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Working Paper 23-05

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Abstract

In this paper, we survey a growing body of academic research at the intersection of climate risks, housing, and mortgage markets, with a focus on the United States. With near unanimity, climate scientists project disasters to increase in frequency, severity, and geographic scope over the next century. While natural hazards, such as hurricanes, riverine flooding, and wildfires have historically posed risks to regional housing markets, the systemic risk that climate change may pose to housing and mortgage markets is of increasing concern. To understand the components of systemic climate risk, we survey existing work relating physical and transition risks to mortgage and housing markets, including both single-family and multifamily segments. Our review of physical risks addresses price, loan performance, and migratory effects stemming from flooding, wildfires, and sea level rise. In surveying transition risks, we discuss papers on energy use and decarbonization as they relate to real estate. Where possible, we explain how these topics may intersect with housing affordability and sustainability, especially for historically disadvantaged communities. We conclude by drawing attention to critical areas for research into flood and other climate-related perils likely to pose significant challenges for real estate in the coming century.

Keywords: climate change · hazard risk · sustainability · affordability

JEL Classification: C5 · E3 · R1 · R3

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1. Introduction

Considerable climate-related risk exists for the world's largest asset class: real estate. One major risk channel is the increasing frequency and intensity of natural disasters. Declines to property values can occur both from realized disaster damage as well as an increased probability of disaster damage. This, in turn, could increase the probability of borrower delinquency, particularly if the borrower lacks appropriate insurance coverage. Another risk channel is that of intensifying chronic stressors like sea level rise (SLR) and drought. It is unlikely that housing markets have fully capitalized the risk associated with these longer-term events due to uncertainty over their precise impact; who will bear the burden of updated beliefs remains an open question.[1] Yet a further risk channel stems from adaptation measures to and mitigation polices against climate change. As governments introduce policies to steer polities toward reduced carbon emissions, communities are likely to experience shocks to labor markets and public services that will ultimately spill over into real estate markets. In sum, the future of housing is intrinsically linked to climate change.

The magnitude of the costs imposed by climate change on real estate markets is subject to a bevy of natural processes for which considerable variance exists in long-term projections as well as policy choices endogenous to those processes. That said, the National Aeronautics and Space Administration reports that Earth is already experiencing sea level rise and more intense heat waves; in addition, severe weather damage will also increase and intensify.[2]. By 2050, scientists anticipate sea levels to rise by one foot on average along the U.S. coast. The Gulf Coast is expected to see the greatest amount of SLR, ranging from 14 to 18 inches. By 2100, assuming that economies continue on their "business-as-usual track," SLR may reach two feet on average for U.S. coastlines. The spread between one and two-feet of SLR could then mean the difference between certain communities being inhabitable and uninhabitable.[3] Then, the extent of the potential future climate-related damages in tandem with market participants' discount rates will influence the course and path of real estate adaptation. For example, some housing markets may adapt to greater flood risk by relatively less costly investments like improved drainage or sump pump installation. Other regions may require

[1] As one example of research exploring this topic, Gourevitch et al. (2023) find that the portion of the U.S. housing market exposed to flood risk is overvalued by approximately $121-237 billion due to unpriced flood risk, depending upon the discount rate used. Furthermore, low-income households are the most at risk.

[2] For further details, see https://climate.nasa.gov/effects/

[3] For further details on SLR, see NOAA's 2022 Sea Level Rise Technical Report at https://oceanservice.noaa.gov/hazards/sealevelrise/sealevelrise-tech-report.html. In this paper, we discuss SLR projections in greater detail in Appendix A.

relative costly investments like structure elevation or even consider strategic retreat. If market participants discount the future to a greater extent, individuals may be less willing to invest in adaptation or relocation measures.

Insurance and perceptions are two other factors that will likely influence whether and how quickly climate change is capitalized into real estate markets. First, insurance currently plays a vital role in limiting mortgage market losses from natural disasters. However, rising insurance costs or insurance market failures can depress property failures in affected areas. Second, beliefs about climate change risk are likely to feed into insurance take-up. In addition, market participants, inclusive of both consumers and lenders, are likely to update their beliefs at different rates given baseline perceptions. This too, is likely to influence the evolution and characteristics of regional market equilibria.

Given the complications associated with climate change and its influence on housing and mortgage markets, let alone asset markets in general, we make certain restrictions to our scope.[4] First, we largely focus our attention on the U.S. housing and mortgage markets as it constitutes the context for most of the work at the intersection of climate change and real estate, although we do point out international findings when applicable. Second, our primary focus is on residential real estate, although we do discuss commercial real estate literature as it applies to multifamily housing markets.[5] By limiting our scope, we hope to gain both the breadth and depth useful to non-technical and technical audiences interested in these markets.

As we cannot summarize this vast literature in a few sentences, we highlight three stylized findings from the research here.[6] First, within the physical risk literature, evidence points to

[4]For more recent general surveys of the climate change and natural disaster literature, see Botzen et al. (2019), Dell et al. (2014), and Canals-Cerda et al. (2021). Additionally, Kousky et al. (2020a) have provided an excellent survey of the flood risk literature. We build on these with a focus on housing and mortgage markets, while also considering natural disasters other than flooding. Most related to our work is Schuetz (2023), although their focus is on household decision making in general rather than housing and mortgage markets specifically. Readers interested in modeling, asset classes other than housing, and general research themes may find Brunetti et al. (2022), Dennis (2022), Giglio et al. (2021a), and Hong et al. (2020) of interest.

[5]A companion piece focused on commercial real estate and how climate change impacts may differ between residential and commercial real estate would be fruitful. However, the commercial real estate literature is relatively less developed at the time of writing, so we leave it to future work to summarize developmentsin that space.

[6]The next section defines these risk terms used here more precisely.

a price discount from disaster risk which varies over time. This is true for both flooding and wildfires, two of the most commonly studied disasters in housing. However, studies find that information, whether from recent damages, other storms, or disclosures, plays a key role in the salience of disaster risk and therefore the existence and size of the discount. In turn, heterogeneity in information and affordability may lead to equity concerns. Second, studies on acute risks show that mortgage performance suffers after a damaging event. However, impacts on mortgage performance may be short lived due to insurance and disaster aid.[7] This finding highlights the need for research on the sustainability of insurance in the face of increasing frequency and severity of acute events. Third, energy efficiency ratings are associated with a price increase for single-family properties, but disagreement exists on whether that translates to better mortgage performance.

While the three key findings we describe above are deep and policy-relevant insights into how climate change will influence real estate markets, they should also make evident how fruitful a climate-related real estate agenda will be in coming years. One of the most critical outstanding needs is an estimation of the longer-term burdens of climate change for real estate markets. Risks like drought and heat stress are difficult to study due to their extended time horizon, but may be among the most costly and impactful for real estate. Furthermore, in the transition to carbon neutrality, local economies dependent on carbon intensive industries may be harmed; however, identifying those regions and plausible adaptation strategies remains challenging. Importantly, how the risks of climate change and natural disasters may influence housing affordability and sustainability, particularly for disadvantaged and vulnerable communities, remains both an overarching concern and a pressing, open (and difficult) question.

Our paper proceeds as follows. To orient the reader, we begin with a review of the basic terminology of climate change and natural disaster risks. In an appendix, we briefly review the scientific consensus on climate science, as well as international and domestic responses by

[7] Ultimately, flooding and SLR receive the bulk of researchers' attention due to the relative destructive nature of flooding on property markets and available data. The Federal Emergency Management Agency (FEMA) and the National Oceanic and Atmospheric Administration (NOAA) make their data on flooding, SLR, precipitation, and hurricanes publicly available at a relatively fine geographic level. Some of the most frequently publicly used datasets are FEMA's data on disaster declarations, assistance programs, and the National Flood Insurance Program (https://www.fema.gov/about/openfema/data-sets), NOAA's SLR data (https://coast.noaa.gov/slrdata/), NOAA's precipitation and temperature data (https://www.ncei.noaa.gov/cdo-web/datasets), and NOAA's hurricane track data (https://www.nhc.noaa.gov/data/).

governments and financial regulators for readers who are interested in background information. The bulk of our paper surveys the peer reviewed academic literature. We first consider physical risks, grouping papers into themes largely corresponding to the outcome variables of interest for the literature to date: price effects, migration, mortgage performance, and insurance take-up. Second, for risks related to the transition to a low-carbon economy, we focus our review on two of the most relevant and developed areas: energy and pollution. In our discussion of physical and transition risk, we highlight where authors find disproportionate effects on vulnerable communities. Finally, we conclude with directions for future research.

1.1 Climate Risk Definitions

Texts produced by private industry, public agencies, and academics alike use the jargon of climate scientists, many of whose definitions may not be apparent to the lay reader.[8] Accordingly, we state and define the vocabulary most relevant to understanding the research we present in subsequent parts of our literature survey.

Especially important to conceptualizing threats posed by climate change to real estate markets are the terms "physical risk" and "transition risk". According to definitions given by the Basel Committee on Banking Supervision (BCBS), which agree with those of the Task Force for Climate Related Financial Disclosures (TCFD), *physical* risks are the "economic costs and financial losses resulting from the increasing severity and frequency of extreme climate change-related weather events or extreme weather events (heatwaves, landslides, floods, wildfires and storms)." BCBS divides physical risks into "acute" and "chronic" categories. Acute physical risks are extreme weather events including "heatwaves, landslides, floods, wildfires, and storms." Chronic physical risks refer to "longer-term, gradual shifts of the climate (changes in precipitation, extreme weather variability, ocean acidification, and rising sea levels and average temperatures)."[9] Meanwhile, BCBS defines *transition* risks as "the risks related to the process of adjustment towards a low-carbon economy." As TCFD points out in its Final Report on the Recommendation of the Task Force on Climate-related Financial Disclosures, transition risks can include policy and legal risks, technology risks (new technology displaces old technology, leading to potential disruptions), market risk (changes in demand and supply for commodities, etc.), and reputation risk.

[8] See the Basel Committee on Banking Supervision's April 2021 publication: "Climate-related risk drivers and their transmission channels" (https://www.bis.org/bcbs/publ/d517.pdf) for a glossary of the most common definitions.

[9] BCBS also notes that there exist indirect physical risks such as "loss of ecosystem services (e.g., desertification, water shortage, degradation of soil quality or marine ecology)."

Distinguishing between physical and transition risks matters, particularly when one considers optimal policy responses to each. Given the above definitions, physical risks are best conceptualized as the totality of negative impacts from more frequent and stronger natural disasters and longer-term climatic shifts. For our purposes, physical risks encompass many of the common risks present in the popular imagination, including direct property damage and loss of collateral value, increases to defaults and foreclosure, and negative health consequences up to and including loss of human life. In contrast, transition risks encompass the consequences of economic shocks associated with shifting to a carbon-neutral economy. For example, as demand for coal wanes, residents in coal-producing communities may be negatively impacted by lower home prices, among other things, if (all else equal) the demand for housing in these areas also decreases due to potential labor market shocks.

Our summary focuses on the financial aspects of physical and transition risks that impact homeowners, lenders, and financial entities. The scope of our work does not consider in any detail the well-founded concerns about loss of human life. We also acknowledge that our scope is limited by there being fewer papers on transition than there are on physical risk. Throughout our survey, we will specifically note areas of the literature that are especially early stage.

2. Physical Risks

To date, physical risks are the focus of the literature on climate-related risks to housing. We begin our survey with Section 2.1, which describes research on discount rates and how they may be affected by climate change. In Section 2.2, we review papers that study the price effects of physical risk from both wildfires and floods. In addition, we explore heterogeneity in the flood risk literature through a meta-regression and investigate the role of beliefs and perceptions. Beyond price effects, we review migration and climate risk incidence in Section 2.3, mortgage performance in Section 2.4, and disaster insurance in Section 2.5. Our physical risk survey concludes with Section 2.6, an underdeveloped sub-literature on other chronic risks; in particular, we draw attention to opportunities to relate Atmospheric Hazards and Temperature Volatility to housing-related outcomes.

We have, in Sections 2.2.1, 2.2.2, 2.2.3, and 2.4 created tables that present, what, in our view, is the headline estimate from a paper. We want to emphasize that the studies that we reference in these tables differ in their empirical strategies, their geographic contexts, and in some cases their independent and dependent variables. While we hope that these serve as future references to the reader and enable quick takeaways of effect magnitudes, we also want to emphasize that by no means should these selected effect sizes be interpreted as generally comparable.

2.1 Climate Discount Rates

Give the significant yet uncertain consequences of climate change for asset markets, it is appropriate to begin our physical risk survey with a discussion of discount rates. Several theoretical and philosophical papers discuss the deeper ethical and conceptual issues; although we will not discuss the arguments or conclusions of any of these papers, we will point the interested reader to some useful papers from which to join the conversation (Gollier and Hammitt, 2014; Dasgupta, 2008; Caney, 2009). Suffice it to be said that there is disagreement on practical and ethical grounds as to whether climate discount rates should be decided by market rates or by some social welfare calculation (Greenstone et al., 2013).[10] More recently, Rennert et al. (2022) discuss discount rates in relation to the social cost of carbon. We recommend also reviewing the Office of Management and Budget's (OMB) recommendations and discussions for governmental use of discount rates.

The standard approach, as explained by Newell and Pizer (2004), is to use a single discount rate like 4% (the calculated average rate of government bonds over the past 200 years at the time of writing). Instead, the authors argue for lower discount rates in the future, stating that government bonds will plausibly yield 2% - 7% in the future, and that over a longer-time horizon bond yields will likely be at the lower end of the proposed range (and will be more uncertain). Similarly, Gollier and Hammitt (2014) also argue for discount rates depending upon length to maturity with a range of 1-4% range. The paper also points out differences in approaches and ranges across governments of different countries. Similarly, building off of the classic Ramsey discounting formula (Ramsey, 1928), several papers have argued for a declining climate discount rate using an expected net present value framework (Arrow et al., 2014; Freeman et al., 2015). To summarize these various approaches, Drupp et al. (2018) survey experts on social discounts; they find that 92% of experts place the discount rate in the 1% - 3% range with a mean of 2.3%. The papers notes that this is lower

[10]See also Fleurbaey and Zuber (2012) for an excellent discussion; they ultimately argue for a social welfare approach. The authors find different discount rates both for different social welfare criteria (equally distributed, average utilitarian, etc.) and for different time horizons. Goulder and Williams III (2012) offer a similar discussion with their distinction of 'social-welfare' discount rate versus 'finance-equivalent' discount rate analysis.

than rates reported in previous studies, although this does not comport with the IPCC's conclusion that "a broad consensus for a zero or near-zero pure rate of time preference" exists among experts. Importantly, the survey points out disagreement between the relative weights assigned to normative versus positive approaches; 62% of researchers use normative justifications for their analysis.

As with the broader literature, the debate on a climate discount rate for real estate has not achieved consensus. Part of the continuing debate may be due to ethical considerations not easily captured by economic or financial models. That said, how climate change can change the discount rate for real estate is of importance to originators; Giglio et al. (2021b) suggest the use of downward-sloping term structure of discount rates. Noting that housing is a risky asset, they argue for lower long term discount rates relative to a constant discount rate of 6% using the average rate of return. The intuition is straightforward: after a disaster strikes, short-term cash flows are riskier due to lag in recovery and resiliency efforts. Hence riskier short-term cash flows are discounted at higher rates than their longer-term equivalents.[11] Gourevitch et al. (2023) illustrates the importance of discount rates for cost/benefit analysis and consequent policy decisions. Consistent with papers we will discuss in Section 2.2.1, they find that U.S. home prices do not capitalize flood risk in its entirety. Specifically, they estimate the extent of the overvaluation in U.S. real estate markets relative to particular discount rates. Under a 'mid' hazard scenario, with a 3% discount rate (the authors' preferred value), properties are overvalued by $187 billion. However, under the same scenario with a 7% (1%) discount rate, properties are now overvalued by $121 ($237) billion. The range of imputed discount rates reflects their sensitivity to modeling assumptions.[12]

In summary, there is an active and vibrant debate centered around the appropriate climate discount rate. The discussion involves theoretical and ethical considerations, some of which may lie outside the scope of economics. Aside from these issues, several papers point out more technical considerations one must consider when doing net present value calculations including the uncertainty of future rates. Some researchers advocate for the use of time-varying discount rates. We stress again the important contribution of Giglio et al. (2021b)

[11]Interestingly, they find that the discount rates for climate *abatements and investments* for climate risk has an upwards-sloping shape, opposite of that for discount rates for housing, though the absolute value is still quite small below the risk free rate for all time horizons.

[12]For example, Foltyn-Zarychta et al. (2021) estimate social discount rates under a variety of models using Polish data and find a wide range, sometimes including negative numbers. They point out the range of discount rates is sensitive to the length of data used as well as tax status.

who connect housing returns to discount rates. We believe this is likely a fruitful area of research for those interested in taking the climate-adjusted discount rate debate to the housing and mortgage market literature.

2.2 Price Effects

Because of the unique characteristics surrounding each type of physical risk, whether they be acute or chronic, it can be challenging both to identify and interpret an amalgamated "risk" price effect. Understandably, the research that has attempted to do so has found mixed results; for example, Dillon-Merrill et al. (2018) find that natural disasters permanently increase housing rents, while the effects on housing prices are ambiguous. Meanwhile, Athukorala et al. (2019) use data on Australian flood and wildfires and find evidence of price decreases, even for homes that were not directly damaged. Similar ambiguity exists over physical risk price effects for commercial properties, especially concerning their permanence and magnitude (Clayton et al., 2021). From a global standpoint, Apergis (2020) takes a sample of natural disasters and house prices across 117 countries over the 2000-2018 period and finds that natural disasters tend to lower prices, with geological disasters having the greatest impact on price.

Magnifying complications with estimation of a general effect is the underlying role of migration and sorting. Boustan et al. (2020) use all federally designated disasters from 1920 to 2010 and find, in a county-level analysis, that after a severe disaster, out-migration rates increase by 1.5 percentage points and (median) housing prices/rents decrease by 2.5–5.0%. [13] Similarly, Dillon-Merrill et al. (2018) argue that disasters may compel mid and low-income households to transition from homeownership to renting while wealthy households do the opposite. Overall, they find that post-disaster homeownership rates fall, particularly after a flooding event in areas without required insurance. Consistent with these heterogeneous effects is a phenomenon that Thompson et al. (2023) call *climate gentrification*, which they define as "a socioeconomic process whereby homebuyers, investors, and thereby flows of capital favor certain places over others because value is attached to characteristics that make properties more resilient to physical climate hazards." The idea is that climate gentrification can compound the effects of traditional gentrification for vulnerable households.

