Lending from the Shadows: Physical Climate Risk and Shadow Bank Mortgage Financing in US Flood Prone Areas

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KEYWORDS

physical climate risk, flood risk, shadow banks, mortgage finance, residential real estate

ABSTRACT

This article aims to investigate the impact of physical climate risk, in particular flood-related property damage on shadow bank mortgage underwriting activity. While existing literature has explored the intersection of physical climate risk and financial markets, the specific impact of shadow banking on mortgage underwriting in flood-prone areas remains underexplored. Using data from the Home Mortgage Disclosure Act (HMDA) and the National Oceanic and Atmospheric Administration (NOAA) from 2010 to 2017, this article analyses shadow banks' lending behaviour in the three states most prone to flood-related property damage: Texas, New Jersey, and Louisiana. The research is particularly timely given that shadow banks currently originate more than 50% of US mortgages by value, and recent estimates indicate that more than $1 trillion worth of private coastal property is at risk from climate change in the US. I find that shadow bank lending, as a proportion of total lending, increases by 5.3%, on aggregate, following a high damage flood event. I believe this is driven by reduced credit supply from depository institutions due to their regulatory constraints and capital requirements, as a result of the Dodd-Frank Act, thus leaving a gap for non-depository institutions to fill. Whilst this paper focuses on Texas, New Jersey, and Louisiana, which in aggregate account for 79.5% of flood-related property damage during the study period, the findings can be applied to the rest of the US with differing orders of magnitude. Overall, this study seeks to contribute to the corpus of literature by examining how shadow bank lending activity changes following a physical climate risk, such as a flood event and how their unique regulatory framework and risk management practices may affect financial stability in flood-exposed areas. These findings have important implications for policymakers concerned with systemic risk, consumer protection, and the resilience of the mortgage market in flood and physical climate risk prone areas more broadly.

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I. **Introduction**

The intersection of finance and climate risk has garnered significant attention in recent years with studies indicating that properties in physical climate risk areas face increasing valuation risks. This emerging body of

research emphasises the need to evaluate how financial institutions, including non-depository financial institutions (also known as shadow banks or NDFIs), are adapting their credit underwriting practices to account for climate risk. The specific impact of shadow bank mortgage underwriting in flood-prone areas, however, remains underexplored and thus presents a critical gap in the literature.

The urgency of this research is underscored by recent developments in both climate science and financial markets. The acceleration of climate change impacts, particularly in coastal areas, has created an unprecedented challenge for the United States (US) housing market, with over $1 trillion in coastal real estate threatened by climate change impacts.[1] This significant exposure, combined with the increasing frequency and severity of climate-related physical events, offers an interesting opportunity to examine how depository and non-depository institutions respond to mortgage underwriting in the presence of physical climate risks.

The role of shadow banks in this context is particularly crucial as they now originate more than 50% of all mortgage issuances in the US,[2] marking a significant shift in the mortgage market landscape since the 2008 financial crisis. NDFIs are increasingly favoured over traditional banks as they are able to offer faster, more flexible mortgage underwriting with little to no regulatory constraints and lower capital requirements. These unique characteristics enable them to serve riskier or non-conforming borrowers that regulated banks often avoid. Therefore, the growing dominance of non-depository institutions in mortgage origination, combined with their unique regulatory framework and risk management practices, raises important questions about the stability of the housing system in the face of increasing climate-related damages and losses.

The interaction between shadow banking practices and physical climate risk presents potentially systemic implications that extend beyond individual property values. As traditional banks are increasingly mandated to incorporate climate risk measures into their lending decisions, the possibility of risk concentration within the unregulated shadow banking sector becomes more pronounced. Whilst climate risk disclosure requirements strengthen the capital adequacy ratio of tradition banks, they create the opportunity for shadow banks to offer more competitive mortgages. This dynamic is particularly concerning given the sector's interconnectedness with the broader financial system and its history of rapid risk transmission, through securitisation, during periods of market stress.

Recent developments, including proposed climate risk disclosure requirements and changes to climate insurance programmes, add another layer of complexity to this research area. The varying responses of shadow banks and traditional banks to these regulatory changes could create new patterns of risk distribution in the mortgage market as shadow banks become more competitive in mortgage underwriting, potentially affecting both financial stability and housing affordability in climate-vulnerable areas. The pertinence of this research is further emphasised by emerging trends in the insurance industry, where major carriers are withdrawing from high-risk areas or significantly increasing premiums.[3] This retreat of traditional insurers creates additional complications for mortgage lending in these regions and raises questions about how lending institutions might adjust their underwriting practices in response. Ultimately this may lead to a change in property values and climate gentrification. The latter is a climate-driven change in neighbourhood desirability which may result

[1] "Impacts, Risks, and Adaptation in the United States." *Fourth National Climate Assessment*, vol. 2, US Global Change Research Program, 2018.
[2] Kim, You Suk, et al. "Non-Banks and Mortgage Securitization." *Annual Review of Financial Economics*, vol. 14, no. 1, 2022, pp. 137-166.
[3] Flavelle, Christopher, and Mira Rojanasakul. "The Home Insurance Crunch: See What's Happening in Your State." *The New York Times*, 13 May 2024.

in the displacement of lower-income households as higher-income households seek to move to climate-resilient areas. This has already been observed in Liberty City, Florida.[4] The potential for shadow banks to fill lending gaps in areas from which traditional banks are retreating, possibly without fully pricing in climate risks, represents a critical area for investigation.

Numerous academics and organisations, such as the Bank of England, the United Nations Environment Programme Finance Initiative, and the Dutch National Bank[5] have attempted to measure the financial risks originating from climate change. In general, climate change poses two primary risks to the financial system: transitional and physical risks. This article will solely focus on the impact of physical risks and therefore not discuss transitional risks.

Physical risks are the threats caused by the increase in extreme weather events such as floods, droughts, wildfires, storms, hurricanes. Due to the complexity and unpredictability of natural events, identifying physical risks is challenging and relies on a great deal of human expertise. Whilst a plethora of physical climate risks affect the US real estate market, floods are the single largest contributor of climate-related property damage. The most recent flash floods in Texas resulted in more than 130 people dead and caused an estimated $18–20 billion in damage, emphasising the catastrophic nature of flood events.[6] For this reason, this study focuses on flood risk in the top three states by flood-related property damage from 2010 to 2017. For context, flood-related property damages account for 79.5% of all property damage during the study period.

For simplicity of argument in this article, it is assumed that climate change is the increase in frequency of natural disaster events.

II. **Literature Review**

This Section will provide an overview of the existing literature by dividing it into three subsections covering: (i) an overview shadow banks, (ii) climate risk in real estate, and (iii) regulation and socio-economic impacts.

A. *An Overview of Shadow Banks*

The term "shadow banking" was first coined by McCulley[7] to describe financial intermediaries operating outside the traditional banking regulations while performing bank-like functions. According to the Financial Stability Board,[8] shadow banking encompasses entities involved in credit intermediation and activities outside the regular banking system. This definition highlights the parallel financial system that has evolved alongside traditional banking, often with less regulatory oversight and transparency. In a similar manner, Claessens & Ratnovski[9] describe shadow banking as "all financial activities, except traditional banking, which require a private or public backstop to operate". This highlights shadow banks' implicit reliance on traditional banking institutions or government guarantees during periods of financial stress, creating a degree of interconnectedness that may amplify systemic risk. In turn, this interconnectedness creates complex risk transmission channels that are difficult for regulators to monitor and control, and for investors to comprehend and price appropriately.

Whilst the concept of shadow banking may appear new, its roots trace back to the 1970s

[4] Contreras, Joseph. "How a Black Miami Neighborhood Became 'Ground Zero for Climate Gentrification'." *The Guardian*, 29 Jan. 2024.

[5] Scott, Matthew, et al. "The Bank's Response to Climate Change." *BoE Quarterly Bulletin,* 2017; "Transition-Related Risks & Opportunities." *Extending Our Horizons,* UNEP FI, 2018; "Physical Risk & Opportunities." *Navigating a New Climate*, UNEP FI, 2018; Vermeulen, Robert, et al. "The Heat Is On: A Framework Measuring Financial Stress Under Disruptive Energy Transition Scenarios." DNB Working Paper No. 625, 2019.

[6] Kaufman, Leslie, and Isabela Fleischmann. "Why Texas Is So Vulnerable to Climate Disasters." *Bloomberg*, 14 Jul. 2025.

[7] McCulley, Paul. "The Shadow Banking System and Hyman Minsky's Economic Journey." *PIMCO Global Central Bank Focus*, May 2009.

[8] "Shadow Banking: Scoping the Issues." *Financial Stability Board,* 2011.

[9] Claessens, Stijn, and Lev Ratnovski. "What is Shadow Banking?" IMF Working Paper WP/14/25, 2015 at p. 5.

with the emergence of money market mutual funds, which offered deposit-like services without being subject to the same regulations as traditional banks.[10] Over time, the sector expanded to include various entities such as hedge funds, investment banks, and private non-depository lenders. The growth of shadow banks was fuelled by financial innovation, regulatory arbitrage, and investors moving up the risk curve in pursuit of higher risk-adjusted returns. This growth in unregulated financial institutions played a significant role in the build up to the Global Financial Crisis (GFC), as shadow banking entities were increasingly involved in the origination and distribution of complex mortgage-backed securities.[11] The GFC exposed the systemic risks posed by the lack of transparency and regulation in this sector, leading to calls for increased oversight. In response, regulatory bodies such as the Financial Stability Board (FSB) have initiated efforts to monitor and regulate shadow banking activities. For the context of this paper, the use of shadow banks only makes reference to non-depository institutions providing mortgage financing.

