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RESEARCH INSTITUTE FOR HOUSING AMERICA **SPECIAL REPORT**

The Impact of Climate Change on Housing and Housing Finance

Sean Becketti

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About the Author

Dr. Sean Becketti is a financial industry veteran with four decades of experience in academics, government, and private industry. Over the last two decades, Becketti has led proprietary research teams at several leading financial firms, responsible for the models underlying the valuation, hedging and relative value analysis of some of the largest fixed-income portfolios in the world. He also has served as chief economist for Freddie Mac and written extensively on housing issues. Becketti is the author of a book on time series analysis and currently is working on a new book on data science. He received his PhD in economics from Stanford University.

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Executive Summary

The Earth's climate is changing. These changes will impact housing and the housing finance industry. Beyond these two certainties, there is a long list of unknowns. What forms will climate change take? How extreme will these changes be? Where will they be most concentrated? And what will be the pace of these changes? Can these changes be reversed or mitigated?

The impact of climate change on housing and housing finance depends on the answers to these and other questions. And the answers depend on the actions taken — or avoided — by governments, businesses and individuals. These actions will affect the future path of climate change and hence will either mitigate or exacerbate the impacts on housing and housing finance.

This paper reviews what we know so far about climate change; the likely impacts to housing and housing finance; strategies that can mitigate climate change or adapt to the part of climate change that cannot be averted; and the things firms in housing and housing finance can do to articulate and measure their exposure to climate change.

The paper is divided into four sections:

THE EARTH'S CLIMATE IS CHANGING

The evidence for global warming is unassailable. Greenhouse gases (GHGs) in the atmosphere regulate the temperature of the Earth. As the concentration of GHGs in the atmosphere increases, so does the Earth's temperature.

For roughly 150 years, since the start of the Industrial Revolution, humans have steadily increased the amount of fossil fuels they burn. In addition, the Earth's population has grown rapidly, further boosting the demand for fossil fuels. The concentration of GHGs in the atmosphere has increased about 55 percent since the preindustrial era. As a consequence, the Earth's temperature has increased by around 1 degree Celsius over the last hundred years. That increase may not seem large, but the effects of that bit of global warming are surprisingly large.

That much is certain. What is open to debate are the precise links between global warming and specific extreme weather events such as flooding, sea level rise, hurricanes, wildfires, drought and more. Also uncertain is the future path of global warming and its effects.

Every few years, the international scientific community issues a summary of the consensus on these uncertainties. Their summaries consider multiple scenarios, because the path of global warming in the 21st century depends on the actions the world takes to limit further additions to atmospheric GHGs. Stringent limitations, as proposed in the Paris Accord, may prevent an acceleration in the pace of global warming, while conditions are likely to be much worse if use of fossil fuels continues on its current trajectory.

In all these possible futures, the consensus projections of the scientific community are unsettling. Sea levels will rise, flooding will increase, and other extreme weather events will become more destructive and more frequent. The second half of the 21st century will see increases in food insecurity as the result of reductions in marine and freshwater populations and declining agricultural productivity. Many land- and water-based species will face extinction. Reliable water supplies will become scarcer. Human health will suffer, especially in poorer regions where the infrastructure lacks resilience to climate change.

CLIMATE CHANGE WILL IMPACT HOUSING AND HOUSING FINANCE

Climate change will impact all governments, industries and individuals. Housing and housing finance will not be spared.

One way to understand the likely impacts is to review the types of disclosures that firms are recommended to make. The Task Force on Climate-Related Financial Disclosures (TCFD) recommended firms disclose two broad categories of climate risks: *physical risks* and *transition risks.* Physical risks comprise the familiar *acute risks* — floods, hurricanes, etc. — that are projected to grow worse as a result of climate change and *chronic risks* such as secular increases in temperature or sea level that may threaten buildings and infrastructure. Transition risks include all the changes firms may be required to take to adapt to the world's response to climate change.

Coastal flooding provides perhaps the best example of how both physical and transitional risks are likely to impact housing. The National Flood Insurance Program (NFIP), the primary system of flood insurance in the United States, has numerous well-known challenges and deficiencies. Increases this century in insurance claims generated by climate change are likely to stretch the NFIP to the breaking point, facing homebuyers, lenders, GSEs and governments with a host of difficult questions. In addition, independent estimates of flood risk suggest that the NFIP currently excludes 2/3 of the at-risk properties, suggesting that the current government approach to disaster recovery may become too expensive to sustain in future.

Even if the weaknesses of the NFIP are repaired, insurance alone may not be enough to sustain the complex system of risk allocation that underlies the housing system. The magnitude and persistence of climate change, particularly in the latter part of the 21st century may overwhelm the ability of insurance to spread and manage risk.

Some of the impacts of climate change on housing and housing finance may not fit neatly in the TCFD categories. In addition to increasing residential property damage, climate change may increase mortgage default and prepayment risks, trigger adverse selection in the types of loans that are sold to the GSEs, increase the volatility of house prices, and even produce significant climate migration.

THERE ARE STRATEGIES FOR MITIGATION AND ADAPTATION

Strategies are available both for mitigating climate change and for adapting to the component of climate change that can't be avoided.

To slow the increase in global warming, the world must find ways to reduce the increase in the concentration of greenhouse gases (GHGs) in the atmosphere. It's as simple — and as complicated — as that. The growth in GHGs that began at the outset of the Industrial Revolution is the driving factor in global warming, and the use of fossil fuels is the leading source of the growth in GHGs.

Prompted in part by the Paris Accord, countries are exploring ways to reduce GHG emissions. Some of those ways, such as the transition to electric automobiles, are obvious. Some, such as removing GHGs directly from the atmosphere, are experimental and may have unanticipated side effects. Most of the methods for reducing GHG emissions require additional investments, at least during transition, and there is some reluctance to making those investments. In any event, climate mitigation will entail changes to the way we live, work, and travel.

Even in the most optimistic projection, some additional global warming is virtually guaranteed along with its consequences of additional flood, wind, and heat risks. Climate adaptation can limit the damage and disruption from these risks. To adapt to climate change, houses and other structures can be modified. To increase resilience to flood risk, the first finished level of a home can be raised a couple of feet above the projected elevation of the 100-year flood. New building materials and techniques can make homes more resistant to wind damage. Passive cooling techniques — common prior to the advent of air conditioning — can be reintroduced. Similar strategies can be employed at the community level to make community infrastructure more resilient.

As with mitigation, adaptation tends to be costly especially when retrofitting existing structures. To date, the public has shown limited appetite for paying a premium for homes that incorporate resiliency features in excess of those required by building codes. Accordingly, builders have little incentive to absorb the costs of those resiliency features in new construction.

FIRMS IN HOUSING AND HOUSING FINANCE ARE WORKING TO QUANTIFY AND MANAGE THEIR CLIMATE RISK

Regulators and investors are demanding more, and more specific, disclosures by firms of climate-related risks. At present, disclosures in annual and quarterly financial reports tend to be qualitative. Firms likely will be asked to quantify these risks in future.

The Climate Disclosure Standards Board, an international consortium of businesses and NGOs, has published guidance on accounting for climate risk in financial statements, and some firms are beginning to provide more detailed estimates and sensitivity analyses. European firms appear to be further along in this process than U.S. firms, and surveys indicate institutional investors in Europe place a heavier weight on this type of information than investors in the U.S. currently. Legislation was introduced recently in the U.S. Congress to require the SEC to provide rules for these types of disclosure, and the SEC has sought public input on climate-related disclosures. The Federal Housing Finance Agency also has published a Request For Information for public input on this topic and collected numerous responses.

To cast a light on the challenges of quantitative disclosure, we consider a thought experiment. While climate change is likely to increase mortgage default risk, current default models generally do not incorporate a view of future climate impacts on mortgage defaults. We trace some of the steps risk managers and modelers may have to take to incorporate this type of information for the case of flood risk. Given the current state of climate science and the lack of substantial historical data on generally-accepted climate risk metrics, it may not be possible at present to provide risk estimates with the level of accuracy that is achievable in measures of interest rate and credit risk.

CONCLUSION

Climate change is real. Under even the most optimistic scenario, global warming and its impacts on weather are projected to get worse over the course of the 21st century.

The physical destruction caused by flooding and other extreme weather events is likely to necessitate changes in the way we currently insure against these risks. The U.S. employs a complex and sophisticated system for allocating risks among homeowners, insurers, lenders, servicers, GSEs, governments, and private investors. There already are signs that this system may have difficulty adapting to climate-triggered changes in these various risks.

Strategies are available both for mitigating climate change and for adapting to the unavoidable component of that change. However, these strategies are costly and require a high degree of adoption and cooperation that does not currently exist.

Firms will be pressed by regulators and investors to provide more quantitative estimates of the climate-related risks they face. In considering the example of estimating the impact of increased flooding on mortgage default risk, it is apparent that better and more standardized predictors of environmental risks will be needed.

Introduction

The Earth's climate is changing. These changes will impact housing and the housing finance industry. Beyond these two certainties, there is a long list of unknowns. What forms will climate change take? How extreme will these changes be? Where will they be most concentrated? And what will be the pace of these changes? Can these changes be limited or reversed?

Stakeholders in housing and housing finance want to understand how these uncertain events will affect them. Will homeowners in areas of growing climate risk face higher hazard and flood insurance premiums? Will the prices of their homes decline? Will insurance companies face steadily increasing claims? Will these companies retreat from offering coverage at all in certain areas? Will lenders see an increase in mortgage defaults in areas of high climate risk? Will avenues for credit risk transfer narrow as uncertainty increases? And what additional responsibilities will firms in housing and housing finance have to shoulder as regulator and investor concerns over climate change increase? How can housing and housing finance firms quantify and manage the risks posed by climate change?

This paper attempts to provide, if not answers to these questions, then the best information currently available on these issues. The hope is that stakeholders and policy makers find this review clarifies the challenges before them as they formulate their responses to climate change.

This paper is divided into four sections. The first section reviews what we know so far about climate change. Where issues are uncertain, the current scientific consensus — or lack of one — is highlighted. The second section discusses the likely impacts of global climate change specifically to housing and housing finance. The third section investigates some of the strategies that can mitigate climate change or adapt to the part of climate change that cannot be averted. Finally, the fourth section considers the things firms in housing and housing finance can do to articulate and measure their exposure to climate change.

1. The Earth's Climate is Changing

The fact is we're long past debating whether climate change is real. —2020 ANNUAL REPORT, JPMORGAN CHASE & CO.

Warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia.
—FIFTH ASSESSMENT REPORT OF THE INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE

KEY POINTS:

- The Industrial Revolution initiated increases in the burning of fossil fuels which, in turn, resulted in increases in greenhouse gases (GHG) in the atmosphere — increases which continue to this day.
- The increases in CO_2 and other greenhouse gases are the primary cause of the roughly 150-year-long increase in global mean temperature known as global warming.
- The international scientific community has compiled convincing evidence connecting global warming to rising sea levels and storm surges; reductions in snow cover, glaciers and arctic ice sheets; warming and acidification of the oceans; increases in heat waves; and changes in the patterns and intensity of precipitation.
- As of the most recent international scientific assessment, evidence is lacking to link global warming to fluvial (river) flooding and to drought.
- Global warming and sea level rise are projected to continue in the 21st century. The amount and rate of increase in global temperature and sea level depend on the international community's willingness and ability to reduce GHG emissions.
- Under a wide range of scenarios — including a scenario consistent with the Paris Accord — the second half of the 21st century will see increases in food insecurity as the result of reductions in marine and freshwater populations and declining agricultural productivity. Many land- and water-based species will face extinction. Reliable water supplies will become scarcer, and extreme weather events will become more frequent. Human health will suffer, especially in poorer regions where the infrastructure lacks resilience to climate change.

To understand climate change, we climb a ladder of increasing uncertainty.

- Global warming — the source of climate change — is certain; 150 years of measurements document it.
- The impacts of global warming on the Earth's climate are more complicated. The international scientific community has compiled convincing evidence that global warming plays an important role in sea level rise, increasing storm surges, reductions in glaciers and snow cover and much more. The evidence for links to some phenomena such as drought and inland (river) flooding is still in flux although recent studies may firm it up.
- Despite decades of research and modeling, projecting future climate change and its impacts remains challenging primarily because the outcome depends crucially on the actions chosen by governments, industry, and households. Given the uncertainty over those actions, the future path of climate change could be almost anything (except better).

Notwithstanding these uncertainties, climate change impacts all governments, industries and individuals, now and in the years ahead. Housing and housing finance — the focus of this essay — will not be spared. This section briefly reviews the consensus of scientific opinion about climate change — from the certain to the more speculative — to set the scene for a discussion of the impacts on housing and housing finance.

GLOBAL WARMING

Global warming — the source of climate change — is easy to explain and to document. (Appendix A presents a more-detailed review of global warming.) The Earth's average temperature is determined by the amount of solar energy it receives and retains. The retention part is crucial. Without some way to keep some of that solar energy from being reflected out into space, the Earth would be much colder than it is. Fortunately, the Earth's atmosphere contains gases that absorb some of the solar energy that would otherwise be re-radiated out to space. These are the so-called greenhouse gases (GHGs), primarily water vapor, carbon dioxide (CO_2), methane and ozone, and their role in regulating the Earth's temperature is the greenhouse effect.

We should be thankful for the greenhouse effect: it accounts for the generally-moderate climate Earth has enjoyed. The average global temperature in 2020 was 57 degrees Fahrenheit (13.9 degrees Celsius). Scientists estimate that without the warming impact of the greenhouse effect, the average global temperature would be around 0 degrees Fahrenheit (-18 degrees Celsius).

Starting roughly 150 years ago, the concentration of CO_2 in the atmosphere began rising. Human activity — industrialization and deforestation combined with population growth — is the likeliest source for the increase in CO_2 and other greenhouse gases. This increase in greenhouse gases generated an increase in the Earth's temperature. In other words, human activity is responsible for the increase in greenhouse gases which, in turn, is responsible for global warming.

Documenting the connections from human activity to increases in greenhouse gases to global warming is straightforward and largely noncontroversial. The impacts of global warming on the Earth's weather, however, are more complicated and can be challenging to predict.

