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When Climate Meets Real Estate: A Survey of the Literature

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Abstract

With near unanimity, climate scientists project natural disasters to increase in frequency, severity, and geographic scope over the next century. We survey academic literature at the intersection of these climate risks and real estate. Our review of physical risks includes price, loan performance, and migratory effects stemming from flooding, wildfires, and sea level rise. We review transition risks, including energy use and decarbonization, as they relate to real estate. Where possible, we explain how these topics may intersect with housing affordability. We conclude by highlighting critical areas for future research.

Keywords: climate change · hazard risk · sustainability · affordability

JEL Classification: C5 · E3 · R1 · R3

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. Both realized disaster damage and an increased probability of disaster damage can lower property values. In turn, this could increase the probability of borrowers' delinquency, particularly if they lack appropriate insurance coverage. Another risk channel is the increasing intensity of chronic stressors like sea level rise (SLR) and drought. Housing markets are unlikely to have fully capitalized the risk associated with these longer-term events due to uncertainty over their precise impact.[1] Yet, a further risk channel stems from adaptation measures to and mitigation polices against climate change. As governments introduce policies to reduce carbon emissions, communities may experience shocks to labor markets and public services that will ultimately spill over into real estate markets.

Much variance exists in both the long-term projections for natural processes and the related policy choices, which, in turn, create great variance in the costs that climate change imposes on real estate markets. That said, the National Aeronautics and Space Administration (NASA) reports that Earth is already experiencing SLR and more intense heat waves. In addition, severe weather damage will also increase and intensify.[2] Thus, 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

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

[2] By 2050, scientists anticipate sea levels to rise by one foot on average along the U.S. coast. By 2100, assuming economies continue 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 habitable. For further details, see https://climate.nasa.gov/effects/ and NOAA's 2022 SLR Technical Report. We discuss SLR projections in greater detail in an online appendix. Our online appendix is accessible through the working paper version of this paper hosted on the FHFA website at https://www.fhfa.gov/PolicyProgramsResearch/Research/Pages/wp2305.aspx.

markets may adapt to greater flood risk by making relatively less costly investments like improving drainage or installing sump pumps. Other regions may require 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 capitalizes 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 values in affected areas. Second, beliefs about climate change risk are likely to feed into insurance take up. In turn, these updated beliefs about market risk may change prevailing market equilibria in housing, mortgage, and insurance markets, thereby affecting many stakeholders.

Given the complications associated with climate change and its influence on housing and mortgage markets, let alone asset markets in general, we restrict the scope of our review of the literature.[3] First, we largely focus on the U.S. housing and mortgage markets as they represent the bulk of work at the intersection of climate change and real estate. However, 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

[3] For more recent general surveys of climate change and natural disaster literature, see Botzen et al. (2019), Dell et al. (2014), Canals-Cerda et al. (2021), and Craig (2022). Additionally, Kousky et al. (2020a) provides an excellent survey of flood risk literature. We build on these studies 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.

to multifamily housing markets.[4] By limiting our scope, we hope to gain both the breadth and depth useful to both 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, postponing the definitions of the key risk terms until the next section. First, the physical risk literature shows a variable price discount from disaster risk over time. This result is true for both flooding and wildfires, two of the more studied disasters in housing. However, studies find that information—whether from recent damages, other storms, or disclosures—is important to internalizing disaster risk and therefore to the existence and size of the discount. Second, studies on acute physical 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.[5] 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 association translates to better mortgage performance.

One of the most critical outstanding needs is to estimate the longer-term burdens of climate change for real estate markets. Risks like drought and heat stress are difficult to study due

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

[5] 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 common publicly used datasets are FEMA's data on disaster declarations, assistance programs, and the National Flood Insurance Program (NFIP) (https://www.fema.gov/about/openfema/data-sets), and NOAA's SLR (https://coast.noaa.gov/slrdata/), precipitation and temperature (https://www.ncei.noaa.gov/cdo-web/datasets), and hurricane track data (https://www.nhc.noaa.gov/data/).

to their extended time horizon but may be among the most costly and impactful for real estate. Furthermore, in transitioning to carbon neutrality, local economies dependent on carbon-intensive industries may face harms; however, identifying those regions and plausible adaptation strategies remain challenging. Importantly, how the risks of climate change and natural disasters may influence housing affordability and sustainability remains a pressing, open, and difficult question.

Our paper proceeds as follows. To orient the reader, we begin by reviewing the basic terminology of climate change and natural disaster risks. In an online appendix, we briefly review the scientific consensus on climate science, as well as international and domestic responses by governments and financial regulators, for readers interested in background information.[6] The bulk of our paper surveys 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 transitioning to a low-carbon economy, we focus our review on two of the most relevant and developed areas: energy and decarbonization. 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.

Climate Risk Definitions

Private industry, public agencies, and academics alike typically use the jargon of climate scientists. Much of the terminology may not be familiar to the lay reader.[7] Accordingly, we review the vocabulary most relevant to understanding the research that we discuss later.

[6] Our online appendix is accessible through the working paper version of this paper hosted on the FHFA website at https://www.fhfa.gov/PolicyProgramsResearch/Research/Pages/wp2305.aspx

[7] See the BCBS' 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.

The two main classifications for the risks posed by climate change and natural disasters are "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." 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)."[8] In short, 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 including loss of human life. Also note that physical risks include the shorter-term (acute) risks from natural disasters like flood and wind damage, as well as the longer-term (chronic) risks from climate change like sea-level rise.

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. In contrast to physical risks, transition risks encompass the consequences of economic shocks associated with shifting to a carbon-neutral economy. For

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

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 researchers writing fewer papers on transition risk than physical risk limits our scope.

Physical Risks

To date, physical risks are the focus of the literature on climate-related risks to housing. We begin our survey by discussing recent research on discount rates and how climate change may affect them. Then, we review papers that study the price effects of physical risk from both wildfires and floods, exploring the heterogeneity in the flood risk literature through a meta-regression while investigating the role of beliefs and perceptions. Beyond price effects, we review literature on migration and climate risk incidence, mortgage performance, and disaster insurance. Our physical risk survey concludes with 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 create tables that present what we believe is the headline estimate from a paper. We want to emphasize that the studies we reference in these tables differ in their empirical strategies, geographic contexts, and in some cases, their independent and dependent variables. While we hope that these studies serve as future references to the reader and enable quick takeaways of effect magnitudes, we also want to emphasize that by no means should readers interpret these selected effect sizes as generally comparable.

Climate Discount Rates

Given the significant yet uncertain consequences of climate change for asset markets, we start our physical risk survey by discussing discount rates. Disagreement exists 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).[9] More recently, Rennert et al. (2022) discuss discount rates in relation to the social cost of carbon. We suggest also reviewing the Office of Management and Budget's (OMB) recommendations and discussions for governmental use of discount rates.

The standard approach, as Newell and Pizer (2004) explain, is to use a single discount rate like four percent (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 two percent to seven percent in the future, and that over a longer time horizon, bond yields will likely be at the lower end of the proposed range (and be more uncertain). Similarly, Gollier and Hammitt (2014) also argue for discount rates depending upon length to maturity with a range of one percent to four percent. The paper also points out differences in approaches and ranges across national governments. Similarly, building off the classic Ramsey discounting formula (Ramsey, 1928), several papers have argued for a declining climate discount rate by 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 and find that 92

[9] 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 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.

percent of them place the discount rate in the one to three percent range with a mean of 2.3 percent. The paper notes that this figure is lower than rates previous studies reported, although it does not comport with the Intergovernmental Panel on Climate Change's (IPCC) 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, as 62 percent of researchers use normative justifications.

As with the broader literature, consensus does not exist in the debate on a climate discount rate for real estate. Giglio et al. (2021b) suggest using 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 six percent 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.[10] Gourevitch et al. (2023) illustrate the importance of discount rates for cost/benefit analysis and consequent policy decisions. Consistent with papers that we discuss later, they find that U.S. home prices do not capitalize flood risk in its entirety. Specifically, they estimate the extent of overvaluation in U.S. real estate markets relative to discount rates. Under a "mid"-hazard scenario, with a three percent discount rate (the authors' preferred value), properties are overvalued by $187 billion. However, under the same scenario with a 7 percent (1%) discount rate, properties are now overvalued by $121 ($237) billion. The range of imputed discount rates reflects their

[10] 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.

sensitivity to modeling assumptions.[11]

In summary, an active and vibrant debate centers around the appropriate climate discount rate. The discussion involves theoretical and ethical considerations, some of which may lie outside the scope of economics (Gollier and Hammitt, 2014; Dasgupta, 2008; Caney, 2009). 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 discount rates. Some researchers advocate using time-varying discount rates. We stress again the important contribution of Giglio et al. (2021b) who connect housing returns to discount rates. We believe this is likely a worthwhile area of research for those interested in taking the climate-adjusted discount rate debate to the housing and mortgage market literature.

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, some research that has attempted to do so has found mixed results.[12] Because most papers in the literature study individual events or physical risk types, we organize this section by type of disaster. We also distinguish the effects of flooding damage from acute events like hurricanes from longer-term, chronic events like SLR. While both are sources of flooding, the differing timelines suggest their consequences on housing

[11] 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.