Given the significance of shadow banks within the global financial system, their role has been researched extensively, particularly in the context of credit intermediation and financial stability. Pozsar et al.[12] find that shadow banks contribute significantly to the credit supply by engaging in maturity transformation and risk transfer activities. This sector's growth and systemic importance first became evident during the GFC, emphasising the need for a deeper understanding of their operations and impacts.[13]

A critical analysis of shadow banking, however, reveals its dual nature in financial markets. While Gorton & Metrick[14] imply that shadow banks provide essential liquidity and credit to markets that might otherwise be underserved, their reliance on the repo market increases systemic risk. This is supported by Acharya et al.[15] who emphasise that the lack of regulatory oversight creates systemic vulnerabilities which arise from maturity mismatches, leverage, and regulatory arbitrage opportunities that shadow banks exploit. The exponential growth of shadow banking assets, $70.2 trillion globally in 2024,[16] further underpins the sector's significance and potential impact on financial stability.

The rise in shadow banking is partially driven by the originate-to-distribute model that defines much of shadow bank lending. The originate-to-distribute model structurally reduces incentives for long-term risk assessment and enables origination activity up the risk curve. Unlike depository institutions that must manage asset-liability mismatches and retain exposure to credit risk over time, shadow banks generally seek to originate and sell loans within 12 months, often with little intention of maintaining servicing rights. As a result, they are less incentivised to evaluate or respond to slow-onset risks such as floodplain expansion, extreme weather intensification, or shifting regulatory frameworks. This issue is further compounded by the lack of environmental covenants or physical risk factors in the standard underwriting process. Loan origination, even in high-risk areas, therefore, can proceed without penalising terms or higher capital charges.

[10] Gorton, Gary, and Andrew Metrick. "Regulating the Shadow Banking System." *Brookings Papers on Economic Activity*, 2010, pp. 261-312; Luttrell, David, et al. "Understanding the Risks Inherent in Shadow Banking: A Primer and Practical Lessons Learned." *Federal Reserve Bank of Dallas: Staff Papers*, no. 18, 2012.

[11] *The Financial Crisis Inquiry Report: Final Report of the National Commission on the Causes of the Financial and Economic Crisis in the United States*. Financial Crisis Inquiry Commission, 2011.

[12] Pozsar, Zoltan, et al. "Shadow Banking." *Federal Reserve Bank of New York: Staff Reports*, no. 458, 2010.

[13] Adrian, Tobias, and Adam Ashcraft. "Shadow Banking Regulation." *Annual Review of Financial Economics*, vol. 4, no. 1, 2012, pp. 99-140.

[14] Gorton, Gary, and Andrew Metrick. "Securitized Banking and the Run on Repo." *Journal of Financial Economics*, vol. 104, no. 3, 2012, pp. 425-451.

[15] Acharya, Viral, et al. "Securitization Without Risk Transfer." *Journal of Financial Economics*, vol. 107, no. 3, 2013, pp. 515-536.

[16] *Global Monitoring Report on Non-Bank Financial Intermediation 2024*. Financial Stability Board, 2024.

Post-GFC literature has revisited shadow banking as a persistent and evolving feature of global finance. Adrian & Ashcraft[17] argue that despite regulatory reforms aimed at strengthening depository and non-depository institutions, the shadow banking sector is able to exploit regulatory arbitrage opportunities thereby making uneven progress in achieving a more stable shadow banking system. However, it is also demonstrate that regulations designed to enhance stability may also incentivise risk to migrate into less regulated spaces such as shadow banking whilst significantly and silently increasing the concentration of systemic risk in the financial sector.[18] Given their lack of balance sheet lending, shadow banks are able to create and exploit neglected tail risk by generating a facade of safety by pooling together seemingly uncorrelated and diversified assets and originating low risk securities through securitisation.[19] When these tail events are triggered, however, these apparently diversified pool of assets can experience significant losses of potentially systemic nature, making the financial system vulnerable to low probability, high impact events such as those linked to climate change. Similarly, Plantin[20] cautions that the migration to shadow banking may lead to structural opacity and delayed risk recognition, which I argue may be magnified in areas involving long-term environmental exposure.

This interaction is particularly visible in the US mortgage market where, in the aftermath of the GFC, non-bank mortgage lenders have captured a growing share of the market by dollar value. By 2017, shadow banks were responsible for 50% of mortgage originations in the US[21] and have increased further to approximately 60% in 2020.[22] This shift is not only attributed to efficiency gains but also to differences in regulatory oversight. Unlike traditional banks, shadow banks face limited capital requirements and no liquidity coverage mandates. In particular, Buchak et al.[23] find that fintech shadow banks increased their market share in residential mortgage origination to 12% from 3% between 2007 and 2015, with shadow banks overall increasing their share to 50% from 30% during the same period. These features have implications for climate-exposed real estate markets, where flood risk, sea-level rise, and storm intensity increasingly shape default probabilities but remain difficult to integrate into standard underwriting and securitisation models. Building on this, Fuster et al.[24] find that fintech lenders process mortgage applications faster, than traditional banks, and are more responsive to exogenous mortgage demand fluctuations. I argue that while technological advancements could enable better identification and pricing of climate risks, automated underwriting may fail to fully incorporate complex climate risk factors that rely on expert judgement.

While traditional banks are increasingly subject to climate stress testing, shadow banks remain largely outside the scope of supervisory guidance. This creates a regulatory blind spot, especially as shadow banks' asset share has increased to almost half of global financial assets, compared to approximately 40% in 2008.[25] Climate credit risk, unlike conventional credit risk, is characterised by long time horizons, spatial asymmetry, inconsistent data quality, and model uncertainty. These features make it particularly prone to mispricing, especially in markets dominated by institutions that do not

[17] Adrian & Ashcraft (n 13) *supra*.
[18] Acharya et al. (n 15) *supra*.
[19] Gennaioli, Nicola, et al. "A Model of Shadow Banking." *The Journal of Finance*, vol. 68, no. 4, 2013, pp. 1331-1363.
[20] Plantin, Guillaume. "Shadow Banking and Bank Capital Regulation." *The Review of Financial Studies*, vol. 28, no. 1, 2015, pp. 146-175.
[21] Buchak, Greg, et al. "Fintech, Regulatory Arbitrage, and the Rise of Shadow Banks." *Journal of Financial Economics*, vol. 130, no. 3, 2018, pp. 453-483.
[22] Kim et al. (n 2) *supra*.
[23] Buchak et al. (n 21) *supra*.
[24] Fuster, Andreas, et al. "The Role of Technology in Mortgage Lending." *The Review of Financial Studies*, vol. 32, no. 5, 2019, pp. 1854-1899.
[25] "Holistic Review of the March Market Turmoil." *Financial Stability Board*, 2020.

retain loan exposure and lack incentives to assess long-term vulnerabilities.

B. *Physical Climate Risk in Real Estate*

In the last decade, the crossover of finance and climate risk has generated substantial theoretical and empirical work. Physical climate risk, such as sea-level rise (SLR), inland flooding, and extreme weather events, is increasingly recognised as material to asset prices, mortgage default risk, loss given default, and broader institutional lending decisions. The acceleration of climate change impacts, particularly in coastal areas, has created an unprecedented challenge for the US housing market, and over $1 trillion in coastal real estate is now threatened by climate change impacts.[26] This significant exposure, combined with the increasing frequency and severity of climate events, presents an interesting opportunity to examine how different types of financial institutions respond to and price climate risk.

Financial markets are beginning to price in some climate-related risks, but unevenly and often with a focus on transition risk rather than physical risk. In general, results from studies assessing how physical climate risks are being priced into real estate and mortgages are mixed. For example, Bin & Landry[27] find that property values in flood-exposed areas tend to decline immediately after major storm events but gradually recover over time, suggesting that market memory is relatively short and incentives to relocate or mitigate exposure remain weak. Ortega & Taşpınar,[28] on the other hand, present a more nuanced view noting that while some prices recover post-disaster, the trajectory is often partial and uneven. Outside of price recovery, Bernstein et al.[29] demonstrate that homes in coastal areas exposed to SLR trade at a discount only in markets where buyers are informed and express a degree of worry towards global warming. Baldauf et al.[30] add nuance to this by showing that property overvaluation is most acute in regions where climate scepticism is prevalent. These findings suggest that market efficiency in pricing physical climate risk is highly uneven, shaped not just by information availability, but also by human behaviour and cultural beliefs. This is especially problematic given the uneven geography of climate exposure and is echoed by Bakkensen & Barrage[31] who also find significant heterogeneity in risk capitalisation based on local climate risk perceptions and expectations. Additionally, Bakkensen & Mendelsohn[32] use a global panel of tropical cyclone events to document that wealthier, denser regions show a higher degree of climate adaptation. This results in lower relative losses for wealthy areas compared to less wealthy and populated areas. They find no evidence of adaption to damage in the US thus resulting in a damage function that is 14 times greater than other developed countries. I believe that this lack of adaptation is partly driven by climate scepticism, as argued by Baldauf et al.[33] On the contrary, Giglio et al.[34] find evidence that climate risks are increasingly capitalised into asset prices; however, significant mispricing persists, particularly in the long end of the risk curve.

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[26] US Global Change Research Program (n 1) *supra*.

[27] Bin, Okmyung, and Craig Landry. "Changes in Implicit Flood Risk Premiums: Empirical Evidence From the Housing Market." *Journal of Environmental Economics and Management*, vol. 65, no. 3, 2013, pp. 361-376.

[28] Ortega, Francesc, and Süleyman Taşpınar. "Rising Sea Levels and Sinking Property Values: Hurricane Sandy and New York's Housing Market." *Journal of Urban Economics*, vol. 106, 2018, pp. 81-100.

[29] Bernstein, Asaf, et al. "Disaster on the Horizon: The Price Effect of Sea Level Rise." *Journal of Financial Economics*, vol. 134, no. 2, 2019, pp. 253-272.

