk pooling and diversification, and hamper economic growth (Baker & Bloom 2013, Baker et al. 2020). The increasing frequency and intensity of weather-related disasters due to climate change (IPCC 2021) exacerbate these impacts.

We witness a trend toward incorporating climate-related risks in financial risk management and regulation for financial sector organizations. Examples include voluntary climate-related financial disclosures proposed by the international Task Force on Climate Related Financial Disclosures (TCFD 2017) and the adoption of sustainability disclosure regulation by the European Commission in 2019. Institutions for occupational retirement provision are also obliged to incorporate, document, and assess environmental, social, and governance factors in their risk management systems (Eur. Comm. 2021).

Incorporating climate-related risks into financial risk management and regulation entails understanding how natural disasters impact the financial sector. Therefore, in this article, we synthesize the evidence for these impacts and also review the assessment methodologies.

This literature review has the following scope. First, it focuses on the physical risk of natural disasters and climate change.[1] Second, it includes a broad set of natural disasters, including climate- and weather-related incidents, earthquakes, and volcano eruptions. Third, it covers the main components of the financial sector—banking, insurance, stock markets, and bond markets—and also captures different types of international financial flows.

Supplemental Material >

The remainder of the article is structured as follows. Section 2 presents a framework for the impact channels and final effects of natural disasters and climate change risks on the financial sector. Section 3 reviews the assessment methods and the impacts for, in turn, the insurance and banking sectors, the equity and bond markets, and international financial flows (see tables A1–A5 in the **Supplemental Appendix** for the corresponding studies). Section 4 discusses the applied methods and offers suggestions for future research. Section 5 concludes.

[1] We exclude transition risks associated with the process of adjustment toward a lower-carbon economy, which are reviewed by Monasterolo (2020) and Semieniuk et al. (2021).

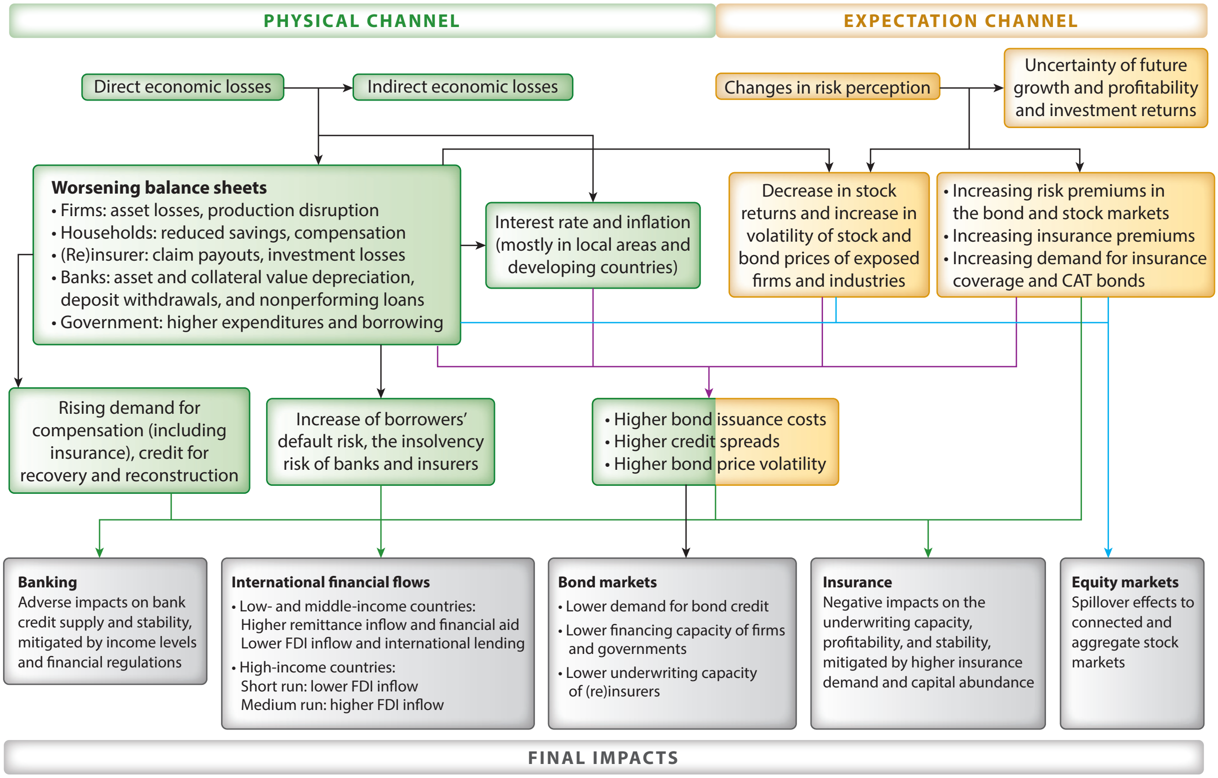

Figure 1

Framework for the main impacts of disasters and climate change risks on the financial sector (banking, international financial flows, bond markets, insurance, and equity markets), divided into a physical and expectation channel. Abbreviations: CAT, catastrophe; FDI, foreign direct investment.

2. A FRAMEWORK FOR THE MAIN FINANCIAL SECTOR IMPACTS

We summarize in **Figure 1** the impact channels and the final impacts of natural disasters and climate change risk on the financial sector. These risks can affect the sector physically and via expectations. Physical factors include the direct and indirect economic impacts of natural hazards. "Expectation" refers to changes in disaster risk perception and uncertainty about future profitability and investment returns caused by a disaster occurrence.

Natural disasters may worsen the balance sheets of households, corporations, financial institutions, and governments. Direct economic losses may lead to production disruption, deposit withdrawals, insurance payouts, investment losses, depreciation of assets and collateral value, increased nonperforming loans and public spending, and decreased tax revenues. These consequences further affect the supply and demand of capital and financial services. For example, the risk diversification capacity of (re)insurers and the lending capacity of banks may be reduced, whereas demand for compensation (including insurance coverage) and credit for recovery and reconstruction may increase. Whether the financial sector can meet the surging demand depends on several factors, including disaster type and intensity, capital abundance, financial regulations (e.g., on own capital and mortgage securitization), and levels of socioeconomic development.

Furthermore, direct economic losses may lower borrowers' credit standing and increase their default risk, hence increasing the insolvency risk of (re)insurers and banks. Also, disaster risks and climate change risks increase the uncertainty of future production and profitability of exposed firms. This uncertainty may reduce the firms' returns and the stability of financial markets. The effects could spill over on aggregate and international stock markets, which depend on market size and the interconnectedness of economies. Climate change risks and the occurrence of severe climate- and weather-related catastrophes may cause insurers and investors to revise upward future disaster risks and demand higher premiums and, hence, lower the risk sharing capacity of financial markets.