THE IMPACT OF GLOBAL WARMING ON THE EARTH'S CLIMATE

The average global temperature has increased about 1 degree Celsius over the last 100 years. An increase of 1 degree Celsius over a century doesn't sound like a big deal, but that amount and rate of increase is unprecedented. In addition, the impacts of that temperature increase on the Earth's climate more generally — atmosphere, oceans, glacier and snow cover, sea level — are surprisingly large. And the combination of these climatic shifts already is influencing changes in flooding, hurricanes, wildfires and other phenomena that directly affect human life.

The links between global warming and the general contour of Earth's climate are complex which can make it difficult definitively to connect the dots between global warming and a specific weather event. The United Nations established the Intergovernmental Panel on Climate Change (IPCC) in 1988 to provide policymakers with regular scientific assessments on the current state of knowledge about climate change. These assessments include qualitative and quantitative judgments that represent the scientific community's current level of certainty about the impacts of global warming. The bullets below summarize the scientific consensus on some of the observable impacts of global warming on the Earth's climate as reported in the Fifth Assessment Report (AR5) of the IPCC published in 2014, the latest of the IPCC reports.[1] (Terms in ***bold italics*** below are the AR5 rankings of the confidence and likelihood of the assessments[2].)

1. Scientific studies of climate change have continued without let-up since the publication of AR5. Based on the evidence since 2014, AR6 is likely to report stronger links between global warming and such phenomena as hurricanes and drought. However, until the publication of the synthesis report of the AR6 in 2022, the AR5 provides the clearest summary of the scientific consensus. The widely reported August 9, 2021, IPCC release, the first in a series of reports that will culminate in the AR6 synthesis report, is briefly discussed at the end of Appendix A.

2. Qualitative assessments combine an evaluation of the strength of the underlying evidence with the extent of agreement within the scientific community to describe the confidence in the assessment. The five confidence categories are *very low, low, medium, high,* and *very high.* Where quantitative assessments are possible, the IPCC reports on the likelihood an assessment is correct. For example, if the likelihood of an assessment is greater than 66%, AR5 describes the assessment as *likely;* If greater than 90%, AR5 describes the assessment as *very likely,* and so on. The AR5 uses ten likelihood categories. For more details, see the AR5 Summary for Policymakers, Box Introduction.2, p.37.

The Atmosphere

- The period 1983 to 2012 was ***very likely*** the warmest 30-year period of the last 800 years in the Northern Hemisphere and ***likely*** the warmest 30-year period of the last 1400 years.

Oceans

- The Earth's oceans serve as a heat sink and dominate the increase in energy stored in the climate system, accounting for more than 90% of the energy accumulated between 1971 and 2010 ***(high confidence).*** It is ***virtually certain*** that the upper ocean (depth from 0 to 700 meters) warmed from 1971 to 2010.

- Oceanic absorption of CO_2 since the beginning of the industrial era has resulted in acidification of the ocean ***(high confidence)*** and has reduced oxygen concentrations in coastal waters ***(medium confidence).***

Glaciers and Snow

- Over the last two decades, the Greenland and Antarctic ice sheets have been losing mass, and glaciers have continued to shrink almost worldwide ***(high confidence).***

- Northern hemisphere spring snow cover has continued to decrease in extent ***(high confidence).***

Sea Levels

- From 1901 to 2010, global mean sea level rose by 0.19 meters (7.5 inches), and the rate of sea level rise since the mid-19th century has been larger than the mean rate during the previous two millennia ***(high confidence).***

- There has been significant variation across regions in the amount of sea level rise. Since 1993, regional rates of increase for the Western Pacific are up to three times larger than the global mean rate of increase, while those for much of the Eastern Pacific are near zero or negative ***(high confidence).***

HOW CLIMATE CHANGE AFFECTS OUR LIVES

Climate is what you expect, weather is what you get —NATIONAL CENTERS FOR ENVIRONMENTAL INFORMATION NEWS ARTICLE (*www.ncei.noaa.gov/news/weather-vs-climate*)

The difference between climate and weather is time. Climate describes characteristics of the weather over a long period in a specific area. Weather describes the mix of conditions right now. Climate usually changes slowly, so important changes may be overlooked, even when, by climatic standards, the changes are happening extraordinarily rapidly (for instance, an increase of 1 degree Celsius in global mean temperature over a century). What we notice and care about is weather. Hurricanes, floods, drought, extreme temperatures, lengths of summer and winter seasons, etc. — the things that affect the livability of a region and the viability of agriculture.

In recent years, extreme weather events have revealed the significant vulnerability of ecosystems and many human systems, such as housing and water and power supplies. Direct and insured losses from weather-related disasters have increased substantially. Is climate change the culprit for these extreme events?

While scientists have reached a firm consensus on global warming and its impacts on the overall climate, research continues on the links between these climatic changes and the weather events that touch us in real time. The high variability in weather conditions from day to day, month to month, and year to year makes it challenging to provide definitive judgments.

The AR5 summarizes the current state of knowledge on these links.[3] Some of the more likely links concern heat waves, precipitation and extreme sea levels.

- The frequency of heat waves has increased in large parts of Europe, Asia and Australia ***(likely).*** Cold days and nights have decreased and warm days and nights have increased ***(likely).***
- There are more land regions where the number of heavy precipitation events has increased than where it has decreased ***(likely).*** The frequency and intensity of heavy precipitation events has ***likely*** increased in North America and Europe, but in other continents, confidence in trends is at most ***medium.*** It is ***very likely*** that global humidity has increased since the 1970s.
- It is ***likely*** that extreme sea levels, such as storm surges, have increased since 1970, primarily as the result of rising sea levels.

On the other hand,

- There is ***low confidence*** that the climate change caused by human activity has affected the frequency and magnitude of fluvial (river) flooding. Confidence is limited by the absence of long-term records from unmanaged catchment areas.
- There is ***low confidence*** in observed global-scale trends in droughts. Differences in definitions of drought and geographical inconsistencies in observed trends make it difficult to form a more definite opinion.
- While it is ***virtually certain*** that intense tropical cyclone activity has increased in the North Atlantic since 1970, there is ***low confidence*** in the attribution of global changes to any particular cause.

Climate change and the associated weather impacts have significant impacts on life on Earth.

- In many regions, changes in precipitation and snow and ice melt are changing the quality and quantity of water resources ***(medium confidence).***
- Many land and water species have already shifted their geographic ranges and migration patterns in response to ongoing climate change ***(high confidence).***
- Negative impacts on crop yields have been more common than positive impacts ***(high confidence).***

WHAT DOES THE FUTURE HOLD?

The increases in greenhouse gases and global temperature since pre-industrial times are well-established. In addition, strong evidence and scientific consensus support connecting global warming to at least some observable environmental changes such as rising sea levels and ocean acidification. Less clear are future trends in global warming and the likely impacts on the environment and human life.

Future increases or decreases in greenhouse gases depend on decisions that international and national organizations — and individuals — make today. The international community has crafted multiple agreements to limit the growth of greenhouse gases. To date, the results have been mixed, but

3. AR5 statements of *likelihood* require an ability to estimate the probability of an assessment (e.g., a statement that extreme sea levels have increased since 1970). AR5 statements of *confidence* combine an evaluation of the strength of the evidence with a determination of the level of agreement among the scientific community. In some cases, assessments have low confidence because of the unavailability of sufficient evidence at present.

they may gain traction going forward. Within most countries, however, some groups question the concern over climate change and object to the types of measures proposed by these international agreements. These serious disagreements make it impossible to predict future trends in the use of fossil fuels and thus the future growth of greenhouse gases.

In light of this uncertainty, the IPCC developed four different scenarios for the evolution of greenhouse gas emissions and atmospheric concentrations, air pollutant emissions and land use in the 21st century. These scenarios are called *Representative Concentration Pathways* (RCPs) and are designed to span a wide range of possible futures.[4] The IPCC uses these scenarios as the basis of a set of simulations of Earth's climate in the 21st century. One of the scenarios, labelled RCP2.6, envisions stringent measures to mitigate the growth of greenhouse gas emissions consistent with limiting additional increases in global warming below 2 degrees Celsius.[5] Two intermediate scenarios, RCP4.5 and RCP6.0 are included, and one scenario, RCP8.5, projects high future greenhouse gas emissions. Two scenarios, RCP6.0 and RCP8.5, do not incorporate any additional efforts to contain emissions and are regarded as baseline scenarios.

Translating these four scenarios into projections of the Earth's climate over the 21st century is not a simple task. The various aspects of Earth's climate — retention of solar radiation, atmospheric and oceanic temperatures, extent of glaciers and snow cover, strength and direction of oceanic currents that transfer heat from one part of the globe to another, and more — all interact in ways that are complex to model.

Instead of developing a single estimate of the outcome, the IPCC relies on the work of the *Coupled Model Intercomparison Project* (CMIP)[6] to produce multiple simulations for each RCP. These multiple simulations draw on coupled sets of competing models for components of the climate to generate a range of projections for each RCP. These ranges help quantify the amount of uncertainty around these forecasts.[7]

Table 1 displays the projections of each of the four scenarios considered by the IPCC for the change in global mean surface temperature and global mean sea level relative to the period 1986-2005. The period 2016-2035 is omitted from the table since there are almost no differences in the projections of these scenarios during that period. For instance, temperature is likely to increase from 0.3 to 0.7 degrees Celsius in all four scenarios.

Table 1: Climate Changes Relative to the 1986-2005 Period

Scenario	RCP	Temp Change		Sea Level Rise	
		2046-2065	2081-2100	2046-2065	2081-2100
High GHG emissions	RCP8.5	2.0	3.7	0.30	0.63
Intermediate Scenario	RCP6.0	1.3	2.2	0.25	0.48
Intermediate Scenario	RCP4.5	1.4	1.8	0.26	0.47
Stringent Mitigation Scenario	RCP2.6	1.0	1.0	0.24	0.40

Global mean surface temperature change in degrees Celsius; global mean sea level rise in meters.
Source: *IPCC, Fifth Assessment Report* (AR5).

The projections begin to diverge in the mid-21st century and become markedly different by the end of the century. By mid-century, global mean temperature is anticipated to increase by 2 degrees Celsius in the high greenhouse gas (GHG) emissions scenario compared to a 1 degree Celsius increase in the stringent mitigation scenario. By the end of the century, the temperature is expected to increase by 3.7 degrees Celsius in the high GHG emissions scenario, while there is no further temperature increase in the stringent mitigation scenario. Sea level rise by the end of the century is expected to be 58 percent greater in the high GHG emissions scenario than in the stringent mitigation scenario.

4. The RCPs are characterized by their projections of GHG concentrations and global mean temperature. AR6 will augment the RCPs with *Shared Socioeconomic Pathways* (SSPs) which provide different possible baseline scenarios of world developments that would affect the chances of climate mitigation. For example, one SSP envisions resurgent nationalism that could make it impossible to achieve the objectives of the Paris Accord. See https://www.carbonbrief.org/explainer-how-shared-socioeconomic-pathways-explore-future-climate-change for a useful explanation of the SSPs.

5. The Paris Accord, adopted in December 2015, set a long-term goal of keeping the rise in global average temperature well below 2 degrees Celsius above pre-industrial levels and to pursue efforts to limit the increase to 1.5 degrees Celsius.

6. The CMIP is one of many climate-related projects of the World Climate Research Programme, a research organization formed in 1980 by the International Science Council (ISC) and the World Meteorological Organization (WMO). A third co-sponsor, the Intergovernmental Oceanographic Commission (IOC) of UNESCO joined in 1993. The CMIP currently is in Phase 6 (CMIP6), but AR5 drew on CMIP5 since AR5 was completed before CMIP6 was ready.

7. Actually, the AR5 forecast process is even more complex and nuanced than described in this paragraph. The IPCC employs three methods for projecting future conditions and risks: *experiments, analogies,* and *models.* Where possible, experiments involve changing one or more climate-system factors to reflect anticipated future conditions while holding other factors constant. Analogies use known circumstances to argue for future impacts in similar circumstances. *Spatial analogies* identify a region currently experiencing conditions similar to those expected in the future. *Temporal analogies* draw on changes in the past — sometimes the very ancient past — to anticipate changes in the future. Models like the CMIP provide quantitative projections.

The projections in Table 1 reflect the average of the many simulations conducted for the AR5. The likely range of projections for the 2081-2100 period suggest that the increase in mean temperature could be as low as 0.3 degrees Celsius (stringent mitigation scenario) or as high 4.8 degrees Celsius (high GHG emissions scenario). Similarly, mean sea level rise could be as low as 0.26 meters or as high as 0.82 meters.[8]

In addition, these projections represent global averages which can obscure significant variation across the globe. For instance, the Arctic region is expected to continue to warm more rapidly than the global mean ***(very high confidence)*** and the temperature increase will be greater over land than over the ocean ***(very high confidence).*** Also, it is ***very likely*** that heat waves will occur more frequently and last longer.

Regardless of which, if any, of these scenarios prevails, climate change will increase the risks to life in the 21st century. A large fraction of species faces increased extinction, especially as climate change interacts with other stressors ***(high confidence).*** Most plant species cannot naturally shift their geographical ranges fast enough to keep up with projected rates of climate change.

Climate change is anticipated to increase food insecurity. Changes in ocean temperature will force redistribution of some species and increasing acidification will decrease some marine populations reducing the viability of some fisheries. In the absence of crop adaptation, production of wheat, rice and maize in tropical and temperate regions will decline. Climate change will reduce surface and groundwater resources in most dry subtropical regions, intensifying competition for water.

Urban areas will face increased risks from extreme weather events (heat, storms, extreme precipitation), flooding, air pollution, water scarcity, sea level rise and storm surges ***(very high confidence).*** Major impacts on rural areas include changes in water availability, food security, and agricultural incomes ***(high confidence).*** Climate change will lead to increases in ill health especially in developing countries ***(high confidence).*** In the high GHG scenario, the combination of high temperature and humidity in some areas for parts of the year will compromise common human activities, including growing food and working outdoors ***(high confidence).***

8. The AR5 projections do not account for a potential Antarctic contribution to global sea level. This potential contribution is an active area of research, and it's possible that Antarctica could add an additional meter of mean sea level rise this century.