[30] Baldauf, Markus, et al. "Does Climate Change Affect Real Estate Prices? Only If You Believe in It." *The Review of Financial Studies*, vol. 33, no. 3, 2020, pp. 1256-1295.

[31] Bakkensen, Laura, and Lint Barrage. "Going Underwater? Flood Risk Belief Heterogeneity and Coastal Home Price Dynamics." *The Review of Financial Studies*, vol. 35, no. 8, 2022, pp. 3666-3709.

[32] Bakkensen, Laura, and Robert Mendelsohn. "Risk and Adaptation: Evidence from Global Hurricane Damages and Fatalities." *Journal of the Association of Environmental and Resource Economists*, vol. 3, no. 3, 2016, pp. 555-587.

[33] Baldauf et al. (n 30) *supra*.

[34] Giglio, Stefano, et al. "Climate Change and Long-Run Discount Rates: Evidence from Real Estate." *The Review of Financial Studies*, vol. 34, no. 8, 2021, pp. 3527-3571.

This is primarily true in areas which have faced significant damages, thereby indicating a learning mechanism. All these findings, however, suggest that climate risk is not fully priced into property values to begin with.

Additionally, there is a degree of inconsistency in the findings with regards to lending activity, across both depository and non-depository institutions, following physical climate events. Keys & Mulder[35] observe that mortgage lenders in Florida did not materially change their origination or securitisation patterns despite repeated storm events. Their findings suggest that underwriting practices and securitisation pipelines remain relatively insensitive to physical climate risk, even when historical events suggest long-term threats. They conclude that this is likely a result of prospective buyers being more pessimistic about climate change risk than prospective sellers. In a similar manner, Brei et al.[36] examine the impact of hurricanes on the banking sector in the Caribbean and find that banks respond to funding shocks by reducing lending and drawing on liquid assets rather than expanding credit. This implies that post-disaster recovery is primarily financed through deposits, rather than through an increase in credit availability.

Conversely, other studies highlight more dynamic responses. Cortés & Strahan, Rehbein & Ongena, and Ivanov et al.[37] find that credit is often reallocated after disasters, with banks reducing lending in unaffected areas to meet new demand in impacted areas. These flows are usually rationalised as post-crisis reconstruction support, but they also reflect underlying assumptions about temporary dislocation rather than permanent loss.

In an effort to further understand if flood risk is capitalised into house prices, numerous academics have used the FEMA flood zones as a basis for their research. The literature suggests that house prices inaccurately reflect underlying flood risk with Hino & Burke[38] concluding that house prices in FEMA flood zones are overvalued by $33–56 billion. A more recent study by Gourevitch et al.[39] finds that US housing is overvalued by $121–237 billion due to unpriced flood risk. The latter study also highlights that overvalued properties are particularly common in coastal areas just outside the official FEMA flood zones. Whilst Sastry[40] analyses credit rationing following flood map changes in Florida, they find that mortgage lenders transfer flood risk to the government through flood insurance contracts, and to under-insured households through higher deposit requirements. They conclude that lenders screen for flood risk when they retain exposure to the loan and thereby have a significant impact on household financial health. In a similar manner, Blickle & Santos[41] find that banks are less likely to lend to low-income and low-FICO borrowers following map changes as a result of the added financial burden of insurance. More recently, Blickle et al.[42] find that lenders are unwilling to

[35] Keys, Benjamin, and Philip Mulder. "Neglected No More: Housing Markets, Mortgage Lending, and Sea Level Rise." *National Bureau of Economic Research*, 2020.
[36] Brei, Michael, et al. "The Impact of Natural Disasters on the Banking Sector: Evidence From Hurricane Strikes in the Caribbean." *The Quarterly Review of Economics and Finance*, vol. 72, 2019, pp. 232-239.
[37] Cortés, Kristle, and Philip Strahan. "Tracing Out Capital Flows: How Financially Integrated Banks Respond to Natural Disasters." *Journal of Financial Economics*, vol. 125, no. 1, 2017, pp. 182-199; Rehbein, Oliver, and Steven Ongena. "Flooded Through the Back Door: The Role of Bank Capital in Local Shock Spillovers." *Journal of Financial and Quantitative Analysis,* vol. 57, no. 7, 2022, pp. 2627-2658; Ivanov, Ivan, et al. "Bank Lending Networks and the Propagation of Natural Disasters." *Financial Management*, vol. 51, no. 3, 2022, pp. 903-927.
[38] Hino, Miyuki, and Marshall Burke. "The Effect of Information About Climate Risk on Property Values." *Proceedings of the National Academy of Sciences*, vol. 118, no. 17, 2021.
[39] Gourevitch, Jesse, et al. "Unpriced Climate Risk and the Potential Consequences of Overvaluation in US Housing Markets." *Nature Climate Change*, vol. 13, no. 3, 2023, pp. 250-257.
[40] Sastry, Parinitha. "Who Bears Flood Risk? Evidence from Mortgage Markets in Florida." Columbia Business School Working Paper, 2024.
[41] Blickle, Kristian, and Joao Santos. "Unintended Consequences of "Mandatory" Flood Insurance." *Federal Reserve Bank of New York: Staff Reports*, 2022.
[42] Blickle, Kristian, et al. "Do Mortgage Lenders Respond to Flood Risk?" *Federal Reserve Bank of New York: Staff Reports,* 2024.

originate mortgages that face unmapped flood risk and that shadow banks are more likely to securitise mortgages in flood prone areas.

Part of this inability to accurately price flood risk stems from limitations in flood risk data and insurance underwriting capabilities. The National Flood Insurance Program (NFIP), which underpins most US residential flood insurance, has long relied on outdated maps and subsidised pricing. FEMA's Risk Rating 2.0 reform which was introduced in 2021, after a one-year delay due to poor uptake and teething problems, aims to resolve this by aligning insurance premiums more closely with actual climate risk.[43] That being said, substantial backlash was initially faced as increased premiums based on risk could disproportionately affect low-income households in climate-prone areas,[44] in line with the findings of Blickle & Santos.[45] Private flood insurance markets are thin, fragmented, and often unaffordable. As a result, property-level flood risk remains poorly reflected through insurance pricing, limiting its role in mortgage underwriting or homebuyer decision-making.

For lenders, this creates a distorted risk environment in which loans can be originated on overvalued and underinsured properties without triggering red flags in conventional credit underwriting models. Interestingly, Keenan & Bradt[46] conclude that local lenders are more likely to transfer risk from mortgages in high-risk coastal areas through securitisation, signifying a level of information asymmetry between local lenders and national or global lenders. Their analysis of mortgage origination and securitisation in coastal communities reveals that lending practices shift in response to perceived climate risk, thereby accelerating socio-economic changes in vulnerable communities. The continuation of such lending practices may disproportionately affect climate-vulnerable populations resulting in reduced access to credit and affordable housing and ultimately leading to climate gentrification.[47]

The potential mispricing of real estate has significant implications for household wealth given that real estate is usually the largest component of a household's investment portfolio, and by far the largest component of a household's debt profile.[48] If physical climate risk is not fully priced into house values, and shadow banks underwrite non-conforming mortgages in the absence of traditional banks, this may lead to residential mortgage-backed security investors holding overvalued collateral and underpriced credit risk. These circumstances could result in conditions that may contribute to financial instability in the wake of climate shocks. Therefore, the growing role of shadow banks in financing climate exposed real estate raises concerns about financial stability and market efficiency whilst increasing the need for transparent and consistent regulation.

C. *Regulation & Socio-Economic Impacts*

Whilst regulation for depository institutions increased substantially in the aftermath of the GFC, red tape for non-depository institutions has been a lot slower. Whilst too much regulation may hinder growth, regulatory blind spots may result in the accumulation of risks within the shadow banking sector, particularly when regulatory frameworks fail to account for evolving risks—such as physical climate risks. Banque de France's[49] financial stability review highlights that regulatory oversight of shadow banking remains at a

[43] "FEMA Defers the Implementation of Risk Rating 2.0." *Federal Emergency Management Agency*, 7 Nov. 2019.
[44] Tesselaar, Max, et al. "Regional Inequalities in Flood Insurance Affordability and Uptake under Climate Change." *Sustainability*, vol. 12, no. 20, 2020.
[45] Blickle & Santos (n 41) *supra*.
[46] Keenan, Jesse, and Jacob Bradt. "Underwaterwriting: From Theory to Empiricism in Regional Mortgage Markets in the U.S." *Climatic Change*, vol. 162, no. 4, 2020, pp. 2043-2067.
[47] Keenan, Jesse, et al. "Climate Gentrification: From Theory to Empiricism in Miami-Dade County, Florida." *Environmental Research Letters*, vol. 13, no. 5, 2018.
[48] Jones, John, and Urvi Neelakantan. "Portfolios Across the U.S. Wealth Distribution." *Federal Reserve Bank of Richmond Economic Brief*, 2023.
[49] "Non-Bank Finance: Trends and Challenges." *Banque de France Financial Stability Review*, no. 22, 2018.

formative stage and that a key structural vulnerability lies in the external credit rating process itself. As credit rating agencies continue to operate under an issuer-pays model, where issuers finance the assessment of their own securities, there remains a potential incentive misalignment that may lead to favourable ratings in order to maintain corporate relationships or win business. This dynamic may perpetuate the underestimation of credit and liquidity risk, thereby propagating systemic financial vulnerabilities over the long run. Adding to this, Campiglio et al.[50] emphasise the need for central banks and financial regulators to develop comprehensive analytical frameworks to assess the potential impact of climate change and the low carbon transition on financial stability. Building upon this, I argue that it is becoming increasingly important to extend regulation to cover the activities of shadow banks. This is particularly crucial for flood-prone areas as they have the potential to facilitate the aggregation of unpriced environmental risks within the financial system as a result of high securitisation rates and artificial external credit ratings.