Ultimately, as the vast majority of papers in the literature study individual events or physical

[13] In earlier work with related coauthors, Boustan et al. (2012) finds evidence of differential migration effects by type of disaster.

risk types, we organize this section accordingly. In particular, we believe it is useful to distinguish the effects of flooding damage from actue events like hurricanes from longer-term, chronic events like sea-level rise. While both are sources of flooding, the differing time lines suggest the consequences on housing and mortgage markets may be treated differently. In Section 2.2.1, we discuss price effects of flood risk on residential and commercial properties. We proceed in Section 2.2.2 to review the price effects of wildfire risk, an increasingly salient risk for real estate markets due to increasing overlap of wildfire-prone areas with densely populated municipalities. Section 2.2.3 investigates the role of beliefs in the rise of price effects; climate perception papers concerned with capitalization of flood risk typically use SLR as a source of variation because of the longer time horizon over which this type of flood risk will manifest and the uncertainty surrounding its ultimate extent. Last, section 2.2.4 presents the results of a meta-regression on the estimated effects of selected recent peer-reviewed work to gain insights into where heterogeneity may be arising across research studies.

2.2.1 Flood Risk and Home Prices

Given the overall size of historic damages from flooding, much of the focus of the literature relating acute physical risks to housing and mortgage markets has been on flood-related risks.[14] If flood risk is a disamenity known to buyers and sellers, then it is likely to be capitalized into the price of a home.[15] An abundance of papers have estimated such price discounts for homes located in a flood zone, where the risk is likely to be more obvious to buyers and sellers since flood insurance must be purchased for federal mortgages for these homes. It is not a trivial exercise to identify the discount strictly associated with increased flood risk; the final sale price of the home will likely encapsulate both a flood risk discount associated with flood risk and a mandatory insurance purchase discount.[16] Some papers that have done such a comparison of the flood discount with the net present value (NPV) of flood insurance premiums include Atreya et al. (2013), Bin et al. (2008), Bin and Polasky (2004), Harrison et al. (2001), Zhang (2016), and Zhang and Leonard (2019). The majority of papers find evidence of a price discount. However, there are mixed results as to whether

[14] NOAA's National Centers for Environmental Information (NCEI) has a dataset of U.S. Billion-Dollar Weather and Climate Disasters since 1980 (https://www.doi.org/10.25921/stkw-7w73).

[15] Though most of the focus of the literature has been on price effects, Turnbull et al. (2012) argue that flood zone status should also affect time on the market. They find that the extent to which risk is capitalized into price rather than a change in time on the market may depend upon the phases of the housing market cycle.

[16] For example, if an individual dislikes increased monthly bills due to mandatory flood insurance payments, we would expect a discount on a property even if the individual was indifferent to flood risk.

the discount is more, less, or equal to the NPV of flood insurance premiums among those that find such negative price effects, so that the direction of the implied risk premia remains subject to active debate. Table 1 of the estimated effect sizes of the papers we reference in this section.

Table 1: Flood Zone Price Discounts for Residential Homes

Authors	Year	Location	Obs.	Effect Size	SE	Table/Col.
Bin and Kruse	2006	North Carolina	4,342	-0.012	0.021	T3
Bin and Polasky	2004	North Carolina	8,375	-0.057	0.011	T3
Bin et al.	2008	North Carolina	3,106	-0.078	0.025	T3/Col(4)
Harrison et al.*	2001	Florida	29,981	-$1,034.38	535.95	T4/Col(3)
Kousky	2010	Missouri	153,185	-0.0386	0.0107	T2/Col(5)
Pommeranz and Steininger	2020	Germany	6,371	-0.012	0.0248	T4 Col(1)
Pope	2008	North Carolina	15,514	-0.042	0.023	T4/Col(3)
Shr and Zipp	2019	US	14,926	-0.1164	0.0556	T3/Col(5)
Yi and Choi	2020	Iowa	51,798	-0.189	0.076	T5/Col(2)
Zhang*	2016	North Dakota	28,154	-0.0434	0.0162	T3/Col(3)
Zhang and Leonard*	2019	North Dakota	13,513	-0.0489	0.0158	T3/Col(4)
Atreya et al.	2013	Georgia	8,042	-0.406	0.0923	T2/Col(3)
Atreya and Ferreira	2015	Georgia	2,685	-0.458	0.150	T6/Col(1)
Bin and Landry	2013	North Carolina	3,360	-0.423	0.226	T4/Col(3)
Bin and Polasky	2004	North Carolina	8,375	-0.046	0.020	T4
Fang et al.	2021	Florida	22,031	-0.045	0.017	T4/Col(2)
Gibson and Mullins	2020	New York	182,667	-0.121	0.0525	T1/Col(4)
Hallstrom and Smith	2005	Florida	5,212	-0.187	0.07	T3/Col(1)
Hino and Burke	2021	US	5,641,317	-0.0143	0.0082	TS3/Col(2)
Kousky	2010	Missouri	424,727	-0.0173	0.0131	T3/Col(5)
Muller and Hopkins	2019	New Jersey	65,626	0.126	0.0128	T7/Col(6)
Yi and Choi	2020	Iowa	51,798	0.284	0.132	T5/Col(2)
Zhang and Leonard	2019	North Dakota	1,062	-0.0819	0.065	T4/Col(1)

Notes: Papers in the top half of the table estimate what we would classify as a static flood zone discount, while papers in the bottom half of the table use a differences in differences approach to see how the flood discount changes over time, perhaps due to an information effect. For the latter group of papers, we report either the interaction effect or flood discount immediately after the event. We used 100 year flood zone, and also avoid terms with damages/inundation (to isolate direct effect of flood zone discount) wherever possible. *Harrison et al. (2001) report estimates in dollars, which is why the numbers are much smaller. To get an approximate percentage discount we add the dollar discount to the mean sale price for homes in flood zones, and then use this as a base price; this leads to a 1.46% discount. Zhang (2016) use a quantile approach, so to make their estimates more comparable with the literature we report only the single point esimate of the median. Similarly Zhang Lenonard (2019) estimate discounts that vary spatially, making a single point estimate difficult to report. We chose to report a baseline estimate of theirs for comparability to the literature, at perhaps risk of ignoring the focus of the paper.

Additionally, researchers have also studied how the flood zone discount varies across time and space, typically finding that the discount is greatest after a flood event occurs (Atreya et al., 2013; Bin and Landry, 2013; Kousky, 2010; Zhang, 2016; Zhang and Leonard, 2019). For example, Zhang and Leonard (2019) find that the price discount for homes in a flood zone (relative to similar non-flood zone homes) varies both spatially and temporally, ranging from 3.5-12.2% across their specifications. Bin and Landry (2013) also find evidence of a changing flood discount over time, ranging from 6-20%, with the largest discount immediately following the event. Using rich transactions data and NOAA data on storms that made landfall in Florida between 2000 and 2016, Zivin et al. (2023) find that prices actually increased after a hurricane in the first three years for homes in exposed areas. However, they find that the probability of a transaction occurring for a given parcel-year falls by 0.7 percentage points (7% of the baseline probability) in exposed areas. Their results suggest a temporary negative supply shock is driving up prices; i.e., the disaster reduces inventory while homeowners wait for aid and repairs to be completed, thus increasing the value of other homes being listed on the market.

Researchers have also attempted to disentangle the opposing effects of coastal amenities from flood discounts. For example, a home on the coast may be exposed to flood and SLR risk but yet also provide seaside views for which consumers are willing to pay a premium. Bin and Kruse (2006) find a 5-10% flood zone discount for inland homes in a coastal North Carolina county, but find price premiums for homes on the coast. They argue that the flood risk may be conflated with amenities. Muller and Hopkins (2019) also find evidence of price premiums in high risk areas, which they suggest could be driven at least partially by amenity effects. Thus, ex-ante it is not clear whether amenity effects or risk effects are the dominant factor, particularly when one considers how heterogeneous coastal amenities and risk preferences are likely to be. In this vein, Hino and Burke (2021) find that flood risk is not always capitalized into home prices, but it is more priced-in for more risk-aware buyers.

Researchers have also asked whether discounts vary across different types of homes, with flood zone status being the most common grouping.[17] Using data from the 1993 Missouri and Mississippi river floods, Kousky (2010) finds that properties inside of the 100-year flood zone showed no statistically significant changes to price. However, properties in the 500-year

[17] Future work could explore other definitions of housing submarkets for possible evidence of heterogeneous discounting.

flood zone (where flood insurance is not mandatory) were likely to experience a decrease in price, suggesting that individuals may update beliefs about flood risk after an event, though the paper did find evidence of diminished effects of a flood over time, implying these updated beliefs may be short lived. Similarly, Yi and Choi (2020) finds that after the great Iowa flood of 2008, homes that did not expect to be inundated experienced discounts. Moreover, for homes within the 100-year floodplain, inundated homes experienced no significant change in prices while homes that escaped damage saw large increases in price, again suggesting that perception of risk is an important driver of home prices. Interestingly, for homes in flood zones that did not see flooding, prices actually increased, which the paper explains as a price rebound effect also due to risk updating (homes are perceived as safer because no damages occurred). Using a quantile regression approach, Zhang (2016) finds that the negative impact of being in a flood zone is larger for lower-priced homes which diminished in magnitude over time.

Some papers study the effects of disasters on properties that were not themselves affected by the storm, i.e. neighboring and distant properties, as part of an identifying strategy to disentangle changes in risk beliefs from damages and other direct effects. Hallstrom and Smith (2005) find that after Hurricane Andrew, homes not damaged by the storm in a neighboring county that were in flood zones saw a 19% decrease in price relative to those (also undamaged) properties that were not in flood zones in the same county, suggesting that home buyers may update risk beliefs (and in different ways) after a major storm. Fang et al. (2023) use a differences in differences approach to show that homes in Miami-Dade County, FL were affected by the distant Hurricane Sandy (New York City). They find that while prior to Sandy homes in high flooding risk areas commanded a price premium of around 4% (perhaps due to offsetting amenities) relative to lower risk areas, after Sandy the premium changed into a time-varying discount. Similarly, using triple differences and New Jersey real estate data, Muller and Hopkins (2019) find that high flood risk homes in communities that participated in public flood awareness activities also saw a decrease in housing prices after a non-local shock (Hurricane Katrina), again presumably due to risk updating.

As may already be evident, many papers have exploited unexpected disasters as a proxy for belief updating. As mentioned earlier, Yi and Choi (2020) find evidence of price discounts due to damages and inundation, with homes facing "unexpected" damages seeing the greatest discounts. Cohen et al. (2021) use a differences-in-differences approach with data from

Hurricane Sandy to study the effects of both expected and unexpected flood risk in New York City. They find a short-run negative 'surprise' effect of 6%–7% per mile between the difference of the property distance to the flood zone and the distance to the actual locations of flooding for homes not expecting to be flooded (i.e., not in flood zones), although in the long run the effect vanishes. On the other hand, they find no evidence of a positive effect for homes in a flood zone unaffected by Sandy. Thus, their results suggest that market participants react to unexpected flood risk, though may "forget" the flood risk after enough time has elapsed. Using data from Dresden, Germany and a spatial hedonic model, Pommeranz and Steininger (2020) analyze direct price effects (i.e., flood zone status) and indirect price effects (i.e., spatial spillovers). While they find no evidence of direct effects, they do find statistically significant indirect effects of -6.5% for houses and -4.8% for condominiums. In a related vein, Atreya and Ferreira (2015) find that "seeing is believing"; inundated properties within a flood zone in Georgia were significantly more discounted than non-inundated properties within the flood zone. Their results point to the importance of not only beliefs, but actual damages.

Related to risk-updating, the literature studies how disclosing flood risk affects home prices as another channel by which beliefs are capitalized into home values. Pope (2008) uses a quasi-random experiment from a North Carolina law that required sellers to disclose the home's flood zone status and finds a 4.3% discount in home prices for homes in flood zones after disclosures were implemented with no evidence of a discount before the law was enacted. Relatedly, Troy and Romm (2004) take advantage of a newly introduced flood disclosure law in California to study the effects of newly disclosed risk on home prices. Their findings indicate a 4.2% discount was introduced for being in a flood zone, when no such discount existed before. Using a natural experiment when flood maps were changed, Shr and Zipp (2019) find that home prices decreased by 11% for homes newly assigned to flood zones. Gibson and Mullins (2020) study three different events related to belief updating: a reduction in flood premium subsidies from the Biggert-Waters Flood Insurance Reform Act of 2012, damages from Hurricane Sandy, and changes in floodplain maps for non-(Sandy) damaged homes. For impacted properties, they find discounts of 3-5%, 5-7%, and 11% for the different events, respectively, suggesting significant flood-risk belief updating is occurring.

The literature also looks at the direct effect of flooding and hurricane damage itself on home prices. In general, it finds a significant negative impact on properties that were either directly or indirectly affected (Fisher and Rutledge, 2021; Gibson and Mullins, 2020; Ortega and Taşpinar, 2018; Pommeranz and Steininger, 2020; Yi and Choi, 2020). Studying the housing market after Hurricane Sandy, Ortega and Taşpinar (2018) find long term price discounts of 8% for those homes not damaged but in flood zones. In contrast, for damaged homes they find large, immediate discounts ranging from 17-22% that decreased to 8% over time. Fisher and Rutledge (2021) study commercial properties and find a discount of around 25% over eight quarters for damaged properties when combining all property types together. Moreover, they find evidence of heterogeneity by building type, where apartment and retail buildings recover faster than other types (office, hotel, and industrial). Yet the literature is unresolved on exactly how long these damage discounts last, even for the same disasters. For example, Ellen and Meltzer (2022) also using data from Hurricane Sandy, finds initial 16% discounts followed by a 12% discount (relative to pre-storm levels) that lasts for 6 years for homes outside of flood zones, while discounts for affected homes in flood zones recovered quickly. The paper also finds evidence of discount recovery heterogeneity across income groups, with lower-income neighborhoods showing signs of slower (if any) recovery, leading to further decline.

In addition to Fisher and Rutledge (2021), Eichholtz et al. (2019) and Holtermans et al. (2022) also study American commercial real estate specifically. Analyzing commercial real estate in New York and Texas after Hurricanes Sandy and Harvey respectively, Holtermans et al. (2022) find a price decline for hurricane damaged areas and larger price declines for properties outside of the FEMA floodplain. The authors find that a decrease in occupancy rates is the primary driver of the post-Harvey discount in Texas; furthermore, pro-environment investors are likely to claim a larger price discount. Using data from Hurricane Sandy, Eichholtz et al. (2019) find evidence of long lasting (at least 5 years, until the end of their sample) negative price effects. They argue one possible mechanism is not a direct damage effect, but rather that higher risk premiums drive up capitalization rates, thus negatively impacting property values. Table 2 summarizes these results.

In summary, there seems to be general agreement that flood discounts exist, vary across location and type of home, and change over time, with the largest discounts occurring immediately after events. This suggests that changing risk perceptions, say after observing a storm or learning about newly disclosed flood risk-related information, may induce a price

Table 2: Price Effects of Flood Risk on Commercial Real Estate

Authors	Year	Location	Obs.	Effect Size	SE	Table/Col
Eichholtz et al.	2019	New York	2,109	-0.197	0.077	T4/Col(B)
		Massachusetts	1,358	0.084	0.032	T4/Col(B)
		Illinois	928	-0.004	0.048	T4/Col(B)
Fisher and Rutledge	2021	US	334,132	-0.259	0.075	T3
Holtermans et al.	2022	New York	10,359	-0.015	0.008	T2/Col(5)
		Texas	15,312	-0.035	0.008	T2/Col(2)

Notes: Effect size corresponds to the estimated log of price discount for real estate in that paper's "preferred specification."

discount for affected homes.[18] Many papers argue that disasters induce the greatest discounts when they are unexpected (e.g., homes not in a flood zone), arguing that risk beliefs are being updated. However, care is needed to separate the discount due to increased insurance premiums from a true risk-belief price discount. Insurance data seem to be particularly useful for this separation.

2.2.2 Wildfire Risk and Home Prices

High-risk wildfire states like California and Colorado contain much of the nation's housing value.[19] Per the EPA, between 1980 and 2021, the United States experienced 20 billion-dollar wildfire events; 16 of those 21 wildfires burned after 2000. This is in part due to an ever-expanding Wildland Urban Interface (WUI). Defined by the U.S. Fire Administration as the "line, area or zone where structures and other human development (meets) or (intermingles) with undeveloped wildland or vegetative fuels." Between 1990 and 2010, the WUI grew in size by approximately 33% to nearly 300,000 square miles. More than 46 million homes with an estimated market value of some 1.3 trillion dollars are in the WUI; some 99 million people

[18] These studies have shown that informed homeowners are more likely to respond and that direct and indirect experience with damages is one way real estate market participants learn. Homeowners and borrowers may learn about climate risks from a variety of sources. A recent national survey produced by Fannie Mae found that the most trusted source of information for flood risk is the government (63%), followed by insurance agents (18%) and family and friends(7%) (Mae, 2022). Relatedly, Cody et al. (2015) finds social media to be an important channel. More research is needed on how best to increase homeowner and borrower knowledge about climate risks.

[19] In 2021, Zillow valued California's housing market at 9.2 trillion dollars (21.3% of national housing value) and Colorado's at 1.2 trillion (2.8% of national housing value), making these states first and ninth in the nation by housing market value, respectively. (https://www.prnewswire.com/news-releases/us-housing-market-has-doubled-in-value-since-the-great-recession-after-gaining-6-9-trillion-in-2021–301469460.html).

reside in the WUI.[20] In summarizing the scientific consensus, the EPA notes that scientists have found that climate change is increasing the length of wildfire season and increasing the frequency of wildfires. Another concerning upward trend reflects the increases to the areas burned by wildfires. In the 1990s, wildfires burned an average of 5,200 square miles annually; in the 2010s, wildfires burned an average of 10,700 square miles annually.[21]

Table 3: Wildfire-related Real Estate Discounts

Authors	Year	Location	Obs.	Effect Size	SE	Table/Col
Hansen Naughton*	2013	Alaska	8,796	-0.057	0.030	T2/Col(4)
Loomis	2004	Colorado	504	-0.16	0.08	T1
McCoy and Walsh	2018	Colorado	88,518	-0.13	0.03	T2/Col(3)
Mueller Loomis*	2014	California	1,762	-0.2546	0.0248	TA1/Col(3)
Mueller et al.	2009	California	2,520	-0.09706	0.018	T4
Stetler et al.	2010	Montana	11,817	-0.137	0.03	T4/Col(1)

Notes: Effect size corresponds to the estimated log of price discount for real estate in that paper's "preferred specification." *Hansen Naughton (2013)'s effect shown is for small wildfires within 0.1km for the entire all sample; they also show that this discount starts at 7.6% for the first 5 years and then becomes statistically significant in the years after. Mueller Loomis (2014) take a quantile approach, so to make their numbers more comparable with the literature we have reported only the median point estimate.