2. Climate Change Will Impact Housing and Housing Finance

[A]nnual damages to residential real estate will be roughly .85% per year, 58% higher than the amount collected by insurers to cover it. —DAVID BURT WRITTEN TESTIMONY BEFORE THE U.S. SENATE SPECIAL COMMITTEE ON THE CLIMATE CRISIS, MARCH 20, 2021

KEY POINTS:

- Climate change increases many of the risks faced by housing and housing finance.
- The Task Force on Climate-Related Financial Disclosures (TCFD) recommends that firms disclose both the familiar ***physical risks*** of climate change and the more-novel ***transition risks*** that firms face as the world transitions to a lower-carbon economy.
- Many of the housing-specific impacts of climate change already are visible in the example of increased coastal flooding, perhaps the most certain of the projected impacts of global warming.
- Climate change impacts additional housing-specific risks beyond the physical damage and insurance risks associated with flooding. Some of these risks may not be immediately obvious and may not fit neatly into the TCFD category of transition risk. Among them: mortgage default and prepayment risk, adverse selection, house price risk and climate migration.

The housing industry will face many of the climate challenges faced by other industries. In addition, housing and, especially, housing finance comprise a sophisticated system for distributing risk across multiple stakeholders. Climate change will place increasing stress on that system with differential effects on the many stakeholders in the system. Stakeholders include consumers (homeowners and renters), landlords, builders, appraisers, originators, servicers, insurance companies, government agencies and GSEs, and mortgage investors. Analysis of the impacts of climate change on housing and housing finance should consider how those impacts are shared among these stakeholders.

Growing recognition of the potential impacts of climate change on all industries has generated demands by regulators and investors for firms to include more comprehensive disclosures about these risks in their financial statements.[9] In 2017, the Task Force on Climate-Related Financial Disclosures (TCFD)[10] issued its final report with recommendations for international harmonization of climate-related disclosures for both financial and non-financial firms. The report recommended dividing climate-related risks into *physical risks* — the climate changes discussed in the first section of this essay and their associated impacts — and *transition risks* — the changes required to adapt to a lower-carbon economy[11] and their impacts on firms. Physical risks can be *acute,* triggered by an event such as a flood or hurricane, or *chronic,* such as secular increases in temperature or sea level that may threaten buildings, infrastructure and activities. Both physical and transition risks can be further subdivided into the risk categories already familiar to firms — legal risk, reputation risk, operational risk, credit risk, etc. While many of these risks are common to all types of firms, some of the transition risks in particular have housing-specific aspects.

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9. MISMO, the real estate finance industry's standards organization, is facilitating collaboration and engagement among lenders, servicers, issuers, mortgage insurers, vendors, investors, government agencies and regulators, GSEs, and all other market participants to foster the development and adoption of standards to support the exchange of ESG information, including, but not limited to, data, terms, and definitions. (See: https://www.mismo.org/get-started/participate-in-a-mismo-workgroup/esg-cop.)

10. The TCFD was created in 2015 by the Financial Stability Board, an international, not-for-profit association that monitors and makes recommendations about the global financial system. The Financial Stability Board is hosted and funded by the Bank for International Settlements.

11. The report of the TCFD defines transitions risks as the potential impacts of the changes of adapting to a *lower-carbon* economy, essentially, the changes faced by firms if the IPCC's projection for RCP2.6 is realized. However, firms also face transition risks along the other projection paths considered by the IPCC. These are the risks firms might face during a transition to higher GHG concentrations and greater global warming.

PHYSICAL RISKS

Physical risks are easier to gauge than transition risks, and acute physical risks are more-easily identified than chronic physical risks. Every year, parts of the world endure hurricanes, floods, wildfires and other natural disasters, that is, acute physical risks. Firms and individuals have always faced these risks, and insurance companies have long been in the business of pricing these risks.

Climate change is projected to increase the frequency and intensity of some of these familiar risks in some parts of the globe. Climate change will change the *degree* of these acute physical risks but not the *kind* of risks. And the portion of acute physical risk attributed to climate change most appropriately refers to the *incremental risk* of natural disasters generated by climate change. In other words, it refers to any increase in the frequency or intensity of natural disasters above prior average experience. In practice, of course, stakeholders will have to find ways to cope with the totality of whatever natural disasters occur without fussing about subdividing the damage into "normal" and "incremental" impacts.

Chronic physical risks are more difficult to measure, in part, because they depend on the future path of global warming which, in turn, depends on world decisions and actions to reduce the growth in greenhouse gases. The four projections reported by the IPCC — the RCPs, or Representative Concentration Pathways — highlight the wide range of potential outcomes. Moreover, the IPCC notes the high uncertainty about the global outcomes associated with each of the RCPs. This uncertainty presents a challenge to policy makers and firms attempting to assess their exposure to chronic physical risk.

With that uncertainty in mind, the TCFD recommends that firms address three chronic physical risks in their financial disclosures: (1) changes in precipitation patterns and extreme variability in weather patterns; (2) rising mean temperatures; and (3) rising sea levels. The TCFD also identifies some of the potential impacts of these risks, including

- Damage to property in high-risk locations leading to write-offs and early retirement of existing assets
- Increased insurance premiums and potential for reduced availability of insurance on assets in high-risk locations
- Increased operating costs (e.g., inadequate water supply for hydroelectric plants or to cool nuclear and fossil fuel plants, increased electricity costs to power HVAC)
- Reduced revenue from decreased production capacity (transport difficulties, supply chain interruptions)

- Higher costs due to negative impacts on workforce (e.g., health, safety, absenteeism).

TRANSITION RISKS

The TCFD identifies four areas of transition risk that firms should address in their financial disclosures.[12]

Policy and Legal

As government and regulatory policies on climate change evolve, firms may face higher costs and litigation risks. Building codes may be expanded to include additional climate-related requirements. As an example, in 2020 California began requiring rooftop solar panels on all new residential buildings with three stories or less. Carbon taxes have been debated for years, but no state imposes them currently.[13] If significant carbon taxes are enacted in future, the relative cost of energy-intensive building materials could increase. Reporting requirements for emissions could be enhanced, placing a burden on builders and apartment owners with older HVAC systems. Stricter regulations might also require expensive retrofitting in older structures, similar to the costs imposed by asbestos abatement.

Technology

Builders may be required — by regulation, by changes in building codes or by consumer demand — to substitute more energy-efficient building materials for existing materials. Builders may be required to adopt new construction methods and technologies. All these changes are likely to be expensive and are likely to involve some amount of trial and error.

12. The TDFC notes that overlap exists in the risks categorized in these four groups.

13. The US does have some charges on fossil fuels, primarily federal excises on automotive fuels, and some states have versions of cap-and-trade regulations.

Market

Abrupt and unexpected changes in energy costs may upend the calculation of the profitability of the construction and ownership of buildings.

Reputation

Public opinion of a firm's commitment to environmental issues may affect the demand for its services.

HOUSING-SPECIFIC RISKS AND IMPACTS: THE EXAMPLE OF FLOOD RISK

The examples above highlight housing-related issues, especially those faced by the construction industry, but climate change has additional housing-specific risks and impacts and not all of them fit neatly into the categories identified by the TCFD. Flood risk highlights many of the most significant housing-specific risks. In addition, flood risk provides a perspective on the thorny questions of risk sharing.

The Extent of Flood Risk

Official estimates of flood risk in the U.S. probably are understated. One common measure of the extent of flood risk is the number of people who live in high-risk areas. While floods can happen anywhere, the Federal Emergency Management Agency (FEMA) maintains Flood Insurance Rate Maps (FIRMs) that identify Special Flood Hazard Areas (SFHAs),[14] that is, areas with at least a one percent annual probability of a flood.[15] In these areas, borrowers must obtain flood insurance for most mortgages, including those purchased by Fannie Mae or Freddie Mac (the GSEs).[16]

FEMA estimates that 13 million people in the United States — four percent of the population — live in SFHAs, the high-flood-risk areas. However, FEMA's maps often are out of date. FEMA is required to revise and update all flood maps every five years. But three-quarters of FEMA flood maps are older than 5 years and 11 percent date back to the 1970s and 80s.[17] According to a 2017 report by FEMA's Inspector General, only 42 percent of FEMA's maps reflected accurate flood risk projections.

Independent calculations[18] published in 2018 estimate that an accurate update of the SFHAs would include roughly 40 million people (12 percent of the population) in the high-risk areas. In a moderate population growth scenario, that number is projected to grow to 60 million by 2050 and 75 million by the end of the century. According to these calculations, far too few properties are required to have flood insurance ***today.*** Climate change and population growth will widen that gap.

Climate Change May Alter the Nature of Flood Risk

As destructive as floods can be, society has coped with flood risk forever. Historically, the residents of flood-ravaged areas bore most, if not all, of the costs of the damage to their homes and communities. In modern times, governments have offered disaster assistance to help flood victims rebuild. And insurance companies have offered policies to cover some flood risks. Nonetheless, the impact of climate change on flood risk may be significant enough to overwhelm these coping mechanisms in some areas.

An increase in the intensity of floods — that is, an increase in the acute physical risk of flooding — may be great enough to make actuarially-fair flood insurance too expensive for most. The intensity of storm surges is expected to increase with the projected increase in the mean sea level. In the IPCC's most pessimistic projection (RCP8.5), the mean sea level is projected to increase between 0.45 and 0.82 meters (1.5 and 2.7 feet) by the end of the century. Moreover, the rise in mean sea level will not be uniform across regions. The IPCC estimates 70 percent of coastlines worldwide will experience increases within ±20 percent of the mean sea level increase. Taking the high end of the projected range and adding 20 percent generates an estimated increase of 0.98 meters (3.2 feet) in mean sea level in some areas. An increase in sea level of more than three feet by itself represents an existential threat to some low-lying coastal areas. An estimated 100 million people around the world live within three feet of the current mean sea level and another 100 million live within six feet of it.[19] And these potential increases in mean sea level will entail increases in the intensity of storm surges. Rebuilding a low-lying coastal area that suffers an extraordinarily intense flood in this type of situation may not be practical, and flood insurance may no longer make economic sense in these types of areas. Entire communities may need to be relocated or abandoned.

14. FEMA further divides SFHAs into different flood insurance rate zones based on the magnitude of the flood hazard.

15. FEMA defines the *base flood* as a flood with a one percent annual probability of occurrence in a given region. FEMA further defines the *base flood elevation* (BFE) of a region as the elevation reached by the *base flood.* SFHAs are areas at an elevation lower than the BFE. In common parlance, the base flood is called the 100-year flood — the flood with 1 chance in 100 of occurring in a given year — and the SFHAs comprise the 100-year floodplain. This nomenclature can be misleading: the probability of a 100-year flood over the life of a 30-year mortgage is 26 percent.

16. More precisely, flood insurance is mandatory for all federal or federally-related financial assistance for the acquisition and/or construction of buildings in SFHAs. The GSE requirement for flood insurance in SFHAs is a legal obligation of the GSEs and not simply a GSE policy. And federal regulators must require their regulated lenders to insure that borrowers obtain flood insurance for mortgages on properties within SFHAs.

17. First Street Foundation (2019).

18. Wing, et al (2018).

19. Elizabeth Kolbert "The Siege of Miami," *The New Yorker,* December 21 and 28, 2015.

Chronic physical risk associated with climate change may also exceed the capacity of insurance and government assistance to sustain some areas. These types of assistance are designed to support rebuilding after a flood recedes. They are unlikely to be viable if the flood never recedes.

The Environmental Protection Agency (EPA) identifies *king tides* as a prediction of future average tides in coastal areas as the mean sea level rises.[20] While "king tide" does not have a scientific definition, the term commonly is used to describe an exceptionally high tide or, sometimes, the highest tide predicted for the year. King tides can cause minor flooding, called "nuisance" flooding, and have become more common in some Southeastern coastal regions of the United States, such as Miami, Florida or Charleston, South Carolina. These nuisance floods can cause landscape damage (from saltwater inundation), road closures, overwhelmed storm drains and compromised infrastructure.[21] If, as the EPA suggests, these occasional king tides become the average tide, the associated minor flooding may become nearly continual flooding.

The precise magnitude of this chronic flooding is uncertain. However, multiple studies employing different methodologies and based on different projections of future sea level rise suggest that the impact of chronic flooding will be significant. A few examples:

- A climate risk assessment published by the Risky Business Project — an organization co-chaired by Michael Bloomberg, Henry Paulson and Thomas Steyer — estimated that between $66 billion and $160 billion worth of real estate will be below sea level by 2050. By the end of the century, the estimate ranged between $238 billion and $507 billion.

- A study by the Union of Concerned Scientists (UCS) focused specifically on the risk of chronic flooding. Based on a scenario[22] that projects a six-foot sea level rise above 1992 levels by the end of the century, the UCS report estimated that 300,000 existing homes and commercial properties with a current cumulative value of roughly $136 billion would be subject to chronic flooding, defined as flooding that occurs at least 26 times per year. By the end of the century, those estimates rise to nearly 2.5 million properties with a current cumulative value of $1.07 trillion.

- A recent analysis by the First Street Foundation projects the growth in the average annual dollar loss (AAL) due to flooding in the contiguous United States.[23] According to this analysis, the AAL is projected to increase 61 percent between 2021 and 2051 as a result of climate change. Further, if all the

20. https://www.epa.gov/sites/production/files/2014-04/documents/king_tides_factsheet.pdf

21. https://discover.pbcgov.org/resilience/Pages/King-Tides.aspx

22. The UCS report relied on sea level rise scenarios developed for the 2014 National Climate Assessment (NCA), a U.S. interagency ongoing project. So far, there have been four NCAs. The first was released in 2000. The most recent was issued in two volumes, with Volume 1 released in 2017 and Volume 2 in 2018. The 2014 NCA developed three scenarios for sea level risk: (1) a low scenario roughly consistent with the Paris Accord (1.6 foot sea level rise by 2100); (2) an intermediate scenario (4.0 foot rise); and (3) a high scenario (6.6 foot rise). The UCS report focused on the high scenario as the most appropriate for situations where risk tolerance is low. Since the home often is the homeowner's most valuable asset, presumably the social tolerance for chronic flooding risk should be low.

23. The First Street Foundation study includes inland flooding as well as coastal flooding. Their analysis reports estimates by state, allowing a rough comparison of the First Street and UCS estimates, which cover only the coastal states. Nonetheless, the methodologies and focuses of these two studies differ substantially.

at-risk properties were covered by NFIP insurance policies, the rates on those policies would need to increase 4.5 times to cover the risk.

These types of estimates could easily be augmented by dozens of other studies by private, governmental and international organizations. While it is difficult to place these various estimates on an apples-to-apples basis, they provide a clear indication of future flood risk on a scale that current safety nets cannot handle.