In practice, implementation of climate risk frameworks has been slow. In the US for example, while there has been some progress in integrating climate-related risks into financial stability frameworks, significant gaps remain with regards to non-depository institutions.[51] Even in the European Union, where sustainability disclosure regimes such as the Sustainable Finance Disclosure Regulation (SFDR) have gained traction, coverage of asset-backed securities and private credit markets remains limited and opaque.

One point to note however, is that lenders may misrepresent information about underlying mortgages even if climate regulation was enforced. Piskorski et al.[52] find that financial intermediaries often misrepresent key aspects of mortgages, such as occupancy status and the existence of second liens, in the RMBS market. These misrepresentations led to higher default rates and were not adequately priced into the securities at issuance. Although they do not directly address climate-specific exposure, it underscores how opacity in loan-level data can compromise investor due diligence and risk assessment in securitised products. More specifically, the role of climate risk disclosures has been explored by Ilhan et al.[53] who find that institutional investors have a strong demand for climate risk disclosures, and many actively engage their portfolio firms for improvements. The increasing demand for climate risk disclosures from institutional investors signifies the critical importance of this study. That being said, not all climate risk disclosures are equal. Bingler et al.[54] find that many firms' disclosures are immaterial, with companies cherry-picking to report primarily insignificant climate risk information. This suggests that voluntary disclosure frameworks may be insufficient for ensuring meaningful transparency, particularly in sectors like mortgage financing where climate-related risks are significant.

Whilst expanding and enforcing regulation is one solution, Battiston et al.[55] indicate the importance of climate policy timing and transparency. Their network-based climate stress-test framework reveals how abrupt shifts in climate policy could trigger sudden asset repricing which may cascade losses across portfolios with high exposure to climate-sensitive areas. Ultimately, policy

[50] Campiglio, Emanuele, et al. "Climate Change Challenges for Central Banks and Financial Regulators." *Nature Climate Change*, vol. 8, no. 6, 2018, pp. 462-468.
[51] "FSB Roadmap for Addressing Financial Risks from Climate Change: 2022 Progress Report." *Financial Stability Board,* 2022.
[52] Piskorski, Tomasz, et al. "Asset Quality Misrepresentation by Financial Intermediaries: Evidence from the RMBS Market." *The Journal of Finance*, vol. 70, no. 6, 2015, pp. 2635-2678.
[53] Ilhan, Emirhan, et al. "Climate Risk Disclosure and Institutional Investors." *The Review of Financial Studies*, vol. 36, no. 7, 2023, pp. 2617-2650.
[54] Bingler, Julia, et al. "Cheap Talk and Cherry-Picking: What ClimateBert Has to Say on Corporate Climate Risk Disclosures." *Finance Research Letters*, vol. 47, 2022.
[55] Battiston, Stefano, et al. "A Climate Stress-Test of the Financial System." *Nature Climate Change*, vol. 7, no. 4, 2017, pp. 283-288.

uncertainty could create arbitrage opportunities where agents with information about climate policy could offload their assets ahead of the policy announcement and repurchase their assets after the re-rating. This, however, is unlikely for physical real estate given its illiquid nature and high transaction costs.

Shadow banks appear less responsive to these signals primarily because many do not service loans or hold them on a balance sheet and so they are removed from the feedback loops that might otherwise encourage caution or adjustment. When institutional incentives are aligned toward origination volume and downstream securitisation, the risk of moral hazard increases, particularly in areas where climate risks are slow-moving, probabilistic, and not yet priced into GSE purchasing standards or credit rating methodologies.

The implications of these institutional dynamics extend beyond financial stability, encompassing issues of spatial inequality and adaptive capacity. The concept of climate gentrification stipulates that climate impacts and adaptations may contribute to differences in property values and have socio-economic consequences.[56] In particular, Keenan et al.[57] find that properties at higher elevations appreciate more rapidly than those at lower elevations, suggesting that concerns over sea-level rise were influencing real estate markets. Ultimately, lower-income and historically marginalised communities in climate vulnerable zones may face rising insurance costs, disinvestment, and deteriorating access to credit unless backstopped by state funding. Best & Jouzi[58] review the concept of climate gentrification and highlight the importance of participatory methods and availability of longitudinal data required to fully grasp the multifaceted nature of climate gentrification. I therefore argue that, if shadow banks are more inclined to extend loans in flood-prone areas, they may inadvertently magnify geographic and socio-economic disparities in climate vulnerable real estate markets.

In this context, climate risk can become a form of hidden leverage which is embedded in highly intermediated mortgage finance systems but not accounted for in capital ratios, pricing, or mandatory disclosure requirements. When combined with mispriced collateral and fragile funding structures, the result is a well-balanced house of cards that appears robust until risk crystallises. A correction may be triggered not just through mortgage defaults but also by insurance withdrawal, zoning policy, or shifts in investor sentiment following flood events. At that point, feedback loops can generate sharp corrections in property values, loan performance, and investor sentiment. Demonstrating the complexity of the subject, Murfin & Spiegel[59] find no evidence that seal level rise risk is already affecting residential real estate markets. This may suggest that local residential real estate markets are short-term profit motivated thereby intentionally ignoring long-term climate risk considerations.

In response to the growing recognition of climate-related financial risks, several policy frameworks and analytical approaches have emerged to address potentially systemic climate vulnerabilities such as the Task Force on Climate-Related Financial Disclosures and the Network for Greening the Financial System.[60] Whilst the former aims to

[56] Flavelle, Christopher. "Climate Change is Already Forcing Americans to Move." *Bloomberg,* 31 Oct. 2016; Bolstad, Erika. "High Ground is Becoming Hot Property as Sea Level Rises." *Scientific American*, 1 May 2017.
[57] Keenan, Jesse, et al. "Climate Gentrification: From Theory to Empiricism in Miami-Dade County, Florida." *Environmental Research Letters*, vol. 13, no. 5, 2018.
[58] Best, Kelsea, and Zeynab Jouzi. "Climate Gentrification: Methods, Gaps, and Framework for Future Research." *Frontiers in Climate*, vol. 4, 2022.
[59] Murfin, Justin, and Matthew Spiegel. "Is the Risk of Sea Level Rise Capitalized in Residential Real Estate?" *The Review of Financial Studies*, vol. 33, no. 3, 2020, pp. 1217-1255.
[60] *see* "The Need for Climate-Related Financial Disclosure." *Task Force on Climate-Related Financial Disclosures*, 2022; "NGFS Scenarios for Central Banks and Supervisors." *Network for Greening the Financial System,* 2022.

standardise climate risk reporting across asset classes, the latter highlights the importance of scenario analysis across the entire financial sector. It should be noted that these frameworks have, to some degree, been used by governments as a foundation for reporting obligations. An example of this is the European Union's Corporate Sustainability Reporting Directive (CSRD) which requires reporting under the European Sustainability Reporting Standards (ESRS). These standards go one step further than the TCFD pillars as they require reporting on double materiality—i.e., the impacts on and of the firm—compared to the TCFD which involves only financial materiality. Whilst European nations have warmed to implementing sustainability reporting, the same cannot be said for the United States.

Bolton et al.[61] introduce the concept of green swan events as climate-related financial shocks that are foreseeable in nature but highly uncertain in timing and impact. They argue that central banks and financial regulators should prepare for such systemic events by adopting more robust climate stress-testing frameworks. The effectiveness of these frameworks, however, is limited by the current lack of mandatory climate disclosures and data quality and availability.[62] This gap is particularly problematic in the context of shadow banks as they operate outside the regulatory perimeter yet still hold significant climate-related risk exposure that could echo through the financial markets in the event of a major climate shock.

Comparative studies suggest that some jurisdictions are moving more decisively than others. In the UK, for example, the Prudential Regulation Authority emphasised the importance of climate scenario analysis in its 2024 priorities to banks and insurers.[63] It specifically highlighted that it expects firms to make significant progress on climate scenario analysis and to limit their reliance on off the shelf climate tools which do not provide the level of detail end users need to effectively undertake asset-level risk. Meanwhile, Australia's Prudential Regulation Authority launched climate vulnerability assessments for major lenders, with explicit mandates to incorporate flood and fire risk into capital planning.[64] Yet such practices remain rare in the shadow banking sector, where oversight is fragmented and data often proprietary. The US, in particular, has struggled to translate climate concern into enforceable standards for non-bank lenders, despite their material presence in mortgage origination.

Given these dynamics, shadow banks may not only contribute to the misallocation of credit in climate-prone areas but also play a pivotal role in amplifying systemic fragility. This may occur through multiple channels: (i) origination of high-risk mortgages without long-term accountability, (ii) reliance on opaque securitisation structures that weaken market discipline and transparency, and (iii) insulation from emerging climate risk regulations that apply to banks and insurers but not to non-depository credit providers. The outcome is a financial framework that, whilst efficient in capital allocation and credit provision, may be structurally incapable of internalising and quantifying slow-moving environmental risks.

This institutional fragility is compounded by information asymmetry between originators, investors, and regulators. As Keys & Mulder show,[65] even post-disaster lending patterns may remain unchanged. This is not because climate risk is absent, but because relevant risk signals are not effectively transmitted. If rating agencies do not adjust their criteria, if

[61] Bolton, Patrick, et al. "Green Swans: Central Banks in the Age of Climate-Related Risks." *Banque de France Bulletin*, vol. 229, no. 8, 2020, pp. 1-15.
[62] Monasterolo, Irene, et al. "Climate Transition Risk and Development Finance: A Carbon Risk Assessment of China's Overseas Energy Portfolios." *China & World Economy*, vol. 26, no. 6, 2018, pp. 116-142.
[63] Bailey, David, and Laura Wallis. "UK Deposit Takers Supervision: 2024 Priorities." *Bank of England PRA*, 2024; Gerken, Charlotte, and Shoib Khan. "Insurance Supervision: 2024 Priorities." *Bank of England PRA*, 2024.
[64] "Climate Vulnerability Assessment." *Australian Prudential Regulation Authority*, 2022.
[65] Keys & Mulder (n 35) *supra*.

regulators do not impose disclosure mandates, and if investors continue to demand volume over transparency, then the conditions for mispricing are likely to persist. In effect, the current configuration of mortgage finance incentivises the transferring, rather than the mitigation, of climate risk. In particular, the structural shift towards shadow bank mortgage origination post-GFC raises important questions about how climate risks are being distributed through the financial system.