Using hedonic analysis methods, researchers have generally found that homes in high-risk wildfire areas experience negative price shocks after a wildfire; however, this shock is transient and localized. Prices typically return to baseline levels two to three years after the fire. Loomis (2004) studies Jefferson County, Colorado and finds price drops of 15% in a community adjacent to a major wildfire event. In a literature review of the short-term price impact from specific wildfire events, Clayton et al. (2021) cites negative price drops of 10% for homes in Southern California (Mueller et al., 2009), 7% to 14% for homes in Montana (Stetler et al., 2010), and 6% to 13% for homes in Alaska (Hansen and Naughton, 2013). McCoy and Walsh (2018), studying the Colorado Wildland Urban Interface, consider how risk salience affects housing demand and prices. They find a 12.6% discount in the first year following a fire, with homes located within a 2-km radius of the fire experiencing more significant price reductions in subsequent years. Mueller et al. (2009) also finds that the home

[20] The definition of the WUI and the statistics that subsequently follow come from the 2022 US Fire Administration report. (https://www.usfa.fema.gov/downloads/pdf/publications/wui-issues-resolutions-report.pdf).

[21] 5,200 square miles is approximately the size of Connecticut; 10,700 square miles is approximately the size of Massachusetts.(https://www.epa.gov/climate-indicators/climate-change-indicators-wildfires).

price effect of a second wildfire is larger in magnitude than the first wildfire; furthermore, the two shocks are statistically distinguishable. Mueller and Loomis (2014) later extend the results to quantile regression. Table 3 recaps these studies.

Differences in the recoveries of wildfire-affected housing markets wildfire may be due to coordination externalities between jurisdictional building code regulations and insurance claim payouts. Issler et al. (2020c) study wildfires in California using a dataset on housing and mortgages from 2000 to 2018. They have two key findings. First, delinquencies and foreclosures increased in regions exposed to wildfires. Second, increases in delinquencies and foreclosures decrease in the size of the wildfire. They argue this decrease is likely due to positive coordination externalities that exist because of interaction effects between county regulations requiring home reconstruction to modern building codes and casualty-insurance covered losses. In conjunction, these two forces increase the value of homes after the fire. Additionally, affordable homeownership may suffer if lenders take note of these facts and restrict credit or impose stricter underwriting conditions for these higher risk loans, particularly if insurers withdraw from the market. Relatedly, Baylis and Boomhower (2019) point out that there may be implicit subsidies for building in wildfire-prone areas due to large public expenditures to mitigate wildfire damages. Thus, while such subsidies may help with affordable homeownership, they may be incentivizing individuals to live in areas with more wildfire risk.

Prospective homeowners may lack complete information about individual properties' wildfire risk.[22] In a study of wildfires in Colorado Springs, Donovan et al. (2007) find that before a ratings system to disclose fire risk implemented by the Colorado Springs Fire Department, fire risk and price were positively correlated, suggesting either that homebuyers were unaware of their properties' wildfire risk at time of purchase or that the risks were outweighed by amenities. However, after the ratings were created the relationship disappeared, suggesting risk beliefs were updated. In a follow-up study, Champ et al. (2009) identify evidence that homebuyers pay more for these homes because wildfire risk is associated with greater amenities.

[22] For example, Champ et al. (2009) issued a survey to Colorado Springs homeowners ($N = 430$). They find that "only 27% of the (homeowners) realized the house they were purchasing was in an area at risk of wildfire before making an offer on the home. Furthermore, 67% did not realize they had purchased in an area at risk of wildfire until after they moved into the home."

Beyond these topics, researchers can investigate second order, but still economically significant, wildfire effects on housing values. For example, one line of inquiry is the relationship between wildfires and air pollution.[23] Air pollution may increase in certain regions due to physical climate risks like wildfires, and we detail in Section 3.2.2, is generally considered a negative amenity for housing values. Furthermore, environmental economists have observed significant short- and long-term effects of air pollution on health.[24] For example, Lopez and Tzur-Ilan (2023) find that wildfire induced air pollution reduced both housing values and rents in Las Vegas. All told, the indirect effects of wildfires may have larger consequences for the long-term health of housing markets in wildfire affected geographies than the direct effects.

In summary, much of wildfire research has studied the direct consequences of wildfires on property values and migration. Future work would be wise to leverage more granular, property-level data. In addition, there are many outstanding inquiries on the implications of insurance market frictions or failures for property values and homeowners' abilities to get mortgages as well as the role of wildfire driven air pollution on housing markets.

2.2.3 Perceptions and Home Prices

Belief in the reality and significance of anthropogenic climate change appears to influence the existence and magnitude of real estate discounts; this is especially salient for American real estate markets, given the vast geographic heterogeneity in climate change perceptions (Howe et al., 2015). Considerable variation exists along coastlines, which presents a challenge for capitalization of chronic flooding risk. The latest Sea Level Rise Technical Report, an interagency effort to synthesize the latest science on sea level rise (SLR), projects that relative sea levels along the continental U.S. will rise as much between 2020 and 2050 as they did between 1920 and 2020.[25] This additional SLR will shift coastal flooding patterns. Major and moderate high tide flood events will occur as frequently as moderate and minor events occurs today. Without additional adaptation and mitigation measures, tens of millions of Americans living in coastal communities will be negatively affected. For example, using a structural model to capture the importance of dynamic adaptation, Desmet et al. (2021) argue that

[23] The EPA presents a summary of the air pollution/wildfire relationship: https://www.epa.gov/wildfire-smoke-course/why-wildfire-smoke-health-concern.

[24] Using changing wind direction, Deryugina et al. (2019) find that that mortality effects are concentrated in about 25 percent of the elderly population

[25] The reader can access the full technical report at https://oceanservice.noaa.gov/hazards/sealevelrise/sealevelrise-tech-report.html.

under an intermediate greenhouse gas scenario, the resulting permanent flooding is projected to reduce global real GDP (0.19%) and reduce welfare (0.24%) as coastal populations decline due to a reduction in local amenities. Additionally, they estimate that losses in coastal areas are more than an order of magnitude larger, suggesting important spatial heterogeneity in the effects of SLR on productivity and welfare.

Table 4: SLR-Related Real Estate Discounts

Authors	Year	Location	Obs.	Unit	Effect Size	SE	Table/Col
Baldauf et al.	2020	US	11,538,986	Property	-0.004	0.035	T3/Col(5)
Bernstein et al.	2019	US	130,685	Property	-0.066	0.015	T2/Col(4)
Filippova et al.	2020	New Zealand	8,436	Property	-0.002	0.02	T2/Col(1)
Fu and Nijman	2021	Florida	77,454	Property	-0.12	0.02	T4/Col(1)
Keys and Mulder	2020	Florida	771	Tract	-0.036	(.000)	T2/Col(1)
Murfin and Spiegel	2020	US	4,292,176	Property	-0.003	0.003	T2/Col(1)
Tyndall	2021	New York	164,026	Property	-0.014	0.004	T2/Col(1)

Notes: Effect size corresponds to the estimated log of price discount for real estate in that paper's "preferred specification." Keys Mulder (2020) reports a p-value instead of a standard deviation.

Since some SLR has already occurred, retrospective studies can benchmark future damages. Many papers have shown SLR-exposed areas are associated with negative price effects (McAlpine and Porter, 2018; Tyndall, 2021; Bin et al., 2011). Keys and Mulder (2020), studying coastal Floridian real estate between 2013 and 2020, use multiple matching estimators to identify a decline in home sales volume among SLR exposed areas, with a delayed lag in relative prices of around 5%-10% below trend. The authors reconcile these findings by proposing that prospective buyers are more pessimistic about climate change risk than sellers, enabling a lead-lag relationship in volumes and prices. Using a high-dimensional fixed effects model, Bernstein et al. (2019), studying 460,000 coastal residential property sales across the United States, identify a 7% discount for SLR exposed homes relative to similar properties equidistant from the beach. They note that the discount is growing over time and is catalyzed by prospective buyers who are concerned about climate change. Consistent with SLR as a long-term chronic risk, the discount for coastal properties exists only in home sales and not in rental rates. Baldauf et al. (2020) find discounts for homes in areas where more residents believe in climate change relative to climate change deniers, which suggests that home prices reflect heterogeneity in beliefs in long-run climate risks.[26] Calibrating a structural model of housing choice to Zillow transaction data, they conclude that homes in climate change "believer" neighborhoods sell at a 7% discount relative to homes in "denier" neighborhoods. Bakkensen and Barrage (2022), implementing a door-to-door survey in Rhode Island to quantify a dynamic housing market model, estimate that coastal prices can exceed fundamentals up to 13% in their baseline area under a business-as-usual climate change scenario. The authors also extend the analysis to other cities, arguing that the Rhode Island estimates are likely conservative. Nearly 40% of surveyed residents in flood zones responded that they were "not at all" concerned about flooding over the next decade. Botzen et al. (2015) find that households overestimate tail risk probability but underestimate potential damage; this leads to underinvestment in adaptation measures. Fu and Nijman (2021) also find evidence of discounts for SLR exposure, though not at every exposure level. Further, they find evidence that owner-occupiers and investors may discount properties differently. These papers speak to the importance of belief heterogeneity for stakeholders and policymakers in building climate resiliency in real estate markets. Further, rich data on beliefs about climate seem promising for future lines of inquiry. We present estimated effects for these papers and others in Table 4.

On the lending side of the market, Bakkensen et al. (2023) find that climate change pessimists (i.e., those that believe more in the negative future consequences associated with climate change) are more likely to leverage and use longer maturity debt to finance property purchases. They verify their theoretical model, which stresses the importance of belief heterogeneity with respect to lenders and borrowers, with real estate data from the Atlantic Coast from 2001 to 2016.[27] They also estimate a SLR discount of around 6%, though as they point out this varies depending upon the buyer's climate beliefs. Nguyen et al. (2022) find evidence of a SLR premium on mortgage interest rates, though only for longer-term loans. Interestingly, the extent of the premium varies with climate beliefs and saliency. Thus lenders may already be thinking about longer-term climate risks.

Nonetheless, there is not total unanimity that flood prices are capitalized even in climate

[26] They develop a model of housing choice with homophily to explain their results. In their model, agents can be either believers or deniers, where believers attach a larger probability to a climate-related event happening than do deniers.

[27] For another recent framework for leverage choice when lenders and borrowers have different beliefs, see Bailey et al. (2019).

pessimist communities. Murfin and Spiegel (2020), using vertical land motion to tease out the unique effect of SLR on home prices, find strong statistical evidence of zero price effects. They argue differences in how SLR is measured may drive their results.[28] Palm and Bolsen (2022), surveying real estate agents, report that agents seemingly believe flood insurance concerns to be more salient in the minds of prospective buyers than SLR risk itself. Though not studying SLR directly, Atreya and Czajkowski (2019) use data from Galveston, Texas to show that there may be a price premium associated with being in a high-risk area on the coast, to which the authors attribute competing amenity values as a possible explanation. Other papers find little or positive effect of SLR on prices (Conyers et al., 2019; Filippova et al., 2020).

In summary, it appears that while SLR-exposure is typically associated with price discounts, amenity effects for SLR-exposed areas may lead to price premiums. On the lender side of the market, we see some evidence for higher long-term rates for borrowers, suggesting affordable homeownership in these areas may be more difficult in the future.

2.2.4 Meta-Analysis of Selected Empirical Work

We have presented dozens of studies concerning the price effects of natural disaster risk on real estate, each of which differ in their geographic context, estimation strategies, and sample characteristics. While we have attempted to qualitatively synthesize these results, a quantitative summary requires the use of meta-analysis. Previous meta-analyses have sought to summarize the entire body of the flood risk discount literature at the time of their writing; see, for instance, Daniel et al. (2009) and Beltrán et al. (2018). Space and scope constrain us from undertaking a full-fledged meta analysis as the aforementioned studies; our goal in this subsection is to benchmark recent empirical work to previously established rules of thumb and to quantitatively understand patterns in effect sizes across geographies and study designs.

We will briefly summarize the principal findings of the two past floodplain discount meta-analyses. First, Daniel et al. (2009) compile 117 estimates from 19 empirical studies. Using meta-regression to explore heterogeneity across study designs, they propose a price elasticity of flood risk to be -0.6. Beltrán et al. (2018) update and build upon the Daniel et al. (2009) estimate; following identical inclusionary criteria to the previous meta-analysis, their meta-sample includes 349 estimates from 37 studies. As we have discussed previously, estimates

[28] They also note the potential role of differences in beliefs and the role of (lack of) knowledge as well.

of flood risk discounts vary greatly; Beltrán et al. (2018) include effect sizes ranging from -75.5% to 61% in their analysis. Yet, after adjusting for 18 moderator variables across 6 groups–flood risk perceptions, flood risk, study context, study control variables, econometric model characteristics, and study characteristics–they find that the price discount associated with location in a 100-year flood zone is -4.6%. In exploring how their estimate is nearly an order of magnitude greater than that from Daniel et al. (2009), Beltrán et al. (2018) find that studies related to coastal flooding are responsible; including only inland studies closes the gap substantially. The authors further argue that studies estimating coastal flooding risk are especially subject to publication bias and suffer from omitted variables bias related to coastal amenities.

Here, we present the results of a more limited exercise than either Daniel et al. (2009) or Beltrán et al. (2018): we use meta-analytical methods to pin down a point estimate for flood risk using 11 effect sizes that we source from 11 peer-reviewed works in premier finance, real estate, and environmental economics journals.[29] From those journals, we identified 11 papers published in the last 10 years addressing flood risk discounts on real estate. We select our age restriction to enable the estimates in our meta-sample to reflect recent methodological advances in applied empirical economics. Within each paper, we selected the coefficient that, in the view of the authors of this literature review, struck the best balance between the preferred estimates of the cited paper and comparability with other coefficients in the meta-sample.[30] While we acknowledge the limitations of our meta-analysis and the subjectivity involved in the construction of the meta-sample, we believe it yields useful insights as to the mean of the distribution of true flood risk discounts and factors that contribute to heterogeneity in estimates across studies.

We begin by presenting a forest plot of the 11 studies we include in our meta-sample in Figure 1. As they differ across their estimation strategies and populations of interest, we

[29]These journals are the Journal of Real Estate Research, the Journal of Real Estate Finance and Economics, Real Estate Economics, the Journal of Environmental Economics and Management, the Journal of the Association of Environmental and Resource Economists, the Journal of Financial Economics, and the Review of Financial Studies.

[30]It is for this reason the coefficient we include in the meta-sample for Zhang and Leonard (2019) is different than that the coefficient we present in Table 1. In the aforementioned table, our aim was the succinctly summarize preferred study estimates without invoking any sense of similitude across rows; here, the meta-analysis framework necessitates comparability across estimates. For Zhang and Leonard (2019), the authors' preferred estimate involved a dynamic interaction term that would have complicated its inclusion in the meta-sample.

estimate a random-effects model.[31] This model weights studies using their inverse error-variance, so that more precise studies are given greater weight in the calculation of the mean of the distribution of true effect sizes. Effect sizes range from a 12.1% discount in Gibson and Mullins (2020) to a 28.4% premium in Yi and Choi (2020); the raw unadjusted mean effect size is -2.1%. The large I^2 statistic of 92.4%, which implies that 92.4% of the variation in the estimated treatment effect by studies is due to heterogeneity in their design rather than by pure chance, further supports our choice of model. Ultimately, we estimate an average discount of 3.9%, which is consistent with the rule of thumb of -4.6% first proposed by Beltrán et al. (2018); in fact, both estimates lie well within each other's 95% confidence intervals. Notably, there is little overlap between our meta-samples; only Bin and Landry (2013) appears in both of our meta-analyses. This, in our view, further substantiates the defensibility of an average flood risk discount on the order of 4%.

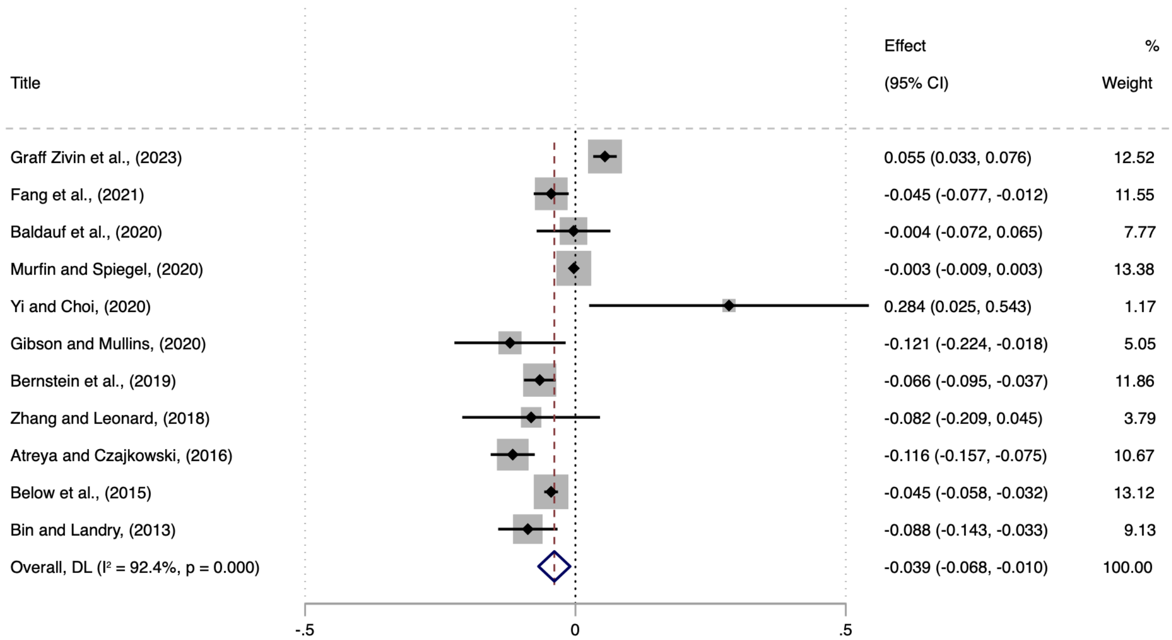
Next, to understand the moderating influence of study setting, risk type, and study design, we use meta-regression. We include three moderators as independent variables in our analysis. The first is a dummy variable for a study which exclusively uses real estate data from the state of Florida, which is the context for three of the 11 studies. At the time of the writing of this study, the value of Florida's real estate market was second only to California's on a state-by-state basis nationwide. In addition, eight of the fastest growing MSAs in 2022 were in Florida; of those, seven are coastal.[32] That Florida, in spite of its known exposure to disaster risk, continues to see such vitality in its real estate markets indicates that it possesses considerable amenity value; our inclusion of the Florida moderator aims to tease out this effect. Second, we include a variable for hurricane risk, which is the underlying source of flood risk for five studies. Hurricanes are by far the largest source of natural disaster risk and also garner the most media attention. Third, we include a moderator variable for the seven studies which use a quasi-experimental difference-in-differences estimation strategy; our aim is to test whether this approach yields substantially different results than more traditional hedonic frameworks using cross-sectional or panel data.