And, as the UCS study calls out, "properties will not be the only things to flood. Roads, bridges, power plants, airports, ports, public buildings, military bases and other critical infrastructure along the coast also face the risk of chronic inundation." Chronic flooding will also diminish the property tax base limiting the ability of communities to rebuild crucial infrastructure. The UCS study estimates that in about 120 coastal communities, the properties at risk by 2045 represent 20 percent or more of the local property tax base. For 30 of those communities, the properties at risk by 2045 represent more than half of the base.

Climate Change will Exacerbate Current Challenges of the National Flood Insurance Program

The current weaknesses of the National Flood Insurance Program (NFIP) are well-known. The NFIP was created in the 1960s to help individuals living in floodplains cope with flood risk, to encourage community efforts to mitigate flood risk, and to discourage further building in the most flood-prone areas. However, Congress has mandated several types of subsidies for NFIP policies, which tends to encourage development rather than discourage it.[24] Moreover, many FIRMs are out of date which can lead policies to be mispriced. Most importantly, rates are calculated based on historical flood experience. Given the consensus of increasing flood risk as a result of climate change, NFIP policies are likely to be priced too low to cover expected future flood risk. These subsidies undercut the goal of discouraging further building in areas of high flood risk.

The NFIP was forced to borrow heavily in the wake of Hurricane Katrina (2005) and Hurricane Sandy (2012). The NFIP reached its borrowing limit of $30.5 billion in 2017 and Congress cancelled $16 billion of NFIP debt to allow the program to continue operation. Currently the NFIP debt totals $20.525 billion which accrues over $1 million per day in interest. FEMA predicts that NFIP will have paid $10.3 billion in total interest expenses by 2029 (Congressional Research Service, 2021).

A significant share of NFIP's costs come from claims for properties that are flooded repeatedly. The Pew Charitable Trust (2016) estimates that repeatedly-flooded properties account for one percent of properties with NFIP insurance but 25-to-30 percent of flood claims. The cumulative cost of claims for repeatedly-flooded properties is larger than half of the NFIPs current debt. Given the projections cited above of increasing chronic flood risk, these costs are likely to grow at an accelerating rate, particularly since FEMA cannot deny policies to properties within a Special Flood Hazard Area (SFHA). At some point, Congress may not be willing to forgive NFIP debt or to increase the NFIP debt ceiling without wholesale changes to the structure of the program.

THE LIMITS OF INSURANCE

Insurance is one of the most ancient and most important financial inventions. Many business endeavors would be well-nigh impossible in the absence of insurance. In housing finance, to narrow the focus, lender appetite for mortgages would be limited if there were no hazard or flood insurance. And it is unlikely that the mortgage-backed securities market would command such a large share of fixed income investment without the default insurance provided — for a fee — by the agencies.

However, while insurance is essential, it cannot solve all problems. Previous sections have highlighted some of the shortcomings of the NFIP, but climate change is poised to test the limits of even a perfect insurance system. The risk management and risk spreading features of insurance face three limits: insurance cannot provide a solution when (1) the actuarially-fair price of insurance becomes too expensive to purchase; (2) the probability distribution of the event to be insured against is impossible in practice to estimate; or (3) the event to be insured against is no longer a risk, that is, it is a certainty (or near certainty). These limits to insurance apply equally to all other forms of risk sharing and risk transfer.

Some coastal communities are doomed. No sand dune engineering or flood wall construction will keep them from eventual inundation. However, "eventual" may be a long and uncertain time in the future. Renewals of one-year insurance policies can continue for the foreseeable future. But, at some difficult-to-predict point, premiums will start to climb. Then companies will begin to limit coverage or decline to renew some policies. If the insurance commission mandates renewals, companies can still decline to write new policies, making properties unsalable.

This hypothetical example emphasizes the limits of insurance over time, but these limits can be observed across geographic areas, if not today, then soon. Prospective purchasers of insurance for floods (or wildfires or hurricanes or heat damage or…) fall into one of four groups. The bulk of homeowners today fall in the Business As Usual (BAU)

24. Congressional Research Service, "Introduction to the National Flood Insurance Program (NFIP)," January 5, 2021.

group. They reside in areas where insurance does not face any unusual challenge or where those challenges have not yet been recognized. In the second group, a significant number of homeowners live where higher risk requires more or more-expensive insurance. An obvious example is homeowners in SFHAs. Evidence suggests the market may not yet be incorporating the impact of the risk efficiently into the price of the house, in part because the insurance is mispriced. The third group, relatively small at present, comprises homeowners who have become uninsurable as a result of climate change such as rising sea levels. These homeowners have suffered large capital losses that may not be fully realized yet. This group has a high risk of mortgage default with few foreclosure alternatives. Finally, some homeowners will become climate migrants when their community is no longer viable. Some of these migrants may be indirect victims of climate change. For example, their homes may be on higher ground with no realistic flood risk, but, if their place of employment and all their local services disappear, they may nonetheless be forced to move.

Based on even the most optimistic of the IPCC scenarios, climate change over this century is expected to decrease the share of homeowners in the BAU group and increase the share in the other three groups.

CLIMATE CHANGE WILL POSE RISKS BEYOND FLOOD RISK

Flood risk is a natural focus in discussions of the impact of climate change on housing and housing finance. Climate scientists are highly confident that sea level will continue to rise and coastal flooding will increase in frequency and intensity even in an optimistic scenario where the objectives of the Paris Accord are achieved. The increases in king tides and sunny-day flooding in the southeastern coastal areas of the U.S. already are undeniable. The financial stresses and failure to discourage development in high-risk coastal areas of the NFIP also are apparent. The risk is clear, the stakes are high, and the current solutions are falling short.

However, flood risk is not the only challenge climate change will present to housing and housing finance. Extreme weather events are projected to threaten urban areas. The increased frequency and intensity of heat waves may limit the ability to conduct work outside during parts of the year. In addition, hotter conditions will increase the demand for electricity for cooling. Making matters worse, coal-burning electrical power plants release additional greenhouse gases. Rural areas will face changes in water availability and instability in agricultural incomes.

Projections of the extent and magnitude of some of these risks are subject to greater uncertainty than projections of coastal flooding and storm surges. And, in contrast to flood risk, where the damage to residences and communities and the strains on the insurance industry are obvious, it can be more difficult to connect these other risks to specific impacts on housing and housing finance. Nonetheless, disruptions to human life of this magnitude will almost surely ripple through the housing system.

CLIMATE CHANGE WILL IMPACT RISK MANAGEMENT IN HOUSING AND HOUSING FINANCE

Risks faced by stakeholders in housing take many forms, and climate change will force stakeholders to modify the ways they manage these risks. Table 2 lists risks that will increase or evolve as a result of climate change along with an indication of the most-directly-impacted stakeholders. The last column indicates approaches stakeholders may employ to manage the risks.

Residential Property Damage

The discussion of flood risk above touched on the most common risk related to residential property damage. However, climate change has avenues other than flood risk for potentially damaging property. Increasingly devastating storms, excessive heat and wildfires, drought, and more all have the capacity to damage and destroy property. The evidence linking climate change to some of these threats is less settled than the evidence for increasing sea level rise, storm surges and coastal flooding. Nonetheless, all of them are potential risks of climate change.

Insurance is the classic risk management technique for property damage. However, as discussed above, the current U.S. flood insurance system incorporates significant deficiencies that are likely to be exacerbated by climate change.

It may seem odd that GSEs are not listed as at-risk stakeholders for residential property damage. The table identifies the most-directly-impacted stakeholders. In theory, GSEs are protected from most property damage by homeowners' insurance and from flood risk in flood hazard areas by flood insurance. GSEs also have well-developed policies for forbearance in disaster areas, which provides homeowners the ability to claim their insurance, rebuild and repair as needed, return to work and resume mortgage payments. Portfolio lenders on the other hand may hold some mortgages in flood hazard areas that do not have adequate (or any) flood insurance. In those instances, these lenders risk a write down on the collateral for the mortgage.

Table 2: Climate-related Risks to Stakeholders in Housing										
Risk	Owners	Buyers	Renters	Lenders	Servicers	GSEs	Investors	Insurers	Govt.	Risk Management Options
Residential Property Damage	X		X	X				X	X	Homeowners and renters insurance Flood insurance
Mortgage Default Risk	X			X	X	X	X			Guarantee fees Loan-loss reserves Risk-based pricing
Mortgage Prepayment Risk					X	X	X			Hedging
Adverse Selection		X				X		X	X	–
Moral Hazard								X	X	Actuarially-fair premiums Change in regulation
House Price Risk	X	X				X	X		X	–
Climate Migration	X			X		X	X		X	–

Mortgage Default Risk

Despite the requirements for property and flood insurance, some victims of climate-change-related natural disasters will be unable or unwilling to continue paying their mortgages. The natural disaster may disrupt or eliminate their employment opportunities. The damage to their property may exceed the sum of their insurance coverage plus their other financial resources. Whatever the reasons, natural disasters will produce increases in mortgage default.[25]

In the event of default, GSEs are required to purchase defaulted mortgages out of securitized pools at par. GSEs and portfolio lenders will attempt to make recoveries on the collateral although the physical damage to the property and the neighborhood will limit those recoveries. Generally, mortgages pass through a period of nonperformance prior to a default,[26] and the cost to service a nonperforming mortgage is significantly higher than the cost to service a performing mortgage. Investors in the GSEs credit-risk transfer (CRT) securities and reinsurance offerings also are exposed to losses when mortgage borrowers in disaster areas default.

To the extent climate change increases defaults via increases in flooding and other natural disasters, GSEs and portfolio lenders may have to increase their loan loss reserves. Under the CECL accounting standard, financial institutions are required to base their reserves on expected future loan losses. It may take some time for regulators, accounting firms, and financial institutions to agree on appropriate methodologies for estimating these future losses. Even optimistic projetions of climate change suggest increasing natural disaster risk, hence estimates based solely on historical experience may underestimate future losses.

The guarantee fees (Gfees) charged by the GSEs to cover losses from mortgage defaults may be too blunt an instrument if natural disasters increase. The GSEs face limitations on adjusting Gfees for variations in geographic risk. For example, the GSEs' protection against increasing flood risk in some coastal areas is solely the requirement that properties in SFHAs carry NFIP-standard flood insurance. As we noted above, many of these policies are mispriced. In addition, delays in updating the FEMA flood maps indicate that many properties with significant flood risk lie outside the current SFHAs.

Private investors in CRT securities and reinsurance contracts face none of these restrictions. They can leverage extensive private and public data resources to develop property-level estimates of future natural disaster risk. With this information, they can refine the risk-based-prices they are willing to pay for CRT securities and reinsurance contracts.

Mortgage Prepayment Risk

To investors in GSE mortgage-backed securities, defaults are indistinguishable from prepayments. If climate-related increases in natural disasters boost mortgage defaults, they also will increase prepayment rates. These changes would imply changes in hedging behavior by servicers, GSEs and investors.

25. For a recent study of the impact of flood damage on mortgage credit risk, see Kousky, Palim and Pan (2020).

26. Since the financial crisis of 2007/08, policies for providing borrowers alternatives to foreclosure tend to extend the period of nonperformance.

Natural disasters are geographically specific. Sea level rises and increasing storm surges impact coastal areas. Wildfires primarily strike forested areas. Thus, jumps in mortgage prepayments may, at times, be predictably-concentrated in areas reeling from recent natural disasters. Investors understandably will want to reprice mortgage securities with concentrations of loans in the affected areas.

In 2019, the GSEs began issuing UMBS, mortgage pools that may contain mortgages from Freddie Mac, Fannie Mae, or some from both GSEs. As part of the preparation for UMBS, the GSEs began issuing very large mortgage pools to assure investors they would receive the national average prepayment rate on the UMBS they purchased. With these large pools, the impacts of geographically-specific natural disasters are averaged in with the performance of all the loans outside the affected areas. Nonetheless, some mortgage securities are backed by loans that are concentrated in specific regions. Older-vintage mortgage pools are much smaller than the large pools issued as UMBS, and investors have, in the past, paid premiums or insisted on lower prices for some geographically-concentrated pools.[27] Reference pools backing CRT securities also may be less diversified than the large UMBS pools.

Adverse Selection and Moral Hazard

Housing and housing finance always have had to cope with the risks of adverse selection and moral hazard. Climate change may add new facets to those risks.

The moral hazard inherent in the NFIP was discussed above. One of the objectives of the NFIP was to discourage further investment in the floodplain. Unfortunately, the availability of underpriced flood insurance in some areas encourages rather than discourages this type of investment.

There have been some suggestions in the academic literature[28] that the GSEs may be the victims of adverse selection. Some research has focused on the origination of mortgages near the conforming limit — the legal limit, revised annually, on the size of a mortgage eligible for purchase by the GSEs. Researchers have looked for evidence that the share of loans just under the conforming limit increases in area where a natural disaster or other event changes lenders' perception of the risk of holding a loan in portfolio.

Private investors have the opportunity, denied to the GSEs, of leveraging property-level climate risk indicators when pricing geographically-concentrated mortgage securities and CRT securities and reinsurance contracts. This difference opens the possibility that the GSEs will face adverse selection in some types of transactions. Reducing geographic concentration, for example, by issuing large, geographically-diversified mortgage pools, can mitigate this risk.

Home buyers also run the risk of adverse selection. Consider a long-established community facing increasing precipitation and more intense storms. Storm drains may be overwhelmed more often resulting in costly flooded basements. But it is unlikely that these storm drains fail uniformly throughout the community. It may be difficult for home buyers to identify which homes are at higher risk of these intermittent events. In such a community, a "market for lemons"[29] may arise, where homes in areas of higher risk are marketed through the multiple listing service while homes at lower risk sell privately at higher prices.

27. In addition to the impact of natural disasters, geographically-concentrated pools may perform differently based on state laws governing foreclosures, refinancings, and the like. In addition, mobility rates, house price trends and more can vary across states. All of these factors can influence the value of a mortgage security.

28. See Ouazad and Kahn (2021).

29. See Akerlof (1970).

House Price Risk

Climate change may impact house price risk through multiple channels.

First, the wide range of uncertainty around projections of future climate risk necessarily increases the uncertainty about the risk of climate-driven damage to properties and communities. In an efficient market and in the absence of the ability to hedge or otherwise insure against this uncertainty,[30] these increases in uncertainty should tend to reduce property values in potentially high-risk regions.