The contribution of this article lies in addressing this critical blind spot. I propose to empirically examine the relationship between shadow bank mortgage origination and physical climate exposure, with a particular focus on the top three states affected by flood events. Using a staggered difference-in-difference framework, this paper will assess whether the share of shadow banks' mortgage lending changes post high damage flood events. This research is positioned at the intersection of environmental finance, financial stability, and regulation. By linking climate exposure to institutional behaviour across the credit chain, I aim to offer new insights into how systemic risk accumulates in decentralised and opaque parts of the financial system. In doing so, the findings seek to inform ongoing policy debates about the need for climate-aligned financial regulation that goes beyond the traditional, deposit-taking, banking sector and into the structures where credit, risk, and accountability are increasingly fragmented and opaque.

III. **Research Gap, Hypothesis & Contribution**

Given the existing gap in the literature, this paper will address the role of shadow bank lending in US regions impacted by physical climate risks, in particular flood events. The focus on the US is driven by the quality and volume of data available, whilst the focus on shadow banks is driven by a lack of stringent regulatory oversight of the practice in comparison to depository institutions. The lack of shadow banking regulation may lead to varying underwriting standards which could result in inadequately accounting flood risk, which in turn may lead to a systemic event. Evaluating shadow bank activity can provide us with insights into potential vulnerabilities in the housing market and is crucial for several reasons.

Firstly, climate change poses significant and growing risks to the housing market. Properties in areas prone to natural disasters are increasingly at risk of property devaluation, which can undermine the stability of mortgage portfolios. Understanding how shadow banks, as major players in the mortgage market (more than 50% of lending value), address these risks is vital for financial stability and consumer protection.

Secondly, coastal properties are facing growing insurance premiums or even the inability to secure insurance due to climate risks. The unregulated lending and securitisation activity of shadow banks may lead to additional household costs if the property owner cannot afford coverage or is exposed to uninsured losses. This creates further instability in the housing market with the potential for higher default rates.

Finally, this research can inform policymakers by identifying gaps in the current regulatory framework and proposing measures to enhance the resilience of the mortgage market in flood-prone areas. It can also contribute to the broader discourse on climate finance by highlighting how shadow banks integrate flood risk into their decision-making processes.

A. *Data*

This paper relies on two externally verified sources for data: (i) Home Mortgage Disclosure Act (HMDA), and (ii) National Oceanic and Atmospheric Administration (NOAA). Both sources are certified and regulated by US government agencies and thereby provide reliability and consistency to this research. However, the large file sizes present several complexities due to the high processing speed and computational power

requirements. Therefore, selecting the three largest states by flood-related property damage and focusing on the most affected counties within those states, provides a more realistic and manageable approach whilst further justifying the focus of this study. To mitigate the computational power requirements, the raw data from each provider has been cleansed and filtered to ensure that only the relevant and reliable data remains. This is discussed in greater detail below.

1. HMDA (**Figures 1, 2, 3**)
Detailed mortgage-level data is publicly available from HMDA from 2007 to 2024 and includes numerous mortgage details such as the loan amount, type and purpose, the lender's regulator, the loan's state, county and MSA code, and the purchaser type among other application details. To avoid confounding effects, the study is limited to cover the eight years from 2010 to 2017 whilst ensuring it is a long enough time period to observe shadow bank lending activity.

By excluding the 2007 to 2009 data, the study removes the impact of the GFC during which depository institutions reduced their lending as a result of weakening economic conditions and increased regulation. Additionally, I opted to end the data period two years prior to the impact of the COVID-19 pandemic in order to further limit the confounding effects. For illustrative purposes, however, the study covers the 2007 to 2017 time period as it highlights the progression of shadow bank lending since the GFC.

To identify if a lending entity is a shadow bank or depository institution, I use the regulatory classification findings from Buchak et al.[66] HMDA identifies the lender's primary regulator, which provides a useful first cut regarding depository versus non-depository institutions. For regulating entities that govern both depository and non-depository institutions, Buchak et al.[67] manually classify the underlying lenders based on their deposit holdings. Using this proportion of shadow bank lending, I can then measure the impact that flood events have on shadow bank activity.

The HMDA data also provides us with information regarding if the loan has been sold to a different entity within one year of origination highlighting the type of purchaser, i.e., FNMA, GNMA, or private securitisation. This allows us to understand if the mortgages are backed by government agencies and thereby who ultimately bears the credit risk. Given the scope of this article, the securitisation aspect of shadow bank lending will not be discussed further, but I recommend this as a next step for future research.

Analysing the HMDA data, it is noted that there have been over 187.5 million mortgage applications across the time period (2007 – 2017), of which 89.2 million were approved. This resulted in a total of $19.8 trillion in new mortgage issuances, of which shadow banks accounted for $7.1 trillion. The majority of approved mortgage applications related to refinancings (56.2%), while 42.1% related to home purchases, and the remaining 1.6% related to home improvements.

During the period, the share of shadow bank lending, both as a percentage of total approved applications and as a percentage of total loan amounts, increased. I hypothesise that this is a result of reduced lending activity from depository institutions following the GFC, which shadow banks were able to capitalise on. The role of shadow banks was then further entrenched by the enactment of the Dodd-Frank Wall Street Reform and Consumer Protection Act of 2010,[68] which led to traditional banks becoming price uncompetitive due to stricter regulation and more costly capital requirements. As shadow banks were not covered under the same regulatory regimes and capital requirements, they were able to fill the lending gap which was caused by the shrinking of depository institution activity.

[66] Buchak et al. (n 21) *supra*.
[67] ibid.
[68] Dodd-Frank Wall Street and Consumer Protection Act. PL 111-203, 124 Stat 1376, 21 Jul. 2010.

2. NOAA (**Figures 4, 5, 6**)
Natural disaster data is gathered from NOAA, which details climate events by type, year, county and state identification code, and property damage among other event details. Whilst NOAA has annual data from 1950 to 2025, I have elected to use the same time period as the HMDA data for consistency.

I have categorised the subset of unique climate event types into broader groups for ease of comparison. For example, all flood event types such as flash flood, coastal flood, and lakeshore flood, have been aggregated into the broader category of floods for comparative simplicity. For context, the definitions of each flood event type are specified by NOAA[69] and listed below:

- Flash Flood: Caused by heavy or excess rainfall in a short period of time, usually less than six hours.
- Coastal Flood: Inundation of land areas along the coast, caused by higher-than-average high tide and heavy rainfall.
- Lakeshore Flood: Inundation of land areas adjacent to the lake, often due to strong winds pushing water onshore.

A total of 684.4 thousand climate events are observed across the study period, of which 67.8 thousand (9.9% of observations) relate to flood events. For context, these flood events account for $122.8 billion or 55.5% of total property damage experienced. The magnitude of flood-related property damage is significantly larger than other event types such as hurricanes (15.3 thousand observations resulting in $27.5 billion of property damage) and wildfires (3.9 thousand observations resulting in $5.1 billion of property damage). The relative increasing magnitude of flood-related property damage further validates the relevance and focus of this study. The aggregate of all floods, hurricanes, and wildfires accounts for 70.2% of total property damage across the time period studied. The largest spike in flood-related property damage was in 2012 as a result of Hurricane Sandy in New Jersey which accounted for 97.2% of all flood-related property damage in that year. This was followed by Hurricane Harvey in Texas during 2017, which accounted for 95.6% of all flood-related property damage that year. The impact of Hurricane Harvey and 2017 more broadly, however, is not necessarily included in this model in order to avoid spillover effects. The third spike was in Louisiana in 2016, which accounted for 85.9% of all flood-related property damage that year, and was a result of heavy rainfall leading to widespread flash floods and river floods.

It should be noted that, the aforementioned flood-related property damages are heavily concentrated in three states, which account for 79.5% of all flood-related property damage. The three states, in order of damage, are: (i) Texas, (ii) New Jersey, and (iii) Louisiana. Given the significance of these states, the study will focus on these and expand the geographic focus as part of the robustness tests.

For simplicity, I have also only used data relating to the 50 states in mainland US and have not included other overseas territories or states, such as Puerto Rico and Hawaii. The rationale behind this is that the sophistication and maturity of financial markets differ materially outside mainland US and thereby would contaminate the results.

3. Data Cleansing & Filtering
Both the HMDA and NOAA datasets had complexities that needed to be dealt with, however that was made easier by the fact that all files, columns, and definitions were consistent. As both organisations make their data publicly available in comma separated value files, the transfer and reading onto R was smooth. That being said, there were numerous adjustments required prior to testing the hypothesis.

With regards to the HMDA data, I began by filtering for only approved mortgage applications as this will allow us to further

[69] "Severe Weather 101: Floods." *National Oceanic & Atmospheric Administration,* 2025.

analyse the difference in lending attitudes between depository institutions and non-depository institutions. I then proceed to format the loan amounts to be in a consistent format to ensure that all approved mortgage amounts are included. For simplicity and consistency with the NOAA data I format all loan amounts to be in single units. Most importantly, I apply the findings from Buchak et al.,[70] as shown in **Table 1** below, to determine whether a lending entity is a shadow bank or depository institution based on its primary regulator. Whilst a manual classification based on regulating entities may have be more accurate, I believe that the current method is an accurate proxy given that six of the seven regulatory entities either almost solely regulate depository institutions or non-depository institutions.