The results of the meta-regression largely align with our priors. In column 1, testing for the moderating influence of studies set in Florida, we find a directionally consistent, if

[31] A fixed-effects model would assume there exists a common effect size subject to sampling error across studies; we find this, in light of earlier discussion, implausible.

[32] These statistics come from the Zillow blog post at this link: https://www.zillow.com/research/most-valuable-housing-markets-32246/

Figure 1: Forest Plot of Flood Risk Studies



Effect size corresponds to the estimated discount for real estate where the dependent variable is the log of sale price for a single-family home. The authors selected effect sizes corresponding to estimates described by paper authors' as preferred, where possible. Weights correspond to the inverse of the variance of the effect estimate and reflect the representativeness of the study in the estimate of the average price discount. I^2 is the fraction of the total effect estimate variation that can be attributed to heterogeneity across studies.

Table 5: Meta-regression results

	(1) Effect Size	(2) Effect Size	(3) Effect Size
Florida	0.064	0.084*	0.085*
	(0.041)	(0.041)	(0.043)
Hurricane		-0.052	-0.099
		(0.038)	(0.088)
DiD			0.052
			(0.086)
Constant	-0.060	-0.041	-0.046
	(0.023)	(0.025)	(0.029)
N	11	11	11

Standard errors in parentheses. *Florida*, *Hurricane*, and *DiD* constitute dummy variables for whether the study used data exclusively from Florida, whether the source of flood risk came from hurricanes, and whether the paper used a difference-in-differences estimation strategy, respectively. $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

statistically insignificant effect that suggests the presence of Florida-specific amenities. In column 2, adding hurricanes as the source of flood risk further clarifies the matter–here, we see that hurricanes depress home prices more than other sources of flood risk–the point estimate is -5.2%–but that Floridian real estate actually dominates the hurricane effect, resulting in a face-value price premium. Lastly, in column 3 adding difference-in-differences as a mediator variable, we find similar effects for Florida and magnified effects for hurricane, although both the hurricane and DiD dummies themselves are insignificantly estimated. This indicates that quasi-experimental studies are not producing estimates that are too different from studies using multivariate hedonic regressions.

2.3 Migration and Vulnerable Communities

Flooding and hurricanes may also impact migration, and thus affect which types of individuals live in high-risk areas (Han and Ye, 2022).[33] Sheldon and Zhan (2019) find lower homeownership rates post disaster; this implies that certain individuals may be priced out of homeownership. Indeed, Dillon-Merrill et al. (2018) find that low- and middle-income individuals may be induced away from home ownership due to climate risk. One possible

[33] For a relatively recent survey of migration, see Berlemann and Steinhardt (2017)

explanation, as discussed previously, is that some homeowners lack information about flood risk, which is consistent with the finding that disclosures about flood risk may reduce home prices (Pope, 2008; Hino and Burke, 2021; Votsis and Perrels, 2016). Lower home prices may help ease affordability concerns, though this means households would be living in areas with higher flood risk.

However, there is not complete agreement about the demographics of those who move into high flood risk areas. Some research has found that low income and minority residents, as well as less affluent and less creditworthy borrowers, are more likely to move into a flood area (Bakkensen and Ma, 2020; Garbarino and Guin, 2021; Ratnadiwakara and Venugopal, 2020); Davlasheridze and Miao (2021) also find worse public housing outcomes after flooding events.[34] Ratcliffe et al. (2020) find further evidence of disproportionate effects of disasters on credit scores and delinquencies for various sub-populations including low income, low credit score, and minority communities.[35] Fan and Davlasheridze (2016) find that age, ethniticity, race, educational attainment, and prior risk exposure explain risk perception, which in term affects willingness to pay and location choice. Galster et al. (2022) use flood risk data from First Street Foundation to document racial and ethnic heterogeneity in flood risk exposure, finding evidence that Hispanics and Native Americans may be disproportionately exposed, though in 21 states non-Hispanic Whites have statistically significantly higher average exposure to flooding than non-Hispanic Blacks (and no states for the converse).

By contrast, other papers find null or positive correlations between income and post-disaster moves; some authors attribute political economic mechanisms. Zivin et al. (2023) find that buyers who move in after an event tend to have larger incomes, though they "conclude that there is no meaningful change to the overall racial or gender profile of buyers post-hurricane". Sheldon and Zhan (2022) find evidence of out-migration both within and between cities, with lower income households being less likely to move, particularly after disasters without much FEMA aid. Bernstein et al. (2022) finds evidence of partisan sorting, specifically homes exposed to SLR are 5 percentage points more likely to be owned by Republicans, but that

[34] Some international research agrees with these findings: Garbarino and Guin (2021), comparing repeated transactions around a major English flood in the winter of 2013-14, find that less creditworthy borrowers self-select into areas of high flood risk, though the UK lenders they study do not appear to capitalize flood risk revelations into their decision making.

[35] In their survey focusing on the effects of flooding and SLR on consumers and banks, Canals-Cerda et al. (2021) argue that while natural disasters may not always affect the average individual, vulnerable groups can experience significant increases in delinquency and bankruptcy.

no such gap exists for renters. Henkel et al. (2022) argue that disaster aid and relief after a hurricane may encourage economic activity to remain in exposed areas. They also argue that this may be driven by political concerns, as they find hurricanes close to election day are associated with larger local post-disaster efforts and increased population inflows into affected areas.

The magnitude of migration post-flood is subject to active debate. Fan and Davlasheridze (2019) use a dynamic computable general equilibrium model to argue that Hurricane Katrina is associated with a permanent loss in population and a 33.57% reduction in county-level gross regional product, arguing a "brain drain" occurred. Other papers have found varying sizes of migration out of disaster affected areas (Boustan et al., 2020; Strobl, 2011).[36] This suggests that migration results should be interpreted with caution; it is challenging to tease apart disaster-related effects from general economic trends. In particular, Fan and Bakkensen (2022) find evidence of heterogeneous household responses to hurricane risk: seniors, college graduates, individuals from states more frequented by hurricanes, and households with fewer children are less sensitive to hurricane risk. While they also find small overall migration changes in respond to projected future hurricane risk, some regions will gain relative population shares at the expense of others, pointing to the importance of spatial heterogeneity in this context.

The evidence for out-migration after wildfires is modest. Out-migration can reduce property tax revenues and hence public services. Consequently, affected areas may experience property value declines. Winkler and Rouleau (2021) find that wildfire or extreme heat events in one year are associated with lower net migration levels in the following year. Furthermore, Sharygin (2021), studying the aftermath of the 2017 Sonoma County fires, finds that only a small fraction (around 6% for one city) of the individuals displaced by the fire permanently left Sonoma County. Berlin Rubin and Wong-Parodi (2022), surveying 1,108 California residents, observe that 15.5% of individuals held a stated preference to leave their current residence in the next five years due to wildfire and smoke risk to some extent. Their model also suggest negative outcomes like wildfire evacuation, property loss, and health issues induced by wildfires may induce migration. An et al. (2023) finds that house prices decrease by 17% 6 quarters after the fire and that net out-migration increased by an additional 4

[36] Interestingly, as Billings et al. (2022) points out there was actually net in-migration to Houston in the year after Hurricane Harvey.

per 100 residents after a fire event. Similarly, McConnell et al. (2021) find evidence of out-migration (but not in-migration) for areas that experienced the largest effects of the wildfires.

It is possible that lender behavior may influence who moves into areas subject to disaster risk. Sastry (2022) finds that lenders screen for flood risk with the loan-to-value (LTV) ratio and not with interest rates. The paper also finds no evidence of credit rationing when lenders do not retain direct exposure to risk, i.e. if the value of the loan is less than the $250,000 maximum coverage that FEMA offers through the NFIP. As a result, the composition of borrowers is richer and higher-credit score, suggesting liquidity constrained borrowers are deterred from purchasing homes in flood zones. Thus even without raising interest rates, lenders' responses to flood risk may pose challenges for affordable homeownership. Several other studies have also looked at the behavior of lenders post disaster and generally find that local bank presence and concentration appears to matter for recovery and volume of lending (Cortés, 2014; Chavaz, 2016; Gallagher and Hartley, 2017). Using changes in flood zone maps to change flood zone status, Blickle and Santos (2022) find that the probability of a loan being accepted, and conditional on acceptance the size of loan, are smaller in flood zones, suggesting that lenders may restrict credit in flood zones, particulary for households with lower relative income and credit scores.[37]

Tangentially related to lending, Gete and Tsouderou (2023) find evidence that yield spreads of credit-risk transfers increase with exposure of natural disasters, suggesting that investors are already pricing in natural disaster risks.[38] The paper also finds evidence of substantial increases in mortgage default for those counties more frequently hit by hurricanes, up to 0.5 percentage points (a 70% higher probability of default).

An active debate exists over the existence of climate risk transfer from lenders to the government-sponsored enterprises (GSEs) Fannie Mae and Freddie Mac. Ouazad and Kahn (2022) contend that lenders are more likely to approve loans which conform to Fannie and Freddie guidelines after a hurricane; they argue that this is consistent with climate-risk be-

[37]Though not directly related to housing, Faiella and Natoli (2018) using loan data from Italy and find that evidence of a negative relationship between flood risk exposure and corporate lending.

[38]Credit-risk transfers are insurance agreements between investors and Fannie Mae/Freddie Mac, whereby the latter pays a regular premium and the former is responsible for payments on certain credit losses. See https://www.fhfa.gov/PolicyProgramsResearch/Policy/Pages/Credit-Risk-Transfer.aspx for more details.

lief updating among lenders who consequently transfer the burden to the GSEs.[39] Recently, Lacour-Little et al. (2022) responded with a critique of the paper, claiming that the paper's main empirical results are not robust to the correction of several coding and rounding errors, although they point out that such risk transfer and adverse selection could potentially occur in the future.[40] At time of writing, both sets of authors are actively responding to the criticisms of their counterparts through follow-up papers. We encourage the reader to keep abreast of this rapidly developing literature.

Taken as a whole, the previously mentioned papers are either implicitly or explicitly arguing that the reductions in credit and changes in lending standards may pose problems for affordable and sustainable homeownership. On the one hand, some borrowers may not be able to qualify for, or to afford, a home loan after a disaster due to changes in lending standards. On the other hand, households who choose to live in flood prone areas, perhaps because homes are cheaper due to a flood discount, may be incurring substantial flood risks (in addition to flood insurance premiums). Some papers have discussed managed retreat as one possible policy solution, whereby households are paid for their homes and no future construction in the area can take place (Hino et al., 2017; Hauer et al., 2020; Mach et al., 2019). Managed retreat and other public policy choices are sensitive issues that, in addition to traditional cost-benefit and economic considerations, are likely to require fairness and environmental justice considerations, among others.

In summary, it generally appears that minority, lower-income, and less-affluent communities are more likely to move into high flood risk areas, though there is some evidence that this may not always be the case. It could be the case that high-risk homes are more affordable for these communities, perhaps by the price discounts we have previously mentioned, though this comes at the cost of additional flood risk. Additionally, it seems that lending is more constrained in higher flood risk areas, where lenders are limiting the amount of credit to borrowers in these areas. This poses challenges to affordable homeownership.

[39] In related work, Keenan and Bradt (2020) argue that lenders who are locally concentrated may retain fewer mortgages (in SLR-exposed areas) in portfolio (i.e., sell more to GSEs on secondary market) relative to larger lenders with more diversified portfolios.

[40] The critique states that "there is no statistical evidence that lenders transfer climate risk by altering their loan origination and securitization behavior. Lenders could do so in the future, especially if climate risk becomes easier to estimate and/or worsens." See Lacour-Little et al. (2022) for more details.

2.4 Mortgage Performance

Researchers have sought to understand how disasters may affect mortgage markets and consumer financial health more generally. Some researchers have found an absence of evidence for lenders fully capitalizing climate risk into their decisions. Using NOAA's Stormevent data which includes multiple types of disasters, Dillon-Merrill et al. (2018) find applications for mortgage applications for low- to midsize-homes decrease; however, after a storm jumbo applications slightly increase. They do not find evidence consistent with changing lending standards after a disaster. Studying mortgage-holders, Ratcliffe et al. (2020) find single-family mortgage performance worsens; in addition, consumers' credit scores decline after natural disaster events. These effects are larger for minorities and low credit score borrowers. Notably, this is of growing concern given projections like that of Dahl et al. (2017), who (under an intermediate-high scenario) project that more than half of effectively inundated communities (defined as 26 or more annual floods covering greater than 10% of the community's usable land area) are home to socioeconomically vulnerable populations.[41]

Other papers have shown evidence that banks are responding to climate and natural disaster risk, though in different ways. There is evidence that lenders are tightening credit standards after a disaster (Duanmu et al., 2022) and in flood zones (Sastry, 2022). Allen et al. (2022) provide evidence that non-bank lenders may be filling a lending void by showing that non-banks are more responsive after disasters relative to traditional banks. Blickle et al. (2022) argues that disasters are not bad for bank performance partially due to the subsequent demand for loans after a disaster and also that banks (particularly local banks) tend to not originate mortgages in flood prone areas in the first place, the latter suggesting lenders may have local knowledge of flood risk. Begley et al. (2022) finds that a one-size-fits-all loan rate (i.e., the rate offered to borrowers is constant, and hence not sensitive to risk factors) may prevent minority borrowers, subprime borrowers, and borrowers in areas with high income inequality from obtaining disaster-relief after a disaster. Even after controlling for income, population, and damages suffered, the paper still finds evidence of higher denial rates for Small Business Administration (SBA) disaster-relief loans for the previously mentioned groups. Thus there is evidence of challenges for affordable homeownership for financially vulnerable households. As mentioned previously, Sastry (2022) finds that banks require larger down payments in flood zones, so that borrowers in flood zone areas may be selected on wealth and higher credit quality. This works to deter liquidity constrained prospective

[41] The paper uses global SLR projects from NCA.

homeowners from purchasing homes in flood zones.

Another strand of the literature looks at how flooding events affect borrower behavior, and generally finds that hurricane and flooding damages do have a significant impact on mortgage performance. For example, many papers find that credit scores decrease, and delinquencies and defaults increase following a disaster (Calabrese et al., 2021; Du and Zhao, 2020; Kousky et al., 2020b; Rossi, 2021). There are some important nuances to these results. For example, Rossi (2021) looks at significant hurricanes (category 3 or higher) and find that loans experiencing such hurricanes were 88% more likely to become 90 days or more delinquent than loans with similar risk factors that did not experience damage in the same location. Instead of looking at multiple hurricanes, Kousky et al. (2020b) look only at Hurricane Harvey. Using detailed damage data, they find that moderate or severe damage increases the odds of becoming delinquent. Similarly, they find that moderate or severely damaged loans are more likely to enter forbearance. Finally, loans that are moderately or severely damaged and outside of the SFHA (no flood insurance) are more likely to receive a modification and more likely to become 180 days or more delinquent or in default. Du and Zhao (2020) compare the impacts of Hurricane Harvey to those of Hurricane Maria on mortgage performance and find that impact on delinquencies is significantly higher for Hurricane Maria than Hurricane Harvey. The authors argue that their results are consistent with the double trigger theory as the damage-adjusted LTV, the annual increase in claims, and the interaction of those two factors explains most of the increase in delinquencies in the case of Maria.[42] Billings et al. (2022) find increased bankruptcy in Houston's flooded neighborhoods, though only for blocks that are majority outside of a flood zone where there is a large share of homeowners not likely to get approved for a Small Business Administration loan (i.e., a disaster relief loan).

Holtermans et al. (2023) investigate the impact of hurricanes on commercial mortgage market performance risk using loans securitized by CMBS. The study analyzes the impact of Hurricanes Harvey and Sandy on the payment behavior of borrowers following these large acute climate shocks. The authors show that the impact of the hurricanes on commercial mortgage delinquency was significant, finding evidence of heterogeneity. The effect of Hurricane Harvey in the Houston area was higher for office/retail buildings than multifamily

[42]For a recent of discussion of double trigger and other mortgage default channels, see Ganong and Noel (2023).

Table 6: Effects of Flood Hazards on Delinquency

Authors	Year	Location	Obs.	Effect Size	Independent Variable	Model
Calabrese et al.	2021	Florida	2,750,000	3.347	Hazard ratio of $\geq$ Cat 3 Hurricane	Cox Hazard Model
Du and Zhao	2020	Texas	12,631,231	0.380	$\geq$ 6 months after Harvey	DiD
	2020	PR	2,330,786	1.19	$\geq$ 6 months after Maria	DiD
Kousky et al.	2020	Texas	27,061	2.59	Hurricane Harvey severe damage	Multinomial Logit
Rossi	2021	US	100,000	1.88	$\geq$ Cat 3 Hurricane	Logit

buildings. The opposite was the case with Hurricane Sandy in New York metropolitan area, where multifamily buildings suffered higher damages. The analysis compares multifamily mortgage performance changes as a result of Hurricane Sandy in relation to the two-year period prior to Sandy making landfall, showing the delinquency effect lasted longer for Sandy.