[12] 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 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.

and mortgage markets may be treated differently.

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.[13] If flood risk is a disamenity of which buyers and sellers are aware, then it is likely to be capitalized into the price of a home.[14] Many 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 because they must purchase flood insurance for federally backed mortgages for these homes. Identifying the discount strictly associated with increased flood risk is not a trivial exercise; 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, along with other confounders.[15] Some papers compare the flood discount with the net present value (NPV) of flood insurance premiums (Atreya et al., 2013; Bin et al., 2008; Bin and Polasky, 2004; Harrison et al., 2001; Zhang, 2016; Zhang and Leonard, 2019). Most of these papers find evidence of a price discount. However, mixed results exist as to whether the discount is more, less, or equal to the NPV of flood insurance premiums among those that find such negative price effects. Hence, the direction of the implied risk premia remains subject to active debate. Table 1 shows the estimated effect sizes of the papers we reference in this section.

[13] 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).

[14] Though most literature focuses 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.

[15] 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.

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	-0.01	0.02	T3
Bin and Polasky	2004	North Carolina	8,375	-0.06	0.01	T3
Bin et al.	2008	North Carolina	3,106	-0.08	0.03	T3/Col(4)
Harrison et al.[a]	2001	Florida	29,981	-$1,034.38	535.95	T4/Col(3)
Kousky	2010	Missouri	153,185	-0.04	0.01	T2/Col(5)
Pommeranz and Steininger	2020	Germany	6,371	-0.01	0.02	T4 Col(1)
Pope	2008	North Carolina	15,514	-0.04	0.02	T4/Col(3)
Shr and Zipp	2019	US	14,926	-0.12	0.066	T3/Col(5)
Yi and Choi	2020	Iowa	51,798	-0.19	0.08	T5/Col(2)
Zhang[b]	2016	North Dakota	28,154	-0.04	0.02	T3/Col(3)
Zhang and Leonard[c]	2019	North Dakota	13,513	-0.05	0.02	T3/Col(4)
Atreya et al.	2013	Georgia	8,042	-0.41	0.09	T2/Col(3)
Atreya and Ferreira	2015	Georgia	2,685	-0.46	0.15	T6/Col(1)
Bin and Landry	2013	North Carolina	3,360	-0.42	0.23	T4/Col(3)
Bin and Polasky	2004	North Carolina	8,375	-0.05	0.02	T4
Fang et al.	2021	Florida	22,031	-0.05	0.02	T4/Col(2)
Gibson and Mullins	2020	New York	182,667	-0.12	0.05	T1/Col(4)
Hallstrom and Smith	2005	Florida	5,212	-0.19	0.07	T3/Col(1)
Hino and Burke	2021	US	5,641,317	-0.01	0.01	TS3/Col(2)
Kousky	2010	Missouri	424,727	-0.02	0.01	T3/Col(5)
Muller and Hopkins	2019	New Jersey	65,626	0.13	0.013	T7/Col(6)
Yi and Choi	2020	Iowa	51,798	0.28	0.13	T5/Col(2)
Zhang and Leonard	2019	North Dakota	1,062	-0.08	0.07	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 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, we report either the interaction effect or flood discount immediately after the event. We used a 100-year flood zone, and avoid terms with damages/inundation (to isolate direct effect of flood zone discount) wherever possible.

[a] Harrison et al. (2001) report estimates in dollars, which make the numbers much smaller. To get an approximate percentage discount, we add the dollar discount to the mean sale price for homes in flood zones to use as a base price, which leads to a 1.46 percent discount.

[b] Zhang (2016) uses a quantile approach, we report only the single point estimate of the median to make the estimates more comparable with the literature.

[c] Zhang and Leonard (2019) estimate discounts that vary spatially, making a single point estimate difficult to report. We chose to report a baseline estimate of their discounts for comparability to the literature, at perhaps risk of ignoring the focus of the paper.

Additionally, researchers also study how the flood zone discount varies across time and space, typically finding that it is greatest after a flood 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 percent to 12.2 percent across their specifications. Bin and Landry (2013) also find a changing flood discount over time, ranging from 6 to 20 percent 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 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, 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 yet also provide seaside views for which consumers are willing to pay a premium. Bin and Kruse (2006) find a 5 to 10 percent 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 price premiums in high-risk areas, which they suggest amenity effect may at least partially drive. Thus, ex-ante the research 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) argue that flood risk is not always capitalized into home prices, but is more priced in for more risk-aware buyers.

Researchers also ask whether discounts vary across different types of homes, with flood zone status being the most common grouping.[16] 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 flood zone (where flood insurance is not mandatory) are likely to experience a price decrease, suggesting that individuals may update beliefs about flood risk after an event. However, the paper finds diminished effects of a flood over time, implying these updated beliefs may be short lived. Similarly, Yi and Choi (2020) find that after the great Iowa flood of 2008, homes that did not expect to be inundated still experienced discounts. Moreover, for homes within the 100-year floodplain, inundated homes experienced no significant change in prices while those 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 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, though the impact diminished over time.

Some papers study the effects of disasters on properties that the storm did not directly affect, 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, undamaged homes in flood zones in a neighboring county saw a 19-percent 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-

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

differences approach to show the distant Hurricane Sandy (New York City) affected homes prices in Miami-Dade County, FL. They find that while prior to Sandy, homes in high flooding risk areas commanded a price premium of around four percent (perhaps due to offsetting amenities) relative to lower risk areas, the premium changed into a time-varying discount after the storm. 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.

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 difference-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 to 7 percent 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 the effect vanishes in the long run. On the other hand, they find no evidence of a positive effect for homes in a flood zone that Sandy did not affect. Thus, their results suggest that market participants react to unexpected flood risk, though may "forget" it after enough time elapses. Using data from Dresden, Germany, and a spatial hedonic model, Pommeranz and Steininger (2020) analyze direct (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 percent for houses and -4.8 percent for condominiums.[17]

[17] In a related vein, Atreya and Ferreira (2015) find that "seeing is believing," where inundated properties within a flood zone in Georgia were significantly more discounted than non-inundated properties within the flood zone, suggesting the importance of not only beliefs, but also actual damages.

Related to risk-updating, the literature studies how disclosing flood risk affects home prices as another channel by which beliefs capitalize 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 to show a 4.3 percent discount in prices for homes in flood zones after disclosure, with no evidence of a discount before the state enacted the law. Relatedly, Troy and Romm (2004) take advantage of a recently introduced flood disclosure law in California to study the effects of newly disclosed risk on home prices. They find a new 4.2 percent discount for being in a flood zone. Using a natural experiment when flood maps changed, Shr and Zipp (2019) find that homes newly assigned to flood zones saw an 11-percent price decrease. Gibson and Mullins (2020) study three different events related to belief updating: reduced flood premium subsidies from the Biggert-Waters Flood Insurance Reform Act of 2012, damages from Hurricane Sandy, and changes in floodplain maps for homes not damaged by Sandy. For impacted properties, they find discounts of 3–5 percent, 5–7 percent, and 11 percent for the different events, respectively, which suggests significant flood-risk belief updating.

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 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 eight percent for undamaged homes in flood zones. In contrast, damaged homes saw large, immediate discounts from 17 to 22 percent that decreased to 8 percent over time. Fisher and Rutledge (2021) study commercial properties and find a discount of around 25 percent over eight quarters for damaged properties when combining all property types together. Moreover, they find 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, find initial 16 percent discounts followed by a 12 percent 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 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), Addoum et al. (2023) and Holtermans et al. (2022) also study American commercial real estate. 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 decreased occupancy rates as 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, Addoum et al. (2023) find evidence of long-lasting (at least five 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.

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

Authors	Year	Location	Obs.	Effect Size	SE	Table/Col
Addoum et al.	2023	New York	2,216	-0.19	0.09	T2/Col(4)
		Massachusetts	1,394	-0.11	0.03	T2/Col(5)
		Illinois	951	-0.02	0.46	T2/Col(6)
Fisher and Rutledge	2021	US	334,132	-0.26	0.08	T3
Holtermans et al.	2022	New York	10,359	-0.02	0.01	T2/Col(5)
		Texas	15,312	-0.04	0.01	T2/Col(2)

Notes: This table presents coefficients for various estimations from papers. Effect size corresponds to the estimated log of price discount for real estate in that paper's "preferred specification", while SE corresponds to that coefficient's standard error.

In summary, general agreement seemingly exists that flood discounts are real, vary across location and type of home, and change over time, with the largest discounts occurring immediately after events. This result suggests that changing risk perceptions, after observing a storm or learning about newly disclosed flood risk-related information, may induce a price discount for affected homes.[18] Many papers argue that unexpected disasters induce the greatest discounts (e.g., homes not in a flood zone), arguing that risk beliefs update. However, care is needed to separate the discount due to increased insurance premiums from a true risk-belief price discount. Insurance data seems to be particularly useful for this separation.