A similar number of amendments were performed on the NOAA data. For example, I began filtering the data to include only the 50 states of mainland US and remove any overseas territories or states, such as Puerto Rico and Hawaii. I further focused the data from the 50 states to only analyse Texas, New Jersey, and Louisiana as they will be the primary focus of this paper given the high concentration of flood-related property damages in these three states.

Similar to the HMDA data, I ensured consistency in the property damage figures by formatting all amounts to be in single units. Finally, all flood event types are aggregated into one main flood group. This is then replicated for hurricanes and wildfires as these can be used for future research.

IV. **Methodology**

To assess the causal impact of flood exposure on the share of mortgage origination by shadow banks, this study employs a staggered difference-in-difference (DiD) based on model specifications by Sun & Abraham.[71]

The staggered DiD approach estimates causal effects by comparing changes in outcomes between treated and untreated groups before and after a treatment event, in this case the occurrence of a top quartile flood event. By doing so, I am able to control for unobserved, time-invariant county characteristics and common temporal shocks. The staggered implementation allows treatment timing to vary across counties, reflecting the fact that flood event occur in different years and locations. This mitigates the bias of traditional two-way fixed-effect estimators, which can assign negative weights when treatment is not simultaneous across units. A standard DiD that pools all treated counties at a single post-flood date would misstate dynamic effects when counties are treated in different years. The staggered DiD, therefore, provides a more reliable estimate of the dynamic response of shadow bank lending to flood exposure over time.

To determine the treated and control groups, counties are ranked by their cumulative flood damage from 2010 to 2017. The top quartile as then assigned as the treated group and the bottom quartile as the control group. This approach results in counties within the same states being compared thereby increasing the accuracy of the study as state unique characteristics are ignored. More specifically, the use of the bottom quartile for the control group results in nearby counties with no flood damage or with minimal flood damage being used. This may be due to those counties being further from the flood source or due to better flood protection systems, such as flood barriers, and enables for an accurate comparison.

Treated counties then receive a cohort year g_c equal to the first calendar year in which they experienced top quartile flood damage, whilst control counties are assigned a unique key to indicate they were never treated. An event-time variable is then constructed which indexes years relative to the first flood.

[70] Buchak et al. (n 21) *supra*.

[71] Sun, Liyang, and Sarah Abraham. "Estimating Dynamic Treatment Effects in Event Studies With Heterogeneous Treatment Effects." *Journal of Econometrics,* vol. 225, no. 2, 2021, pp. 175-199.

The econometric model is as follows—

$$Y_{clt} = \sum_{\kappa \neq -1} \beta_\kappa 1\{\kappa = g_c - t\} + \gamma_c + \delta_t + \varepsilon_{clt}$$

where:

- Y_{clt} is the shadow bank lending share in county c, for lender type l, in year t;
- g_c is the first treatment year for county c, also known as cohort;
- $1\{\kappa = g_c - t\}$ is an indicator equal to 1 if year t is exactly κ years relative to that county's first flood—for example:
    - when $\kappa = -2$, two years before the flood
    - when $\kappa = 0$, the flood year itself
    - when $\kappa = +2$, two years after the flood
- the sum $\sum_{\kappa \neq -1} \beta_\kappa 1\{\kappa = g_c - t\}$ stacks a full set of event-time coefficients β_κ for κ (excluding $\kappa = -1$), where each β_κ measures the average difference in shadow bank share in treated counties at time κ relative to the year before the treatment ($\kappa = -1$) and relative to the control group;
- γ_t is the area fixed effect (county) to control for time-invariant county characteristics;
- δ_t is the time fixed effect (year) to account for temporal dynamics in mortgage lending;
- ε_{clt} is the error term capturing unexplained variation.

By incorporating staggered treatment timing, this model effectively accounts for heterogeneity in treatment timing and reduces biases arising from dynamic treatment effects. For proof of parallel trends, I test $\beta_\kappa = 0$ for all $\kappa < 0$. Statistical insignificance confirms that treated and control counties exhibit similar pre-flood trajectories in shadow bank lending share. Whilst post-treatment coefficients $\beta_\kappa \geq 0$ track the timing and persistence of any flood-related shift towards non-depository lending.

By identifying the change in lending activity, this study offers valuable insights into the risk transfer mechanisms and systemic vulnerabilities of the US housing market. The findings may play a crucial role in informing policymakers and regulators on the role of shadow banks in amplifying flood-related financial risks.

Overall, I hypothesise that shadow bank lending increases as a proportion of total lending activity following a top quartile flood event. I assume this is driven by the fact that depository institutions are more risk averse given their capital and regulatory requirements as a result of the Dodd-Frank Act. As such, the gap left in the mortgage market is quickly filled by shadow banks who seek to capitalise on higher interest mortgages before packaging them and externalising their risk through securitisation.

This study therefore seeks to test the hypothesis that shadow bank mortgage lending increases, as a proportion of total lending, in treated counties relative to untreated counties.

V. **Results**

This Section presents the empirical results and provides a discussion on the impact of flood-related property damage on shadow bank lending between high flood-damage areas (treated group) and low flood-damage areas (control group).

The estimates in **Table 2**, below, present the staggered DiD results using the Sun & Abraham event-study estimator,[72] with standard errors clustered at the county level. The dependent variable is the proportion of total approved mortgage lending originated by shadow banks, i.e., the shadow bank share of lending. The key parameter of interest is the interaction of a treated-period indicator with the post-flood period.

The row labelled "Shadow Bank Share x Post" in **Table 2** corresponds to the aggregate post

[72] ibid.

treatment indicator. Its estimate indicates that treated counties experience an immediate and persistent increase in shadow bank lending share of 5.3%, on aggregate, relative to the control group. I believe that the use of the bottom quartile flood damage counties for the control group is an appropriate approach as the use of counties with no flood damage at all resulted in a significant reduction in observations.

By construction, the omitted reference period is one year before treatment ($\kappa = -1$), so the coefficient at event time zero (β_0) measures the effect relative to that benchmark. The findings indicate that in the initial flood year itself, there is a 3.8% increase in the shadow bank share followed by a continuous positive and statistically significant increase in every subsequent year, with a peak at 8.6% increase six years post flood event. This pattern suggests not only a contemporaneous shift toward shadow banks in flood-hit counties, but also a cumulative strengthening of that shift in the years following the shock.

These results demonstrate that flood exposure induces a sizable and sustained redistribution of mortgage originations away from regulated depository institutions and toward shadow banks, consistent with the hypothesis that non-bank lenders expand credit supply in regions where traditional banks pull back from following flood events. The implications of these results are discussed in the section below.

A. *Parallel Trends & Robustness Tests*

The parallel trends assumption is a critical requirement to ensure the internal validity of the staggered DiD method. To validate the above results, a parallel pre-trend analysis is conducted and is shown in **Table 2**. Row (1) of the table verifies that no statistically significant change existed in the share of shadow bank lending prior to the flood event and is expressed by the coefficient being near zero and the 95% confidence interval straddling zero. This result indicates that the parallel pre-trend assumption holds true, providing further validity of the empirical method used.

To further evaluate the validity of the findings, I also conducted two additional changes to the base case model. Firstly, I expanded the geographic focus to include all additional states which account for more than 1.0% of annual flood-related property damage. The expanded list of states accounts for 93.9% of all flood-related property damage and include: Texas, New Jersey, Louisiana, Tennessee, Michigan, Iowa, New York, Vermont, Illinois, Florida, Mississippi, and California.

By expanding the geographic scope of the study, I am able to assess if shadow bank activity is consistent across states and verify the common trends assumptions. I hypothesise that, as the geographic focus expands to include states with a proportionally smaller share of flood-related property damage, the change in shadow bank lending post flood event will increase at a lower rate and remain positive but will be smaller compared to the top three states test. I assume this is due to the capital requirements of depository institutions not being linear in nature. The result confirms the existence of parallel trends and is in line with the hypothesis highlighting that the share of shadow bank lending increases by 3.2% (statistically significant at 0.01% level) following a high damage flood event. This finding further validates that the base case results may hold true for the rest of the US.

Secondly, I conducted a placebo test to assess whether the findings truly reflect a causal response between flood events and shadow bank lending. As such, artificial flood dates are randomly assigned to treated counties and re-estimated with the Sun & Abraham[73] staggered DiD model on these placebo cohorts. The result of the placebo test indicates that both pre- and post-treatment coefficients hover closely around zero and none are statistically significant. In particular, there is no shift in shadow bank lending during pre-treatment

[73] ibid.

period and no spurious increase at or after the flood event. These null placebo coefficients confirm that the original staggered DiD results are not driven by idiosyncratic time-trends, seasonal patterns, or other data driven noise. Had there been no actual flood shock, an increase in shadow bank lending share would not have been observed post-flood event. Thus, this robustness test reinforces the credibility of parallel trends and implies that the 5.3% aggregate increase in post-flood shadow bank lending reflects a genuine shift in credit supply.

VI. **Discussion**

The finding that exposure to high damage floods leads to a persistent and economically meaningful shift in mortgage origination toward shadow banks carries several important implications for financial stability, regulatory policy, and household financial health. This is consistent with my hypothesis. The observed increase in the share of shadow bank lending, from 3.8% in the flood year to 8.6% six years afterwards, suggests that non-depository institutions play a vital role in restoring credit flows in areas where traditional banks have withdrawn from. These findings add nuance to the works of Cortés & Strahan, Rehbein & Ongena, and Ivanov et al.[74] who find that credit is often reallocated after disasters, with banks reducing lending in unaffected areas to meet new demand in impacted areas. Whilst traditional banks may reallocate capital towards affected areas after climate events, they do so at a slower rate than shadow banks, thereby allowing the share of shadow bank lending to increase.