Second, several researchers have presented evidence that real estate in regions of high climate-related risk may be significantly overvalued. To cite just one recent study, Hino and Burke (2021) examine two decades of sales data in floodplains and conclude there is little evidence that markets fully price information about flood risk. They note that homes drop roughly two percent in price when they are zoned into a floodplain. However, factoring in the cost of fully insuring against the higher flood risk in the floodplain implies a price drop of between 4.7 and 10.6 percent. According to their estimates, single-family homes in flood zones in the U.S. currently are overvalued by almost $44 billion dollars.

It should come as no surprise that investors have begun looking for ways to profit from this type of systematic mispricing. David Burt — founder of DeltaTerra Capital and one of the investors featured in *The Big Short,* Michael Lewis's account of the house price collapse in 2008 — has compared this mispricing to the house price bubble leading up to the 2008 financial crisis.[31]

Climate Migration

Chronic flooding can make houses uninsurable, unsalable and, ultimately, unlivable. Commercial establishments and infrastructure also are exposed to the same risk. As a result, communities may be forced to relocate, leaving behind homes and businesses. Such a relocation might start with an exodus of renters, who do not have to abandon real property when they leave. In 2005, Hurricane Katrina displaced a large share of residents in New Orleans, and many never returned to the area.

This scenario of increased flooding forcing residents out of their community is only one possible source of climate migration. Changes in climate that damage agricultural productivity or threaten water sources also have the ability to incent or force people to move. The Dust Bowl of the 1930s in the U.S. induced 3.5 million people to migrate from the Great Plains to surrounding areas and to the West Coast. In one year, over 86,000 people migrated to California alone, a larger influx than during the 1849 Gold Rush. Worldwide, climate migration is a serious risk. In a 2018 study of Latin America, sub-Saharan Africa and Southeast Asia, the World Bank estimated that 143 million additional climate migrants will be generated by 2050.[32]

30. House price volatility has proved difficult to hedge. In an attempt to provide a hedge, futures on house price indices have been launched in the past, but they failed to gain traction.

31. https://www.schatz.senate.gov/imo/media/doc/DaveBurtWrittenTestimony.pdf

32. https://openknowledge.worldbank.org/handle/10986/29461

3. There Are Strategies for Mitigation and Adaptation

What cannot be cured must be endured.
—ROBERT BURTON, THE ANATOMY OF MELANCHOLY, 1621

And all the future's there for anyone to change, still you know it seems it would be easier sometimes to change the past. —JACKSON BROWNE, "FOUNTAIN OF SORROW"

KEY POINTS:

- Strategies for mitigating climate change are available and are being actively explored.
- However, even the most optimistic climate change projection of the IPCC suggests increasingly challenging conditions through the end of the century.
- Additional strategies are needed to make housing and housing finance more resilient in the face of the portion of climate change that cannot be forestalled.
- At the household and apartment building level, multiple modifications can make buildings more resilient. It is easier and less costly to adopt these modifications in new construction, but there exist some options for existing structures.
- Communities will have to consider modifications to roads, bridges, water and power systems, and other infrastructure. Some of these modifications are very costly and take a long time to implement. In some areas, retreat may be the only viable option.
- Climate change is likely to stress the current housing finance system's ability to share and manage risk.
- While practical technical approaches to mitigation and adaptation are available, the uneven burden of adopting these techniques and the necessity for global cooperation pose challenges to addressing climate change.

Actions taken now will influence the trajectory of climate change over the remainder of this century. The world may be able to reduce the increase in global warming. And the housing industry may be able to increase the ability to endure the global warming that can't be avoided.

Two approaches are available: climate mitigation and climate adaptation. Climate mitigation comprises strategies that aim to directly limit global warming. Climate mitigation is a global strategy. It cuts across all geographic regions and economic sectors.

Climate adaptation comprises strategies designed to increase resilience in the face of climate change. In the housing industry, adaptation focuses on strengthening residential structures and the community infrastructure — roads, water and power supplies, etc. — that support residents. This type of adaptation is local. Adaptation in coastal communities will focus on resilience to flooding. Adaptation in forested communities will focus on adaptation to wildfires. In the housing finance industry, adaptation focuses on methods for measuring and managing climate-driven changes in financial risk.

STRATEGIES FOR CLIMATE MITIGATION

Actions taken now will influence the trajectory of climate change over the remainder of this century. Relative to the most pessimistic projection of the IPCC, the world may be able to reduce the increase in global warming 50 percent by 2065 and 73 percent by 2100 if the objectives of the Paris Accord are attained.[33] Similarly, sea level rise may be reduced 20 percent by 2065 and 37 percent by the end of the century.

33. The assumptions of the IPCC's RCP2.6 projection are roughly consistent with the Paris Accord.

To slow the increase in global warming, the world must find ways to reduce the increase in the concentration of greenhouse gases (GHGs) in the atmosphere. It's as simple — and as complicated — as that. The growth in GHGs that began at the outset of the Industrial Revolution is the driving factor in global warming, and the use of fossil fuels is the leading source of the growth in GHGs.

Several related terms are used commonly to summarize the path to climate mitigation. As both a practical goal and a handy mnemonic, advocates for climate mitigation have emphasized ***carbon neutrality,*** that is, balancing CO_2 emissions and CO_2 removal[34] from the atmosphere by, for instance, planting additional trees which absorb CO_2. The term ***net-zero emissions*** describes a similar balance between emissions and removals but includes all GHGs, not just CO_2.[35] [36] ***Climate neutrality*** is the broadest term of all; it is achieved when actions have no net effect on the climate.[37]

Most proposals for climate mitigation urge replacing fossil fuels by carbon-neutral, renewable energy[38] sources such solar power, wind power, hydroelectric power, geothermal power and nuclear power. In practice, most of these power sources are used to produce electricity.[39] As a result, much of the discussion revolves around replacing oil, gas and coal with electricity as the proximate source of power.

Currently, many electric power plants burn fossil fuels to create electricity. As a result, the production of electricity and heat account for the greatest share of GHG emissions (Table 3).[40] The growing use of solar and wind power combined with the use of battery farms to provide electric power without interruption may eventually reduce that share. Additionally, the growing use of solar panels in homes allows expanded use of electrical power without increased GHG emissions.

Table 3: Share of Greenhouse Gas Emissions by Sector

Sector	Share (%)
Electricity and heat production	25
Agriculture, forestry and other land use	24
Industry*	21
Transportation	14
Buildings	6
Other	10

Source: IPCC estimates from 2010 as reported by the Environmental Protection Agency, https://www.epa.gov/ghgemissions/global-greenhouse-gas-emissions-data.

* Emissions from industrial electricity use are included in "Electricity and heat production."

Land use accounts for almost as much GHG emissions as electricity and heat production. Agricultural activity not only contributes to GHG emissions, but some land use practices such as deforestation eliminates trees and other plants that otherwise would absorb atmospheric CO_2. Governments are likely to have to take a large role in improving land use, since they are the largest landowners, especially of undeveloped land.

After governments, perhaps the largest individual landowner is the Catholic Church. The Church's assets include not only cathedrals and convents but also farms, forests, and an estimated two hundred million acres of land. A cartographer and climate activist named Molly Burhans has been attempting to document the global landholdings of the church, in part, to give the church the ability to assess ways to manage its holdings so as to slow the pace of global warming.[41] Working with the Vatican, she discovered that the Church lacks a central record of its holdings. Her project, still underway, may eventually provide the Church the ability to manage its landholdings in ways that support the objectives of "Laudato Si", Pope Francis's 2015 encyclical on consumerism, ecological degradation and global warming.

Cars and trucks account for 82 percent of the GHG emissions produced by the transportation sector.[42] Electric vehicles have the potential of reducing the share of GHG emissions contributed by the cars and trucks. The market share of

34. Firms may purchase carbon credits to balance their CO_2 emissions rather than actually removing carbon themselves.

35. An increase in the production of cattle for human consumption may be consistent with carbon neutrality but not net-zero emissions since cattle are a significant source of methane, another GHG.

36. Even achieving net-zero emissions globally might not halt global warming, at least immediately. Some impacts of global warming have changed the initial conditions. For instance, glaciers and snow cover reflect solar radiation. The reduction in glaciers and snow cover allows more solar energy to be absorbed by the earth which tends to melt more glaciers and snow cover which allows more solar energy to be absorbed and so on. These types of considerations play a part in debates about *tipping points,* the idea that there are developments which, if they occur, may make it impossible to halt global warming.

37. Developments which replace green space with buildings and heat-absorbing pavement fail climate neutrality even if they incorporate techniques for net-zero emissions.

38. Not all renewable energy sources are carbon-neutral. For instance, biomass, the use of plant or animal material as a fuel, may not be carbon neutral. In addition, some sources of renewable energy, such as hydroelectric or tidal power, may have other undesirable environmental impacts.

39. Also heat.

40. Table 3 reports global shares. In the U.S., transportation accounts for the largest share of GHG emissions (28%), followed by electricity (27%), industry (22%), and agriculture (10%). See https://www.epa.gov/greenvehicles/fast-facts-transportation-greenhouse-gas-emissions.

41. Owen (2021).

42. https://www.epa.gov/greenvehicles/fast-facts-transportation-greenhouse-gas-emissions

electric vehicles in Europe and China is significant.[43] Their penetration is smaller in the U.S but growing. IHS Markit projects that sales of battery-electric vehicles will exceed 3.5 percent of the U.S. market in 2021 and electric vehicles will comprise more than 10 percent of the market by 2025.

Airplanes account for 9 percent of the GHG emissions from the transportation sector. While work on electric aircraft is in progress, the wait for commercially-viable electric air travel likely is measured in decades rather than years. Trains and ships each account for 2 percent of the transportation GHG emissions. Ships are not projected to get greener in the near term.[44] On the other hand, electric trains are common today, and the International Energy Agency rates rail as "among the most energy efficient modes of transport for freight and passengers."[45] Rail carries 8 percent of the world's passengers and 7 percent of its global freight but represents only 2 percent of total transport energy demand.

Almost all homes use electricity while only 58 percent of homes use natural gas. Nonetheless, natural gas accounts for a slightly larger share of home energy use (44 percent) than electricity (41 percent). Natural gas is used for furnaces, water heaters, washers and dryers, and stoves and ovens. A debate has broken out recently over proposals from some municipalities to wean homeowners and renters off natural gas by limiting or forbidding new gas hookups.[46] San Francisco, Seattle, Denver and New York all have either enacted or proposed such measures. To prevent the spread of this practice, Arizona, Texas, Oklahoma, Tennessee, Kansas and Louisiana have enacted laws outlawing these types of municipal regulations.

Simply reducing GHG emissions will not be enough to achieve the objectives of international agreements such as the Paris Accord. GHGs currently in the atmosphere will need to be removed and stored. The World Resource Institute (WRI) identifies six approaches[47] for removing carbon from the atmosphere.

- **Forests:** Plants absorb carbon from the atmosphere via photosynthesis. The distinctive seasonal pattern of growth in atmospheric CO_2 concentration reflects the seasonal swings in vegetation in the Northern Hemisphere. WRI estimates that the carbon-removal potential of forests and trees in the U.S. alone equals all annual emissions from the U.S. agricultural sector. Moreover, approaches to remove CO_2 through forests appear to be relatively inexpensive compared to alternative approaches

- **Farms:** Soil stores carbon and increasing soil carbon improves crop yields. However, intensive agricultural practices currently limit the ability of carbon storage in farmland. Nonetheless, the vast amount of agricultural land indicates that even small increases in the amount of carbon stored in the soil can have a large impact. Increasing the use of cover crops and

43. https://www.globalfleet.com/en/manufacturers/north-america/features/highest-ever-electric-car-market-share-us?a=BUY03&t%5B0%5D=Tesla&t%5B1%5D=EV100&curl=1.

44. International shipping was omitted from the Paris Accords and is regulated by the International Maritime Organization (IMO), a United Nations agency. A recent article in the New York Times details the challenges faced by the IMO in crafting plans and regulations for reducing the GHG emissions generated by shipping: https://www.nytimes.com/2021/06/03/world/europe/climate-change-un-international-maritime-organization.html?searchResultPosition=1

45. https://www.iea.org/reports/the-future-of-rail

46. https://www.wsj.com/articles/battle-brews-over-banning-natural-gas-to-homes-11622334674?mod=trending_now_news_pos1

47. https://www.wri.org/insights/6-ways-remove-carbon-pollution-sky

compost, integrating trees and developing plants with deeper roots all can contribute to an increase in soil carbon.

- **Bio-energy with carbon capture and storage (BECCS):** Replacing fossil fuels with biomass — organic matter used as fuel — while capturing and storing the carbon released in the process has been proposed. This approach has potential, especially if it generates increased production of CO_2-consuming biomass. The approach is controversial though and measuring its net effect on CO_2 emissions has proven difficult.

- **Direct air capture:** Direct air capture is a new technology. Multiple techniques for chemically scrubbing CO_2 directly from the air and storing it underground or otherwise sequestering it are in various stages of development and testing. These approaches are similar to the methods already used to by power plants to capture emissions. The difference is direct air capture pulls carbon directly from the air rather than from a factory smokestack.

  A technological solution to global warming is a tempting prospect, but direct air capture has some challenges. The technique currently is expensive and energy-intensive. In addition, some observers have raised concerns about the uncertain environmental impact of removing carbon from the atmosphere. As the scientific community has emphasized, the global climate is a complex web of interacting systems and the results of removing carbon now, after glaciers have melted and ocean currents and salinity have changed, are not completely predictable. Removing CO_2, while important, may not simply retrace the time path of climate change.

- **Carbon mineralization:** Some minerals naturally react with CO_2, turning it from a gas to a solid. The process, though, is slow, and scientists are exploring ways to speed it up, for instance, by crushing mineral deposits to increase their surface area. Research is at an early stage and the potential and financial viability of this approach is uncertain.

- **Ocean-based concepts:** Several proposals for increasing the ocean's potential to store carbon have been proposed. All of these proposals are at an early stage of development and there are questions about unintended ecological impacts of some of them.

STRATEGIES FOR CLIMATE ADAPTATION

Even in the most optimistic projection, some additional global warming is virtually guaranteed along with its consequences of additional flood, wind, and heat risks. Climate adaptation can limit the damage and disruption from these risks.