Wildfire Risk and Home Prices

High-risk wildfire states like California and Colorado contain much of the nation's housing value.[19] Per the Environmental Protection Agency (EPA), between 1980 and 2021, the United States experienced 20 billion-dollar wildfire events, 16 of which burned after 2000. This result is partly 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 approximately 33 percent to nearly 300,000 square miles. More than 46 million homes with an estimated market value of some $1.3 trillion and around 99 million people reside in the WUI.[20] In summarizing the scientific consensus, the

[18] These studies show that informed homeowners are more likely to respond and that direct and indirect experience with damages is a way that real estate market participants learn. Homeowners and borrowers may learn about climate risks from a variety of sources. A recent Fannie Mae national survey 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 (21.3 percent of national housing value) and Colorado's at $1.2 trillion (2.8% percent 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).

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

EPA notes that scientists find that climate change is increasing both the length of the wildfire season and the frequency of wildfires. Another concerning trend reflects the increases to the areas that wildfires burn. In the 1990s, wildfires burned an average of 5,200 square miles annually; in the 2010s, the number increased to 10,700 square miles.[21]

[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).

Table 3: Wildfire-related Real Estate Discounts

Authors	Year	Location	Obs.	Effect Size	SE	Table/Col
Hansen Naughton*	2013	Alaska	8,796	-0.06	0.03	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	-0.25	0.02	TA1/Col(3)
Mueller et al.	2009	California	2,520	-0.10	0.02	T4
Stetler et al.	2010	Montana	11,817	-0.14	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 and Naughton (2013)'s effect shown is for small wildfires within 0.1km for the entire 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 and Loomis (2014) take a quantile approach, so to make their numbers more comparable with the literature. We reported only the median point estimate.

Using hedonic analysis methods, researchers generally find that homes in high-risk wildfire areas experience negative, but transient and localized, price shocks after a wildfire. 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 percent for homes in Southern California (Mueller et al., 2009), 7 to 14 percent for homes in Montana (Stetler et al., 2010), and 6 to 13 percent for homes in Alaska (Hansen and Naughton, 2013). McCoy and Walsh (2018), studying the Colorado WUI, consider how risk salience affects housing demand and prices. They find a 12.6 percent discount in the first year following a fire, with homes located within a two-kilometer radius experiencing more significant price reductions in subsequent years. Mueller et al. (2009) also finds that the home 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 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 find delinquencies and foreclosures increased in regions exposed to wildfires, though decreased in the size of the wildfire. They argue this decrease is likely due to homes being required to be reconstructed to (higher quality) modern building codes, thereby increasing property values and casualty-insurance covered losses. 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 also incentivize individuals to live in areas with more wildfire risk.

Prospective homeowners may lack complete information about individual property's wildfire risks.[22] In a study of wildfires in Colorado Springs, Donovan et al. (2007) find that before the fire department implemented a ratings system to disclose fire risk, fire risk and price were positively correlated, suggesting either that homebuyers were unaware of their properties' wildfire risk at time of purchase or that amenities outweighed the risk. However, the relationship disappeared after the fire department created the ratings, suggesting homeowners' risk beliefs 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.

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 as we detail later, 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

[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."

[23]The EPA summarizes 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.

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.

Perceptions and Home Prices

Belief in the reality and significance of climate change appears to influence the existence and magnitude of real estate discounts; this belief 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 SLR Technical Report, an interagency effort to synthesize the latest science on SLR, projects that relative sea levels along the continental United States 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 under an intermediate greenhouse gas scenario, the resulting permanent flooding is projected to reduce global real gross domestic product (0.19 percent) and reduce welfare (0.24 percent) as coastal populations decline due to reduced 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.

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

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	-0.00	0.04	T3/Col(5)
Bernstein et al.	2019	US	130,685	Property	-0.07	0.02	T2/Col(4)
Filippova et al.	2020	New Zealand	8,436	Property	-0.00	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	-0.04	(.000)	T2/Col(1)
Murfin and Spiegel	2020	US	4,292,176	Property	-0.00	0.00	T2/Col(1)
Tyndall	2021	New York	164,026	Property	-0.01	0.00	T2/Col(1)

Notes: Effect size corresponds to the estimated log of price discount for real estate in that paper's "preferred specification." Keys and 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 show 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 to 10 percent 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 percent discount for SLR-exposed homes relative to similar properties equidistant from the beach. They note that the discount is growing over time and that prospective buyers concerned about climate change catalyze it. 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 percent 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 percent in their baseline area under a business-as-usual climate change scenario. The authors also analyzed other cities, arguing that the Rhode Island estimates are likely conservative. Nearly 40 percent of surveyed residents in flood zones responded that they were "not at all" concerned about flooding over the next

[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.

decade. Botzen et al. (2015) find that households overestimate tail risk probability but underestimate potential damage, leading to underinvestment in adaptation measures. Fu and Nijman (2021) also find discounts for SLR exposure, though not at every exposure level. Further, they find that owner-occupiers and investors may discount properties differently. 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 percent, though as they point out, this varies depending upon the buyer's climate beliefs. Nguyen et al. (2022) find an 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, total unanimity that flood prices are capitalized, even in climate pessimist communities, does not exist. 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) report that real estate agents 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

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

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

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).

Meta-Analysis of Selected Empirical Work

We present 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 attempt to synthesize these results qualitatively, a quantitative summary requires meta-analysis. Previous meta-analyses summarize the entire 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 understand patterns in effect sizes quantitatively across geographies and study designs.

We 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 previously discussed, estimates of flood risk discounts vary greatly; Beltrán et al. (2018) include effect sizes ranging from -75.5 to 61 percent in their analysis. Yet, after adjusting for 18 moderator variables across six 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 percent. 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 favoritism and suffer from omitted variables 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 identify 11 papers published in the last 10 years that addressed 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 select the coefficient that, in our view, struck the best balance between the preferred estimates of the cited paper and comparability with other coefficients in the meta-sample.[30]

We begin with 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 estimate a random-effects model.[31] This model weights studies using their inverse error-variance, so

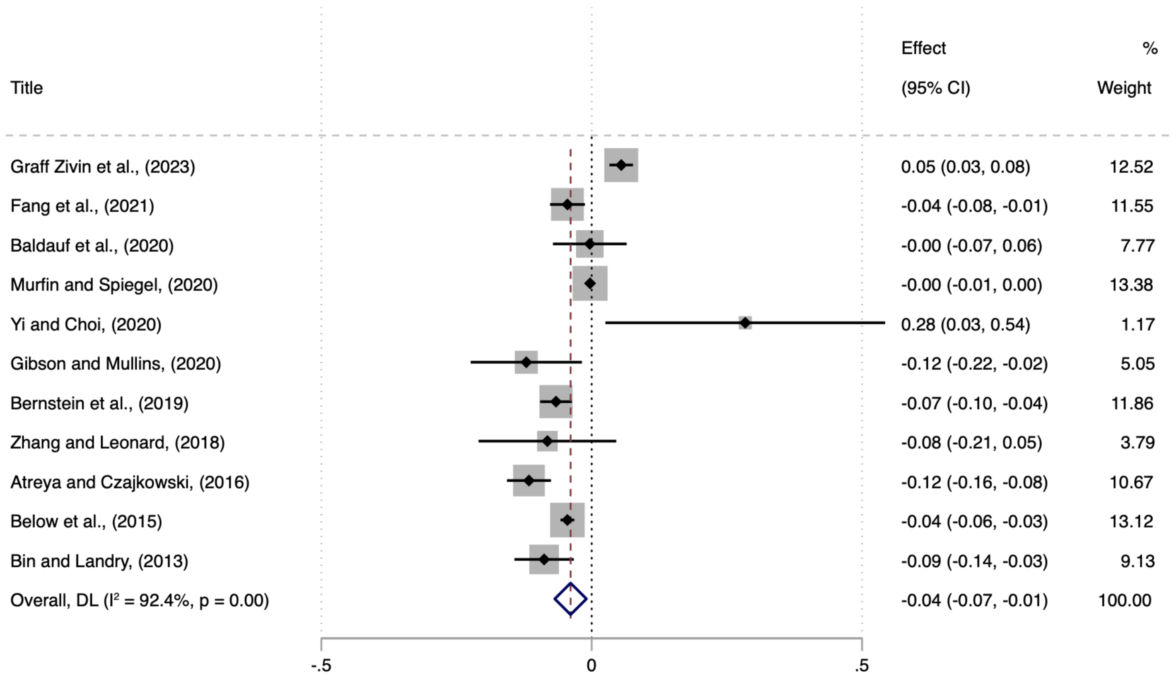
[29] These journals are the Journal of Real Estate Research, the Journal of Real Estate Finance and Economics, Real Estate Economics, the Journal of Environmental Economics and Management, the Journal of the Association of Environmental and Resource Economists, the Journal of Financial Economics, and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

[30] This reason explains why 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 is to summarize preferred study estimates succinctly 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.

[31] A fixed-effects model would assume there exists a common effect size subject to sampling error across Studies. We find this assumption, considering earlier discussion, implausible.