In the immediate aftermath of flooding, however, depository institutions may tighten underwriting standards or reduce lending in order to repair capital buffers and manage disaster-related losses. Meanwhile, shadow banks which are unconstrained by the same deposit-funding requirements and regulatory capital ratios, step in to fill this credit gap, thereby maintaining access to mortgage finance for affected homeowners and potential buyers. From a household credit perspective, this substitution could be value accretive if it smooths the supply of credit and prevents material downturns in local real estate markets. In theory, given their unconstrained capital, shadow banks would be able to provide post-flood credit at competitive rates. However, given the lack of credit supply and relatively higher cost of capital compared to traditional banks this is not the case.

The persistent rise in shadow bank lending also raises concerns regarding risk allocation and consumer protection. Non-bank lenders rely on more complex and expensive wholesale funding,[75] employ less standardised and prudent underwriting, and face looser regulatory oversight relative to traditional banks. As a result, households in flood-impacted counties may face higher interest rates or less favourable contract terms, potentially further exacerbating financial vulnerability among already distressed borrowers. Regulators should therefore monitor the post-flood expansion of shadow bank credit to avoid predatory lending practices or an accidental buildup of systemic risk outside the traditional banking system.

The evidence of parallel trends highlights that credit reallocation is neither transient nor anticipated. Instead, it reflects a structural, long-run recalibration of the mortgage finance market in regions subject to flood events. Policymakers aiming at enhancing local real estate market resilience should therefore recognise that simply restoring the physical built environment may not be enough, and that ensuring equitable access to credit post-flood events is equally important. Post-flood programs such as targeted guarantee schemes, disaster-loan assistance, or reinsurance pools could be calibrated to incentivise traditional banks and insurers to maintain lending and insurance coverage even in the face of large losses, thereby mitigating reliance on less regulated and opaque market participants.

[74] Cortés & Strahan (n 37) *supra*; Rehbein & Ongena (n 37) *supra*; Ivanov et al. (n 37) *supra*.

[75] Pozsar et al. (n 12) *supra*.

For example, by deploying targeted guarantee schemes that partially backstop new originations in flood prone areas, a public guarantor (e.g., the Federal Housing Administration) would absorb a pre-specified share of losses and thereby lower the expected loss for households. The success of this scheme, however, relies on robust underwriting, continuous insurance coverage, and lenders caping their interest rates and fees. By lowering the expected loss given default for depository institutions, the funding cost gap to shadow banks should narrow, thereby reducing the spike in post-flood event shadow banking activity. The scheme could also be tailored to favour low- and middle-income households or first-time buyers by tying the guaranteed percentage to borrower income, loan-to-value ratios, or the implementation of property-level mitigation measures.

Similarly, disaster-loan assistance programmes, such as low-interest federal disaster loans that already exist, could be expanded to integrate forecasted climate-related expected losses or refinancing costly post-flood mortgages into more affordable government-backed debt structures. In parallel, the use of re-insurance pools could stabilise primary insurers' capacity and pricing in flood prone regions. As insurers group together to jointly provide reinsurance coverage, this allows them to share the risks they may not have otherwise been able to underwrite alone, increasing their capacity to handle large or unusual events. This approach can already be seen in the UK with the Flood Re scheme.[76]

Additionally, coastal properties are experiencing rising insurance premiums, or in some cases an outright unavailability of insurance coverage, driven by the increasing frequency and severity of flood events.[77] Traditional depository lenders often require borrowers to maintain adequate hazard insurance as a condition of mortgage approval, effectively offloading catastrophic risk to insurers. Shadow banks, however, operate with minimal regulatory requirements and may securitise pools of mortgages without rigorous verification of insurance status or with allowances for expired coverage. When insurers retreat from high-risk coastal zones or impose higher insurance premiums, the homeowners in the affected areas may find themselves unable to secure or afford the policies that banks require. Within shadow banking, such coverage gaps translate into increased exposure to uninsured losses which households must self-fund. The resulting monetary impact on households may diminish their ability to service their mortgage obligations, thereby magnifying default risk in markets struggling to recover from flood events.

These regulatory gaps stem from the design and implementation of the National Flood Insurance Program's (NFIP) Mandatory Purchase Requirement (MPR), established under the National Flood Insurance Act of 1968 and the Flood Disaster Protection Act of 1973.[78] The MPR requires borrowers to purchase and maintain flood insurance only if they have a mortgage from a federally regulated or federally backed lender and the property lies within a FEMA-mapped flood zone. Borrowers outside these zones, with non-federally regulated lenders, such as shadow banks, therefore, are out of scope for MPR.

To correct these shortcomings, the flood insurance requirements could be extended beyond the federally chartered banks to include non-bank mortgage lenders and servicers. Whilst this would help ensure appropriate coverage at origination it would fall short in assessing this requirement during the life of the mortgage. Therefore, it would also be appropriate to strengthen the enforcement by mandating periodic post-origination verification of coverage for all mortgages in specified risk bands. In turn this would require standardised reporting of

[76] Browning, Steve. "Flood Re and Household Flood Insurance." *House of Commons*, 6 Jul. 2023.

[77] Flavelle & Rojanasakul (n 3) *supra*.

[78] PL 93-234; PL 90-448.

insurance status to regulators. To address the equity implications of stricter mandates, these obligations could be paired with means-tested premium subsidies or tax credits targeted at lower-income households in high-risk areas. One feasible option would be to explicitly require both banks and shadow banks to offer loss-mitigation options such as term extensions or rate reductions to borrowers facing large uncovered losses. The financial institutions would then be able to claim the losses back from government agencies or via tax credits.

More importantly, the securitisation of these loans further transmits risk throughout the financial system, making it harder for regulators to track credit risk concentrations. In aggregate, these dynamics have the potential to destabilise local housing markets and threaten systemic financial stability. As mortgage performance deteriorates and foreclosures rise, property values may weaken, further amplified by reduced insurance coverage, thus triggering a feedback loop of tightening credit conditions, especially to the most vulnerable communities ultimately leading to a debt spiral and climate gentrification.

Securitisation based on such weak credit profiles, uninsured properties and increasing climate risk poses a significant threat to the residential mortgage-backed securities (RMBS) market as default rates flow through the tranches. Given that RMBSs are priced and split into tranches at origination, there is potential for risk to have increased in subordinated tranches thereby resulting in investors receiving lower-than-expected risk-adjusted returns. Whilst the argument of geographic diversification does offer some risk relief, the systemic nature of climate events poses a potential threat across all tranches. However, given the scope of this article, securitisation will not be explored any further.

The speed at which credit demand is met by shadow banks reflects positively on the capital allocation efficiency of the market as equilibrium is retained. However, the cost and terms of the new credit may result in market disequilibrium in the long run as losses materialise.

VII. **Limitations & Further Research**

Whilst the study was developed in a rigorous manner, its limitations must be acknowledged when interpreting the results and accounted for appropriately in future research.

Although one of the article's strengths is the fact that it covers the three largest states which account for 79.5% of flood-related property damage, it does not cover the whole US and therefore it cannot be certain that the findings are representative of the wider market. Although one of the robustness tests did expand the geographic focus to the top 12 states (93.9% of flood-related damage), this does not necessarily verify that the model is truly representative. Additionally, the US has a significantly more developed and active shadow banking market compared to other developed economies. These considerations further signify that the findings should also be examined in an international context.

While the parallel trends assumption held true in this study, this could be further improved by accounting for additional independent variables such as applicant FICO score, race and gender, household income, LTV ratio, and delinquency rate. By controlling for these variables, I would be able to strengthen the accuracy of the findings. In particular, I hypothesise that FICO scores and delinquency rates play a significant role as shadow banks are more prevalent at the lower end of the credit score spectrum where delinquency rates are higher. The untreated group could use a blind matching technique based on counties with similar characteristics such as population density, household income, and average FICO score to test the parallel trends assumptions across states in the US. An additional amendment to further assess the validity of the results would be to use other staggered DiD models, such as Callaway &

Sant'Anna.[79] If the results were similar, this would strengthen the validity of the current findings and confirm the appropriateness of the independent variables used.

Regulatory changes to capital requirements and deposit-funding should also be accounted for. Changes in regulation, for both depository and non-depository institutions, can have a significant impact on the interpretation of these findings. Therefore, any actual or potential changes to capital requirements should be accounted for as these may lead to changes in lending patters.

The staggered DiD framework implemented offers a template for evaluating the impact of other climate-related events, such as wildfires and hurricanes, on credit markets. As extreme weather events become more frequent as a result of climate change, further research seeking to understand how different segments of the financial system respond to natural disaster events is essential for designing robust regulatory policy and public-private partnerships. It is also important to note that, climate events rarely occur independently and thereby their true impact is likely to be larger than these findings which only focus on one type of climate event.

An additional area of study would be to assess the sensitivity of shadow banks to FICO scores before and after climate events. This could help inform policymakers about the potential socioeconomic outcomes of climate events and the potential need for shadow bank regulation. Furthermore, the second-round effects of climate events on MBS would allow investors and regulators to get a better understanding of where credit risk truly lies. In the context of investors, such as pension funds, this is crucial as their risk-adjusted returns may be lower-than-expected resulting in an asset-liability mismatch whilst hiding systemic risks. Finally, the duration of shadow bank lending post-flood events should also be examined. Whilst depository institutions may be quick to withdraw from flood-affected areas, it is unclear at what stage depository institutions return to previously flooded areas. By understanding this volatility in lending behaviour, regulators can better seek to protect households and provide stability to local real estate markets.