Increasing the Resilience of Residences

Technical modifications to homes and apartments can go a long way toward increasing resilience to climate change. These modifications are specific to the type of climate risk faced.

One method to increase resilience to flood risk is to raise the first finished level of a home a couple of feet above the base flood elevation, that is, the elevation reached by the 100-year flood. For new construction, the foundation of the house can be raised the desired amount and landscaping and other design elements can mask the increased height of the first floor. Often the house will not incorporate a basement. Instead, openings in the foundation will permit water to flow under and out of the house during flooding, preventing the accumulation of water underneath the house. When the ground level of a lot lies well below the base flood elevation, placing the house on stilts may be the only practical alternative.

The mechanical components of a house also require protection from flooding. They may need to be raised as well. In a stilt house, water and gas lines may be contained within a protective column to protect against water damage.

Existing homes also can be raised, a practice that is becoming more common in areas experiencing nuisance flooding. For homes experiencing repeated flooding, raising the home may be the only viable option. Raising an existing home is likely to be more expensive than increasing the elevation of a newly-constructed home. Moreover, the structural integrity of an existing home may be compromised during the process of raising the home.

Other types of risks call for other types of adaptation. In hurricane-prone areas, making homes resistant to wind and wind-driven water damage is a priority.[48] New building methods and materials can reduce the risk that high winds will lift off siding, shingles, and roofs. Better ways of sealing windows and siding can limit the chance that wind-driven water will penetrate and damage a structure. Organizations such as the Home Innovation Research Labs[49] regularly test building techniques and materials that improve resilience and make recommendations.

48. In the wake of a hurricane, it may be difficult to determine what share of the damage is due to flooding and what share is due to high winds. Since insurance policies may cover one of these risks but not the other, this uncertainty can pose an obstacle to collecting an insurance claim.

49. The Home Innovation Research Labs, founded in 1964, is a wholly-owned, independent subsidiary of the National Association of Home Builders.

Global warming is increasing the length and intensity of heat waves and, thus, increasing the demand for home cooling. Increased use of air conditioning may place an unsupportable demand on the electric grid leading to rolling blackouts. In places where electrical power generation relies on fossil fuels, the increased demand for electricity may exacerbate the problem by boosting GHG emissions.

To limit the demand for air conditioning, homes can incorporate *passive cooling,* a building design approach that focuses on low- and no-energy techniques for limiting the absorption of heat and dissipating accumulated heat in a building. There are many techniques for passive cooling. Some revive design techniques employed in hot climates long before industrialization and the invention of air conditioning and fiberglass insulation. Buildings with thick masonry walls, small exterior windows, central open-air atria and rooms that encourage internal air flow and cross ventilation can prevent heat build-up. In dry climates, evaporative cooling techniques can be effective.[50] Use of shade and natural heat sinks provide additional cooling. The list of techniques is extensive, and many are low-cost when incorporated during a building's design and construction.

Increasing the Resilience of Communities

They paved paradise, put up a parking lot.
—JONI MITCHELL, "BIG YELLOW TAXI"

The resilience of a home depends in part on the resilience of its community. A home can be raised above the base flood elevation, but, if the surrounding roads are routinely flooded, the home becomes an island with limited access to essential services.

Traditionally, community growth has incorporated replacement of open land and green space with *hardscape,* relatively impermeable sidewalks, roads, plazas, etc. Hardscape prevents absorption of rainwater that otherwise would take place. The rainwater may flow into storm drains, across roads, and collect in low spots. As more open land is replaced by hardscape, the ability of existing drainage systems to absorb water buildup is limited and essential systems may be compromised.

In some areas, communities are adopting growth standards that allow continued development while increasing resilience to flooding. Developers may be required to incorporate retention ponds and swales to better absorb stormwater. Requirements for strategic incorporation of parks and green space increase the desirability of a neighborhood while safely absorbing water flows. Permeable materials can be used for paving. As usual, these techniques are most cost-effective when incorporated in new development.

Is Housing Finance Resilient Enough?

The current system of housing finance is likely to face increasing stress as the consequences of global warming mount.

The impact on property insurance is perhaps easiest to trace. As the expected damage from rising sea levels and coastal flooding increase, the difference between actuarially fair premiums and NFIP premiums is likely to grow. As the NFIP reserve fund evaporates, Congress will have to decide if it wants to fund growing insurance losses with taxpayer money or to restructure the NFIP in some way. Regardless of the situation of the NFIP, some properties — and communities — will become uninhabitable and thus uninsurable. Affected homeowners are likely to seek some form of relief from local, state, and Federal governments, confronting these governments with difficult choices.

Over the course of the century, climate change is projected to increase both the frequency and the loss severity of mortgage defaults. These losses will be borne by portfolio lenders — who account for about a quarter of recent first lien originations — the Federal government via FHA/VA (roughly 15 percent), and the GSEs (between 55 and 60 percent). The growth of credit-risk transfer (CRT) programs at the GSEs can shift some of these losses to private investors.

50. For instance, rooftop evaporative coolers, so-called "swamp coolers," once were common in Southern California. A small pump sprayed water on a large tray of absorbent material while a fan drew air through the absorbent material and circulated it through the home's ducting. Growth in automobile use eventually increased the humidity in heavily populated areas, making evaporative cooling ineffective.

These growing losses will influence the behavior of each of these stakeholders differently.

- **Portfolio lenders** may increase interest rates or upfront fees on loans for houses in high-risk locations. At some point, they may refuse to provide mortgages in especially high-risk areas. Some researchers have suggested that lenders may choose to securitize some riskier loans with the GSEs.

- **GSEs** are limited in their ability to vary acquisition prices and guarantee fees by geography and, as a result, subsidize riskier loans at the expense of less-risky loans. GSEs typically cannot refuse to buy loans that meet the requirements of their seller/servicer guides. As a result, increasing default costs would provide an incentive to lower acquisition prices and/or increase guarantee fees generally. In conservatorship, however, GSE pricing is set by FHFA, hence GSEs may not be able to adjust their acquisition prices or guarantee fees.

- **The Federal government,** through the FHA/VA programs, faces some of the same challenges as the GSEs, although they do not face the same constraints.

- **Investors** in CRT securities and reinsurance programs will reprice those investments as their assessment of default risk and loss severity changes. If spreads on CRT securities widen significantly, the CRT market may cease to provide a practical way for the GSEs to transfer risk.[51]

In the U.S., the government plays a large role in housing and housing finance. As a result, taxpayers sometimes end up on the hook when stakeholders in the housing system face extreme challenges. The deposit insurance system helps sustain bank lenders and regulators can and do step in to resolve failing institutions. The central role of the GSEs in providing liquidity, stability and access to mortgage finance — and the 30-year fixed rate mortgage, in particular — justified significant government support in the wake of the 2008 financial crisis. And, of course, the NFIP has cemented government participation in insuring homes in SFHAs against flood damage. It is easy to visualize scenarios where climate change triggers significant increases in taxpayer support for the existing pillars of the housing finance system.

THERE ARE WAYS, BUT IS THERE A WILL (AND FINANCING)? CHALLENGES TO MITIGATION AND ADAPTATION.

As discussed above, there are many ways to mitigate climate change and to adapt to the changes that cannot be avoided. The growth of GHG emissions clearly can be limited, and technological approaches for removing GHGs from the atmosphere may even allow for the reversal of some climate change that already has occurred. Changes in building codes and practices and approaches to economic and community growth can protect existing living and safety standards despite climate change.

However, challenges stand in the way of mitigation and adaptation. The first and most obvious challenge is the cost of many strategies for mitigation and adaptation. In many cases, affected homeowners and communities may not be able to afford the short-term costs of adaptation even when the present value of the long-term benefits outweighs those costs.

Even when adaptation strategies are affordable, they may not be implemented. In 2019, the Home Innovation Research Labs conducted two surveys — one of consumers, the other of builders — to gauge willingness to invest in more resilient houses.[52] Consumers believed that newer homes are generally resilient and expressed reluctance to pay more than a nominal amount of money for materials and building techniques that increase resilience beyond the requirements of current building codes. Understandably, home builders believed increasing the resilience of a house above the standards of the building codes did not provide a competitive advantage. Some builders stated that they would not adopt new materials and techniques to improve resilience unless required by changes in the building codes or mandated by other laws or regulations.

Costly mitigation techniques pose an even greater challenge. Indeed, mitigation often is a type of prisoner's dilemma. The benefits of mitigation accrue only if the entire world participates, but individual stakeholders may be better off — at least in the short run — by retaining their current practices. This consideration likely played a part in accounting for the decades it took the world to craft the Paris Accord.

51. A recent paper by Rossi (2020) suggests using catastrophe bonds as a way to extract hurricane risk from CRT transactions. A link to the paper is available at this site: https://www.rhsmith.umd.edu/centers/financial-policy/risk-management.

52. The consumer survey can be found at https://www.nahb.org/-/media/NAHB/advocacy/docs/top-priorities/codes/codes-and-research/resiliency-report-consumer-2019.pdf. The survey of home builders can be found at https://www.nahb.org/-/media/NAHB/advocacy/docs/top-priorities/codes/codes-and-research/resiliency-report-builder-2019.pdf.

Climate mitigation benefits everyone, but the costs are not shared by everyone. Many of the proposals for mitigation fall heavily on specific industries that supply or depend on fossil fuels. Firms in those industry are understandably reluctant to take steps that may reduce their profitability or, perhaps, drive them out of business completely.

Recently, there are signs of an increasing readiness to implement more mitigation and adaptation strategies. Institutional investors have increased pressure on firms to go beyond sometimes vague and qualitative ESG disclosures and instead to take actions to reduce their contributions to climate change. In May 2021, shareholders replaced several directors at Exxon with candidates recommended by an activist hedge fund, a step vigorously contested by Exxon management. In the same month, a court in the Netherlands ruled that Shell must reduce its CO_2 emissions by 45 percent compared to 2019 levels, the first time a company has been legally obliged to align its policies with the Paris Accord.

A recent bill introduced in the California state senate suggests there may be ways to align competing interests in order to resolve thorny climate issues. Some California coastal communities face eventual inundation as the sea level rises. Where it is impractical to save homes, other areas of the community could be protected by removing the homes and implementing a coastal property plan that includes engineered sand dunes or other adaptation techniques. However, the owners of the affected homes stand to suffer a severe financial loss. Senate Bill 83, introduced by Senator Ben Allen in December 2020, proposes a Sea Level Rise Revolving Loan Program that makes it easier for communities to implement these types of coastal property plans while insulating those who are losing homes from some of the financial losses. Under SB 83, communities with approved plans would be eligible for low-interest loans from the state that would be used for purchasing impacted homes from willing sellers. The loans would be repaid by renting the homes back to the residents until they become uninhabitable.

4. Firms in Housing and Housing Finance Are Working to Quantify and Manage Their Climate Risk

When you can measure what you are speaking about, and when you can express it in numbers, you know something about it; but when you cannot measure it, when you cannot express it in numbers, your knowledge is of a meagre and unsatisfactory kind. —LORD KELVIN

KEY POINTS:

- Firms in housing and housing finance face calls to increase and improve disclosure of climate risks.
- ESG tends to be qualitative, but investors, accounting organizations, NGOs and legislators are calling for more specificity.
- The Climate Disclosure Standards Board has identified principles for accounting for climate in financial statements. In these statements, qualitative disclosures turn into quantitative estimates.
- For firms in housing and housing finance, there is a need to quantify the expected costs of future weather events, the expected costs of climate mitigation activities the firm will undertake, and the expected costs of future regulations and laws.
- A thought experiment traces the steps required to quantify the climate-related component of mortgage default risk and highlights some of the challenges faced by portfolio lenders, GSEs and investors.
- Risk managers and modelers need to incorporate indicators of climate risk in existing models, but it is not yet clear which of the available risk indicators will prove most useful.

Climate change brings with it a host of new responsibilities for firms in housing and housing finance. Firms must decide what climate mitigation and adaptation actions they will take and how they will measure progress toward their objectives. Firms must learn to measure and manage their climate risks. Public firms also must disclose their actions, progress, risks and risk management. All of this in the glare of media, regulatory and investor scrutiny.

The Task Force on Climate-Related Financial Disclosures (TCFD) identified four pillars for disclosure — Governance, Strategy, Risk Management, and Metrics and Targets — and recommended the types of disclosures within each pillar. All the recommended disclosures for the first three pillars are qualitative: who is accountable for overseeing and managing climate-related risks; what strategies for dealing with climate risk has the firm adopted; what is the process for measuring and managing climate risk. Quantitative disclosures fall under the fourth pillar: how large are the firm's GHG emissions; which metrics does the firm use to measure its impact on the climate and the climate risks it runs; and what are the firm's targets for reducing its impact and risks.

In practice, qualitative and narrative disclosures are more common than hard-edged quantitative assessments. In part, this imbalance reflects the measured approach required for forward-looking assessments of a firm's risks and opportunities. But this imbalance also is an acknowledgment of the difficulty in sizing the impacts of global climate risk on a specific firm.

Momentum for more, and more-specific, disclosures is growing in the U.S. On April 20, 2021, co-sponsors Senator Elizabeth Warren and Representative Sean Casten introduced the Climate Risk Disclosure Act of 2021. This Act directs the SEC to issue rules within two years that require public companies to disclose

- Their GHG emissions;
- The total amount of fossil-fuel related assets they own or manage;
- How their valuation would be affected if climate change continues at its current pace or if policymakers successfully restrict greenhouse gas emissions to meet the 1.5 degrees Celsius goal; and
- Their risk management strategies related to climate-related physical and transition risks.

Regulators already have asked for input from the housing industry and the public to assist them in refining their oversight of the climate-related risks faced by firms. On March 15, 2021, the SEC issued a request for public responses to 15 questions on climate-related disclosures.[53] Several of the questions relate to the desirability of relying on existing disclosure standards — such as the ones issued by international organizations such as the TCFD and the Climate Disclosure Standards Board (CDSB) — industry consortiums or self-regulatory organizations, or, alternatively, on new standards designed specifically for U.S. public companies. And in January 2021, FHFA — the regulator of the GSEs and Federal Home Loan Banks and the conservator of the GSEs — issued a Request For Information (RFI) on Climate and Natural Disaster Risk Management at the Regulated Entities.[54]

Investors appear to be farther along in articulating the climate-related disclosures and actions they expect from firms. In several surveys in recent years, investors confirm they view climate risk as a material risk that requires disclosure.[55] And investor demands for climate-related disclosures and actions appear to prompt greater disclosure by companies. A study summarized in the *Harvard Business Review*[56] finds that companies increase disclosure by 4.6 percent on average for each environment-related shareholder proposal submitted. If the proposal is submitted by an institutional investor, the effect increases to 6.8 percent.