An et al. (2023) find an significant increase in mortgage default in regions impacted by wildfire burns. They also extend the analysis to look at the impact from the pollution and smoke of a wildfire, finding evidence that mortgage defaults increased after large wildfire events in California though with varying significance. Given the the ability for wildfire related pollution to travel great distances, the impact of increasing severity in wildfires from climate change may have broader impacts on mortgage markets than the direct damages of wildfires. Similarly, Ho et al. (2023) use Canadian data to show that areas that experienced wildfire damages were more likely to see mortgage delinquencies, with greater damages being associated with greater delinquencies.

In summary, it appears that hurricanes and wildfires appear to worsen mortgage performance. We summarize these results in Table 6. Borrowers outside of the flood zone seem to be affected the most. Thus, flooding may create financial distress for borrowers, particularly those who were less likely to expect flooding. An open question is if and how the repricing of climate and disaster risk over time induces more more default.

2.5 Insurance

Flood insurance also plays a key role in understanding how flood risk and damages might impact the housing finance market. There are two main research questions this literature has attempted to answer. First, what are the drivers and unintended consequences of mandatory flood insurance? Second, what are the effects of insurance on lending and mortgage behavior?

Besides the price of the policy, papers show that insurance take-up rates are positively correlated with education, home values, income, age, social network interactions, and recent exposure to flood damages (Atreya et al., 2015; Bradt et al., 2021; Gallagher, 2014; Kousky et al., 2020a; Netusil et al., 2021; Hu, 2022).[43] Although, Kousky et al. (2020a) and Bradt et al. (2021) find that the uptake of insurance after recent flood damages could be driven by FEMA's requirements that receivers of certain aid after a disaster purchase flood insurance. The flood insurance market is also characterized by low willingness to pay, relatively inelastic demand, and asymmetric information (Atreya et al., 2015; Bradt et al., 2021; Netusil et al., 2021; Wagner, 2022). In particular, Wagner (2022) uses a rich data set of flood insurance policies from the NFIP to estimate whether there is over or under-provision of insurance and whether there is adverse selection. She finds evidence of a gap in willingness to pay for flood insurance, that the mispricing of natural disaster insurance is complex, and that there is evidence of adverse selection on observables but not for unobservables. Liao and Mulder (2021) find that insurance take-up follows house price dynamics closely, with a home price elasticity around 0.3 and that mortgage default may act as implicit disaster insurance. Chivers and Flores (2002) argue that many borrowers either were not aware of flood risks or their costs at the time of purchasing a property.

The impact of flood insurance on the mortgage market has primarily been studied by looking at how loans with and without flood insurance perform after a flood event. As noted previously, Kousky et al. (2020b) find that properties with flood insurance (in the SFHA) were less likely to need a loan modification and less likely to default after Hurricane Harvey. Both Kousky et al. (2020b) and Gallagher and Hartley (2017) find that prepayments increase after a hurricane event and that the likely explanation is flood insurance. On the lending side, the literature is less developed. However, Blickle and Santos (2022) found that flood insurance

[43] In a related work, Dombrowski et al. (2020) show that while most flood insurance holders choose the default deductible option, individuals in high income and high-premium areas were more likely to select the maximum deductible.

mandates may lead to reductions in lending and that those reductions are most pronounced for low-income and low-FICO borrowers. Kousky et al. (2018b) find evidence that federal disaster assistance may crowd out private insurance on the intensive margin on average by $4000 - $5000 in years following a disaster, but no effects on the extensive margin (take-up rates) are apparent. Oh et al. (2022) develop a metric of extent of regulations for insurers at the state level to determine if the prices charged by insurers to policyholders are actuarially fair. Their results suggest that in response to being unable to raise rates adequately to cover losses, insurers in highly regulated states effectively cross-subsidize by charging policyholders in less regulated states more.

Wildfire insurance markets likewise exist and may take on increasing importance as the WUI continues expansion. As noted in Issler et al. (2020c), insurers subject to a relatively flat-fee structure may be subject to growing adverse selection as wildfire risk broadly increases, meaning the solvency of California's wildfire insurance market may continue to deteriorate in the future. Kousky et al. (2018a) propose a series of policy reforms to strengthen wildfire resilience in California given the poor incentives in that state for reducing wildfire risk; these include but are not limited to defining mitigation levels in advance of wildfires and drawing on lessons from NFIP for California's Fair Access to Insurance Requirement (FAIR) plan. The insurance crisis is not limited to California. The Center for Insurance Policy Research, the National Association of Insurance Commissioners (NAIC), Risk Management Solutions, and Insurance Institute for Business and Home Safety jointly published a report documenting low adoption and willingness-to-pay across several states. Given the weaknesses that characterize private natural disaster insurance markets, Czajkowski et al. (2020) further document some suggestions to reduce physical damage from wildfires. They note that certain structural modifications can reduce wildfire risk up to 40% relative to a baseline of a well-built wildfire-resistant structure from a neutral property setting. The combination of structural and vegetation modifications can reduce wildfire risk up to 75%.

The ability for structural modifications to reduce risk highlights how new residential construction can also work to mitigate losses. Baylis and Boomhower (2022) find that a wildfire is about 40% less likely to destroy a 2008 or newer home than a 1990 home. The authors find that these effects are likely due to state and local building code changes. The authors find positive spillover effects as well, consistent with reduced structure to structure spread of the fire. Done et al. (2018) finds that new construction under stronger building codes can also reduce losses from hurricanes. However, there is evidence that, at least in North Carolina, substantial new housing construction is taking placing in flood zones, so that the net direction of risk is unclear (Hino et al., 2023). Kim (2020) finds that structural elevation and green infrastructure are positively associated with the value of nearby housing in Miami-Dade County and New York City during 2009-2018. Additionally, they find mixed evidence for the effect of other mitigation measures on price appreciation: "adaptation measures for storm surges provide a particularly strong impact on housing price appreciation", while "properties near public building reinforcement and equipment retrofitting projects, hurricane shelters, or adaptation projects for wind protection show no evidence of such effects."

In summary, flood and wildfire insurance plays a pivotal part in the housing finance markets as it can price risk into the housing markets and protect homeowners and lenders after a disaster occurs from losses. However, imperfect information, mandatory requirements, monitoring, and outside options such as defaulting or disaster aid, may lead to insurance market distortions or outright failure. In addition, future work on the returns to adaptation measures would be especially fruitful.

Before moving on, we note that at present the future of the property insurance market is uncertain.[44] While the National Flood Insurance Program is the dominant flood insurer in the United States, private insurers make up the largest portion of homeowner's insurance, which covers other perils.[45] Due to increased frequency and severity of disasters, private homeowner's insurers are effectively withdrawing from high risk areas. As of the writing of this article, State Farm and Allstate, the largest and fourth largest issuers of homeowners insurance in California respectively, are no longer offering new policies in the state due to increased costs of insuring wildfires.[46] Similarly, many private insurers in Florida have entered into receivership due to increased costs, leaving many turning to Citizen's Property Insurance Corporation, a publicly funded insurer of last resort. Future policy makers will be forced to grapple with difficult issues such as potentially uninsurable areas, cross-subsidization, and the role of government in subsidizing housing in risky areas.

[44]We tend to think of property insurance as a more general term that includes homeowner's insurance and flood insurance as specific types.

[45]Notably, lightning and hail are typically included with homeowner's insurance, while earthquakes and flooding are not.

[46]https://www.nytimes.com/2023/06/04/business/allstate-insurance-california.html

2.6 Chronic Physical Risks

Relative to acute risk, less work exists on the consequences of chronic risk for housing markets. As mentioned previously, chronic physical risks are best thought of as long term changes due to climate change. We address two chronic risks that we see as particularly understudied: storm activity and droughts. As mentioned previously, these long-term chronic changes are likely to be associated with a higher frequency of short-term acute events. For example, droughts will likely mean more wildfires. The focus in this section is on the expected effects of these chronic risks, with attention paid to individual beliefs and expectations about the future.

2.6.1 Atmospheric Hazards

The center of the spatial distribution of severe thunderstorm and tornado activity has shifted eastward in the last four decades; a continuation of this trend will increase the percentage of the housing stock exposed to wind and flood damage.[47] As this is a systemic shift of weather patterns rather an increase in the frequency and/or severity of one-off weather events, we have classified these atmospheric hazards as a potential chronic physical risk. Although researchers have observed this trend since 1979, the relationship between climate change and the frequency of atmospheric hazards, i.e., severe thunderstorms and consequent tornado events, remains uncertain. To date, climatologists have not pinned down a specific causal mechanism between the two. The correlates of severe thunderstorms, including low-level moisture and vertical wind shear, are highly localized and climate change models have not achieved sufficient granularity to make consistent predictions (Taszarek et al., 2021). Nonetheless, this trend is of special concern for housing markets since the eastward shift of intense tornado activity would increase the number of households and by consequence homes exposed to wild and hail damage. The traditional "Tornado Alley," a geographic area stretching from northern Texas to South Dakota, is among the most sparsely populated geographies in the country.

In the past 40 years tornadoes, high winds, and hail have caused an average of 5.4 billion dollars of damage annually. More recently, outbreaks—the generation of multiple tornadoes from the same weather system—including the 2011 Super outbreak and the 2020 Easter tornado outbreak are more likely to rise above 10 billion dollars in damages (Gensini and Brooks, 2018). Ewing et al. (2007), studying six metropolitan statistical areas frequently

[47] The National Weather Service has more information on the geographic shift of tornado frequency at https://www.weather.gov/lmk/niu_tornado_frequency_study.

exposed to wind damage from tornadoes and hurricanes, identify a 4-quarter negative transient shock to housing prices. Their time series analysis finds losses on the order of 0.5 to 2% of total housing value, though the effects do quickly fade. Sutter and Poitras (2010), studying manufactured housing, a category of housing especially at risk to wind damage due to structural weakness, find that an additional death per million from wind damage reduces demand for manufactured housing by 3%. Gallagher et al. (2023) find evidence that businesses are more likely to fail and also that federal assistance can help with household finance by allowing them to avoid costly credit card debt after a tornado, pointing to the importance of aid. Using tornado (and also other natural disasters common in Arkansas), Tiurina (2022) finds that some evidence that supplemental credit in the form of installment loan credit (shorter-term, unsecured debt) contributes to borrower's financial well-being in the form of better credit scores and lower likelihood of delinquency.

Despite the nontrivial quantities of economic damage inflicted by tornadoes, and severe thunderstorms in general, the literature on the effects of atmospheric hazards on housing markets is especially scarce. Given the new spatial patterns associated with these events, empirical research evaluating historical incidence and projecting future damages and consequences for the housing finance market would be helpful.

2.6.2 Droughts and Temperature Volatility

Drought is an imbalance between evaporation and precipitation. A consequence of higher temperatures is a faster water cycle; this increase has made historically wet areas wetter and historically dry areas drier. Such prolonged periods without rain, and conversely, prolonged periods of extreme inundation, can disrupt agriculture, water supplies, energy production, and human health. Between 2000 and 2020, between 20 and 70% of the United States was experiencing abnormally dry conditions at any given time. The most severe droughts are in the American Southwest, with the rest of the country experiencing normal or wetter than average conditions. Since 1990, the Southwest has experienced one of the most persistent droughts on record.[48] The economic effects of these conditions are nontrivial; of the 26 billion-dollar droughts in the last forty years, the average event cost was $9.6 billion.[49]

Researchers have written little on the consequences of drought for housing finance; accord-

[48] The EPA provides further technical details on drought at: https://www.epa.gov/climate-indicators/climate-change-indicators-drought.

[49] The interested reader may review the tables at https://www.drought.gov/news/high-cost-drought.

ingly, there are opportunities for empirical studies. The most direct impacts of droughts are on agriculture: dry conditions reduce production and raise costs. The viability of rural economies, and hence the liquidity of their housing markets, may be negatively influenced by extended periods of drought. Studies looking back at historical episodes of drought may yield insights into this topic. Furthermore, mandatory reductions to residential water usage may depress real estate values. Farzanegan et al. (2021), evaluates this relationship in the only paper that we are aware of that has specifically studied drought and its effects on real estate prices. Studying Iranian real estate markets, they identify a positive effect of increased water availability on home prices. From a domestic perspective, differing water use restrictions by localities, particularly if some localities are better endowed with freshwater access than others, may lead to sorting. Studies of real estate sales across water supplier boundaries could be fruitful. Besides home prices, policymakers could benefit from understanding how property-level restrictions shape perceptions and beliefs about the future trajectory of climate change.

Cardoso and Wichman (2020) note that water affordability issues may intensify in the the next two decades. Using a census block-group-level socioeconomic dataset matched to water and sewer rates for 45% of the US population, they find that the lowest decile of income is especially vulnerable to increasing water and wastewater service fees. Wichman et al. (2016), using a panel dataset of residential water consumption data in six North Carolina municipalities, find that low-income households and relatively low-consumption households are more price sensitive. They find that voluntary and mandatory water use restrictions effectively manage demand and may be more attractive solutions for demand management than price increases, which they implicitly characterize as regressive.

Associated with drought incidence is temperature volatility. Preliminary research has suggested some role for volatility with real estate prices. Semenenko and Yoo (2019) identified an inverse relationship between daily temperature volatility and real estate returns. That the first and second moments of the temperature distribution are increasing is also relevant for mountainous states—Butsic et al. (2011) identify reductions in home prices adjacent to ski resorts known for inconsistent snowfall. Similarly, Parthum and Christensen (2022) find regional variation in marginal willingness to pay for mountain snowpack. Meanwhile, Duan and Li (2022) find evidence that abnormally high temperatures may be discouraging traditional lenders from lending as much, with Fintech lenders stepping in to partially fill the gap. Winkler and Rouleau (2021) also find that extreme heat is associated with out migration.[50] More generally, Bloesch and Gourio (2015) find that the especially cold winter of 2013 and 2014 had a significant, short-lived effect on economic activity; however, the effects were especially concentrated in utilities, construction, and hospitality.

To summarize, the marginal contribution of research investigating the influence of droughts on housing prices is large. It is especially so given projected increases to drought severity in the coming century. There is also some evidence that temperature volatility may impact housing markets. More research is needed in this area to determine household and lender responses to higher temperatures. A challenge of this literature is that the warming scientists is gradual, and may be difficult to use in an empirical study. We postpone discussion of this until later when discussing energy efficiency in our transition risks section.

3. Transition Risks

In this section, we address research on the effects of transition risk to housing and mortgage markets. Section 3.1 begins with a discussion of the effects of energy performance upgrades on real estate prices and quality-of-life considerations. It then reviews papers that evaluate the relationship between energy efficient homes and mortgage performance. Then, Section 3.2 describes a literature on the heterogeneous effects of the energy transition for regional economies and discusses the capitalization of various forms of waste into real estate prices. The topics we explore in this section should not be taken as exhaustive of all possible transition risk to real estate topics; indeed, as the global transition to a low carbon economy remains uncertain, much remains to be understood about how transition risk will shape housing and mortgage markets.

3.1 Energy Use

Improved home energy performance will be significant component of the net-zero transition; the residential sector, inclusive of both single- and multifamily properties, accounts for about 1/5th of the United States' energy usage.[51] Furthermore, climate change will lead to an increase in residential energy use. Using Swedish data, Dodoo and Gustavsson (2016) find that between 1996 and 2005, buildings' heating needs decreased by 3% while buildings' cooling

[50] Outside the scope of this paper, extreme heat can have wide ranging impacts on human health and in turn chronic extreme heat could have lasting impacts on regional economies. See https://time.com/6201615/heat-pollution-health-risk/ for a discussion of extreme heat and air pollution on human health.

[51] See the EIA's page for a breakdown of energy usage by sector: https://www.eia.gov/energyexplained/use-of-energy/

needs increased by 18% relative to long term historical measures. When the authors apply future climate change scenarios, heating demands could decrease by 23-29% and cooling demands could increase by 48-126% by mid-century. Similarly, Wang et al. (2022) find that for high thermal insulation buildings, cooling demands are higher and more sensitive than heating demands especially for apartment buildings. For example, under reasonable climate change scenarios, cooling needs for apartment buildings would increase by 22.1% relative to 5% for office spaces in the 2080s.

We anticipate improvements to home energy performance to have direct and indirect effects on the workings of real estate markets. We discuss the direct effects, including capitalization, improved quality-of-life, and associated costs, in Section 3.1.1. It is also possible that energy efficient homes may reduce the share of household income dedicated toward energy bills relative to a less efficient counterfactual; we address this topic in Section 3.1.2.

3.1.1 Energy Efficiency

One potential way to decrease energy use is to invest in energy efficiency improvements. Energy efficiency investments have the potential to reduce energy use and provide financial savings to homeowners and renters by decreasing energy intensity of appliances and HVAC or by renovating homes to limit heating and cooling leaks. For a discussion on the potential adoption of energy efficiency and the gap in adopting energy efficiency, see Gerarden et al. (2017).

In this vein, policymakers have attempted to make progress through energy efficiency rating certification programs over the last few decades. Perhaps the most significant of these is the EPA's Energy Star certification which began in 1992.[52] Energy Star certifies new homes that are at least 10% more energy efficient than homes built to code.[53][54] The aim of these certifications is to reduce information asymmetries as many of the improvements to home performance (e.g. duct sealing) are not necessarily evident to prospective homeowners or home inspectors.

[52] See https://www.energystar.gov/about/how_energy_star_works/history.

[53] For more details on the benefits of Energy Star certified homes and the methodology used to assign scores and certifications, see https://www.energystar.gov/newhomes/features_benefits?s=mega.

[54] Other important certifications include the US Green Building Council's Leadership in Energy & Environmental Design certification (LEED) and the Residential Energy Services Network's (RESNET) Home Energy Rating System (HERS). In addition to these nation-wide programs, state and local governments have created their own standards, including California's GreenPoint program and Austin, Texas' Austin Energy Green Building Program (AEGB).

Results on the influence of energy efficiency ratings on property values are largely positive. Using a hedonic approach, Argento et al. (2019) found that homes rated as energy efficient sold for 2.7% more than non-rated homes. On the intensive margin, better rated homes sold for 3 to 5% more than lesser rated homes. Similarly, Cassidy (2023) studied the City of Austin's Energy Conservation Audit and Disclosure policy. Using a repeated sales specification, she also finds a correlation between energy efficient improvements and property value; however, this only holds for less observable improvements, such as duct and attic upgrading. This finding is consistent with imperfect information in the market; Austin's disclosure policy revealed information to prospective homeowners that caused them to revise upward their valuations of properties with less observable energy efficient improvements. Walls et al. (2017), using propensity score matching together with a hedonic regression, identify positive returns to Energy Star certifications in the North Carolina Research Triangle and Portland, Oregon.