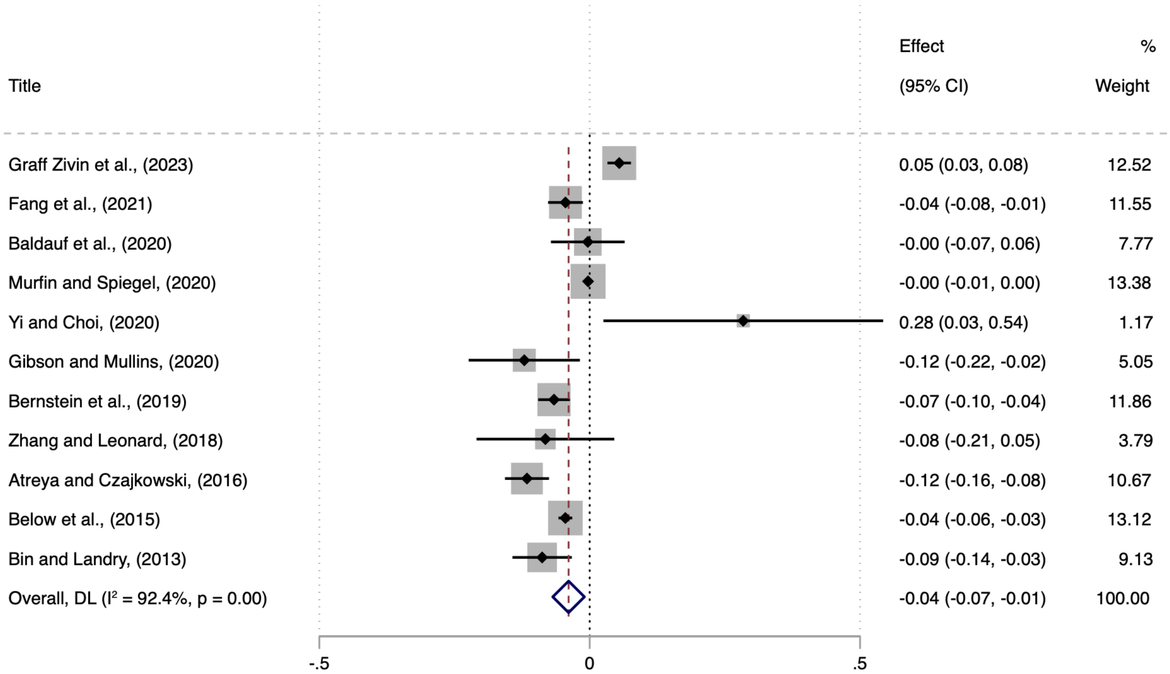
that we give more precise studies greater weight in calculating the mean of the distribution of true effect sizes. Effect sizes range from a 12.1 percent discount in Gibson and Mullins (2020) to a 28.4 percent premium in Yi and Choi (2020); the raw unadjusted mean effect size is -2.1 percent. The large I^2 statistic of 92.4%, which implies that 92.4 percent 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 percent, consistent with the rule of thumb of -4.6 percent that Beltrán et al. (2018) first propose. In fact, both estimates lie well within each other's 95-percent confidence intervals. Notably, little overlap exists between our meta-samples; only Bin and Landry (2013) appears in both of our meta-analyses. This fact, in our view, further substantiates the defensibility of an average flood risk discount on the order of 4 percent.

Figure 1: Forest Plot of Flood Risk Studies



Notes: 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 select effect sizes corresponding to estimates the paper authors described 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 we can attribute to heterogeneity across studies.

Figure 1: Forest Plot of Flood Risk Studies



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 that 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 metropolitan statistical areas (MSAs) in 2022 were in Florida—seven of those are coastal.[32] That Florida, despite its known exposure to disaster risk, continues to see such vitality in its real estate markets indicates that it likely possesses considerable amenity value. We include the Florida moderator 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 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.

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

Table 5: Meta-regression results

	(1) Effect Size	(2) Effect Size	(3) Effect Size
Florida	0.06	0.08*	0.09*
	(0.04)	(0.04)	(0.04)
Hurricane		-0.05	-0.10
		(0.04)	(0.09)
DiD			0.052
			(0.086)
Constant	-0.06	-0.04	-0.05
	(0.02)	(0.03)	(0.03)
N	11	11	11

Notes: This table shows the results of our meta-regression of the flood risk discount on a vector of covariates we hypothesized to correlate with the estimated effect size: *Florida*, *Hurricane*, and *DiD*. These three variables are binary indicators 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. Standard errors in parentheses: $p < 0.10$, ** $p < 0.05$, and *** $p < 0.01$.

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, though statistically insignificant, effect that suggests the presence of state-specific amenities. In column 2, adding hurricanes as the source of flood risk further clarifies the matter. We see that hurricanes depress home prices more than other sources of flood risk—the point estimate is -5.2 percent—but that Floridian real estate 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 hurricanes, although both the hurricane and DiD dummies themselves are insignificantly estimated. This result indicates that quasi-experimental studies do not produce estimates that are too different from those using multivariate hedonic regressions.

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; implying that certain individuals may be priced out of homeownership. 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 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.

Magnifying complications with estimating 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 to 5.0 percent.[34] 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 homeownership rates fall post-disaster, particularly after a flooding event in areas without required insurance.

Complete agreement does not exist about the demographics of those who move into high flood risk areas. Some research has found that low-income residents, as well as less affluent

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

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

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.[35] Fan and Davlasheridze (2016) find that age, educational attainment, and prior risk exposure explain risk perception, which in turn affects willingness to pay and location choice.

By contrast, other papers find null or positive correlations between income and post-disaster moves, with some authors attributing political economic mechanisms. Zivin et al. (2023) find that buyers who move in after an event tend to have larger incomes, though other demographic characteristics are unchanged. Sheldon and Zhan (2022) find 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) find partisan sorting, specifically that homes exposed to SLR are five percentage points more likely to be owned by Republicans, but that 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 political concerns may drive this activity, as they find that 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 show that Hurricane Katrina is associated with a permanent loss in population and a 33.57-percent reduction in county-level gross regional product, arguing a "brain drain" occurred. Other papers have

[35] 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 U.K. lenders they study do not appear to capitalize flood risk revelations into their decision making.

found varying sizes of migration out of disaster affected areas (Boustan et al., 2020; Strobl, 2011).[36] These findings suggest that we should interpret migration results with caution; it is challenging to tease apart disaster-related effects from general economic trends. Fan and Bakkensen (2022) find heterogeneous household responses to hurricane risk: seniors, college graduates, individuals from states more frequented by hurricanes, and households with fewer children are less sensitive. While they also find small overall migration changes in response 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 six percent for one city) of the individuals that the fire displaced permanently left Sonoma County. Berlin Rubin and Wong-Parodi (2022), surveying 1,108 California residents, observe that 15.5 percent 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 suggests negative outcomes like wildfire evacuation, property loss, and health issues may induce migration. An et al. (2023) finds that house prices decrease by 17 percent in the six quarters after the fire and that net out-migration increased by an additional four per 100 residents after a fire event. Similarly, McConnell et al. (2021) find out-migration (but not in-migration) for areas that experienced the largest effects of the wildfires.

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

Lender behavior may possibly 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. Resultingly, the composition of borrowers is richer and has higher credit scores, 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 size of the loan on acceptance, are smaller in flood zones, suggesting that lenders may restrict credit in flood zones, particularly 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 substantial increases in mortgage default for counties more frequently hit by hurricanes, up to 0.5 percentage points (a 70 percent higher probability of default).

Holistically, the previously mentioned papers either implicitly or explicitly argue that reducing credit and changes in lending standards may pose problems for affordable and sustainable

[37] Though not directly related to housing, Faiella and Natoli (2018) find that yield spreads of credit-risk transfers increase with exposure of natural disasters, suggesting that investors already price in natural disaster risks.

[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.

homeownership. On one hand, some borrowers may be unable to qualify for, or to afford, a home loan after a disaster due to changes in lending standards. Alternatively, households who choose to live in flood prone areas, perhaps because homes are cheaper due to a flood discount, may incur 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 require cost-benefit and economic considerations.

In summary, we see that lower-income and less-affluent communities are more likely to move into high flood risk areas, though evidence exists that this may not always be the case. High-risk homes may be more affordable for these communities, perhaps by the price discounts we have previously mentioned, though this benefit comes at the cost of additional flood risk. Additionally, lending seems more constrained in higher flood risk areas, where lenders limit the amount of credit to borrowers. This situation poses challenges to affordable homeownership.

Mortgage Performance

Researchers have sought to understand how disasters may affect mortgage markets and consumer financial health more generally. Some researchers do not find lenders fully capitalizing climate risk into their decisions. Using NOAA's Storm Events Database, which includes multiple types of disasters, Dillon-Merrill et al. (2018) find that mortgage applications for low- to midsize-homes decrease; however, after a storm, jumbo applications slightly increase. They do not find 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 low-credit score borrowers. Notably, these effects are 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 percent of the community's usable land area) are home to socioeconomically vulnerable populations.[39]

Other papers show that banks are responding to climate and natural disaster risk, though in different ways. Evidence exists that lenders are tightening credit standards after a disaster (Duanmu et al., 2022) and in flood zones (Sastry, 2022). Allen et al. (2022) demonstrate that non-bank lenders may be filling a lending void by showing that nonbanks are more responsive after disasters than traditional banks. Blickle et al. (2022) argue that disasters are not bad for bank performance partially due to the subsequent demand for loans after a disaster and 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) find 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 subprime borrowers and borrowers in areas with high income inequality from obtaining disaster relief. Even after controlling for income, population, and damages suffered, the paper still finds higher denial rates for Small Business Administration (SBA) disaster-relief loans for the previously mentioned groups. Thus, the authors see challenges for affordable homeownership for financially vulnerable households.