To date, most climate-related disclosures take the form of narrative reporting — the "front-half" of annual reports and separate ESG reports. Fewer examples of material climate-related information appear in financial reporting — the "back-half" of annual reports. However, the trends highlighted above suggest that all firms, including those in the housing and housing finance industries, are likely to increase this more-quantitative reporting in future.

53. https://www.sec.gov/news/public-statement/lee-climate-change-disclosures.

54. https://www.fhfa.gov/Media/PublicAffairs/Documents/Climate-and-Natural-Disaster-RFI.pdf

55. One recent example from PGIM, the global asset management arm of Prudential Financial, Inc., finds 90 percent of large (> $3 billion in assets under management) institutional investors view climate change as an important issue for their organization. However, only 47 percent of North American investors actively incorporate climate change into their investment processes, compared to over 80 percent of European investors. https://www.businesswire.com/news/home/20210416005002/en/Climate-change-investment-approach-has-North-American-investors-trailing-the-world-PGIM-survey.

56. https://hbr.org/2021/04/shareholders-are-pressing-for-climate-risk-disclosures-thats-good-for-everyone.

Perhaps the sharpest prod to quantifying climate risk arises from accounting standards. A 2020 publication by the Climate Disclosure Standards Board explores the issues facing accountants and auditors incorporating the impact of climate risk in financial statements. This publication discusses the principles guiding financial estimates of climate impact and presents examples that illustrate the application of international accounting standards.[57] In addition, the publication compares legal and regulatory disclosure requirements in Canada, the EU, France, New Zealand, the UK and the US.

QUANTIFYING CLIMATE RISKS TO HOUSING AND HOUSING FINANCE FIRMS

Quantifying climate risks in the housing and housing finance industries is easier for some types of firms than others. The insurance industry has a long history of quantifying the financial risk of natural disasters. The catastrophe models the industry relies on can draw on both the records of past disasters and the projections of organizations like the IPCC to price the risk of future disasters. In contrast, homebuilders may be challenged to forecast the future path of building codes, legislative mandates, and climate-related litigation. They may, however, have good estimates of the costs of new materials and building techniques they may be mandated to adopt.

Lenders who securitize their loans with the GSEs may face additional rep and warrant costs and risk as the GSEs revise their requirements in response to climate change. Today, lenders must guarantee that loans for homes in SFHAs carry NFIP-approved flood insurance. In future, the GSEs might require lenders to perform additional due diligence to determine the need for flood insurance. The lag in updating the FEMA flood maps may force lenders to incorporate additional sources of information on flood risk. GSEs may not be allowed to purchase loans on homes with finished first levels too close to the base flood elevation, requiring lenders to obtain additional detailed information from appraisers.

A THOUGHT EXPERIMENT: QUANTIFYING CLIMATE-INDUCED DEFAULT RISK

Estimated default costs are a key ingredient in assessing profitability, loan loss reserves and economic capital for portfolio lenders, GSEs, private mortgage insurers, CRT investors, and mortgage servicers. If incremental defaults due to climate change turn out to be material for one or more of these stakeholders, regulators and investors are likely to require those stakeholders to quantify the impact of those incremental defaults and to gauge the sensitivity of those estimates to key assumptions.

57. The CDSB document relies on the IAS standards used internationally which are not identical to the GAAP standards used in the U.S.

Firms currently rely on highly-developed processes and sophisticated models for estimating default costs. Tracing, at a high level, some of the steps in estimating climate-related incremental default costs can highlight areas where existing processes and models may need to be revised and augmented. And reflecting on the areas where change may be needed also may cast light on the level of difficulty of those changes.

Typically, expected loss is calculated in three steps.[58] The first step estimates the probability a loan defaults. The second step estimates the loss severity as a fraction of the firm's exposure.[59] The third step estimates the firm's exposure at the point of default.

How Climate Risk Affects the Probability of Default

The probability of default depends on the borrower's ability and willingness to pay. Weather events clearly can affect the ability to pay. Natural disasters can disrupt the ability of homeowners to make mortgage payments.[60] Homeowners may be injured and unable to work. Their place of employment may be damaged or destroyed even if their house is spared, halting business for a period. Damage to roads and bridges may make it impossible to get to work. Credit-constrained borrowers without adequate insurance may be unable to make their payments.

These examples highlight the *potential* impact of weather events. But mortgage default models have to assess the probability of default prior to any weather events that may or may not occur. To capture the impact of climate risk on the probability of default, models could include risk scores, indicators of the location-specific probabilities of future natural disasters. Information about the borrower's financial condition and debt burden can be combined with these climate risk scores to help predict the borrower's ability to continue making payments in the event of a

58. This paragraph describes estimating default cost from the perspective of a mortgage modeler. The reflection of expected loss in financial statements is governed by accounting standards, which are not discussed here. CDSB (2020) provides some guidance from the perspective of the IAS standards. U.S. firms are subject to GAAP, which differs in places from IAS. The modeling process discussed here is in common use although important aspects can vary depending on the type of firm. The rules and practices for GSEs are not identical to those for large banks which are not identical to those for community banks and so on. However, the described process is consistent at a high level with the CECL standard.

59. Equivalently, the second step can estimate the recovery rate as a fraction of the firm's exposure, since loss severity is equal to one minus the recovery rate.

60. In a study of the aftermath of Hurricane Harvey, Kousky, Palim and Pan (2020) find prepayments increased on homes inside SFHAs, where flood insurance is required, while delinquencies and defaults increased outside SFHAs. In a theoretical model of mortgage default as a result of declining house prices, Campbell and Cocco (2015) find that the probability of default increases for credit-constrained borrowers.

climate-related interruption of their employment. This type of financial information may already be incorporated in a firm's default model.

Many climate risk indicators are available but, until recently, they have not been leveraged widely for predicting the probability of mortgage default. Moreover, no best practice method for incorporating these indicators in default models has surfaced yet. Contrast this situation with industry approaches to modeling creditworthiness. The use of credit scores such as the FICO™ and Vantage™ scores is virtually universal, and mortgage models routinely include additional indicators of creditworthiness.[61]

There are a number of challenges to incorporating climate risk scores in mortgage models. One challenge is the dizzying array of different risk scores available (see Appendix B for some examples). Some are freely available; some are offered for a fee. Some cover individual risks (e.g., pluvial flood risk), others combine multiple risks into an aggregate score. Some provide information only at the regional level (e.g., county, census tract, FEMA flood zone), others are available at the property address level. Some provide probabilities of specific weather events (e.g., 100-year flood), others provide broad, rank-order categories (high, medium, low risk). Some estimate the probability of a specific risk today, others provide longer-term estimates of the type needed for mortgage modeling (5-year risk, 30-year risk, etc.). Some focus solely on the likelihood of a specific risk, while others translate the risk into an estimate of annual loss. And, of course, competing indicators don't always agree.

A second challenge is the difficulty of linking a risk score to a time series of weather outcomes. The most common mortgage type in the U.S. is the 30-year fixed rate mortgage, and, while few mortgages reach the end of their 30-year term, modelers need to estimate risk over an extended period. Regulators and model validation teams generally insist that models are estimated on substantial historical data sets, large enough to permit hold-back samples, including out-of-time samples. It may not be possible to meet those requirements when incorporating climate risk in mortgage models.

A third challenge is the fact that the climate ***is*** changing. Of necessity, models rely on historical data to estimate the relationship between current indicators of climate risk (e.g., the difference between the first finished level of a house and the base flood elevation) and the probability of mortgage default. But future climate conditions almost certainly will differ in important ways from historical observations.

The average annual loss from, say, flood risk is likely to be higher in future than what was observed in the past. As an example, where houses situated on particularly-low-lying lots flooded occasionally in the past, large sections of the surrounding community may also flood in future, making disruptions to employment likelier. In order to overcome this challenge, modelers will have to augment historical estimates with assumptions about future climate trends. Unfortunately, as the four IPCC projections demonstrate, the range of plausible climate scenarios is great.

Given the uncertainty about future climate conditions, it will be important to apply extensive sensitivity analysis to models that incorporate the effects of climate change. Firm management will want to know how the probability of mortgage default changes if natural disasters are more or less frequent, or more or less destructive, than projected.[62]

The unavoidable uncertainty of the impacts of climate risk on the probability of default will make it challenging for firm management to rely on models that incorporate climate change, especially if the predicted impact of climate change is large. However, this challenge is not new. Prepayment models have required significant changes after each of the refinance waves of the past few decades, and mortgage delinquency and default modeling was turned on its head by the 2008 financial crisis. Modelers and risk managers will find ways to measure and manage these risks as they evolve. And, to the extent these risks are material, they will have no other choice.

61. For example, SATO, the spread between the interest rate on a borrower's loan and the prevailing mortgage rate at the time the mortgage was originated often is included as a proxy for unobserved elements of a borrower's creditworthiness.

62. In some surveys of the investor community, investors expressed a preference for companies to assume that the goals of the Paris Accord will be achieved. This scenario, roughly consistent with ICPP RCP2.6, is conservative for firms likely to bear the brunt of transition costs. For firms in housing and housing finance, where the impacts of climate-related disruption may be more important than the costs of transition to a lower-carbon environment, projections that incorporate more extreme climate change, such as RCP 8.5, may be more conservative.

How Climate Risk Affects Loss Severity

The impact of climate change on loss severity depends directly on the projected trend of climate change. If the trend follows a more-optimistic scenario, sea level rise and storm surges will be smaller and wind damage will be more limited. If the trend follows a more-pessimistic scenario, the reverse will occur.

Of particular concern is the possibility that more extreme climate change may threaten the viability of entire communities. Repairing or replacing damaged homes in a still-functioning community is an insurable risk. Rebuilding a community is a political decision. Private investors may be reluctant to purchase the municipal bonds needed to rebuild infrastructure. Even if a community can recover, a large-magnitude natural disaster may depress local house prices indefinitely, increasing both the probability of mortgage defaults and loss severity.

THREE OBSTACLES TO QUANTIFYING CLIMATE RISK

The thought experiment described above focuses on one specific financial risk — the risk of climate-induced mortgage defaults — to highlight the enormity of the challenges facing modelers and risk managers as they attempt to quantify the variety of climate risks facing firms in housing and housing finance. From the discussion above, three obstacles stand out: (1) the choice of climate scenario; (2) the lack of a recognized measure of climate risk; and (3) the lack of a sufficient historical record of the available climate risk metrics.

1. Choice of a Climate Scenario

Estimates of risk depend on a view of the likelihood of future circumstances. For example, an estimate of mortgage prepayment risk — essential to valuing mortgage-backed securities and mortgage servicing rights — requires a view of future mortgage rates. At first, modelers relied on one or more deterministic scenarios to gauge prepayment risk. Later, so-called short rate models provided an estimate of the future probability distribution of rates. Single-factor short rate models gave way, initially, to more-sophisticated two-factor models and, eventually, to market models based on observable rates.

Nothing like the modern interest rate model exists for climate change. The range of possible climate futures is enormous. More importantly, the future depends crucially on the types and timing of a host of actions taken by governments, firms, and individuals. Predicting the actions of these stakeholders is a task several orders of magnitude more difficult than predicting homeowners' decisions to prepay their mortgages.

The IPCC acknowledged the difficulty of projecting the path of climate change under these circumstances by providing four representative scenarios in its Fifth Assessment Report. And associated with each of these scenarios is a range of climate projections that varies depending on which assortment of models in the CMIP toolkit is employed.

In this situation, firms will be hard-pressed to defend any climate change scenario they choose to gauge their exposure to climate risk. And if different housing and housing finance firms base their risk estimates on different climate scenarios, regulators and investors will find it difficult compare estimates across firms.

The CCAR and DFAST stress tests conducted by banks and other financial firms avoid this type of problem by relying on selected stress scenarios specified by the regulators. The Bank of England has adopted a similar strategy in its initial Climate Biennial Exploratory Scenario, the first stress test of Britain's largest banks' and insurers' resilience in the face of climate change. The BOE has divided risks into transition risks and physical risks as recommended by the TCFD and specified the climate scenarios to be used by the respondents.

2. Lack of a Standardized Climate Risk Indicator

A stumbling block to quantifying a firm's climate risk is the lack of a generally-accepted indicator of the likelihood of extreme weather events. Consider, as a contrast, the risk measures used in current mortgage models. To assess interest rate risk, modelers rely on observed interest rates and auxiliary models that project the likely future paths of rates. To assess default risk, modelers use borrower credit scores and measures of indebtedness. To assess potential exposure at default, modelers measure loan-to-value ratios and auxiliary models that project future house prices. These measures of financial risks are quantitative, widely available, and generally accepted, and they allow modelers to estimate the relationships between these observable and projected variables and future losses.

There is no shortage of climate risk measures. For the most part, these metrics measure the risk of a specific event such as a flood or a wildfire, although some all-climate-risk aggregates exist. (See Appendix B for a review of some representative flood risk metrics.) Most of these metrics attempt to gauge the probability of the weather event, but some also provide expected financial losses. Some indicators provide information on a broad geographic area while others are defined at the street-address level.

Modelers face a similar challenge incorporating climate risk indicators in their models. Many of these indicators are available only for the relatively recent period. Furthermore, the value of the available historical measurements is tempered by the rapid evolution both of climate science and of the fundamental climate relationships themselves. As an example, a recent study by World Weather Attribution (WWA) suggests that the June/July extreme heat wave in the Western U.S. and Canada may indicate that nonlinear interactions in the climate may have increased substantially.[63] According to Dr. Geert Jan van Oldenborgh, one of the co-founders of WWA, "We are much less certain about how heat waves behave than we were two weeks ago."[64]

While many climate risk metrics are available, at present there are no generally-accepted metrics for modeling purposes. Best practice has yet to be defined. This situation should not be surprising. Climate modeling is a young science, and the scientific consensus is revised regularly. The IPCC's Fifth Assessment Report (AR5) relied on the fifth version of the Coupled-Model Intercomparison Project, but CMIP6 already has supplanted CMIP5. And AR5 is scheduled to be replaced by AR6 in the near future.