Energy efficiency investments may also improve quality of life. Norton et al. (2016) argue that energy efficiency efforts in multifamily properties can create beneficial non-energy economic and health benefits for their residents as energy improvements are positively associated with reductions in fire hazard exposure, improvements in thermal comfort, and reductions in adverse air pollutants (CO2 and PM2.5) and their respiratory effects. However using data from Slovakia, Földváry et al. (2017) finds that some tenants reported dissatisfaction with indoor air quality after energy efficiency upgrades as some renovated units had lower indoor air quality, reflected in CO2 and other air quality metrics, partially as a result of tighter insulation retrofits.

While the literature has found benefits from energy efficiency investments, the investments are not without cost and the relationship between savings and costs of energy efficiency retrofits is less clear. Taylor et al. (2016b) measures first year electricity savings from retrofits to 232 units in four apartment complexes in Florida. They find annual savings per unit averaged 2094 kWh (22%) and ranged from 1700 kWh (18%) to 3811 kWh (29%) across complexes. Based on these findings, tenants saved an average of $272 on their annual electric bills. Frozyna and Badger (2013) finds that adding outdoor boiler reset controls can potentially save 5% annually in property heating energy consumption and reduce annual heating energy consumption costs by about 10%. Whereas, upgrading the building water pumps can save more than 70% per year in pump operation costs compared to older pump settings. McKittrick and Henze (2021) observe that smaller buildings reach net zero goals more effectively; two-story buildings can reach annual net zero energy consumption with an increase in construction cost of about 4.4–5.6%. Three-story buildings in warmer climates can achieve annual net zero energy efficiency with an increase in construction cost of about 5.1%, while those in colder climates cannot reach this target goal. Fowlie et al. (2018) finds that savings from energy efficiency can be over estimated relative to actual savings (by a factor of three). Further, the authors found that costs of the the Weatherization Assistance Program in Michigan is approximately twice the savings.

This literature finds a positive relationship between energy efficiency ratings and real estate prices indicating that homeowners value energy efficient investments. However, more research is needed in this area to understand the savings and costs trade offs of energy efficiency investments. Such research would have important implications for sustainable and affordable home ownership.

3.1.2 Energy and Mortgage Markets

Variations in energy efficiency investments and fluctuations in energy costs will have important implications for mortgage markets during the transition to a low carbon economy. In the context of energy efficiency, Argento et al. (2019) found no significant differences in delinquency rates of rated and unrated homes after controlling for borrower and underwriting characteristics. Investigating heterogeneous borrower characteristics, they conclude that high DTI mortgages on rated homes are less likely to be delinquent than similar mortgages on unrated homes. Using U.K. data, Bell et al. (2023) finds no evidence that lenders charge higher rates for riskier mortgages against properties with lower energy efficiency. This contrasts with a number of other studies including Kaza et al. (2014) and Pigman et al. (2022) in the U.S., and Billio et al. (2022) and Guin et al. (2022) in Dutch and British contexts, respectively. All of those studies identify an inverse relationship between home energy performance and mortgage delinquency. Guin et al. (2022) supports these findings and rigorously explores mechanisms that may be responsible. Their research finds that the share of high efficiency properties in payment arrears is 7% and 18% lower than that for medium and low efficiency properties, respectively. They propose two mechanisms for these results. First, energy savings imply lower costs that ease the burden of monthly payments for liquidity constrained borrowers. Second, higher income borrowers are more likely to select into high efficiency homes. However, as their results are qualitatively unaffected after controlling for income, the authors argue that the first mechanism dominates the second. The results of these studies are summarized in Table 7. While we risk over-repetition, we again want to emphasize that this table intends to provide to the reader quick takeaways of effect magnitudes and by no means should these selected effect sizes be interpreted as comparable between studies without closer investigation of study context and empirical design.

Table 7: Estimates of Energy Efficiency Ratings on Mortgage Performance

Authors	Year	Location	Obs.	Unit	Program	Effect Size	SE
Argento et al.	2019	US	46,035	Property	RESNET	-0.034	0.07
Billio et al.*	2022	NL	125,560	Property	EPC	-1.6523	0.07319
Guin et al.	2022	UK	1,822,569	Property	EPC	-0.0005	0.0002
Kaza et al.	2014	US	71,062	Property	Energy Star	-0.39	0.03
Pigman et al.	2022	US	13,258	Property	HES	-0.28	N/A

Notes: Effect size corresponds to the estimated log of price discount for real estate in that paper's "preferred specification." * Billio et al (2022) do not have access to actual EPC ratings, and so construct approximations for them.

In the context of energy costs, Jaffee et al. (2012) develop a model that accounts for the effect of energy costs on the property's net operating income and apply the model to a sample of 1,390 commercial mortgages in 28 U.S. cities. They find that energy costs account for approximately 5% variation in mortgage risk pricing. In a similar study, Issler et al. (2020a) test for the effect of energy cost on default risk using sudden increases in electricity usage and operating inefficiency and data on Fannie Mae multifamily mortgages. Their results indicate that a 10% increase in energy costs increases the loan's probability of default by about 12 basis points on or before the balloon date. The authors highlight the importance of these results considering that the average sample default risk is 62 basis points. Issler et al. (2020b) perform a test on a sample of 610 commercial real estate mortgages securitized through Commercial Mortgage-Backed Securities (CMBS). Using the property's Energy Use Intensity (EUI), which measures energy efficiency as a function of energy cost and property size, the empirical analysis shows that less efficient buildings can have higher mortgage pricing risk. Specifically, the model indicates that a 1% shock in EUI leads to a change in required pricing points of 4 basis points. In a pilot application, Mathew et al. (2021) studies the relationship between energy costs on debt service coverage ratio (DSCR) and default risk. The authors find that energy risks vary across properties and across years for the same property and conclude that energy risks should be considered in the overall evaluation of a loan.

Importantly for understanding housing affordability, the literature has found though that there is heterogeneity in energy costs. The energy burden is defined as the share of expenditures on electricity, natural gas, and other home heating fuels as a share of household income and Lyubich (2020) finds that the black households bear a larger energy burden than white households at nearly all levels of the income distribution. She finds evidence that this gap is consistent with differences in housing stock and energy efficiency investments between black and white households. Her findings are substantiated by Reames (2016), Bednar et al. (2017), and Kontokosta et al. (2020), who likewise find that high minority share neighborhoods have higher energy burdens than lower minority share neighborhoods.[55]

In summary, energy efficiency has a largely positive relationship with mortgage performance and risks due to rising or variable energy costs pose a threat to mortgage performance. However, the literature shows that there is heterogeneity in energy costs which has implications for equitable access to housing.

3.2 Decarbonizing the Economy

In this section, we survey papers related to the implications of decarbonization for real estate markets. On the one hand, the transition to a decarbonized economy may hurt local economies that rely on carbon intensive industries. On the other hand, the transition may appreciate home prices in some areas due to clean-up of environmental pollutants, although these effects would likely be heterogeneous across socioeconomic strata. Historical studies can provide suggestive evidence as to the direction and magnitude of how lower pollution is capitalized into home prices. We discuss these two topics in Section 3.2.1 and 3.2.2, respectively.

[55] The notion of the energy burden is inherently related to the implementation of a carbon tax; while discussion of such a tax is outside the scope of this paper, the reader may consult Grainger and Kolstad (2010), Cronin et al. (2019), and Goulder et al. (2019) for some key papers analyzing the incidence of carbon tax proposals.

3.2.1 Industry Composition and Regional Economies

Locations dependent on carbon intensive services and industries will be affected by the economic transition; it is likely that this effects will reverberate in their real estate markets.[56] For example, Du and Karolyi (2022) use data from the U.S. Energy Information Administration to study the effects of a decline in coal production. Using similar energy producing ("resource rich") counties that did not produce coal as a control group, they find that the reduction in coal is associated with a 6% drop in employment, a 4% drop in wages, and a reduction in both population and mortgage applications. To estimate the potential impact of the energy transition on people living in fossil fuel extraction regions, Blonz et al. (2023) use the decline in the Appalachian coal industry from 2011 to 2018; they find that decreases in the demand for coal are associated with decreased credit scores and increased credit utilization, delinquencies, amounts in third party collections, bankruptcy rates, and the number of individuals with subprime status.

Another relevant area of research is the decarbonization the new build sector for residential real estate. Due to recent policy changes at the state and local level of banning natural gas in new construction, electrification of new builds is of particular focus. One risk associated with this is the increased costs associated with fully electric new builds. Davis (2023) finds that a mandate on electrification makes households in warm states worse off by less than $350 annually on average and households in cold states worse off by more than $1000 annually. Davis (2023) notes that this estimate does not account for preferences for gas or electric cooking or hot water heating and is limited to home heating. Davis also notes that these results are based on historical data and cannot account for future technological changes like increasing efficiency of heat pumps. Less understood is how these costs might vary by income. There is also a strong need for additional research on the costs of electrification as well as the trade offs between the costs of electrification, the reduced risks of climate change, and the potential benefits of air pollution reduction that are discussed in the next section.

Lending work likewise remains quite nascent. Despite our U.S. focus, we wish to mention some international papers working in adjacent literatures. Ho and Wong (2022) use data from emerging market economies to show that lenders to firms have been pricing in transition risks since the Paris Agreement (2016) in the form of a transition risk premium (i.e., a loan

[56]For an overview of what regions might be impacted in the U.S. see Raimi (2021), which provide maps and discussion of fossil fuel dependent regions.

spread), higher collateral requirements, and shorter loan tenure. Using data from China, Li and Wu (2023) find evidence that lenders for corporate loans have decreased loan supply, though they argue this can be mitigated by monetary expansion and other government policies. Also using Chinese data, Liu et al. (2020) find evidence that cities with shrinking populations are associated with less energy efficiency and higher carbon emissions, suggesting that the transition to a carbon neutral economy will likely pose more of a challenge for some areas than others.

3.2.2 Reductions in Air Pollution

Lower levels of environmental pollutants are likely to constitute an amenity that enters into real estate hedonic functions. Researchers have explored this relationship using the implementation of the Clean Air Act (CAA). The act imposes significant penalties on polluters who failed to meet federal standards for total suspended particulates.[57] Chay and Greenstone (2005) study the implementation of the CAA. Using the nonattainment status of counties to CAA Amendments as an instrumental variable for particulates, they identify a causal return of $45 billion to the value of housing stock in counties identified by CAA standards as especially polluted. They further estimate an elasticity of between -.2 and -.35 for housing values to particulate concentration. A third key finding is that the marginal benefits of particulate matter reduction was less in especially polluted counties pre-CAA, suggesting the importance of preference-based sorting. Zheng et al. (2014) finds that cities with reductions in air pollution experience increases in local home prices. A related study by Davis (2011) focuses on power plant construction in the 1990s. Using restricted Census microdata, he finds that housing values and rents in neighborhoods within 2 miles of a newly constructed plant decreased by 3 to 7%. Understanding these benefits (or if an increase in pollution costs) will be especially important for renters. Using Swedish data, Langer and Bekö (2013) shows that air quality is worse in multifamily properties. Relatedly, using data from Singapoore, Sharma and Balasubramanian (2019) finds that apartment indoor pm2.5

[57] In the initial version of the Clean Air Act, the EPA considered total suspended particulates when assigning penalties to producers. Subsequently, it evolved the regulation to consider PM10 in 1987 and PM2.5 in 1997. The numbers following PM reflect the size of the particle (less than 10 micrometers and 2.5 micrometers respectively). Researchers have found PM2.5 to have especially deleterious effects on respiratory system function and long-term health; for more, see `https://ww2.arb.ca.gov/resources/inhalable-particulate-matter-and-health`.

air pollution may exceed guidelines. [58] Muehlenbachs et al. (2016) finds mixed house price returns to shale gas extraction, depending on whether or not the home was dependent on groundwater. Walsh et al. (2017) finds positive home price returns to water quality in the Chesapeake Bay. These findings are suggestive of the distributional consequences of further reductions to airborne and water pollutants associated with the energy transition.

A similar strand of literature pertains to the home price effects of cleaning up hazardous waste sites.[59] Researchers have sought to understand whether the benefits of addressing these areas of contamination outweigh the high costs.[60] The most fruitful inquiries have studied "superfund" sites. The Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) of 1980, colloquially known as the Superfund law, invests in the EPA to authority to cleans up toxic waste site, referred to as superfund sites.[61] Greenstone and Gallagher (2008) research the effects of superfund cleanups through CERCLA. Using both an instrumental variable and a regression discontinuity design, they find small local benefits incommensurate to the average $43 million cost of a cleanup. In a complementary study, Gamper-Rabindran and Timmins (2013) study superfund sites the census block level, which use a finer geographic level than the census tract of Greenstone and Gallagher (2008). They conclude that cleanup leads to a 14.7% appreciation in home values. They also find that these effects are largest for homes in the left tail of the within-tract level distribution of home values. Even though they identify positive effects where Greenstone and Gallagher (2008) found inconclusive effects, Gamper-Rabindran and Timmins (2013) note that their study suggests that the returns to cleanup are especially local and hence the previous cost-benefit analysis may still hold.

There are other studies independent of superfunds that have found significant effects to living

[58] For the interested reader, Andersson-Sköld et al. (2015) review ways to manage urban design to address air quality standards and find support for housing settings that involve compact, mid-rise buildings with green areas and trees near the buildings. The authors also point out the need for proper shading and increased vegetation as well as the use of light exterior structure colors to improve air quality and other related harmful climate change effects, including heat stress.

[59] Hazardous waste, as defined by the EPA, refers to wastes with properties that make them "dangerous or capable of having a harmful effect on human health or the environment." More information can on hazardous wastes can be reviewed at the EPA's website: `https://www.epa.gov/hw/learn-basics-hazardous-waste`.

[60] For example, the recently passed Bipartisan Infrastructure Law set aside an addition $3.5 billion to clean up superfund sites. See this EPA factsheet at `https://www.epa.gov/infrastructure/cleaning-superfund-sites-highlights-bipartisan-infrastructure-law-funding` for more information.

[61] The "superfund" refers to the EPA's trust fund established to finance the cleanup of some of these sites.

in proximity to a source of toxic pollution. Currie et al. (2015), studying the opening and closing of 1,600 industrial plants, found that plant openings reduced home values within 0.5 miles of the plant by 11%. Haninger et al. (2017), studying the EPA's Brownfields Program, which provides funds to redevelop contaminated lands colloquially known as "brownfields", find property value returns between 5 and 15.2%, depending on what one is willing to assume about the stability of the hedonic price function. Consistent with the superfund literature, this paper also concludes that the returns the home prices are highly localized. Sullivan (2017), applying Haninger et al. (2017) estimates to back out increased property tax revenues from brownfield cleanups, finds returns of between 29 and 97 million dollars per annum for 48 such sites. These returns either slightly or greatly exceed the cost of the cleanups themselves. Lang and Cavanagh (2018) identify heterogeneous effects of remediation, with ex-ante low value neighborhoods experiencing price declines following cleanup and ex-ante high value neighborhoods experiencing price increases. Taylor et al. (2016a) identifies the existence of stigma effects associated with homes near both non-toxic commercial sites as well as brownfields; however, these stigma effects are ameliorated following remediation of the contaminated site.

In summary, this area of research has found mixed results. In addition, the spatial granularity of the underlying empirical work appears to matter significantly in interpreting results. Further efforts into understanding home price returns to remediation and transitioning to a carbon-neutral economy would be fruitful.

4. Conclusion

Our paper surveys research at the intersection of real estate and environmental economics. Our review finds agreement across the literature that climate risks are at least partially capitalized in housing values and influence lending and consumer behavior. Minorities and borrowers of less creditworthiness appear to be modestly affected by changing lending standards; they are also projected to bear a disproportionate amount of the climate risk burden. This has implications for the affordability and sustainability of homeownership for disadvantaged groups. That said, there remains considerable uncertainty as to the magnitude of these effects. Existing heterogeneity may be partially explained by information, or the lack thereof, of climate risks. In addition, perceptions over the reality and extent of climate change are relevant.

A key takeaway from our review of the academic literature is the need for highly granular data on physical and transition risks; housing and mortgage finance models deliver their strongest predictions when paired with such data. These constraints on data availability lead to three stylized facts. The first is that many of the papers have focused on flood and sea level risk. More work on the effects of other disasters and climate events is needed. The second is that the majority of the research, at least as it applies to physical risk, focuses on the United States. More international work is needed, especially once one considers institutional and environmental/geographical differences. The third is that the multifamily markets are understudied relative to the single-family market. Taken together, these three facts indicate that important research questions are still unanswered and that both academic researchers and policy makers will benefit from the development and publication of new datasets related to physical and transition risks.

Throughout the paper we note open research questions, and we again highlight two areas here. Drought, a significant chronic physical risk, impacts where homeowners can locate without overly burdensome water access costs. Real estate and lending markets in the American West may be negatively affected by the persistence of drought conditions in the American West. Additional research is needed to understand which regions will be most affected and how large those effects will be. If water access becomes cost prohibitive in certain regions, then there will be significant implications for sustainability and affordability of home ownership. There is also significant uncertainty surrounding transition risks. For example, further research on which real estate markets will face spillover effects from changes to industry value can highlight areas of potential concern for mortgage performance. Alternatively, new policy incentives to retrofit housing or ban certain fuel sources may have important equity implications given preexisting variation in age and structure of the current housing stock across socioeconomic groups. In general, if building costs rise accommodate climate change adaptation measures, more research is needed to understand how that will affect the affordability and sustainability of home ownership. As housing is a significant component of owners' and renters' budgets, focusing on how transition risks impact residential real estate and mortgage markets will be necessary for policy makers as they navigate the global shift to a low-carbon economy. We conclude with a general call for holistic research on the heterogeneous impacts of climate risks on real estate and mortgage markets and their implications for affordability and sustainability.

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A Overview of Climate Science

The scientific community engages in research related to climate change and natural disasters. While it is beyond the scope of this report to survey the entirety of the climate science literature, we state what we believe to be the main findings and conclusions of several widely recognized authorities and scientific experts on the subject. Further, we mention only those findings and conclusions that we believe are germane for housing and mortgage markets.