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

[39] The paper uses global SLR projections from the National Climate Assessment (NCA).

et al., 2020b; Rossi, 2021). These results have some important nuances. For example, Rossi (2021) looks at significant hurricanes (Category 3 or higher) and find that loans experiencing such hurricanes were 88 percent 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 loans 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 Special Flood Hazard Area (SFHA) (no flood insurance) are more likely to be modified and 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 the impact on delinquencies is significantly higher for the latter. The authors argue that their results are consistent with the double-trigger theory as the damage-adjusted LTV, annual increase in claims, and interaction of those two factors explain most of the increase in delinquencies from Maria.[40] 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 an SBA loan (i.e., a disaster relief loan).

[40] For a recent 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	3.35	Hazard ratio of $\geq$ Cat 3 Hurricane	Cox Hazard Model
Du and Zhao	2020	Texas	12,631,231	0.38	$\geq$ 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

Notes: This table presents coefficients from different models, not necessarily comparable. The coefficient reported is taken to be the main coefficient of interest for the paper, which depends on the model used. Here DiD corresponds to a difference-in-differences or event study approach.

Holtermans et al. (2023) investigate the impact of hurricanes on commercial mortgage market performance risk using commercial mortgage-backed securities (CMBS) loans. Specifically, they analyze 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 and heterogenous. The effect of Hurricane Harvey in the Houston area was higher for office/retail buildings than multifamily buildings. The opposite was the case with Hurricane Sandy in the New York metropolitan area. The analysis compares multifamily mortgage performance changes resulting from Hurricane Sandy in relation to the two-year period prior to Sandy making landfall, showing the delinquency effect lasted longer for this storm.

An et al. (2023) find a significant increase in mortgage default in regions that wildfires impacted. They also extend the analysis to look at the impact from the pollution and smoke of a wildfire, finding that mortgage defaults increased after large events in California, though with varying significance. Given 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 with wildfire damages were more likely to see mortgage delinquencies, with greater damages 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 it. An open question is if and how the repricing of climate and disaster risk over time induces more default.

Insurance

Flood insurance also plays a key role in understanding how flood risk and damages might impact the housing finance market. This literature attempts to answer two main research questions. First, what are the drivers of insurance take up and the 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 positively correlate 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).[41] Although, Kousky et al. (2020a) and Bradt et al. (2021) find that FEMA's requirements that receivers of certain aid after a disaster purchase flood insurance could drive the uptake of insurance after recent flood damages. 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). 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 adverse selection exists. She finds a gap in willingness to pay for flood insurance, that the mispricing of natural disaster insurance is complex, and that evidence exists 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

[41] In 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.

a property.

Looking at how loans with and without flood insurance perform after a flood event has been the primary way to study its impact on the mortgage market. As we noted previously, Kousky et al. (2020b) find that properties with flood insurance (in the SFHA) were less likely to both need a loan modification and 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 mandates may lead to reduced lending, particularly for low-income and low-FICO borrowers. Kousky et al. (2018b) find that federal disaster assistance may crowd out private insurance on the intensive margin on average by $4,000–$5,000 in the 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 insurers charge 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 may take on increasing importance as the WUI continues expanding. As Issler et al. (2020c) note, 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 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 the 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 percent 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 percent.

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 percent 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. They find positive spillover effects as well, consistent with reduced structure to structure spread of the fire. Done et al. (2018) find that new construction under stronger building codes can also reduce losses from hurricanes. However, evidence exists, at least in North Carolina, that substantial new housing construction is occurring 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 positively associate 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 play a pivotal part in the housing finance markets as they can price risk into the housing markets and protect homeowners and lenders from losses after a disaster occurs. However, imperfect information, mandatory requirements, monitoring, and outside options such as defaulting or disaster aid may lead to insurance market distortions or outright failure. At present, the future of the property insurance market is uncertain.[42] Due to increased frequency and severity of disasters, private homeowner's insurers are effectively withdrawing from high-risk areas.[43] Future policy makers will have to grapple with difficult issues such as potentially uninsurable areas, cross-subsidization, and the role of government in subsidizing housing in risky areas. These changing conditions require additional research, with future work on the returns to adaptation measures would be especially fruitful.

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. These long-term chronic changes likely associate with a higher frequency of short-term acute events. For example, droughts will likely mean more wildfires. The focus in this section is the expected effects of these chronic risks, with attention paid to individual beliefs and expectations about the future.

[42] We tend to think of property insurance as a more general term that includes homeowner's insurance and flood insurance as specific types. While the NFIP is the dominant flood insurer in the United States, private insurers make up the largest portion of homeowner's insurance, which covers other perils. Notably, lightning and hail are typically included with homeowner's insurance, while earthquakes and flooding are not.

[43] For example, as of the writing of this article, State Farm and Allstate, the largest and fourth-largest issuers of homeowners insurance in California, respectively, no longer offer new policies in the state due to the increased costs of insuring wildfires.https://www.nytimes.com/2023/06/04/business/allstate-insurance-california.html. Similarly, many private insurers in Florida have entered receivership due to increased costs, leaving many to turn to Citizen's Property Insurance Corporation, a publicly funded insurer of last resort.

In the past 40 years, tornadoes, high winds, and hail have caused an average of $5.4 billion 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 expected to rise above $10 billion in damages (Gensini and Brooks, 2018). Ewing et al. (2007), studying six metropolitan statistical areas frequently exposed to wind damage from tornadoes and hurricanes, identify a four-quarter negative transient shock to housing prices. Their time series analysis finds losses on the order of 0.5 to 2 percent 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 percent. Gallagher et al. (2023) find that businesses are more likely to fail and that federal assistance can help with household finance by allowing them to avoid costly credit card debt after a tornado. Using tornado (and other natural disasters common in Arkansas), Tiurina (2022) finds some evidence that supplemental installment loan credit (shorter-term, unsecured debt) contributes to borrowers' financial well-being via better credit scores and lower likelihood of delinquency.

Likewise, researchers have written little on the consequences of drought for housing finance; accordingly, opportunities exist for empirical studies. The most direct impacts of droughts are on agriculture: dry conditions reduce production and raise costs. Extended droughts may negatively influence the viability of rural economies, and hence the liquidity of their housing markets. Studies looking back at historical episodes of drought may yield insights. Furthermore, mandatory reductions to residents using water may depress real estate values. Differing water use restrictions by localities, particularly if some localities are better endowed with freshwater access than others, may lead to sorting.

Cardoso and Wichman (2020) note that water affordability issues may intensify in the next two decades. Using a census block-group-level socioeconomic dataset matched to water and sewer rates for 45 percent of the U.S. 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 suggests some role for volatility in real estate prices. Semenenko and Yoo (2019) identify an inverse relationship between daily temperature volatility and real estate returns. The first and second moments of the temperature distribution increasing is also relevant for mountainous states. Butsic et al. (2011) identify reduced 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 that abnormally high temperatures may discourage traditional lenders, with fintech lenders stepping in to fill the gap partially. Winkler and Rouleau (2021) also find that extreme heat is associated with out migration.[44] More generally, Bloesch and Gourio (2015) find that the particularly 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.

[44] 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 how extreme heat and air pollution affects human health.

To summarize, the marginal contribution of research investigating the influence of chronic risk on housing prices is large. The contribution is especially so given projected increases to atmospheric hazards and drought severity in the coming century. Some evidence also suggests that temperature volatility may impact housing markets. We need more research in this area to determine household and lender responses to higher temperatures and stronger storms, especially considering their changing spatial patterns. A challenge of this literature is that this evolution of chronic risks is gradual and hence may be difficult to use in an empirical study. We postpone discussing this topic until later when we cover energy efficiency in our transition risks section.

Transition Risks

In this section, we address research on the effects of transition risk to housing and mortgage markets. First, we discuss the effects of energy performance upgrades on real estate prices and quality-of-life considerations, reviewing papers that evaluate the relationship between energy efficient homes and mortgage performance. Then, we describe literature on the heterogeneous effects of the energy transition for regional economies and discuss the capitalization of various forms of waste into real estate prices. Readers should not take the topics we explore in this section 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 for us to understand about how transition risk will shape housing and mortgage markets.

Energy Use

Improved home energy performance will be a significant component of the net-zero transition; the residential sector, including both single and multifamily properties, accounts for about

1/5th of U.S. energy usage.[45] Furthermore, climate change will lead to increased residential energy use. Using Swedish data between 1996 and 2005, Dodoo and Gustavsson (2016) find a decrease of 3 percent in cooling needs and an increase of 18 percent in heating needs relative to long-term historical measures. When the authors apply future climate change scenarios, heating demands could decrease by 23 to 29 percent and cooling demands could increase by 48 to 126 percent 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 up to 22.1 percent relative to 5 percent for office spaces in the 2080s.