Disaster risks also affect international financial flows. After the occurrence of disasters, remittance inflows and international disaster aid increase, whereas foreign direct investment (FDI) inflows and international lending decrease in low- and middle-income countries. By contrast, post-disaster FDI inflows and international lending increase for high-income countries in the medium and long term, despite some setbacks in the immediate aftermath. This positive effect on FDI inflows is observed in the manufacturing, construction, and tourist sectors.

3. THE FINANCIAL SECTOR IMPACTS OF DISASTERS AND CLIMATE CHANGE RISKS

3.1. The Insurance Sector

The insurance industry is generally viewed as the part of the financial sector that is most directly affected by climate change, because various insurance products cover extreme weather losses (Botzen 2021; Mills 2005, 2012). Examples include property insurance that covers damage from floods and windstorms; commercial insurance for business interruption losses from extreme weather events; and agriculture insurance for weather-related impacts, such as droughts.

The spreading of risk by natural disaster insurance fulfills an important function for households and businesses located in disaster-prone areas. Insurance coverage gives peace of mind, and loss compensation also facilitates rebuilding damaged properties, which contributes to economic recovery after a disaster (Botzen 2021, Kousky 2019). A substantial proportion of natural disaster risks are not retained by primary insurers, but are reinsured through reinsurance companies, which further spreads risks geographically and across financial markets (Niehaus 2002, Von Dahlen & Von Peter 2012). Moreover, in various countries, the government plays a role in either reinsuring natural disaster risks or directly offering compensation, so that across different countries, private, public, and mixed public-private insurance systems are available (Hudson et al. 2020). Natural disaster insurance markets are mainly confined to developed countries (Munich Re 2020).

Natural disasters impact the insurance sector in the following ways. If the destroyed physical assets and infrastructure and business interruption losses are insured, (re)insurance companies will need to pay out insurance claims. With large losses, they may need to increase the (re)insurance premium for recapitalization, and in the worst case, they may even become insolvent. Higher premiums may exceed the willingness to pay and become unaffordable for insurance consumers. This may reduce the risk diversification capacity of the (re)insurance market. Moreover, severe natural disasters can devalue and reduce the returns of investment portfolios of (re)insurance companies. On the other hand, disasters may also stimulate more demand for insurance products and hence increase the profits and stock returns of the insurance sector (the so-called gaining from loss hypothesis).

3.1.1. Assessments of insured natural disaster risks. Assessments of natural disaster risks are an important input in decisions that insurance companies make about setting coverage conditions, premium levels, and their financial risk management, such as required reserves and reinsurance coverage. Statistical models of insurance claims following extreme weather events and catastrophe models that simulate damage of hypothetical, but realistic, natural disasters are commonly used for assessing natural disaster risks.

One example of a database of insured natural disaster loss records with global coverage is the NatCatSERVICE database collected by Munich Re. Hoeppe (2016) used this database for statistical trend analysis of loss records since 1980 and found that both the number of natural disasters around the world and the insured losses have increased over time. This trend is attributable to weather-related events, such as storms and floods, from which damages have been mainly increasing due to socioeconomic developments, notably population and economic growth (Hoeppe 2016). Nevertheless, several studies have found that part of the trend in natural disaster losses at the local level may also be caused by climate change (Estrada et al. 2015, Hoeppe 2016). To assess natural disaster risks for their insurance portfolios, insurance companies typically use local historical records of claims following extreme weather events with sufficient observations (Dlugolecki 2008).

Backward-looking statistical approaches for assessing risks may not adequately reflect the continuously changing drivers of risks, such as climate change (Charpentier 2008). Hence, some studies have conducted forward-looking risk assessments using statistical analysis that establishes relationships between insurance claims and natural hazard conditions (e.g., Botzen & Bouwer 2016, Botzen et al. 2010, Pinto et al. 2012). These relationships are then used for extrapolations that assess how risks may change according to future hazard conditions under various climate change scenarios. An exemplary contribution on this is given by Botzen & Bouwer (2016), who estimated statistical relationships between daily insured hailstorm damages to motor vehicles and various precipitation and temperature indicators in the Netherlands. Based on these relationships, they showed that hailstorm damage will increase by up to 33% in 2050 due to climate change (Botzen & Bouwer 2016).

One limitation of statistical methods for assessing natural disaster risks for insurance is that they require sufficient loss records at the local level, which often do not exist for natural disasters with a low probability of occurrence at a particular location. This is why catastrophe models are commonly applied to assess natural hazard risks for insurance (Botzen et al. 2019, Grossi & Kunreuther 2005). These models simulate natural hazard conditions at a particular location with various degrees of severity and occurrence probabilities, such as inundation extents and depths for various potential flood events. The resulting damage is estimated based on the value of exposed properties and their vulnerability, i.e., their susceptibility to damage (e.g., de Moel et al. 2015).

Catastrophe models have also been used in forward-looking risk assessments that simulate risk distributions under hazard conditions in a future climate. They derive resulting damage predictions based on future exposure that is assumed to develop in line with exogenous scenarios of population and economic growth (e.g., IPCC 2012). An important contribution was conducted by Kunreuther et al. (2013), who applied a catastrophe model to estimate how hurricane risk in Florida is expected to develop under climate change and to assess the implications for insurance pricing. Their results showed that total annual insurance premiums were expected to rise to $25 billion by 2020 and to $32 billion in 2040, compared with $13 billion in 1990. An especially noteworthy aspect of this study is that the catastrophe model was also applied to assess risk reduction strategies. This analysis showed that building codes that enhance resilience to wind damage are an effective adaptation strategy for limiting future hurricane risks.

Although some catastrophe model applications for assessing future climate change risks account for adaptation through such simplified scenarios, most other studies assume that vulnerability remains constant (Aerts et al. 2018). Recent developments in this field integrate agent-based models (ABMs) with catastrophe models to account for household and government adaptation decisions that limit the exposure and vulnerability of properties over time in response to changing risks and the occurrence of disasters. Haer et al. (2017, 2019), in an innovative contribution, incorporate interactions and feedbacks between environmental and human systems. In their model, for instance, the occurrence of flood events raises individual risk perceptions that trigger the implementation of adaptation measures, which limit flood damage. They find that neglecting these interactions leads to the overestimation of future flood risk. A remaining challenge with these ABMs is to adequately ground their behavioral rules that determine risk reduction actions in economic and psychological theories, as well as to calibrate and validate these rules based on empirical data (Schrieks et al. 2021).

3.1.2. Equilibrium effects on supply and demand. The supply and demand sides of the insurance sector can be simulated by partial equilibrium models. One primary example is the Dynamic Integrated Flood and Insurance (DIFI) model, which estimates current and future riverine flood risk in the European Union under scenarios of climate change using a catastrophe model approach (Hudson et al. 2020; Tesselaar et al. 2020a,b, 2022). This serves as input for an insurer supply module that estimates flood insurance premiums. It is also used for a consumer module that estimates demand for coverage based on expected utility maximization and affordability of insurance, and household investments in adaptation measures that limit flood risk.