As early as 2009 there was already a scientific consensus on climate change, with more than 18 scientific organizations (American Association for the Advancement of Science (AAAS), American Chemical Society, American Statistical Association, etc.) agreeing that "climate change is occurring, and rigorous scientific research demonstrates that the greenhouse gases emitted by human activities are human drivers."[62] In 2014, AAAS published a "What We Know" report to educate the public on the reality, risks, and response to climate change. Among the many findings in the report are the acceleration of sea-level rise and that climate change may make natural disasters worse in both frequency and severity.[63] The views presented by AAAS are representative of the scientific consensus. In what follows and at slight risk of repetition, we provide detail and context from major U.S. government scientific agencies to give more details about what these views are.

Climate scientists have generated projections and conducted scenario analyses to form estimates of climate change consequences. Indeed, as we mention shortly, the Federal Reserve has already developed such scenario analysis to assess climate-related financial risks in a pilot program. Such scenarios are likely to be widely used for forecasting in housing and mortgage markets once they become more standardized. The Intergovernmental Panel on Climate Change (IPCC) is the preeminent international body producing climate forecasts.[64] IPCC's scenarios are referred to as Representative Concentration Pathways (RCPs), which vary by their anticipated Greenhouse Gas (GHG) emissions.[65] Figures 2 and 3, taken from the latest IPCC synthesis report, illustrate different scenarios for temperature and sea level change

[62]The AAAS letter: https://www.aaas.org/sites/default/files/1021climate_letter1.pdf. A list of additional international organizations who have adopted this position is here https://climate.nasa.gov/scientific-consensus/.

[63]See https://www.usgs.gov/faqs/how-can-climate-change-affect-natural-disasters for more on the relationship between climate change and natural disasters.

[64]IPCC's latest report is its Synthesis Report of its Sixth Assessment Report (AR6) in 2023 (https://www.ipcc.ch/report/ar6/syr/).

[65]A more detailed discussion of the RCPs can be found on the IPCC's (website).

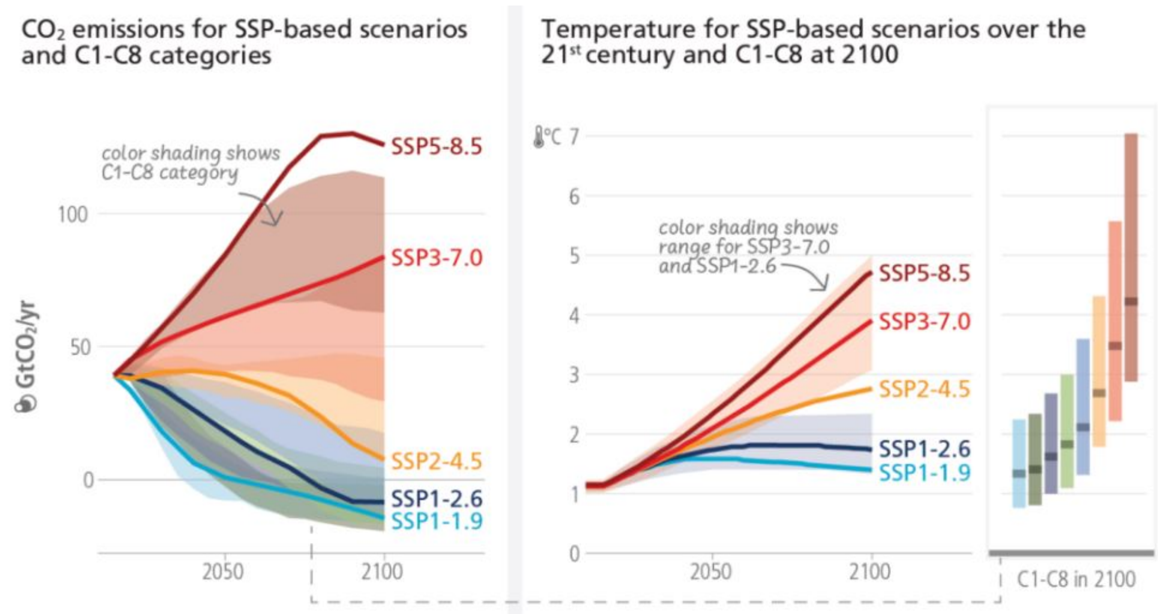

Figure 2: Source: IPCC AR6 SYR Longer Report

for the next 75 years.[66] For our purposes, we only mention that for the latest report, the different scenarios (e.g., SSP1-1.9, SSP1-2.6) correspond to different Shared Socio-Economic Pathways (SSP). Roughly speaking, these scenarios build off of the RCPs discussed previously and correspond to different amounts of greenhouse gas (GHG) emissions and CO_2 emissions that will occur.[67]

The U.S. Global Change Research Program (USGCRP), a coordinating body for 14 federal agencies, relies in part on the IPCC's RCP scenarios in its National Climate Assessments (NCA).[68] As of the writing of this article, the most recent (2018) version of the NCA is comprised of two volumes. The first focuses on scientific findings, which agree with the general findings of the AAAS. We list some of the NCA's many conclusions below.

[66]These come from Chapter 4, though as the report points out the contents are currently a work in progress and subject to editing. We refer the interested reader to the report for a much more comprehensive picture of climate forecasts and the most recent figures and results.

[67]For example, SSP3-7.0 corresponds to high GHG and $C0_2$ emissions, where these levels double from 2015 levels in 2100 and 2050, respectively. In contrast, SSP1-1.9 corresponds to very low GHG and CO_2 emissions, where both are projected to be net zero by 2050 and the latter is net negative afterwards. We refer the interested reader to the report, which contains much more discussion of the scenarios.

[68]The USGCRP is currently working on their 5th National Climate Assessment. See https://www.globalchange.gov/nca5. for more information

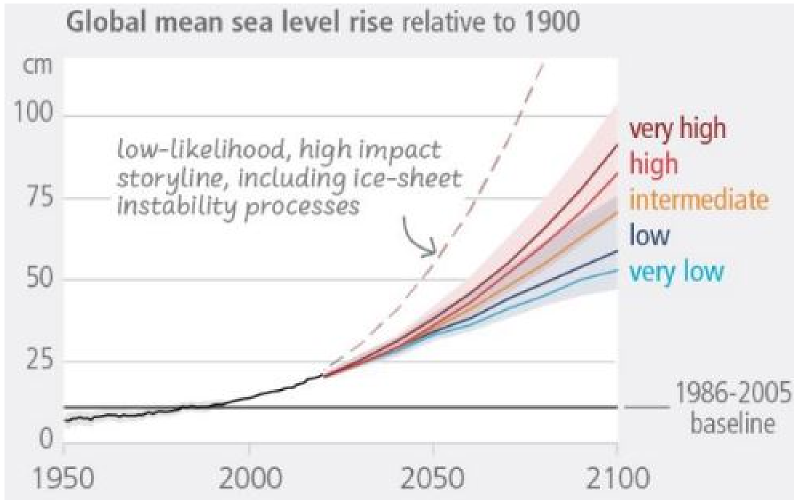

Figure 3: Source: IPCC AR6 SYR Longer Report

1. This period is now the warmest in the history of modern civilization.
2. Thousands of studies conducted by researchers around the world have documented changes in surface, atmospheric, and oceanic temperatures, melting glaciers, diminishing snow cover, shrinking sea ice, rising sea levels, ocean acidification, and increasing atmospheric water vapors.
3. Global average sea levels are expected to continue to rise—by at least several inches in the next 15 years and by one to four feet by 2100. A rise of as much as eight feet by 2100 cannot be ruled out.
4. Heavy rainfall is increasing in intensity and frequency across the United States and globally and is expected to continue to increase.
5. The magnitude of climate change beyond the next few decades will depend primarily on the amount of greenhouse gases (especially carbon dioxide) emitted globally .

What is immediately apparent from these conclusions and discussed in the main body of the text is that housing markets will be impacted by these changes. For example, higher temperatures mean changing energy costs, which has immediate consequences for sustainable homeownership, particularly for financially vulnerable households. Additionally, higher sea levels and increases in the frequency and severity of rainfall mean flooding is more likely.

Lenders are likely to respond to such changes as they represent real collateral and credit risks.

The USGCRP Fourth National Climate Assessment's second volume focuses on welfare, societal, and environmental aspects of climate change.[69] Assuming no changes to emission growth rates, USGCRP estimates hundreds of billions of dollars in annual losses for some economic sectors by the end of the century. Beyond general economic impacts, the report specifically draws attention to coastal regions transforming due to rising seas, whereby many communities will likely see higher costs and lower property values as chronic high-tide flooding increases. In fact, such chronic flooding could lead flood insurers to exit markets, making mandatory flood insurance required for some mortgage less affordable, potentially unavailable without public intervention.

These views expressed in the NCA and AAAS reports are similarly shared by many agencies and institutions. For example, the National Aeronautics and Space Administration (NASA) and National Oceanic and Atmospheric Administration (NOAA) agree with this assessment. NASA argues we are already experiencing rapid climate change, pointing to rising global temperatures, warming oceans, shrinking ice sheets, retreating glaciers, rising sea levels, and more frequent extreme events, among others. In particular, NASA points out that scientists predict global temperature increases from human-made greenhouse gases will continue and severe weather damage will also increase and intensify.[70] Similarly, NOAA points out that the sea level has risen 8-9 inches since 1880, with the rate of accelerating. Additionally, NOAA notes that almost 30% of the population lives in high population-density coastal areas, i.e. areas where SLR may have adverse consequences such as flooding, shoreline erosion, and other hazards from storms. Taken together, these two findings imply that coastal properties will likely experience negative effects due to flooding and SLR.[71]

[69] These agencies are the Department of Agriculture; Department of Commerce; Department of Defense; Department of Energy; Department of Health and Human Services; Department of the Interior; Department of State; Department of Transportation; Environmental Protection Agency; National Aeronautics and Space Administration; National Science Foundation; Smithsonian Institution; U.S. Agency for International Development. The National Oceanic and Atmospheric Administration (NOAA), a scientific and regulatory agency within the Department of Commerce, acts as the administrative agency.

[70] Further discussion of predictions and estimated effects of climate change can be found here: https://climate.nasa.gov/effects/.

[71] NOAA also produces monthly Global Climate Change Reports, which contain more detailed information about land and ocean temperatures and precipitation.

In summary, the scientific community has formed a consensus that climate change is underway. Furthermore, the consequences of climate change may likely include, but are not limited to, greater frequency of natural disasters, increased severity of such disasters, and general SLR that threatens coastal communities and livelihoods. These impacts will have significant consequences for the global economy and financial system, including housing and mortgage markets. An obvious first channel for these risks to affect housing and mortgage markets is due to the increase in frequency and severity of flooding, thereby increasing flood risk for many homes and loans.

B U.S. Response to Climate Change

In the United States, many parties have expressed interest in the effects of climate and natural disaster risk for financial regulation. For example, in January 2021, President Joe Biden issued an executive order prioritizing a domestic response to climate change. In October 2021, the Financial Stability Oversight Council (FSOC) released its Report on Climate-Related Financial Risk. The detailed report discusses (then) to-date progress made by various U.S. financial regulators, as well as data and disclosure issues related to climate-related risks, among other things. The report also stressed the need to understand impacts of climate risks on financially vulnerable populations, populations which may be at risk for achieving sustainable homeownership. In the next subsections we describe, again chronologically, the U.S. response to natural disasters, climate-related changes to the U.S. regulatory regime, and climate-related concerns for infrastructure. Note that we focus primarily on federal regulators and policies. Though summarizing policy positions adopted by the financial regulators of each state would be beyond the scope of this article, we do recognize their importance, particularly in insurance markets.

2.1 U.S. Federal Response to Flooding and the NFIP

A multitude of federal agencies have responded to climate and natural disaster risks. As the primary focus has been on flood risk in the U.S., we restrict attention to each agency's position on flood risk. In what follows we give a brief overview of flood zones and flood insurance requirements, as well as challenges to insuring flood risk in the face of non-compliance.

Perhaps the most prominent of the U.S. agencies that deal directly with flood risk is the Federal Emergency Management Agency (FEMA), which manages the National Flood Hazard Layer (NFHL) database. The NFHL contains current effective flood risk data for over

90% of the U.S. population. The National Flood Insurance Act of 1968 and subsequent amendments created the National Flood Insurance Program (NFIP) and also mandated that all federally backed mortgages (i.e., loans made by the U.S. government, acquired by government-sponsored enterprises, etc.) in high-risk areas carry flood insurance.[72] FEMA classifies many different levels of flood risk using its NFHL. For the purposes of this survey, note that only certain levels of risk require flood insurance (i.e. those that start with "A" or "V"), which are commonly called special flood hazard areas (SFHA).[73] At some risk of confusion, we follow the terminology in the literature and use flood zone, floodplain, and SFHAs interchangeably unless otherwise noted.[74] The significance of flood zone status cannot be underestimated as it serves a dual purpose of being arguably the most common signal of flood risk and also an indicator whether extra flood risk insurance payments must be made. In other words, it serves as both a source of information and also as a tax. It is the most commonly used measure of a home's flood risk. However, as we discuss shortly, criticisms have been made that it is an imperfect measure.

As the manager of the NFIP program, FEMA effectively determines both who will be required to purchase flood insurance (if there is a federally-backed mortgage) and how much coverage will cost.[75] Generally speaking, a SFHA is one in which a flood is expected to happen with a 1% annual chance.[76] On April 1, 2022, FEMA implemented the final phase of the NFIP's Risk Rating 2.0: Equity in Action, which changed pricing rules for flood insurance while leaving flood designations intact. We refer the interested reader to FEMA's website for more information on pricing and coverage. For our purposes, we merely note that the new pricing scheme aims to make pricing more reflective of risk, and in the process erode implicit subsidies that borrowers with higher-valued homes received. Coverage limits are $250,000 for the property and up to $100,000 for personal property contents. Thus higher-valued properties with replacement costs more than $250,000 may run the risk of being underinsured. It is still too early to determine the effects of changes in NFIP pricing, though we believe this will be an active area of research in the future.

[72] Further information on laws pertaining to the flood insurance mandate can be found here: https://www.fema.gov/flood-insurance/rules-legislation/laws.

[73] More details can be found at: https://www.fema.gov/glossary/flood-zones and https://help.riskfactor.com/hc/en-us/articles/360048256493-Understand-the-differences-between-FEMA-flood-zones.

[74] Technically speaking, there are flood zones that do not require flood insurance, though we opt to follow the usage of the literature at the risk of confusion.

[75] There are exceptions as individuals can protest and appeal their designation of flood zone status.

[76] For these reasons, flood zones are sometimes referred to as 100-year floodplains.

The NFIP program is very important and will likely continue to be very important in the future, particularly if private insurers exit markets. According to the Congressional Research Service (CRS), the NFIP is the main source of flood insurance in the United States, collecting $4.6 billion in premiums, fees, and other charges for more than five million policies.[77] The literature finds that the private flood insurance market is very small ($<$ 5% of all policies) and that the most common type of flood insurance is supplemental to NFIP. The second most common type is private insurance in lower risk areas (Kousky, 2018).

A July 2021 report from the U.S. Government Accountability Office (GAO) noted that FEMA's floodplain maps "may not reflect current flood hazards or the potential from flooding from some types of events, such as heavy rainfall."[78] The report recommends using other measures of risk besides FEMA's flood zones, pointing out that besides being inaccurate and not encapsulating all types of flood risk, the maps do not reflect future flood risk. Additionally, the report points out that take-up rates for flood insurance outside of SFHA are very low, suggesting there may be uninsured risk for properties which have actual flood risk yet are not required to purchase flood insurance.[79] Alarmingly, the GAO report also documents instances of noncompliance with the mandatory purchase requirement, finding between 2% and 23% of the examinations [by FDIC, the Federal Reserve, NCUA, and OCC] identified violations, with the most common violation (42%) being lack of flood insurance coverage. Similarly, the Department of Housing and Urban Development (HUD), also investigating gaps in insurance coverage, contracted with 2M Research in March 2020 to better understand the Federal Housing Administration (FHA) portfolio's flood risk exposure by using NFIP data in Florida and North Carolina.[80] The HUD study found that despite a very flood-risk exposed portfolio, only about one-half of those homes required to have insurance actually do. The HUD report study also finds evidence of low take up rates outside of flood zones. This has immediate implications for mortgage markets, whereby lenders or others may be holding unanticipated risk.[81] The implicit recommendation is that financial regulators might consider requiring frequent monitoring of servicers to ensure flood insurance

[77] See CRS report: Introduction to the National Flood Insurance Program (NFIP)

[78] See GAO-21-578

[79] For example, Bradt et al. (2021) also find that low take up rates of only 3.9% of all housing units in the continental U.S. for 2019. Outside of the 100-year floodplains, the 2019 take up rate was even lower at 2.2%.

[80] See 2M Research Report

[81] For example, the servicers of loans in particular are likely to be affected. For Enterprise-backed loans, it is the responsibility of the servicer to ensure flood insurance is in place. As such, the servicer would be responsible for damages to an uninsured property from a legal point of view, at least for Enterprise backed loans.

remains in place for those properties that require it.

Finally, we point to the discussion in a February 2021 report from First Street Foundation (FSF) entitled The Cost of Climate: America's Growing Flood Risk, which finds that nearly 4.3 million residential homes nationwide were subject to a greater than 1% annual risk of economic damage. FSF's projections indicated that total expected annual loss for risky properties would grow from $20 billion dollars in 2021 to $32.2 billion dollars in 2051, an increase of some 61%. Its research attributed these increased risks to climate change. For NFIP to accommodate all risky properties holding its current pricing structure constant, it would have to increase its rates by 450%. Overall, FSF's findings are consistent with the GAO report—economic flood risk in littoral (i.e., shore of sea or lake) and riverine regions is systematically underestimated. The underestimation of flood risk is likely to impact directly many stakeholders including homeowners, lenders, servicers, and securitizer's of loans.