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

Energy Efficiency

One potential way to decrease energy use is to invest in energy efficiency improvements. Energy efficiency investments could reduce energy use and provide financial savings to homeowners and renters by decreasing the energy intensity of appliances and heating, ventilation, and air conditioning (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 achieving energy efficiency, see Gerarden et al. (2017).

[45]See the Energy Information Administration's (EIA) page for a breakdown of energy usage by sector: https://www.eia.gov/energyexplained/use-of-energy/

In this vein, policymakers have attempted to make progress through energy efficiency rating certification programs over the last few decades. Perhaps the most significant is the EPA's Energy Star certification, which began in 1992.[46] Energy Star certifies new homes that are at least 10 percent more energy efficient than homes built to code.[47,48] 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.

Results on the influence of energy efficiency ratings on property values are largely positive. Using a hedonic approach, Argento et al. (2019) finds that homes rated as energy efficient sold for 2.7 percent more than non-rated homes. On the intensive margin, better-rated homes sold for 3 to 5 percent more than lesser rated homes. Similarly, Cassidy (2023) studies 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; the city of 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.

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

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

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

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 positively associate with reduced fire hazard exposure, improved thermal comfort, and reduced 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 after energy efficiency upgrades as some renovated units had lower indoor air quality, reflected in CO2 and other air quality metrics, partially due to tighter insulation retrofits.

While the literature finds benefits from energy efficiency investments, they are not without cost and the relationship between savings and costs of energy efficiency retrofits is less clear. Taylor et al. (2016b) measure first-year electricity savings from retrofits to 232 units in four apartment complexes in Florida. They find annual savings per unit averaged 2,094 kilowatt hours (kWh) (22%) and ranged from 1,700 kWh (18%) to 3,811 kWh (29%) across complexes. Based on these findings, tenants saved an average of $272 on their annual electric bills. Brozyna and Badger (2013) find that adding outdoor boiler reset controls to an apartment building can potentially save 5 percent 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 percent 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 increased construction cost of about 4.4 to 5.6 percent. Three-story buildings in warmer climates can achieve annual net zero energy efficiency with an increased construction cost of about 5.1 percent, while those in colder climates cannot reach this target goal. Fowlie et al. (2018) find that savings from energy efficiency can be overestimated relative to actual savings (by a factor of three). Further, the authors found that costs of 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 tradeoffs of energy efficiency investments. Such research would have important implications for sustainable and affordable home ownership.

Energy and Mortgage Markets

Variations in energy efficiency investments and fluctuations in energy costs will have important implications for mortgage markets when transitioning to a low-carbon economy. In the context of energy efficiency, Argento et al. (2019) find 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 debt-to-income (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) find no evidence that lenders charge higher rates for riskier mortgages against properties with lower energy efficiency. This finding contrasts with numerous other studies, including Kaza et al. (2014) and Pigman et al. (2022) in the United States., and Billio et al. (2022) and Guin et al. (2022) in Dutch and U.K. contexts, respectively. All 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 percent and 18 percent 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. We summarize the results of these studies in Table 7. While we risk over repetition, we again want to emphasize that we intend this table to provide quick takeaways of effect magnitudes and by no means should the reader interpret these selected effect sizes 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	-0.03	0.07
Billio et al.*	2022	NL	125,560	Property	EPC	-1.65	0.07
Guin et al.	2022	UK	1,822,569	Property	EPC	-0.00	0.00
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." Here Energy Performance Certificates (EPC), Energy Star, Department of Energy's Home Energy Score (HES), and the Residential Energy Services Network (RESNET) all correspodn to different energy efficiency ratings systems. *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 percent 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 percent 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) test a sample of 610 commercial real estate mortgages securitized through 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 one percent shock in EUI leads to a change in required pricing points of four basis points for apartment properties. In a pilot application, Mathew et al. (2021) study 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 when evaluating a loan.

Decarbonizing the Economy

In this section, we survey papers related to the implications of decarbonization for real estate markets. On one hand, the transition to a decarbonized economy may hurt local economies that rely on carbon-intensive industries. Alternatively, the transition may appreciate home prices in some areas due to cleaning up 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 capitalizes into home prices. We discuss these two topics in later sections.

Industry Composition and Regional Economies

The economic transition will affect locations dependent on carbon-intensive services and industries; it is likely that these effects will reverberate in their real estate markets.[49] For example, Du and Karolyi (2022) use data from the Energy Information Administration (EIA) 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 reduced coal associates with a 6 percent drop in employment, a 4 percent drop in wages, and reduced 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 associate 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 of the new build sector for residential real estate. Due to recent policy changes at the state and local level banning natural gas in new construction, electrification of new builds is of particular focus. One risk associated with these changes is the increased costs associated with fully electric new builds. Davis (2023) finds that mandating 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 $1,000 annually.[50] Less understood is how these costs might vary by income. A strong need

[49] For an overview of what regions might be impacted in the United States, see Raimi (2021), who provide maps and discussion of fossil fuel dependent regions.

[50] However, the paper notes that this estimate does not account for preferences for gas or electric cooking or hot water heating and is limited to home heating. The authors also note that they base these results on historical data and cannot account for future technological changes like increasing efficiency of heat pumps.

exists for additional research on the costs of electrification as well as the tradeoffs between the costs of electrification, the reduced risks of climate change, and the potential benefits of air pollution reduction that we discuss in the next section.

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

Reductions in Air Pollution

Lower levels of environmental pollutants are likely to constitute an amenity that enters 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 fail to meet federal standards for total suspended particulates.[51] Chay and Greenstone (2005) study the implementation of the CAA. Using the non-attainment 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 that CAA identifies as especially polluted.

[51] In the initial version of the CAA 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.

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 reduced 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 two miles of a newly constructed plant decreased by 3 to 7 percent. 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 Singapore, Sharma and Balasubramanian (2019) find that apartment indoor PM2.5 air pollution may exceed guidelines. [52] Muehlenbachs et al. (2016) find mixed house price returns to shale gas extraction, depending on whether the home was dependent on groundwater. Walsh et al. (2017) find positive home price returns to water quality in the Chesapeake Bay. These findings suggest the distributional consequences of further reductions to airborne and water pollutants associate with the energy transition.

A similar strand of literature pertains to the home price effects of cleaning up hazardous waste sites.[53] Researchers have sought to understand whether the benefits of addressing

[52] 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.

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

these areas of contamination outweigh the high costs.[54] 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, gives the EPA authority to clean up toxic waste sites, referred to as Superfund sites.[55] 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 at 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 percent 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.

Other studies independent of superfunds have found significant effects to living 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 percent. 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 percent, depending on what one is willing to assume about the stability of the hedonic price function. Consistent with Superfund litera-

[54] 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.

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

ture, this paper also concludes that the returns to home prices are highly localized. Sullivan (2017), applying Haninger et al. (2017) estimates to back out increased property tax revenues from brownfield cleanups, find 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) identify stigma effects associated with homes near both non-toxic commercial sites as well as brownfields; however, these effects ameliorate following the contaminated site being remediated.

Conclusion

Our paper surveys research at the intersection of real estate and environmental economics. Our review finds agreement that climate risks are at least partially capitalized in housing values and influence lending and consumer behavior. Borrowers of less creditworthiness appear to be affected modestly by changing lending standards. This fact has implications for the affordability and sustainability of homeownership. That said, considerable uncertainty remains as to the magnitude of these effects. Information, or the lack thereof, of climate risks may partially explain existing heterogeneity. 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 recommendations for future research. The first is that many of papers focus on flood and SLR. We need more work on the effects of other disasters and climate events. The second is that most research, at least as it applies to physical risk, focuses on the United States. We need more international work, 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 developing and publishing 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. The persistence of drought conditions may negatively impact real estate and lending markets in the American West. We need additional research to understand which regions will be most affected and how large those effects will be. If water access becomes cost prohibitive in certain regions, significant implications for sustainability and affordability of home ownership will arise. Significant uncertainty also exists 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 implications given preexisting variation in age and structure of the current housing stock across socioeconomic groups. In general, if building costs rise to accommodate climate change adaptation measures, we need more research 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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Overview of Climate Science

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

As early as 2009, a scientific consensus existed 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."[56] 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 are that accelerating sea level rise (SLR) and climate change may make natural disasters worse in both frequency and severity.[57] The views that AAAS presented represent the scientific consensus. In the following, and at slight risk of repetition, we provide detail and context from major U.S. government scientific agencies about these views.

Climate scientists have projected and conducted scenario analyses to estimate climate change consequences. Indeed, as we mention shortly, the Federal Reserve pilot program has already developed such scenario analysis to assess climate-related financial risks. Once they become more standardized, such scenarios are likely to be used widely for forecasting in housing and mortgage markets. The Intergovernmental Panel on Climate Change (IPCC) is the pre-eminent international body producing climate forecasts.[58] IPCC's scenarios are referred to as Representative Concentration Pathways (RCPs), which vary by their anticipated Greenhouse Gas (GHG) emissions.[59] Figures 2 and 3, taken from the latest IPCC synthesis report, illustrate different scenarios for temperature and sea level change for the next 75 years.[60] For our purposes, we only mention that different Shared Socio-Economic Pathways (SSP) correspond to the different scenarios (e.g., SSP1-1.9, SSP1-2.6) in the latest report. Roughly

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

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

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

[59] The IPCC has a more detailed discussion of the RCPs here: `https://ar5-syr.ipcc.ch/topic_futurechanges.php`.