The DIFI model was developed by Hudson et al. (2020), who showed that under a single climate scenario, the average flood insurance premium in the European Union may double between 2015 and 2055. They performed a multi-criteria analysis to evaluate whether it is desirable to implement various reforms of flood insurance markets to cope with climate change. They proposed to introduce public-private flood insurance arrangements, in which the government offers reinsurance that is combined with insurance purchase requirements and financial incentives for consumers to take adaptation measures that limit flood risk.

Tesselaar et al. (2020a) augmented the DIFI model by examining the influence of soft and hard reinsurance markets in which capital is, respectively, abundant or scarce. They showed that premium increases as a result of climate change are especially high in hard reinsurance markets and may materialize in years with many severe natural disasters. Tesselaar et al. (2020b) showed that severe climate change may cause a collapse of insurance in the future in various European regions where premiums become unaffordable. Finally, it appears that the insurance coverage gap due to a lack of demand in the future widens especially in countries with generous government compensation for flood damages, which crowds out demand for private insurance (Tesselaar et al. 2022).

3.1.3. Profitability, underwriting capacity, and stability. Severe natural disasters reduce the profitability, underwriting capacity, and stability of insurers. Most evidence shows that natural disasters reduce profitability. A panel fixed effects analysis finds that the unexpected frequency and large economic losses of natural disasters lowered the profitability of US property/casualty insurance for the period 2008–2012 (Benali & Feki 2017). Hagendorff et al. (2015) found modest wealth losses for insurers in 1996–2010 from major catastrophes. Similar negative effects were found in a cross-country study (Chen & Chang 2021). However, Wang & Kutan (2013) found mixed impacts on profitability (negative in the United States but positive in Japan). They argued that the sharp increase in demand for insurance coverage after natural disasters exceeds the claimed losses in Japan (supporting the gaining from loss hypothesis) but not in the United States. According to Born & Viscusi (2006), the losses and loss ratios of US home insurers increased considerably after floods, storms, fires, and earthquakes between 1984 and 2004, especially for those with low levels of premiums. Moreover, unexpected catastrophes reduced both the total premiums earned and the total number of firms writing insurance coverage, and even caused some exits, whereas remaining insurers typically raised insurance rates to adapt to these catastrophic risks (Born & Viscusi 2006).

Severe natural disasters reduce the underwriting capacity more for home insurance than for commercial insurance in the United States for three reasons (Born & Klimaszewski-Blettner 2013). First, home insurance is less flexible to adjust to risk changes due to regulation. Second, home insurance is less geographically diversified than commercial lines. Third, the insurers of homeowners are more likely to withdraw from a market after an unexpected severe loss event (Born & Klimaszewski-Blettner 2013). Cummins et al. (2002) found that although the property-liability insurance industry could adequately fund an extreme event, such an event would cause numerous insolvencies and severely destabilize US insurance markets.

3.2. The Banking Sector

Banks are critical to the financial system and the economy (Allen et al. 2014). Bank lending to households and businesses is an important driver of economic growth, and its disruption may adversely affect the economy.

Disasters may impact the supply and demand of bank credit, as well as the profitability and stability of banks. Disasters may worsen banks' balance sheets by reducing their asset and collateral values and investment returns. Disasters may weaken the loan processing capacity of banks that experience direct damage to their property, branches, and data centers. Moreover, disaster damage can also lower borrowers' credit standing and increase their default risk. On the other hand, post-disaster recovery and reconstruction may increase the demand for bank credit.

3.2.1. Assessment of the impacts. The most common assessment method for impacts on banks is applying statistical analysis to panel data for disaster-stricken areas at different levels of aggregation (e.g., mortgage, bank, and local) for either one country (e.g., Blickle et al. 2021, Bos et al. 2018, Chavaz 2016, Koetter et al. 2020, Noth & Schüwer 2023, Schüwer et al. 2019) or multiple countries (Chen & Chang 2021, Klomp 2014). Frequently used statistical methods include panel fixed effects, difference-in-differences, and the system generalized method of moments estimator. But the disaster impacts derived from such methods are mostly short-term local effects.

Two studies stand out with their forward-looking assessment of the future impact of climate change. First, Bos et al. (2018) not only identified the effects of natural disasters on banks' asset structures with a difference-in-differences approach but also proposed a dynamic multiple-asset credit rationing model. Their combination of model calibration and simulation is largely absent in the current literature. Researchers can adjust their model and simulate the future impact of climate change on the asset structure and profitability of banks for different countries. However, their model cannot account for adaptation actions and incorporates only the increasing (perceived) probability—but not the increasing intensity—of natural hazards due to climate change.

Lamperti et al. (2019) examined how climate-related damage influences the stability of the banking system by calibrating a global agent-based integrated assessment model. Their calibration results demonstrated the importance of both including the banking sector in the impact assessment and incorporating climate change risks in financial regulation.

A relatively novel approach in the assessment of the impacts of natural disasters on the banking sector is through climate risk stress testing, an approach often applied by central banks (Hallegatte et al. 2022). Stress tests estimate potential consequences experienced by the banking sector under severe but plausible circumstances, where the vulnerability of a financial actor is being assessed (Hallegatte et al. 2022). These stress tests typically look at the profitability, solvency, and liquidity of banks. An important contribution is that of Batten et al. (2016), who assess the impact of climate change and policies on the performance of central banks. They find that natural disasters may trigger macroeconomic and financial instability through damage to the balance sheets of firms, households, banks, and insurers.

3.2.2. Impact on bank stability. Bank stability can be measured by an institution's distance-to-default,[2] likelihood of insolvency, return on assets, and equity-to-assets ratio. Studies show mixed impacts from natural disasters on bank stability. The effects depend on disaster features and other factors such as income level of the country, quality of local infrastructure, government compensation, and financial regulation.

Some findings show that natural disasters reduce bank stability in low- and middle-income countries. Specifically, Klomp (2014) found that especially geophysical and meteorological disasters reduced the distance-to-default of commercial banks in emerging economies (but not in advanced economies). Chen & Chang (2021) also conducted a cross-country panel study and found no direct impact but significant negative moderating effects of natural disasters through financial risk on the banking system, which decrease with higher income levels. Moreover, the model calibration of Lamperti et al. (2019) showed that climate change will increase the frequency of banking crises (by 26–148%) and deteriorate banks' balance sheets.

The studies that zoom in on local areas of a country find mixed effects of hurricanes and floods on bank stability. For example, no excessive risk taking or rent seeking was found in the recovery lending of local banks after the 2003 Elbe flood in Germany, except for shock-exposed banks without access to diversified interbank markets (Koetter et al. 2020). But natural disasters have either no or negative impacts on the stability of US commercial banks. Noth & Schüwer (2023) found that property damages from weather-related events and geological disasters weakened the stability of banks with business activities in affected regions within two to three years, using bank-level damage data between 1994 and 2012. By contrast, Blickle et al. (2021) found that the average US Federal Emergency Management Agency disaster declaration was not detrimental to bank stability for both single-county and multi-county banks using county-level property damage estimates in 1995–2018. Only extreme disasters (90th percentile in terms of damage) had some negative effects on stability, but not on solvency. Finally, Brei et al. (2019) also found no signs of deterioration in loan defaults and bank capital after hurricanes in the Eastern Caribbean islands.