2.2 State-Specific Responses to Natural Disasters

Although it is beyond the scope of this paper to review the universe of state-level legislative responses to natural hazards, we will direct the reader's attention to two natural disaster-prone states that have also introduced legislative initiatives to address hazard risk, Florida and California. Florida, in the aftermath of Hurricane Andrew, then the costliest U.S. disaster ever, created home insurers of last resort by legislative statute. California, especially vulnerable to wildfire risk, created the California Wildfire Fund to address those risks. The challenges faced by these state-level initiatives to address disaster risk may foretell nationwide threats to the solvency of insurance and reinsurance solvency in the climate change era, which of course has immediate implications for housing and mortgage markets. For example, changes in liability natural disasters, say through less insurance coverage, means the ultimate holder of the risk may either be the lender or homeowner, thus changing incentives in both markets. Following the devastation of Hurricane Andrew in 1992, hundreds of thousands of Florida homeowners were unable to find home insurance coverage in the private market. Consequently, the state created the Florida Hurricane Catastrophe Fund as a source of reinsurance to private insurers. Additionally, the Florida legislature created two insurers of last resort. In 2002, it passed legislation to merge these entities into a single insurer of last resort: the Citizens Property Insurance Corporation (Citizens). While the policies Citizens provides have fluctuated since its formation, following Hurricane Ian, the number of policies stands at nearly 1.15 million.[82] In response to a surge in demand for the insurer of last resort as private insurance firms exited the Florida market or went insolvent following Ian, the Florida legislature stepped in with Senate Bill 2A (SB-2A). Besides making a series of reforms to the private insurance market, SB-2A notably introduces a new mandate for properties covered by Citizens to secure supplementary flood insurance irrespective of location in a SFHA. The mandate is to be phased in by 2027.

In July 2019, California enacted Assembly Bill 1054 (AB-1054), an attempt to shore-up the solvency of utility companies in the face of wildfire risk. Before AB-1054, utilities were strictly liable to property owners for any damages caused by fires sparked by their own equipment, regardless of the negligence or fault of the property owner. This led to credit-rating downgrades for utilities whose growth of liabilities due to wildfires outpaced the insurance coverage they were able to obtain. AB-1054 set aside a 21-billion-dollar fund to reimburse Californians negatively affected by utility-caused wildfires.[83] Utilities can only use monies from the fund if they receive a safety certification through the then-newly established California Wildfire Safety Advisory Board. In addition, utilities are no longer strictly liable for equipment-caused wildfires. The state will presume to have acted reasonably so long as they are board-certified. The burden now falls on property owners to prove unreasonable behavior on the part of the utility. Although AB 1054 has worked to stave off bankruptcy of major utility companies, academics and policymakers have criticized it as a bailout of investor-owned utilities and for failing to address one of the root causes of high wildfire damages: older building stock not built to fire-safe code standards (Thurman, 2022). In short, wildfire risk has prompted the government of California to relax liabilities for utility companies.

Similar to Florida's Citizens, California's FAIR plan has seen surging enrollments over the past few years.[84] Recently, wildfire damages and reconstruction costs are also cited by State Farm Insurance as why they will no longer issue new homeowners insurance policies

[82] Citizens projects that it will insure 1.7 million policies at the end of 2023 with more than $5.1 billion in premium volume. In 2019, Citizens wrote $877 million in premiums insuring 447,000 policyholders. This would constitute "5-year growth rates in premium and policyholders of 486% and 276%, respectively." More statistics on the growth of this insurer of last resort can be found in Citizens' 2023 Operating Budget (https://www.citizensfla.com/documents/20702/42553/2023+Budget.pdf/92120046-28bf-e346-25c1-564ddee4fc35?t=1671034691765).

[83] This fund is half paid for by utilities and half by a statewide $30 annual surcharge on electricity bills.

[84] The goal of the FAIR plan is to be a temporary safety of insurance until homeowners can acquire traditional insurance. See https://www.cfpnet.com/about-fair-plan/

in the state of California.[85] Soon after State Farm announced their decision to stop issuing new policies, Allstate also announced they were stopping issuing new homeowners insurance policies in California.[86]

Growing concern about the exit of private insurers in both Florida and California may mean that other states may soon follow suit. Research has shown that insurance has played a key role in minimizing losses after disasters. The limited availability of insurance or reliance on insurers of last resort could have significant implications for housing markets in the future.

Finally, though too numerous to mention individually, state insurance regulators are also important for understanding climate risks. Representing the interests of the chief insurance regulators from all 50 states, the District of Columbia, and five U.S. territories, the National Association of Insurance Commissioners (NAIC) formed a climate and resiliency task force and released a report ("Adaptable to Emerging Risks") of state regulators' activities, also highligting the importance of climate risks.

2.3 U.S. Regulatory Response to Climate Change

Financial regulators in the United States have begun to integrate climate risk into their oversight. Here we summarize only a few of the most recent (as of writing) updates. Generally speaking there is agreement that climate risks are a priority, though implementing changes to address these risks are still in the early stages. In particular, the proposed yet not finalized (as of the writing of this article) SEC rule for climate disclosures is in the early stages.

In October 2021 the FSOC released a report that identified climate change "as an emerging and increasing threat to U.S. financial stability", and stressed the need for more information. In response, FSOC created a Climate-related Financial Risk Committee (CFRC) to address

[85] State Farm Insurance was the largest property insurer in California as of 2021

[86] See https://www.latimes.com/business/story/2023-06-02/allstate-state-farm-stop-selling-new-home-insurance-in-california

outstanding challenges.[87] Leaders of the Federal Deposit Insurance Corporation (FDIC), Federal Reserve, and the Office of the Comptroller of the Currency have made similar statements recognizing the importance of climate risks. Additionally, the Federal Reserve Board announced a climate scenario analysis exercise in which the six largest banks would participate. Non-banking financial regulators have also started addressing climate-related financial risks, including the Federal Housing Finance Agency (FHFA), Consumer Financial Protection Bureau (CFPB), and the U.S. Commodity Futures Trading Commission (CFTC).[88] In particular, the CFTC also calls for economy-wide carbon pricing, greater international coordination to form common definitions and standards for climate-related data and financial products, judicious use of scenario analysis, and an enhanced disclosure regime. In sum, these responses are likely to foster standardization of metrics and scenarios for assessing climate risk. In turn, this will plausibly allow lenders to be better prepared to mitigate climate risk.

There has also been interest in information disclosures for climate risk. In March 2022, the Securities and Exchange Commission (SEC) proposed rules to enhance and standardized climate disclosures for registrants. These changes would mandate registrants to describe information about climate risks that were reasonably likely to affect their business operations in registration statements and periodic reports. Furthermore, the SEC would require the inclusion of climate-related financial statement metrics in audited financial statements as well as disclosure of their GHG emissions. These rules would be consistent with those proposed by the Task Force on Climate-Related Financial Disclosures (TCFD), which is an outgrowth of the Financial Stability Board (FSB), an association of G20 countries and

[87] FSOC is composed of ten voting members who head the U.S. Department of the Treasury, the Board of Governors of the Federal Reserve System (Federal Reserve Board or FRB), the Office of the Comptroller of the Currency (OCC), the Consumer Financial Protection Bureau (Bureau or CFPB), the Securities and Exchange Commission (SEC), the Federal Deposit Insurance Corporation (FDIC), the Commodity Futures Trading Commission (CFTC), the Federal Housing Finance Agency (FHFA), and the National Credit Union Administration (NCUA), along with the independent member with insurance expertise, plus five nonvoting members. Two of the nonvoting members head the Office of Financial Research (OFR) and the Federal Insurance Office (FIO). The other three nonvoting members are a state insurance commissioner, a state banking supervisor, and a state securities commissioner designated by their peers. See https://home.treasury.gov/system/files/261/FSOC-Climate-Report.pdf for more details.

[88] For example, in December 2021, then-Acting FHFA Director Sandra Thompson released a statement recognizing climate change as a threat to the U.S. housing finance and also instructed Fannie Mae and Freddie Mac, the government sponsored enterprises (GSEs), to actively consider climate change's effects in their decision making. In September 2020, the CFTC unanimously voted to adopt a report entitled Managing Climate Risk in the U.S. Financial System, which presents 53 recommendations to manage climate-related financial risk.

other international organizations.[89] Though as of the writing of this report the SEC has not yet published a final report, we believe that a final rule, in any form, is likely to have significant impacts on markets, particularly if demand for Environmental-Social-Governance (ESG) assets increases. With new disclosures, investors with preferences for ESG assets will likely reduce holdings of entities with large carbon footprints. Alternatively, home buyers and lenders are likely to be better informed in market transactions with the new rule. We predict a rich set of papers to study the effects of such a disclosure rule change.

In summary, as with international regulators, U.S. regulators recognize the importance of climate-related risks and are in the beginning stages of developing risk identification and risk management. Many have formed task forces and started the information gathering process. With respect to flooding, changes occurred this last year in pricing for flood insurance through the NFIP and withdrawal of private insurers in some markets. Additionally, several published reports argue for more advanced measures of flood risk. We believe standardization of metrics for climate risk and information disclosures will likely play a large role in market transactions in the future.

2.4 Risks to U.S. Infrastructure

CFTC draws attention to financial system vulnerabilities and interdependencies that at first glance have little to do with climate change. Beyond the direct physical threat imposed by climate change on the housing stock that we previously discussed, CFTC further notes that declines in property values may adversely affect property taxes, which reduces state and local capacity to build infrastructure key to climate change adaptation. Additionally, the possible displacement of populations and communities in the United States due to climatic factors may generate large economic losses for households and investors. [90]

The U.S. Department of Energy (DOE) also notes that higher global temperatures mean more stress on the nation's energy infrastructure as we experience more wildfires, drought, and high electricity demand. Additionally, they point out that severe weather, the leading cause of power outages and fuel supply disruption in the United States, is likely to worsen. The DOE is working to increase energy efficiency of appliances, homes, businesses, and

[89] The reader may view the TCFD's recommendations here: https://assets.bbhub.io/company/sites/60/2021/10/FINAL-2017-TCFD-Report.pdf.

[90] See Managing Climate Risk in the U.S. Financial System: Report of the Climate-Related Market Risk Subcommittee, Market Risk Advisory Committee of the U.S. Commodity Futures Trading Commission

vehicles.[91]

C International Response (Central Banks and System-wide Regulators)

While our paper focuses on the U.S., other central banks and international financial regulators have started to recognize and address climate-related financial risk. Though still in the early stages, much of the work so far focuses on data gaps, identifying key risk definitions and plausible channels/mechanisms for these risks to manifest themselves, appropriate scenario analysis and stress testing, and challenges of incorporating climate risk into traditional risk frameworks. In what follows, we present in more detail the findings of the main reports from international financial regulators in chronological order to give the reader a sense of the history of how climate risks were recognized and addressed. Across all reports we discuss, there is a general agreement that climate is a concern and that it must be addressed. In particular, there is a shared view that climate risks could be incorporated into existing risk frameworks, though this may be more challenging than one realizes. We view the reports as building off of one another, hence our choice for a chronological presentation order. We try only to mention what each new report added to the conversation. Finally, to be more explicit about the connection to housing and mortgage markets, we believe that in order to fully understand the impact of climate risks one must understand not only the consequences of the the risks themselves (holding the regulatory environment unchanged), but also anticipate the likely regulatory responses to such risks.

Starting in Europe, in December 2019 the Bank of England's published its proposal for the 2021 Climate Biennial Exploratory Scenario (CBES), which is used to assess climate change risks. Its approach includes a 30-year horizon and multiple scenarios.[92] Notably, the report includes detailed descriptions of both physical and transition risk CBES scenarios. In November 2020, the European Central Bank (ECB) published the final version of its guide on climate-related and environmental risks. In this guide, the ECB provides high level recommendations and supervisory expectations for climate-related and environmental risks under its current prudential framework. Though not binding, the guide illustrates how the ECB expects institutions to consider climate and environmental risks. It expects

[91]See https://www.energy.gov/climate-change.

[92]See https://www.bankofengland.co.uk/stress-testing/2021/key-elements-2021-biennial-exploratory-scenario-financial-risks-climate-change for more information on the Bank of England's climate stress testing plans.

organizations to develop their own management for these types of risks, incorporate them into their existing frameworks and ensure capital adequacy, and publish meaningful information and key metrics related to these risks in their disclosures.

Next, the Basel Committee on Banking Supervision (BCBS) similarly released many reports on climate-related financial risks; we focus on three. In April 2021, BCBS released a report on Climate-related financial risks – measurement methodologies, which outlines general issues, discusses current approaches by banks and supervisors, and provides a high-level summary of the strengths and weaknesses of the main types of measurement approaches. Among its key findings are that managing climate-related financial risks has unique features (such as a necessity for highly granular data, e.g. high-resolution geospatial data for physical risks) that may make it challenging to incorporate into existing risk frameworks. The report identifies data challenges for both physical and transition risks, including geospatial and financial data.

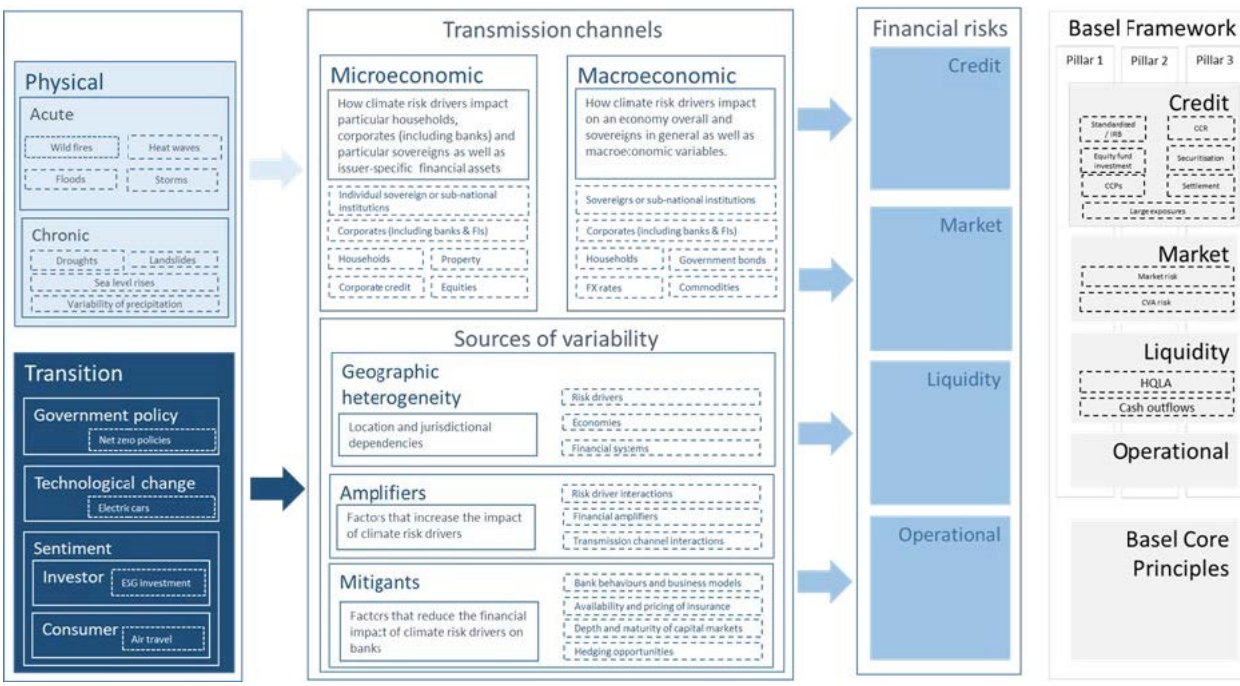

Figure 4: From the BCBS April 2021 Report: Climate-related risk drivers and their transmission channels

Relatedly, the report points to a lack of a systematic way to translate climate change scenarios into standard financial risk. The report also finds that banks and supervisors have (as of April 2021) placed emphasized credit risk, with less focus on market, liquidity, and operational risk.

BCBS released an additional report on Climate-related risk drivers and their transmission channels. In Figure 2 (Figure 1 from BCBS's report) we present BCBS's basic framework and likely transmission channels for both physical and transition risks. As an example, flooding is a type of physical acute risk. Flooding has both microeconomic (e.g., changing borrower behavior) and macroeconomic (e.g., employment in a flood-affected area may decline temporarily) consequences for how individuals and the economy will respond. These changes in economic behavior and outcomes, such as delinquency due to income loss, may increase credit and market risk, among others.

The report points out important heterogeneity across geographies, sectors, and economic/financial system development, noting that climate-related events and risks are uncertain and may be non-linear. To size these financial risks, regulators can require their regulated entities to perform scenario analysis to assess their exposures due to physical and transition risk drivers. While some work already occurs on this front (e.g., the IPCC and CBES scenarios previously mentioned), the report encourages more research about risk drivers and transmission channels for risk. Finally, the report agrees with prior reports in that climate-related financial risks can be captured using traditional risk categories with the Basel Framework.

In June 2022, BCBS released Principles for the effective management and supervision of climate-related financial risk, which develops high-level principles for climate risk management and supervisory practices within the existing Basel framework. The report formalizes 18 principles, 12 for banks and six for supervisors, which range from corporate governance to risk management and disclosure requirements, among others.[93] We believe that these principles (and others like it) are likely to influence future work for financial regulators.

Finally, the Network for Greening the Financial System (NGFS) is an international group of central banks and supervisors that meet to "share best practices and contribute to the development of environment and climate risk management in the financial section and to mobilize mainstream finance to support the transition toward a sustainable economy." It has published many reports, including a Final Report on Bridging Data Gaps, a Guide to

[93]These principles provide guidance on various topics including corporate governance, internal control framework, capital and liquidity adequacy, risk management process, management monitoring and reporting, comprehensive management of credit risk, comprehensive management of market, liquidity, operational and other risks, scenario analysis, prudential regulatory and supervisory requirements for banks, and finally responsibilities, powers and functions of supervisors.

Climate-Related Disclosures, Annual Reports, and a Progress Report on Scenario Analysis, among others. Notable is its May 2020 report titled Guide for Supervisors: Integrating climate-related and environmental risks into prudential supervision, which provides definitions as well as guidance for identifying and assessing climate-related and environmental risks and setting supervisory expectations, among other aspects.

In summary, international financial regulators and central banks are in the early stages of developing regulatory frameworks to address climate change and natural disasters systematically. They have generally agreed upon definitions of key climate risk terms and general principles, while much work remains in the details of implementation. Scenario analysis is in the early stages, with much work remaining to be done on standardization. There also appears to be agreement for the different risk channels in which climate and natural disasters will manifest themselves. The direction forward appears to be integrating these new climate and natural disaster risks into existing risk management systems while recognizing the unique challenges associated with this exercise. Such regulatory changes will likely have impacts on mortgage markets, as lenders will likely be required to adjust their lending behavior in response to such risks.