[60] These scenarios 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.

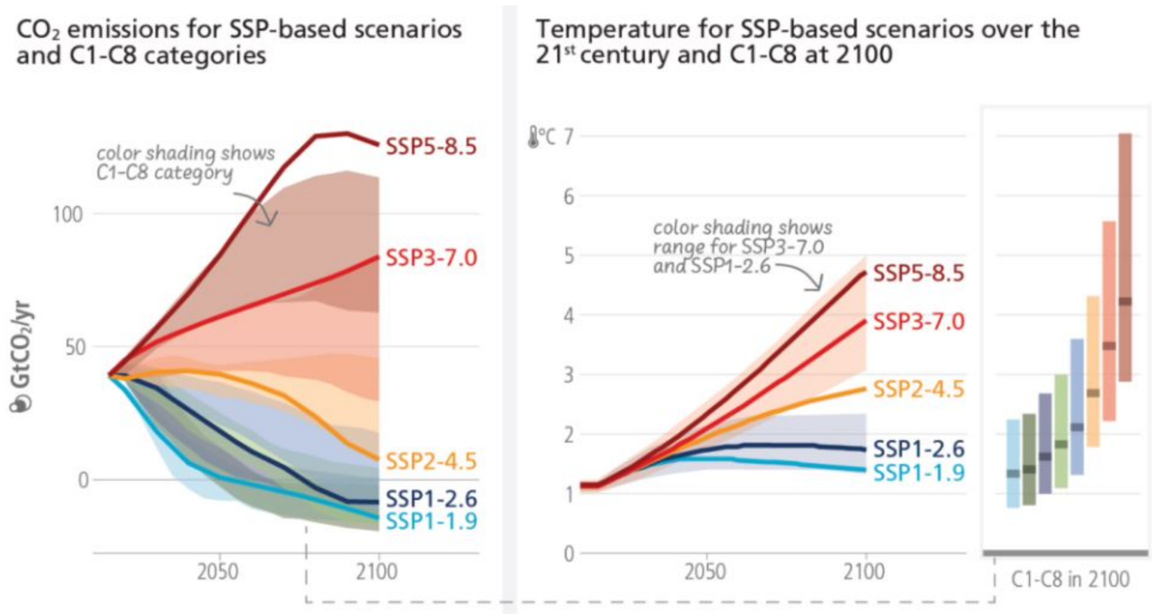


Figure 2: Source: Intergovernmental Panel on Climate Change Sixth Assessment Report, Synthesis Longer Report

speaking, these scenarios build off the RCPs discussed previously and correspond to different amounts of greenhouse gas (GHG) emissions and CO2 emissions that will occur.[61]

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 Assessment (NCA).[62] The 2018 version of the NCA is comprised of two volumes. The first focuses on scientific findings, which agree with the general findings of AAAS. We list some of the NCA's many conclusions below.

1. This period is now the warmest in the history of modern civilization.
2. Researchers around the world have conducted thousands of studies that document changes in surface, atmospheric, and oceanic temperatures; melting glaciers, diminishing snow cover, shrinking sea ice, rising sea levels, ocean acidification, and increasing

[61] For example, SSP3-7.0 corresponds to high GHG and CO_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, with both projected to be net zero by 2050 and the latter net negative afterwards. We refer the interested reader to the report, which contains much more discussion of the scenarios.

[62] The latest National Climate Assessment is linked here: https://nca2023.globalchange.gov/

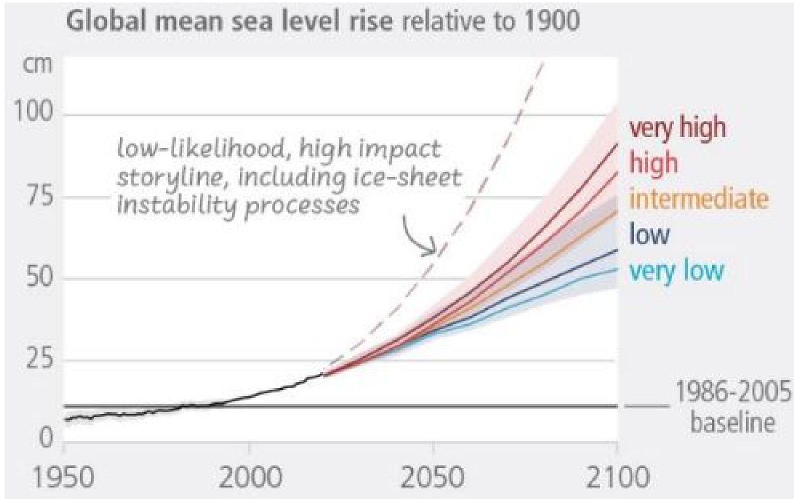


Figure 3: Source: Intergovernmental Panel on Climate Change Sixth Assessment Report, Synthesis Longer Report

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 these changes will impact housing markets. 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 make flooding more likely.

Lenders are likely to respond to such changes as they represent real collateral and credit risks. The USGCRP Fourth NCA's second volume focuses on welfare, societal, and environmental aspects of climate change.[63] 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 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 mortgages less affordable, potentially unavailable without public intervention.

Many agencies and institutions share the views the NCA and AAAS reports express . For example, the National Aeronautics and Space Administration (NASA) and the 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. It points out that scientists predict global temperature increases from human-made greenhouse gases will continue and severe weather damage will also increase and intensify.[64] 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 percent 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.[65]

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

[63] 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, NASA, National Science Foundation, Smithsonian Institution, and the U.S. Agency for International Development. NOAA, a scientific and regulatory agency within the Department of Commerce, acts as the administrative agency.

[64] Readers may find further discussion of predictions and estimated effects of climate change here: : https://climate.nasa.gov/effects/.

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

mortgage markets. An obvious first channel for these risks to affect housing and mortgage markets is the increase in frequency and severity of flooding, thereby increasing flood risk for many homes and loans.

U.S. Response to Climate Change

In the United States, many parties are interested 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, 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 that the financial regulators of each state adopted would be beyond the scope of this article, we do recognize their importance, particularly in insurance markets.

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 U.S. flood risk, we restrict attention to each agency's position on it. We then briefly overview 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 FEMA, which manages the National Flood Hazard Layer (NFHL) database. The NFHL contains current effective flood risk data for over 90 percent of the U.S. population. The National Flood Insurance Act of 1968 and subsequent amendments created NFIP and mandated that all federally backed mortgages (i.e., loans the U.S. government makes, which governmentsponsored enterprises (GSEs) acquire, etc.) in high-risk areas carry flood insurance.[66] 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).[67] At some risk of confusion, we follow the terminology in the literature and use flood zone, floodplain, and SFHAs interchangeably, unless otherwise noted.[68] We cannot understate the significance of flood zone status as it serves a dual purpose of being arguably the most common signal of flood risk and an indicator whether homeowners must make extra flood risk insurance payments. In other words, it serves as both a source of information and as a tax. Flood zone status is the most used measure of a home’s flood risk. However, as we discuss shortly, some criticize it is an imperfect measure.

As the manager of the NFIP program, FEMA effectively determines both who must purchase flood insurance (if there is a federally backed mortgage) and how much coverage will cost.[69] Generally speaking, a SFHA is one in which a flood is expected to happen with a one percent annual chance.[70] On April 1, 2022, FEMA implemented the final phase of the NFIP’s Risk Rating 2.0, 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. We cannot yet determine the effects of changes in NFIP pricing, though we believe this will be an active area of research in the future.

The NFIP program is very important and will likely continue to be so in the future, par-

[66] Readers may find further information on laws pertaining to the flood insurance mandate here: https://www.fema.gov/flood-insurance/rules-legislation/laws.

[67] Readers may find more details 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.

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

[69] Exceptions exist as individuals can protest and appeal their designation of flood zone status.

[70] For these reasons, we sometimes refer to flood zones as 100-year floodplains.

ticularly 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 5 million policies.[71] The literature finds that the private flood insurance market is very small (¡ five percent 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."[72] The report recommends using other measures of risk, pointing out that besides being inaccurate and not encapsulating all types of flood risk, the maps do not reflect future risk. Additionally, the report points out that take-up rates for flood insurance outside of SFHA are very low, suggesting potential uninsured risk for properties which have actual flood risk yet are not required to purchase flood insurance.[73] Alarmingly, the GAO report also documents instances of noncompliance with the mandatory purchase requirement, finding between 2 percent and 23 percent of the examinations [by the Federal Deposit Insurance Corporation (FDIC), the Federal Reserve, National Credit Union Administration (NCUA), and Office of the Comptroller of the Currency (OCC)] identified violations, with the most common (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.footnoteSee 2M Research Report 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 low take-up rates outside of flood zones. This fact has immediate implications for mortgage markets, whereby lenders or others may be holding unanticipated risk.[74] The implicit recommendation is that financial regulators might consider requiring frequent monitoring of servicers to ensure flood insurance

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

[72] See GAO-21-578

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

[74] For xample, the servicers of loans 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 one percent annual risk of economic damage. FSF's projections indicated that total expected annual loss for risky properties would grow from $20 billion in 2021 to $32.2 billion in 2051, an increase of some 61 percent. 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 percent. Overall, FSF's findings are consistent with the GAO report—economic flood risk in littoral (i.e., seashore or lake) and riverine regions is systematically underestimated. Underestimating flood risk is likely to impact many stakeholders directly, including homeowners, lenders, servicers, and securitizers of loans.