3.2.3. Impact on bank credit supply. Worsening balance sheets and disruption to bank stability may reduce banks' lending capacity, whereas the surging demand for recovery and reconstruction funds may stimulate more bank lending. Overall, the evidence for the impacts of disasters on bank credit supply is mixed.

Some studies find negative impacts of natural disasters on the credit supply of directly exposed banks. Banks in the Eastern Caribbean islands lowered their loan supply in response to deposit withdrawals after hurricanes (Brei et al. 2019). Bank lending in Thailand was reduced up to 22 months after the Indian Ocean tsunami (Nguyen & Wilson 2020). The number of bank branches located in affected regions helped mitigate these adverse effects on credit supply. Hosono et al. (2016) found that firms located outside Kobe earthquake–stricken areas received less credit from their main banks that domiciled in the disaster-stricken areas and experienced direct damages. Model simulations show that climate change risks will reduce bank lending due to worsening balance sheets and an upward revision of (perceived) disaster risks (Bos et al. 2018, Lamperti et al. 2019).

By contrast, other studies find the opposite effect on bank lending. Multi-market banks and local banks with more capital in the United States tend to increase their credit supply after disasters (Blickle et al. 2021, Bos et al. 2018, Chavaz 2016, Cortés & Strahan 2017). Local banks in Germany also increased their corporate recovery lending after the Elbe flood (Koetter et al.

[2]Distance-to-default reflects the number of standard deviations that a bank's return on assets has to drop below its expected value before equity is depleted and the bank is insolvent.

2020). Firms domiciled in flooded counties that were connected to banks in unflooded counties increased borrowing by 16% (Koetter et al. 2020).

3.2.4. Financing for recovery and reconstruction and the role of public support. To understand these mixed impacts on bank lending, we examine the literature for how banks finance recovery lending, and we identify four main channels. The first is to increase sales of liquid loans and low-risk liquid assets such as government securities (Bos et al. 2018, Brei et al. 2019, Ouazad & Kahn 2021, Schüwer et al. 2019). The second is to increase mortgage-backed securitizations (MBSs) (Chavaz 2016). Some banks also reallocate capital toward the market with a high credit demand from unaffected but connected markets (Cortés & Strahan 2017, Ivanov et al. 2020, Koetter et al. 2020). Access to diversified interbank markets also helps for providing recovery lending (Koetter et al. 2020).

These four financing sources suggest the importance of financial development and financial regulation. MBSs are an important avenue for banks in economies with an advanced financial sector to transfer disaster risks to investors, but their role is limited in countries with a low level of financial development (Board Gov. Fed. Reserve Syst. 2021). Also, the positive impacts on recovery lending are mostly observed among banks with high bank capital ratios (Schüwer et al. 2019).

Local banks are important for local economic recovery and growth. They often have more incentives to continue lending to local markets, where their businesses are highly concentrated (Gallagher & Hartley 2017). They may also have better knowledge about local disaster risks and asset values than other diversified banks and hence can more efficiently serve local markets (Berger et al. 2017, Bos et al. 2018, Chavaz 2016, Cortés & Strahan 2017, Koetter et al. 2020, Nguyen & Wilson 2020, Schüwer et al. 2019).

However, public policies to support banks should be carefully designed and implemented. Ouazad & Kahn (2021) showed that commercial banks in the United States adversely select to issue and securitize more mortgages below the conforming loan limit for loan securitization after a natural disaster. Such banks also typically hold less liquidity on their balance sheets and are less likely to have federal deposit insurance. Public capital injections into damaged Japanese banks after the Tohoku earthquake appear to have weakened the natural selection of firms and reduced the productivity of the economy (Uchida et al. 2015).

3.3. The Equity Market

Apart from bank financing, the equity market is another important source for businesses to raise capital by issuing stocks to investors. A well-functioning equity market provides accurate pricing of securities and liquidity for investors, gives signals for the allocation of scarce capital resources, and is positively associated with economic growth (Levine & Zervos 1996). The equity market is particularly important for corporate investment decisions in market-based economies (Fischer & Merton 1984).

Equity markets typically yield higher returns and exhibit excessive price volatility compared with the risk-free interest rate, which cannot be fully explained by the underlying risk aversion of investors. These are the so-called equity premium puzzle and excess volatility puzzle (Mehra & Prescott 1985, 2003).

Asset-pricing models that incorporate the (time-varying) probability of rare economic disasters can explain these puzzles (Barro 2006, Wachter 2013). Rare economic disasters are significant negative consumption shocks. Investors may become more risk averse, increase their perception of future disaster risks, and thus demand higher investment returns for regional risks (Bourdeau-Brien & Kryzanowski 2020). In addition, investors holding assets in disaster-stricken areas may experience losses in equity markets due to depreciation of their assets and payouts to damage claims. Furthermore, production disruption may increase the uncertainty of future profitability of firms (Burke et al. 2015) and, hence, increase the price volatility of their stocks.

3.3.1. Assessing the impacts on stock markets. An event study approach is widely used to assess the impacts of disasters on stock returns and volatility. This methodology rests on the efficient market hypothesis, which is that market prices have incorporated and reflect all value-relevant information. Specifically, this approach compares abnormal returns during and shortly after a disaster with average daily stock market indices for one market or multiple markets, to identify the size and significance of the event on stock returns and volatility.

A regression-based event study approach adds a disaster/intervention dummy to statistical models of abnormal returns or volatility to capture the impact on stock returns and volatility. Generalized autoregressive conditional heteroskedasticity models offer an approach for this (Ferreira & Karali 2015; Lanfear et al. 2019; Lee et al. 2007, 2018; Robinson & Bangwayo-Skeete 2016; Schneider & Troeger 2006; Scholtens & Voorhorst 2013; Seetharam 2017; Wang & Kutan 2013; Worthington 2008), which explicitly model the time-varying and possibly autocorrelated variances of stock returns (Engle 2001). Other statistical models for impact assessment include the autoregressive moving average model (Worthington & Valadkhani 2004), the vector autoregression model (Baker et al. 2020), and the fixed effects model (Chen & Chang 2021).

3.3.2. Impacts on stock market returns and volatility. Natural disasters can have significant effects on stock returns, creating what is known as the wealth effect. The impact of these disasters on stock returns varies, depending on factors such as the characteristics of the disaster, specific stock data used, and assessment methods employed, although some studies have found no wealth, suggesting that financial markets are able to effectively diversify disaster risks. Additionally, natural disasters can also increase stock price volatility, contributing to the risk effect, and these effects can spill over into other markets, leading to contagion effects both domestically and internationally.