VIII. **Conclusion**

This article has demonstrated that shadow banking institutions play a distinct role in meeting credit demand for mortgages following flood events in Texas, New Jersey, and Louisiana. The findings show that shadow banks' share of total mortgage originations rises by 5.3%, on aggregate, following high-damage flood events. The findings also highlight how regulatory frictions on depository institutions can leave critical credit gaps which non-depository, unregulated, institutions can fill. This result is economically significant and may have material implications for household finances, financial regulation, and the stability of local real estate markets.

Shadow banks currently originate more than 50% of all US mortgages by dollar value, and my geographic focus accounts for 79.5% of national flood-related property damage. As such, the post-flood lending shift observed represents a sizeable reallocation of credit supply away from traditional, tightly capitalised banks and toward entities that are not subject to comparable risk-management standards or capital requirements. This change in lending behaviour is assumed to be a form of regulatory arbitrage whereby depository institutions retreat after high-damage flood events due to costlier capital requirements, caused by the post-Dodd-Frank regulatory era. In turn, shadow banks step in to fill the newly created credit gap while potentially extending credit to borrowers whose collateral is most exposed to future flood events.

[79] Callaway, Brantly, and Pedro Sant'Anna. "Difference-In-Differences With Multiple Time Periods." *Journal of Econometrics*, vol. 225, no. 2, 2021, pp. 200-230.

By underwriting mortgages on flood damaged or high-risk properties without robust insurance coverage, shadow banks may amplify local housing market volatility and magnify borrower vulnerability to future disasters, beyond flooding. The securitisation of such loans further complicates the tracing and management of geographically concentrated credit risk, thereby raising the possibility of hidden spillovers across the housing market and financial system more broadly.

From a policy perspective, the results suggest that climate resilience in mortgage markets requires more than infrastructure adaptation or floodplain management. It also requires a review of regulatory equivalence across lender types and further implementation of government schemes, such as targeted guarantees, disaster-loan assistance, and reinsurance pools, to support equitable access to credit post-flood events. By aligning capital, disclosure, and insurance requirements to account for climate-driven concentration risks across both banks and shadow banks, regulators could mitigate the rise in shadow bank activity following flood events. Enhancing transparency around post-flood lending practices and insurance coverage may also support more informed origination decisions and consumer protections whilst enforcement of post-origination insurance verification could result in reduced uninsured losses. Additionally, closing regulatory gaps such as the ones present under the MPR currently would not only bring the regulatory requirements up to date with modern finance, but would also enable for a more competitive bidding process between banks and shadow banks that would ultimately benefit consumers.

While this article focused on three high damage states, future work should extend the scope nationwide, and to other climate events such as wildfires and hurricanes. This study contributes to a nascent but growing area of study which is at the intersection of climate risk, mortgage finance, and financial regulatory policy. The research also highlights the urgent need for a coherent framework to govern credit provision in an era of intensifying climate events.

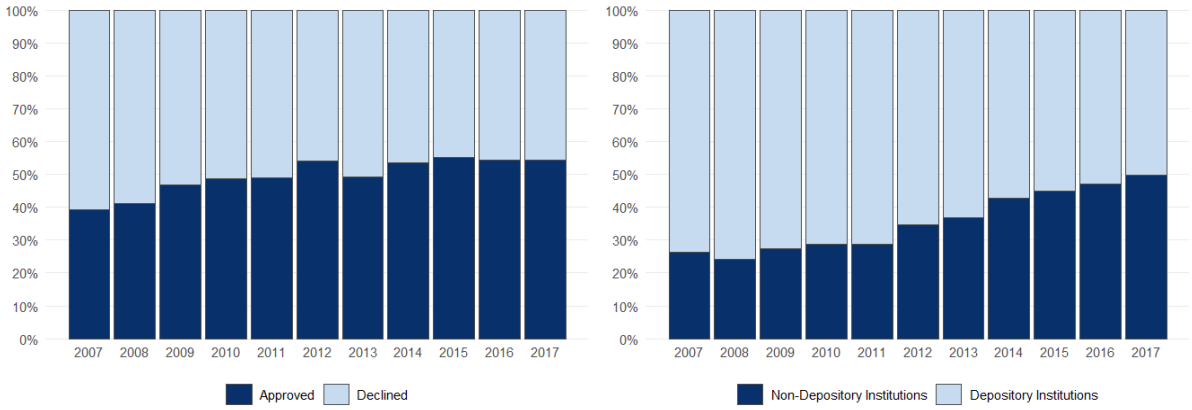
Overall, the findings suggest that flood-exposed credit demand for mortgages can be met by non-depository institutions. However, careful oversight and increased regulatory scrutiny are needed to balance market efficiency with consumer protection and systemic resilience.

Regulatory Agency	**Classification Distribution**	
	Bank	**Shadow Bank**
OCC	100.0%	0.0%
FRS	62.9%	37.1%
FDIC	99.9%	0.1%
OTS	100.0%	0.0%
NCUA	100.0%	0.0%
HUD	0.3%	99.7%
CFPB	97.4%	2.6%

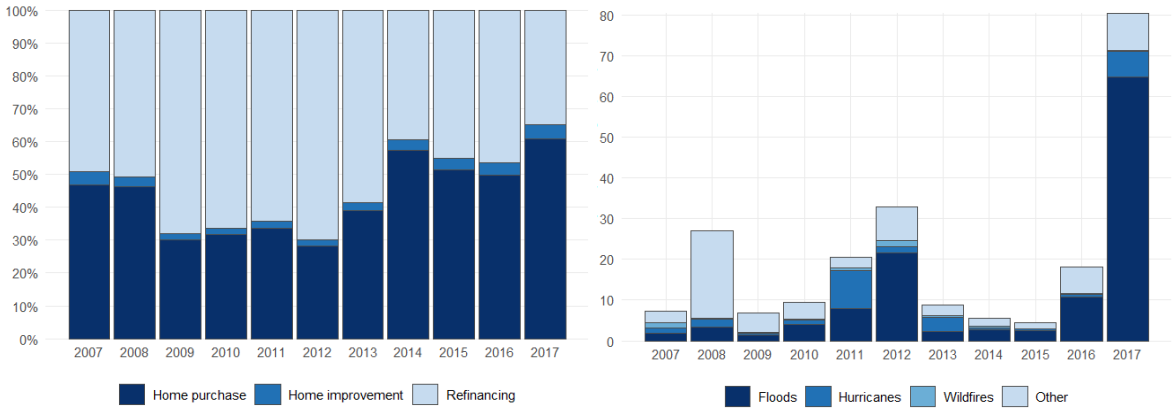
Table 1: Regulatory Agency Classification Distribution (Data Source: Buchak et al.).

	Coefficient	***Standard Error***	***t-value***
Shadow Bank Share	*-0.00970*	*0.02113*	*-0.45920*
Shadow Bank Share x Post	***0.05259******	***0.01251***	***4.20498***
Shadow Bank Share x Post$_0$	*0.03800****	*0.00977*	*3.88871*
Shadow Bank Share x Post$_1$	*0.04644**	*0.01929*	*2.40811*
Shadow Bank Share x Post$_2$	*0.04740****	*0.01138*	*4.16577*
Shadow Bank Share x Post$_3$	*0.05046****	*0.00985*	*5.12111*
Shadow Bank Share x Post$_4$	*0.05536****	*0.01028*	*5.38769*
Shadow Bank Share x Post$_5$	*0.06529****	*0.01495*	*4.36639*
Shadow Bank Share x Post$_6$	*0.08613**	*0.03812*	*2.26027*
Area Fixed Effect		*Yes*	
Time Fixed Effect		*Yes*	
Observations		*26,144*	
R-squared		*0.75643*	

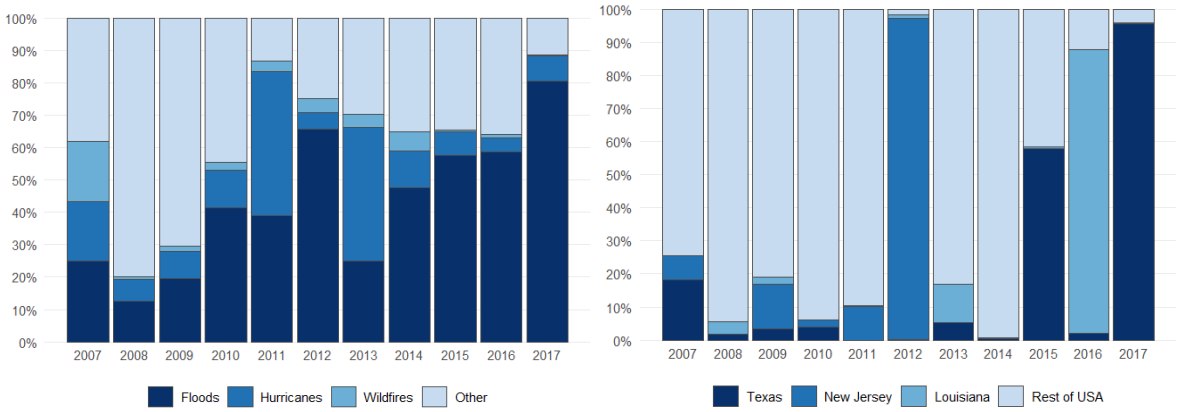
*Table 2: Staggered DiD Results. Notes: * p < 0.05, ** p < 0.01, *** p < 0.001. Standard errors are robust to heteroskedasticity.*



Figures 1 & 2: Mortgage Approval Rate (Transactions, %) (L); Share of Mortgage Lending (Loan Amount, %) (R) (Data Source: Author / HMDA).



Figures 3 & 4: Purpose of Mortgage Undertaking (Loan Amount, %) (L); Total Property Damage by Event (USD bn) (R) (Data Source: Author / HMDA / NOAA).



Figures 5 & 6: Total Property Damage by Event Type (%) (L); Total Flood-Related Property Damage by State (%) (R) (Data Source: Author / NOAA).