State-Specific Responses to Natural Disasters

Although reviewing the universe of state-level legislative responses to natural hazards is beyond the scope of this paper, 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 these state-level initiatives face 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, the Citizens Property Insurance Corporation (Citizens). While the policies Citizens provides have fluctuated since it formed following Hurricane Ian, the number of policies stands at nearly 1.15 million.[75] 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 state is phasing in the mandate 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 wildfire damages that their own equipment created, regardless of the negligence or fault of the property owner. This situation led to credit rating downgrades for utilities whose growth of liabilities due to wildfires outpaced the insurance coverage they could obtain. AB-1054 set aside a $21 billion fund to reimburse Californians negatively affected by utility-caused wildfires.[76] 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 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.[77] Recently, State Farm Insurance cited wildfire damages and reconstruction costs as why it will no longer issue new homeowners' insurance policies in California.[78] Soon

[75] 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 figure would constitute "5-year growth rates in premium and policyholders of 486% and 276%, respectively." Readers may find more statistics on the growth of this insurer of last resort in Citizens' 2023 Operating Budget).

[76] Utilities pay half this fund and a statewide $30 annual surcharge on electricity bills pays the other half.

[77] 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/

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

after State Farm announced its decision to stop issuing new policies, Allstate announced the same thing.[79]

Growing concern about the exit of private insurers in both Florida and California may mean that other states may soon follow suit. Research shows 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 formed a climate and resiliency task force and released a report report ("Adaptable to Emerging Risks") of state regulators' activities, also highlighting the importance of climate risks.

U.S. Regulatory Response to Climate Change

U.S. financial regulators 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, agreement exists that climate risks are a priority, though implementing changes to address these risks are still in the early stages. In particular, the proposed Securities and Exchange Commission (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 outstanding challenges.[80] Leaders of the FDIC, Federal Reserve, and the OCC have made

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

[80] FSOC is composed of 10 voting members who head the U.S. Department of the Treasury, Board of Governors of the Federal Reserve System (Federal Reserve Board), OCC, CFPB, SEC, FDIC, CFTC, FHFA, and NCUA, along with an 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, state banking supervisor, and state securities commissioner that their peers designated. See https://home.treasury.gov/system/files/261/FSOC-Climate-Report.pdf for more details.

similar statements recognizing the importance of climate risks. Additionally, the Federal Reserve Board announced a climate scenario analysis exercise with the six largest banks. 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).[81] 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 metrics and scenario standards for assessing climate risk. In turn, these standards will plausibly better prepare lenders to mitigate climate risk.

Information disclosures for climate risk has also been a topic of interest. In March 2022, the SEC proposed rules to enhance and standardize climate disclosures for registrants. These changes would mandate registrants to describe climate risks that were reasonably likely to affect their business operations in registration statements and periodic reports. Furthermore, the SEC would require audited financial statements to include climate-related financial statement metrics and GHG disclosures. These rules would be consistent with those the Task Force on Climate-Related Financial Disclosures (TCFD) proposed. The task force an outgrowth of the Financial Stability Board (FSB), an association of G20 countries and other international organizations.[82] 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 impact markets significantly, particularly if demand for Environmental-Social-Governance (ESG) assets increases. With new disclosures, investors who prefer ESG assets will likely reduce holdings of entities with large carbon footprints. Alternatively, the new rule is likely to better inform home buyers and lenders in market transactions. 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

[81] For example, in December 2021, then-Acting FHFA Director Sandra Thompson released a statement recognizing climate change as a threat to U.S. housing finance and instructed Fannie Mae and Freddie Mac, the GSEs, to consider climate change's effects actively 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.

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

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 private insurers withdrawing in some markets. Additionally, several published reports argue for more advanced measures of flood risk. We believe standardizing metrics for climate risk and information disclosures will likely play a large role in market transactions in the future.

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 climate change imposes on housing stock that we previously discussed, CFTC further notes that declining property values may adversely affect property taxes, which reduces state and local capacity to build infrastructure key to adapting to climate change. Additionally, possibly displacing populations and communities in the United States due to climatic factors may generate large economic losses for households and investors.[83]

The Department of Energy (DOE) also notes that higher global temperatures increase 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. DOE is working to increase the energy efficiency of appliances, homes, businesses, and vehicles.[84]

International Response (Central Banks and System-wide Regulators)

While our paper focuses on the United States, 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

[83]See Managing Climate Risk in the U.S. Financial System
[84]See https://www.energy.gov/climate-change.

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 they recognized and addressed climate risks. Across all reports we discuss, general agreement exists that climate is a concern and must be addressed. In particular, a shared view exists 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 one another, hence our choice for a chronological presentation. 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 to fully understand the impact of climate risks, one must understand not only the consequences of the risks themselves (holding the regulatory environment unchanged), but also anticipate the likely regulatory responses to such risks.

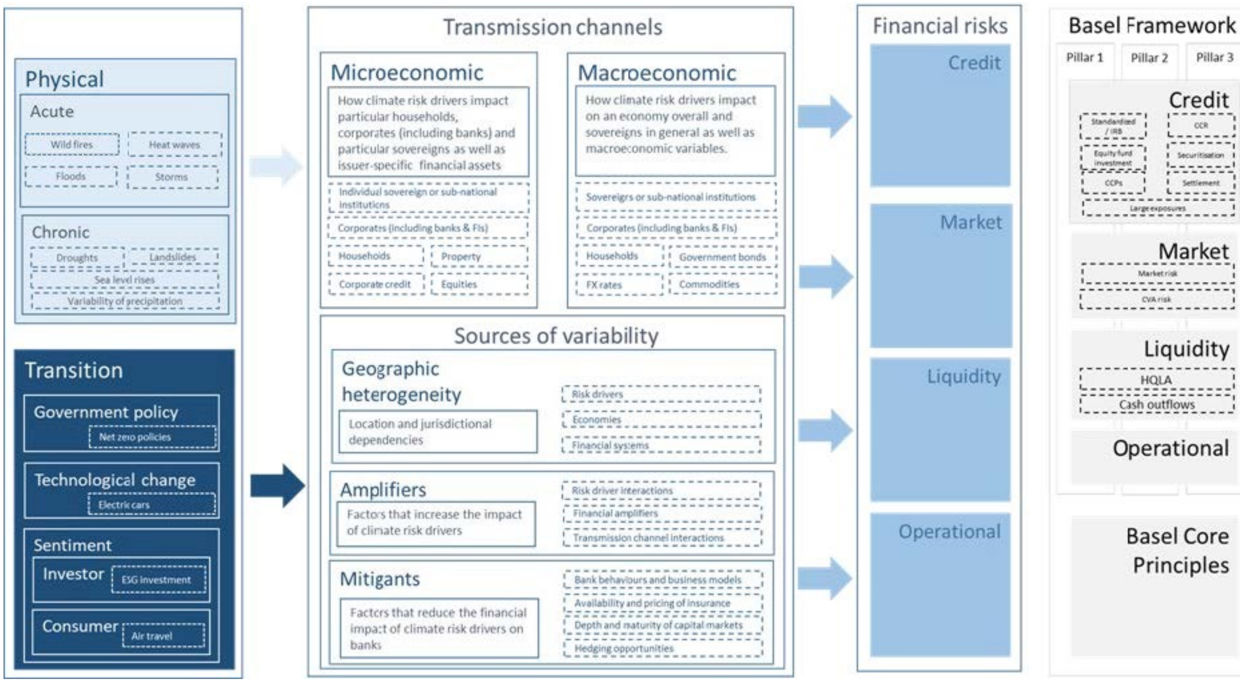
Starting in Europe, in December 2019 the Bank of England published its proposal for the 2021 Climate Biennial Exploratory Scenario (CBES), which it used to assess climate change risks. Its approach includes a 30-year horizon and multiple scenarios.[85] Notably, the report includes detailed descriptions of both physical and transition risk CBES. 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 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.

[85]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.

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: Transmission Channels for Climate Risks. Source: the Basel Committee for Banking Supervision 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) 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 4 (Figure 1 from BCBS' report), we present BCBS' basic framework and likely transmission channels for both physical and transition risks. As an example, flooding is a type of physical acute risk. It 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 to physical and transition risk drivers. While some work already occurs on this front (e.g., the CBES and IPCC scenarios previously mentioned), the report encourages more research about risk drivers and transmission channels for risk. Finally, the report agrees with prior publications in that using traditional risk categories within the Basel Framework can capture climate-related financial risks.

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.[86] 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 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 system-

[86]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.

atically. They have generally agreed upon definitions of key climate risk terms and general principles, while much implementation details remain. Scenario analysis is in the early stages, while much standardization work remains. Agreement also seems to exist 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.