3.3.2.1. Wealth effect: stock returns. Disasters may increase or decrease stock returns, which depend on disaster characteristics, on the stock data used (e.g., for specific firms or industries exposed or for the aggregate stock market), and on the assessment method. Wealth effects are also influenced by the macroeconomic resilience and risk diversification capacity of a country.

Some studies find no wealth effects from natural disasters on aggregate stock market returns, and financial markets can diversify disaster risks well (Ferreira & Karali 2015, Wang & Kutan 2013, Worthington 2008). Specifically, Worthington (2008) found no significant effects of storms, floods, wildfires, cyclones, and earthquakes on Australian stock market returns over the period 1980–2003. Similarly, the composite stock markets in the United States and Japan can diversify the impacts on stock returns from earthquakes, tsunamis, cyclones, and volcanic eruptions with well-balanced investment portfolios (Wang & Kutan 2013). Ferreira & Karali (2015) also found no wealth effects of earthquakes on 35 stock markets. They suggested that income levels, trade openness, and earthquake characteristics may have mediated the impact on abnormal stock returns.

On the other hand, significant impacts (mostly negative) from natural disasters on stock returns have also been found. For example, Worthington & Valadkhani (2004) found significant effects from bushfires (positive), cyclones (negative), and earthquakes (first negative but turning positive later). Moreover, Chen & Chang (2021) identified significant negative direct and moderating effects (through financial risk) from natural disasters. Hurricanes caused stock market losses that were much larger than the direct damage in Jamaica but had no spillover effects on stock markets in the Eastern Caribbean and the Bahamas (Robinson & Bangwayo-Skeete 2016). Earthquakes also reduced stock market value by 6–12% in 21 countries in 1973–2011 (Scholtens & Voorhorst 2013). An innovative approach was developed by the Cambridge Centre for Risk Studies (2018), who explored the financial impacts of six hypothetical trillion-dollar natural catastrophes and concluded that all scenarios significantly reduced equity market indices by 6–20%.

Disasters cause abnormal returns for firms and industries that are directly exposed, with the impact lasting from a few days up to three months. The price responses were found to be the strongest for local markets, airlines and hotels (Brounen & Derwall 2010), and insurance companies (Wang & Kutan 2013). Bourdeau-Brien & Kryzanowski (2017) found no impact after the first one to five days but a significant impact two to three months after severe weather events (positive for firms in real estate and telecommunication and negative for firms in the transportation sector). Lanfear et al. (2019) documented strong negative abnormal effects of hurricane landfall on stock returns and illiquidity for microcap,[3] growth and high-momentum (i.e., stocks with the capability to increase rapidly in value), high–return-on-equity (ROE), and low–investment-to-assets (I/A) stocks for the period 1990–2017. However, the impact is less definite on value stocks and on low-momentum, low-ROE, and high-I/A stocks. Only a fraction of the abnormal returns are explained by deterioration in liquidity and/or tail risk. Seetharam (2017) estimated that the stock market valuations of companies exposed to storms are 0.3–0.7 percentage points lower than the returns of nonexposed companies, which translates into about $9 million to $22 million losses in the market valuation of exposed firms between 1980 and 2014. The number of subsidiaries helps mitigate the negative impacts of disaster risks.

3.3.2.2. Risk effect: stock price volatility. Stock market volatility is seen to increase after the occurrence of natural disasters. It is triggered by the uncertainty of the direct and indirect impacts caused by hazards. Natural disasters increase the volatility of the composite stock market in the United States as well as the stock prices of the insurance sector in Japan and the United States (Wang & Kutan 2013). Earthquakes caused risk effects only on the Japanese composite stock market but not on the other 34 stock markets studied by Ferreira & Karali (2015). Moreover, major natural hazards such as hurricanes, floods, winter storms, and episodes of extreme temperatures doubled the volatility of stocks of local firms in disaster areas in the United States, but other types of natural hazards did not (Bourdeau-Brien & Kryzanowski 2017).

3.3.2.3. Spillover effects. There is a contagion effect when the effect of a disaster spreads from one market to another. Ehrmann et al. (2011) identified significant spillover effects in financial markets (i.e., money, bond, and equity markets, and exchange rates) between the United States and the euro area during 1989–2004, particularly for shocks on US financial markets.

Local natural disasters can generate international spillover effects via trade and finance (Dornbusch et al. 2000, Phylaktis & Xia 2009). The Cambridge Centre for Risk Studies (2018) showed a large contagion effect of the hypothetical trillion-dollar natural catastrophes on financial markets, especially for catastrophes occurring in the US stock market spillover effects on neighboring economies and important trading partners have also been found after Hurricane Katrina (Lee et al. 2018), the 2004 Indian Ocean tsunami (Lee et al. 2007, 2018), the 2011 Tohoku earthquake in Japan (Asongu 2012, Lee et al. 2018), and the Sichuan earthquake in China (Lee et al. 2018). The only exception is the work of Ferreira & Karali (2015), who found no spillover effects on financial markets from earthquakes.

3.4. The Bond Market

Bonds are tradable debt financing tools issued by governments (at all levels), institutional investors, mutual funds, and corporations to investors to raise money (ECMI 2020, MAPFRE Econ. Res.

[3]A microcap stock has a small market capitalization of between $50 million and $300 million.

2018). Moreover, (re)insurance companies and state/international catastrophe funds issue catastrophe (CAT) bonds (i.e., insurance-linked securities) to transfer disaster risks to investors in the financial market (Litzenberger et al. 1997, Loubergé et al. 1999). In return, investors receive interest over the life of the bond and receive their principal back upon maturity if payouts to CAT bond issuers are not triggered. If payouts are triggered due to the occurrence of a prespecified event, such as an earthquake or a tornado, the issuers' obligation to pay interest and return the principal is either deferred or completely forgiven.

Investors in the bond market bear three major risks: interest rate risk, inflation risk, and default risk (Weinstein 1981). A rise in interest rates will reduce the demand for older bonds with lower rates of return, causing bond prices in the secondary market to fall. A fall in interest rates will have the opposite effect. Bondholders may have to sell their bonds at a loss. Inflation deteriorates the real returns of bonds. Investors will experience losses if bond issuers default.

Major disasters may affect interest rates, inflation rates, and default risk, especially in disaster-prone areas and developing countries (Cambridge Centre for Risk Studies 2018, Klomp 2020, Parker 2018). Natural disasters may also increase individuals' risk aversion temporarily at the local level (Bourdeau-Brien & Kryzanowski 2020, Cameron & Shah 2015). Hence, investors may demand higher risk premiums for their investments, resulting in higher borrowing costs and lower borrowing capacity of companies and governments.

3.4.1. Assessment of the impact on bond markets. Statistical analysis is the main method used in the literature to estimate the impact of natural disasters on the bond market using primary and secondary bond data. Examples include ordinary least squares, fixed effects, nonparametric quantiles-based method, and panel vector autoregressive regression (Beirne et al. 2021; Fowles et al. 2009; Goldsmith-Pinkham et al. 2022; Gupta et al. 2019; Gürtler et al. 2016; Herrmann & Hibbeln 2021; Huynh & Xia 2020, 2021; Kling et al. 2018; Massa & Zhang 2021; Painter 2020). Another way to quantify the impact on bond markets is by calibrating either a real business cycle (RBC) model that incorporates economic disaster risk (Gourio 2013), a dynamic general equilibrium model for asset pricing (Dieckmann 2010), or sovereign ratings models (Klusak et al. 2021).

It is notable that literature on bond market impacts is predominantly available for advanced economies, and the United States in particular. Accordingly, hurricanes, extreme winds, and earthquakes—common disasters in advanced economies—are the most frequently studied events in terms of their effects on the bond market.

3.4.2. Credit spread and bond price volatility. A credit spread is defined as the difference in yield between a risk-free bond (e.g., a US Treasury Bill) and another debt security of the same maturity but with different credit quality. We can observe large, volatile, and countercyclical credit spreads in bond markets. Such trends can be replicated by RBC models that incorporate a small, exogenously time-varying risk of economic disasters, of which the study of Gourio (2013) is an important contribution. This suggests that natural disasters and climate change risks can in theory increase both the level and volatility of credit spreads. This prediction is corroborated by other studies, reviewed below in Sections 3.4.2.2 and 3.4.2.3.

3.4.2.1. Sovereign bonds. Gupta et al. (2019) tested the theoretical claim that rare disaster risks (i.e., political crises) affect government bond market movements using a nonparametric causality-in-quantiles framework. They found that rare disaster risks affected only the volatility and not the returns of long-term (i.e., 10-year) government bonds in the United States, the United Kingdom, and South Africa. COVID-19-related volatility shocks were found to be more persistent in sovereign bond markets than equity markets, particularly in Italy and Germany (Pagnottoni et al. 2021).

However, climate change risks increase sovereign borrowing costs, which increase with the degree of climate vulnerability (Beirne et al. 2021, Kling et al. 2018). One additional unit increase in climate vulnerability could increase borrowing costs by 1.17% on average (Kling et al. 2018). Klusak et al. (2021) simulated the effect of climate change risks on sovereign credit ratings based on 1,385 annual long-term foreign-currency sovereign ratings for the period 2004–2020 for 108 countries. They found evidence of climate-induced sovereign downgrades as early as 2030. Climate change could increase the annual interest payments on sovereign debt by $22 billion to $33 billion under representative concentration pathway (RCP) 2.6, rising to $137 billion to $205 billion under the highest emission scenario RCP 8.5.

3.4.2.2. Municipal bonds. The studies on municipal bonds are exclusively based on the United States and conclude that municipalities bearing higher disaster risks pay higher borrowing costs, especially after Hurricane Katrina and for long-maturity bonds (Fowles et al. 2009, Goldsmith-Pinkham et al. 2022, Painter 2020).

For example, municipalities in California have paid premiums that are proportional to their assessed underlying earthquake risks since Hurricane Katrina (Fowles et al. 2009). Municipal bond markets began pricing the increased risk of sea level rise exposure projected in 2013, with uncertainty about sea level rise's future impact being the main force driving up the credit spreads (rather than flood-inflicted asset depreciation) (Goldsmith-Pinkham et al. 2022). Finally, an important study in this field is by Painter (2020) who assessed the pricing of climate change risks in a comprehensive dataset of more than 325,000 municipal bond offerings. Painter (2020) finds that countries more exposed to climate change risks pay more in underwriting fees and initial yields to issue long-term municipal bonds (but not short-term municipal bonds) compared with countries unlikely to be affected by climate change.

3.4.2.3. Corporate bonds. Climate vulnerability also increases corporate borrowing costs and credit spreads. Using firm-level panel data for 71 countries over the period 1999–2017, Kling et al. (2021) showed that climate vulnerability restricted access to finance and hence increased the cost of debt. Firms in countries with a greater exposure to climate change risks are financially more constrained and borrow at higher costs. Huynh & Xia (2020) found that bonds issued in periods with more climate change news earn lower future returns, which is consistent with the asset pricing implications of demand for bonds with high potential to hedge against climate change risks. Investors in US corporate bond and stock markets overreact to the occurrence of a disaster by depressing current bond and stock prices, causing future returns to be higher (Huynh & Xia 2021). Firms with a strong environmental profile have lower corporate bond credit spreads, especially in a market where investors are concerned about climate change (Huynh & Xia 2020, 2021).

Natural disasters also affect the bond market directly via the insurance sector. Insurers may need to liquidate their bond holdings to finance claim payouts after a natural catastrophe. This liquidation drives down bond prices, drives up credit spreads, and induces a long-term shift from bond financing to bank-based borrowing as well as a shortening of debt maturities (Massa & Zhang 2021).

3.4.2.4. Catastrophe bonds. Studies for CAT bonds focus on hurricanes in the United States and conclude that severe hurricanes significantly increase CAT bond spreads and premiums. Moreover, CAT bond premiums show a strong seasonal pattern.

First, a model calibration shows that the cost of capital for reinsurance companies increased by 15–20% after Hurricane Katrina and that CAT bonds had higher yield spreads than other equally rated corporate bonds because Hurricane Katrina brought investors closer to their subsistence level and increased investors' perceived disaster risk (Dieckmann 2010). This higher perceived risk after Hurricane Katrina was also found by Gürtler et al. (2016), who examined the impact of Hurricane Katrina and the financial crisis on CAT bond premiums using secondary market data for the period 2002–2012. They showed that the increase in expected losses from natural catastrophes increased both premiums and unaffordability, which reduced the demand for CAT bonds and hence reduced the disaster risk sharing capacity of the financial market.

CAT bond yields exhibit a strong seasonal pattern (Herrmann & Hibbeln 2021). Hurricane seasonality explains about 47% of the fluctuations in such yields, with bond yields being larger at the start of the hurricane season (when storms are more likely to occur) than at the end of the season. The magnitude of the seasonality increases with the expected loss and the approaching maturity of a bond.

3.5. International Financial Flows

International financial flows mainly consist of private capital flows such as FDI, foreign portfolio investment, international lending, and remittances, as well as international financial assistance and aid. FDI and remittances are the two largest sources of international capital flows for low- and middle-income countries (World Bank 2019). Remittance inflows are an important source of external financing and risk sharing against domestic economic shocks for developing countries (Balli & Rana 2015).

Natural disasters are economic shocks and, thus, may affect international financial flows. For example, disasters increase information asymmetries and heighten investors' risk aversion, and hence deter FDI as well as foreign lending and portfolio investment. On the other hand, disasters may stimulate international financial aid and remittances to smooth negative consumption shocks. Post-disaster recovery and reconstruction raise the demand for capital and investment returns, which may stimulate more capital inflow in the longer term.

3.5.1. Assessment of the impact on international financial flows. The evidence for the impact of natural disasters on international financial flows is derived exclusively from statistical analyses, using either cross-country panel data combined with the EM-DAT database (Becerra et al. 2014, Doytch 2019, Ebeke & Combes 2013, Escaleras & Register 2011, Khan et al. 2020, Mohapatra et al. 2012) or panel data for one country (Anuchitworawong & Thampanishvong 2015). Assessment methods used include cross-country fixed effects approaches (Arezki & Brückner 2012, Bettin & Zazzaro 2018, Mohapatra et al. 2012, Yang et al. 2008), dynamic panel data models (David 2011, Doytch 2019, Ebeke & Combes 2013, Khan et al. 2020, Neise et al. 2022), and the event study approach (Becerra et al. 2014).

3.5.2. Low- and middle-income countries. Remittance inflows tend to increase in low-income countries after a natural disaster (Bettin & Zazzaro 2018, David 2011, Yang et al. 2008). This increase can be attributed to a large share of people from low- and middle-income countries living abroad. Remittances seem to function as a substitute for less efficient financial systems for both disaster risk preparedness and post-disaster reconstruction (Bettin & Zazzaro 2018, Ebeke & Combes 2013, Mohapatra et al. 2012). Households in China and India that received remittances from abroad had a higher adaptive capacity to extreme weather events (Banerjee et al. 2019). The risk sharing of remittance inflows increases with a greater diversity of migration destinations and a higher proportion of remittance inflows from distant countries (Balli & Rana 2015). Remittances tend to decrease as a country recovers (Arezki & Brückner 2012), and remittance inflows are still insufficient to fully counteract disaster losses (Ebeke & Combes 2013).

Notably, the risk sharing of remittance inflows is uneven across households. Mainly middle- and high-income households received remittances, suggesting that low-income households are most vulnerable to natural disasters (Le Dé et al. 2015).

Moreover, foreign aid and assistance also tend to increase after a natural disaster in low-income countries (David 2011, Yang et al. 2008), but the increase is moderate, accounting for only about 3% of the estimated economic damage (Becerra et al. 2014). Both the intensity of the event and the country characteristics (e.g., country size, income level, stock of foreign reserves) determine the level of foreign aid (Becerra et al. 2014).

Contrary to remittance inflows and foreign aid, net bank lending and FDI decrease after a disaster has started (David 2011). FDI inflows were seen to decrease in Thailand (Anuchitworawong & Thampanishvong 2015) and in countries that are a part of China's Belt and Road Initiative (Khan et al. 2020). Decreases in private capital flows, therefore, may amplify the negative consequences of disasters in developing countries.

3.5.3. High-income countries. For high-income countries, FDI flows are the main focus, with only one study on international lending that found a positive effect on lending from multilateral institutions (Yang et al. 2008). The impact on FDI flows is influenced by disaster risk, market size, and the studied time horizon and economic sector.

First, the aggregate impact of disasters on FDI inflow is negative in the short term but positive in the medium and long term (Escaleras & Register 2011, Neise et al. 2022). This is because disasters have negative effects on labor stocks, social infrastructure, and physical capital in the short term. Investors also perceive a higher risk after the occurrence of natural disasters and reduce their investments abroad. The more recent the natural disaster, the more it drives down investment decisions. This negative impact can be mitigated by market size (i.e., diversification capacity).

Second, the disaster impact on FDI flows differs across economic sectors. Post-disaster FDI inflow is positive in the manufacturing (Doytch 2019, Neise et al. 2022) and construction sectors involved in the rebuilding process as well as tourism sectors (Neise et al. 2022). The latter effect arises when investors in tourism consider the location advantages of disaster-prone areas (e.g., their unique landscapes) to be more important than disaster risks. There is no significant effect on FDI flows in the creative sector as this sector is flexible and not bound to a specific area (Neise et al. 2022). For other service industries, the effect on FDI tends to be negative for climate (e.g., droughts, wildfires) and hydrological disasters (e.g., floods, landslides) but insignificant for meteorological disasters (e.g., storms, temperature extremes) (Doytch 2019).

4. DISCUSSION AND RECOMMENDATIONS FOR FUTURE RESEARCH

It is noteworthy that most studies of the impacts of natural disasters focus on developed countries with comparatively advanced financial sectors, with only some cross-country studies that include developing countries (e.g., Arezki & Brückner 2012, Beirne et al. 2021, Chen & Chang 2021, David 2011, Khan et al. 2020, Kling et al. 2018, Klomp 2014, Mohapatra et al. 2012, Scholtens & Voorhorst 2013, Yang et al. 2008). By contrast, few studies on this topic zoom in on specific developing countries that are more exposed and vulnerable to risks from natural disasters and the effects of climate change than developed countries (IPCC 2021). One reason for this research gap is the lack of financial and disaster data for these countries.

The limited evidence for developing countries generally shows more severe adverse impacts from these risks on the financial sector than for developed countries, which may include a decrease in local and international bank lending and FDI inflows, higher volatility of stock and bond prices, and higher bond issuance costs and credit spreads. This is mainly due to higher vulnerability, as well as lower levels of socioeconomic development and lower quality of infrastructure (e.g., Anuchitworawong & Thampanishvong 2015, Brei et al. 2019, Nguyen & Wilson 2020, Robinson & Bangwayo-Skeete 2016). Given these findings and the scarcity of literature with this geographical focus, it is especially relevant for future research on climate change risks for the financial sector to broaden the scope to include the developing world.

For assessment methods, the relevant studies on the insurance sector show a good balance of computational modeling (e.g., Hudson et al. 2020; Pinto et al. 2012; Tesselaar et al. 2020a,b) and statistical analyses with a forward-looking risk assessment (e.g., Born & Viscusi 2006, Born & Klimaszewski-Blettner 2013). The forward-looking risk analyses that are commonly applied for the insurance industry are especially important in view of the changing frequency and intensity of extreme weather events under climate change. This makes these approaches exemplary for future research focusing on other financial institutions, such as banks. For the other financial components, the literature for the insurance industry mostly applied statistical methods to historical financial data combined with disaster damage data (e.g., Beirne et al. 2021, Bourdeau-Brien & Kryzanowski 2017, Doytch 2019, Escaleras & Register 2011, Kling et al. 2018, Klomp 2014, Noth & Schüwer 2023). ABMs could offer a new perspective to assessments of climate risks for the insurance market, where the interactions between human and environmental systems are incorporated through adaptation actions in response to changing natural disaster risks; Haer et al. (2017, 2019) provided innovative examples. Moreover, partial equilibrium models offer a comprehensive approach by simulating both supply and demand for the insurance sector in a changing climate (Hudson et al. 2020; Tesselaar et al. 2020a,b).

With rich and credible data, statistical methods can provide a good assessment of the impacts of natural disasters (Kolstad & Moore 2020). But such effects are often local and sector-specific without considering inter-region and inter-sector interactions. Hence, the insights are useful only for specific firms in local regions or sectors. In addition, many statistical models assume a linear disaster impact, whereas climate change is often characterized by nonlinear socioeconomic effects (Arnell et al. 2016, Burke et al. 2015, Carter et al. 2018, Monasterolo 2020). Besides, statistical approaches are not able to fully account for long-term adaptations to climate change (Carter et al. 2018). Moreover, data availability and data quality are often an issue in statistical analyses, particularly for climate-vulnerable developing countries. Finally, bias in the estimated financial impacts remains in cross-country studies that fail to fully control for the large cross-country heterogeneities that may be correlated with disaster measures.

Given the short-term, local, and linear nature of statistical methods as well as the scarcity of financial and disaster data in many countries, computational modeling can compensate for the shortcomings of statistical analysis to some extent. For example, in the absence of detailed local disaster damage data, catastrophe models enable us to assess the potential direct damage of natural disasters (Botzen et al. 2019). Next, recorded or model-inferred damage can be used as an input for climate-macroeconomic models or computable general equilibrium models to assess the widespread economic and financial impacts of natural disasters and climate change risks (Carrera et al. 2015, Pauw et al. 2011). These computational models can take changes in risk perception and adaptation actions into account to better assess the future effects of climate change (e.g., Monasterolo 2020). So far, there are limited studies in theoretical or computational modeling, including catastrophe and partial equilibrium models that assess the impacts of natural disasters and climate change on the insurance industry (e.g., Grossi & Kunreuther 2005; Hudson et al. 2020; Tesselaar et al. 2020a,b). New perspectives have emerged on topics including asset allocation models (Bos et al. 2018), agent-based integrated assessment models (Lamperti et al. 2019), climate risk stress testing (Batten et al. 2016) for the banking sector, asset pricing models for the stock market (Barro 2006, Dieckmann 2010, Wachter 2013), and a RBC model for the bond market (Gourio 2013). Another innovative study was performed by the Cambridge Centre for Risk Studies (2018), who took a forward-looking approach on the equity and bond markets by simulating an in-house portfolio impacts model assessing impacts of hypothetical trillion-dollar natural disasters, which are events that have not happened until this day. Theoretical and computational modeling could play a more prominent role in future research to assess the financial impacts of climate change risks.

However, these models are not without their limitations and need further improvements. For example, some of the assumptions made and parameter values used in climate-macroeconomic models, such as the assumed recovery time after a disaster, have not been firmly grounded in findings and insights from empirical studies (Botzen et al. 2019). Consequently, these regression models are complementary to the climate-macroeconomic models, as they can provide valuable input data to these forward-looking approaches. Moreover, the simulated future impacts using the backward-looking macroeconomic and asset pricing models may be less accurate for climate change risks (e.g., Barro 2006, Dieckmann 2010, Gourio 2013, Wachter 2013). In addition, ABMs that are used to model adaptation actions by agents use ad-hoc behavioral rules, which are often not rooted in economic and behavioral theories (Schrieks et al. 2021).

Furthermore, much evidence for financial sector impacts is derived from single disaster events rather than correlated and compound disasters. Natural hazards are often correlated across space and different types of natural hazards (Hillier et al. 2020, Quinn et al. 2019). For example, storms are often associated with floods and both cause damage, while natural disasters can occur consecutively after each other. Moreover, compound natural catastrophes are likely to occur more often due to climate change (AghaKouchak et al. 2020, IPCC 2021). This implies that the financial impacts of natural hazards assessed in current studies, based on historical data of single hazards, may not be representative for future financial impacts. Examining the impacts of correlated multi-hazard and compound natural disasters is therefore an important avenue for future research.

5. CONCLUSION

This article has reviewed the impacts of a wide range of natural disasters and climate change risks on the main components of the financial sector, including the insurance and banking industries, the equity and bond markets, and international financial flows.

The effects on the financial sector of such extreme events are generally negative, especially for low-income and climate-vulnerable countries. Climate change reinforces the negative disaster impacts. Factors such as income levels, financial development, market size, trade openness, quality of infrastructure, and adaptation strategies help alleviate the adverse effects. Specifically, the underwriting capacity and stability of the insurance sector are negatively affected due to large payouts and losses in investment from severe disasters. Insurance demand may increase when individuals increase their perception of future disaster risk, but it may decrease when insurers raise premiums and when government compensation for uninsured damage is generous.

Natural disasters tend to reduce bank stability and increase the credit supply of banks in developed countries such as the United States and Germany, but they lower credit supply in developing countries such as Thailand and the Eastern Caribbean islands. Local banks are important for local economic recovery, with their strong local business interests and superior knowledge regarding local risks and assets. Therefore, financial regulation and public support that ensure sufficient bank capital and reduce risky lending facilitate economic recovery.

Disasters decrease the returns and stability of the stocks of directly exposed firms and industries. There is some evidence of spillover effects on aggregate and connected international stock markets. Market diversification attenuates the contagion effects on aggregate stock markets, while proximity to exposed areas and high economic interconnectedness can intensify international spillover effects.

Natural disasters tend to increase bond issuance and borrowing costs, as well as price volatility, particularly for bond issuers that are more exposed to natural disaster risks and climate change. Adaptation action can lower both the costs and price fluctuation.

After a natural disaster, low- and middle-income countries often experience an increase in remittance inflows and international financial aid, on the one hand, but a decrease in international lending and FDI inflow, on the other. Remittance inflows and international financial aid can smooth the negative consumption shocks, but only partially.

For high-income countries, natural disasters generally increase FDI inflows in the medium and long term, especially in the manufacturing, construction, and tourism sectors. Natural disasters also stimulate lending from multilateral institutions to these countries.

The evidence of financial impacts summarized above is mainly derived from statistical analyses, with some limited use of theoretical and computational modeling. Future research should focus more on computational modeling to assess the economy-wide effects of natural catastrophes and climate change. This is because modeling can, to some extent, fill the data gap in many low-income and climate-vulnerable countries by simulating natural disaster losses, and it can also incorporate economic interactions between sectors and regions.

The rising risk from climate change is another important reason to call for more effort in computational modeling. The financial sector impacts of historical events may not be representative of future impacts from climate change due to uncertainties in future socioeconomic development and changes in climate policies. Computational modeling can incorporate these uncertainties and changes to obtain a holistic understanding of the future financial impacts of climate change risks. The assessment of climate impacts and their interaction with adaptation behavior allows for a dynamic extension of these models. Finally, the increasing climate risk and the correlation of natural hazards across space, time, and various hazard types call for more research on the financial impact of correlated multi-hazard and compound natural disasters.

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