3. Lack of Historical Values of Climate Risk Indicators

The financial crisis of 2007/08 initiated an eventual drop in U.S. house prices of roughly 25 percent, a drop not seen since the Great Depression of the 1930s. At the beginning of the crisis, modelers struggled to incorporate price declines of this magnitude in existing models. The data available for model estimation did not include any similar experiences. In the absence of a usable historical record, modelers were forced to employ a remarkable amount of judgment to estimate mortgage defaults and eventual losses. Judgments varied widely across modelers, and many guesses turned out to be wildly inaccurate. It took the slow accumulation of observations to produce something resembling a consensus about the impact of significant house price declines, something that remains a bit of a work-in-progress.

63. "Western North American extreme heat virtually impossible without human-caused climate change," July 7, 2021, World Weather Attribution, https://www.worldweatherattribution.org/western-north-american-extreme-heat-virtually-impossible-without-human-caused-climate-change/.

64. "Climate Change Drove Western Heat Wave's Extreme Records", *New York Times,* July 7, 2021, https://www.nytimes.com/2021/07/07/climate/climate-change-heat-wave.html?action=click&module=In%20Other%20News&pgtype=Homepage.

Conclusion

Climate change triggered by global warming already has happened and will continue to happen at a difficult-to-predict pace in the future. Its global impacts are significant, and the housing and housing finance industries will feel these impacts along with all other industries. In particular, climate change will add stress to the complex system of allocating risks across stakeholders in housing and housing finance.

Climate change can be mitigated by reducing greenhouse gas emissions. Methods for reducing GHG emissions are available, but some are costly and require international cooperation. The international community has forged agreements to mitigate climate change, most recently in the Paris Accord. However, significant political disagreements both within and across countries raise doubts about the eventual success of these agreements. Even if the objectives of the Paris Accord are achieved, global warming will increase this century, and methods for adapting to the unavoidable components of climate change may need to be adopted.

Firms generally face increasing demands from regulators and investors to quantify and report on their exposure to climate risk. Firms in housing and housing finance face steep challenges in meeting these demands. At present, the ability to quantify climate risks is likely to fall short of the existing standards in disclosing interest rate and credit risk.

Appendix A: The Evidence for Global Warming

THE GREENHOUSE EFFECT

In the 1820s, the mathematician and physicist Joseph Fourier noted that, given Earth's size and distance from the sun, the planet should be colder than it is if solar radiation is the only source of heat. He concluded that the Earth's atmosphere acts as an insulation layer, trapping some of the heat that otherwise would escape into space. The increase in Earth's temperature due to the insulating property of the Earth's atmosphere is called the *greenhouse effect,* although that term for Fourier's discovery wasn't coined until about 80 years later.[65]

Not all of the gases in Earth's atmosphere are *greenhouse gases,* that is, not all of them play a significant role in retaining solar energy. Water vapor, carbon dioxide (CO_2), methane and ozone are four of the major greenhouse gases.

We should be thankful for the greenhouse effect: it accounts for the generally moderate climate Earth has enjoyed. The average global temperature in 2020 was 57 degrees Fahrenheit (13.9 degrees Celsius). Scientists estimate that without the warming impact of the greenhouse effect, the average global temperature would be around 0 degrees Fahrenheit (-18 degrees Celsius).

INCREASES IN CO_2

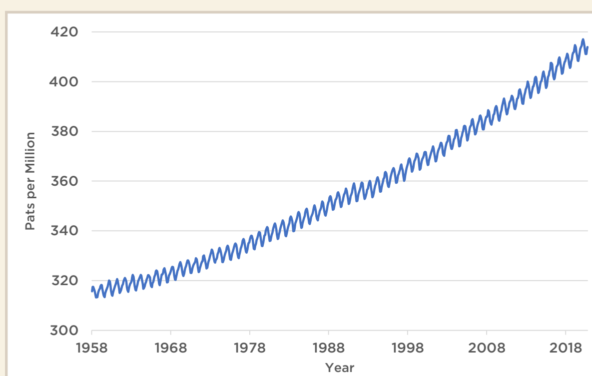
At the end of the 19th century, the Swedish scientist Svante Arrhenius was working on a theory to explain Earth's ice ages. Arrhenius was particularly interested in the possibility Earth might enter a new ice age. Arrhenius was familiar with Fourier's theory of the greenhouse effect, and he took comfort from the increases in CO_2 generated by increases in coal burning associated with increasing industrialization. He predicted that these increases in atmospheric CO_2 would eliminate the possibility of another ice age. And he welcomed the increase in global temperature, believing that warmer temperatures would unleash the agricultural potential of colder regions.

Arrhenius's theories were hotly debated, but no reliable, consistent record of the atmospheric concentration of CO_2 was available at the time to settle the debate. It was not until the second half of the 20th century that such a record was constructed.

As a post-doctoral fellow in geochemistry at the California Institute of Technology, Charles Keeling developed an instrument able to reliably measure CO_2 in atmospheric samples. While on a camping trip at Big Sur, Keeling tested his device and obtained readings that suggested an increase in the concentration of CO_2 since the 19th century. Keeling joined the Scripps Institution of Oceanography in 1956, and in 1958 he obtained funding to establish a research base on the slopes of the Mauna Loa volcano in Hawaii, two miles above sea level. The staff at the Mauna Loa base began taking regular measurements of atmospheric CO_2 concentrations.

Regular atmospheric CO_2 readings from Mauna Loa continue to this day and have documented an increasing trend in the concentration of CO_2 in the Earth's atmosphere. The graph of these readings, displayed below, has been named the *Keeling curve* and is considered by some to be one of the most important scientific works of the 20th century.

FIGURE A1: ATMOSPHERIC CO_2 CONCENTRATIONS



Source: Scripps CO_2 Program, scrippsco2.ucsd.edu

The concentration of CO_2 exhibits a definite upward trend, increasing roughly 30 percent from 1958 to 2020. The concentration also varies seasonally, reaching a peak in May and a trough in September. This seasonal pattern is associated

65. The term *greenhouse effect* is slightly misleading. The physical process by which the solar radiation bathing Earth is retained is more complicated than described above and is essentially different than the mechanism by which an ordinary greenhouse traps heat. The result, however, is similar — a higher temperature than would otherwise prevail.

with seasonal variations in the quantity of vegetation in the Northern hemisphere, the hemisphere where most of the Earth's land is located. New plant growth in the Northern spring and summer absorbs CO_2 during photosynthesis. Dead and decaying plants and leaves in the Northern autumn and winter release CO_2 back into the atmosphere.

While the pattern in Figure A1 is striking, it is reasonable to ask if it is representative of global conditions. In other words, is there something unique to the Mauna Loa location that accounts for these results? As it happens, the Mauna Loa data match closely readings taken at many other locations.

Another concern is the limited time span of the Mauna Loa data. Is this rate of increase in CO_2 concentration in Figure A1 a new phenomenon or is it merely a tiny snapshot of a much longer process of normal swings in CO_2 concentration? To answer that question, scientists looked to ice core samples from Antarctica and Greenland where layers of snow and ice have accumulated without disturbance for thousands of years. Small air bubbles trapped in these cores provide evidence of atmospheric CO_2 concentration in the past. Samples from the deeper parts of the ice core contain air bubbles from farther back in the past. And measurements of samples from the top layers of the core — samples that overlap in time with the Mauna Loa data — closely match the measurements taken directly from the atmosphere.

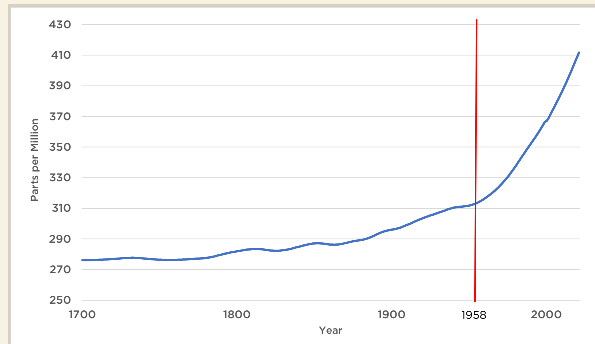
Figure A2 displays ice core data spliced together with the atmospheric readings from Mauna Loa data.

FIGURE A2: ATMOSPHERIC CO_2 CONCENTRATIONS: 13 CE TO 2020 CE

Source: Scripps CO_2 Program, scrippsco2.ucsd.edu

The recent increase in CO_2 concentration is unprecedented. Note, however, that the increase in CO_2 concentration commenced well before Charles Keeling began recording measurements at Mauna Loa in 1958. Figure A3 zooms in on the period from 1700 CE on.

FIGURE A3: ATMOSPHERIC CO_2 CONCENTRATIONS: 1700 CE TO 2020 CE



Source: Scripps CO_2 Program, scrippsco2.ucsd.edu

The CO_2 concentration began increasing slowly sometime in the late 1700s or early 1800s. The increase accelerated a bit starting sometime in the late 1800s and accelerated again sharply just after Keeling began taking measurements.

The source of these dramatic increases is human activity.[66] The timing and pace of the increases correlates closely with the growth in the use of fossil fuels triggered by the Industrial Revolution. The first commercially successful steam engine was invented in 1712. Steam engines were used initially to pump water from mines, but improvements by James Watt and others paved the way for steam engines to replace other forms of power for a wide variety of activities. Growth in the use of steam engines in factories, in locomotives and boats generated increases in the demand for coal to power these engines. The development of the internal combustion engine in the 1800s opened the door to the growth of the automobile and the airplane in the 20th century and thereby increased the use of petroleum products. Burning coal and oil has released additional CO_2 into the atmosphere.

The increase in CO_2 concentration triggered by the Industrial Revolution was exacerbated by the simultaneous acceleration in population growth (Table A1), which, in part, was made possible by the technical progress of the Industrial Revolution. The increase in population increased the demand to burn fossil fuels to power factories, generate electricity, provide transportation, and so on.

66. Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC), Summary for Policy Makers, Sections 1.2 and 1.3.

Table A1: World Population (millions)

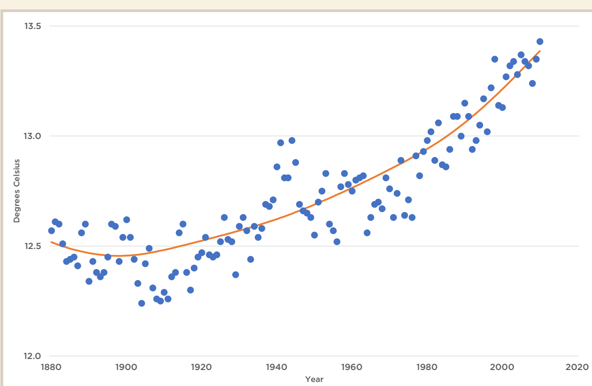
Year	Population	% Increase
1500	452	—
1600	539	19
1700	600	11
1800	931	55
1900	1,634	76
2000	6,105	274
2100	10,875	78

Source: Average of various estimates published by Our World In Data (ourworldindata.org).

GLOBAL WARMING

Figure A4 displays the last 140 years of annual average global temperature. These estimates are published by the National Centers for Environment Information (NCEI), an agency that is part of the National Oceanic and Atmospheric Administration (NOAA).[67] The scatterplot highlights the substantial year-over-year variation in global temperature. The solid line[68] running through the scatterplot clarifies the upward trend that produced the roughly 1 degree Celsius increase in average global temperature during the 20th century.

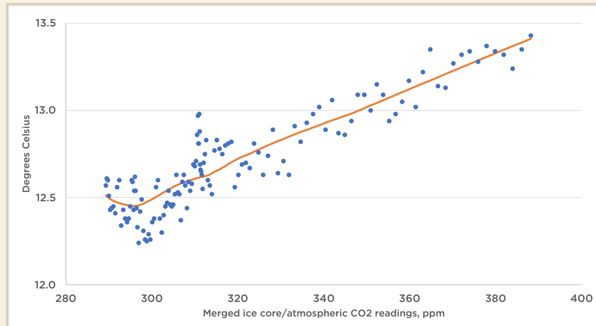
FIGURE A4: AVERAGE GLOBAL TEMPERATURE: 1880 TO 2020



Source: National Centers for Environmental Information, NOAA

The increase in greenhouse gases (primarily CO_2) is the proximate cause of this temperature increase. Figure A5 makes clear the close association between the concentration of CO_2 in the atmosphere and the average annual global temperature.

FIGURE A5: AVERAGE GLOBAL TEMPERATURE AND CO_2 CONCENTRATION: 1880 TO 2020



Source: National Centers for Environmental Information, NOAA

NEW (AUGUST 2021) FINDINGS FROM THE IPCC

The characterization of climate change and its impacts in this essay is based on AR5, the IPCC's fifth, and most recent, summary of the international scientific consensus. AR5 was completed in 2014. Since that time, research has continued apace and a new generation of climate models, CMIP6, has been developed.

On August 9, 2021, the IPCC released *Climate Change 2021: The Physical Science Basis,* the first in a series of reports that will culminate in the AR6 synthesis report in September 2022. Three working groups are preparing the components of AR6. This latest component is the product of Working Group 1 (WG1) and, as the title indicates, WG1 is tasked with summarizing the physical science basis for climate change. WG2 will report in February 2022 on impacts, adaptation and vulnerability. WG3 will report in March 2022 on mitigation of climate change. Following the release of those reports, the synthesis report will be compiled.

SO WHAT IS NEW IN THE REPORT OF WG1?

- Global mean temperature is projected to be 0.7 to 0.9 Celsius higher in 2100 than the comparable projections in AR5. The 1.5 Celsius and 2.0 Celsius boundaries highlighted in the Paris Accord are likely to be crossed sooner than previously projected.

- The August 9 report projects modestly higher sea level rise than AR5 due in part to a larger contribution from Antarctic melting.

67. These temperature readings were downloaded on April 12, 2021 from the Climate At A Glance page on the NCEI web site (https://www.ncdc.noaa.gov/cag/global/time-series) using the following search settings: Timescale=12-month; Month=December (retrieves January-December average); Start Year=1880; End Year=2021; Region=Global; Latitude=0; Longitude=0; Surface=Land and Ocean.

68. This trend line was estimated using the lowess scatterplot smoother in the Stata® statistical package.

- Confidence bounds around these new projections are tighter than the AR5 confidence bounds. Some of the reduction in uncertainty derives from the use of the CMIP6 generation of models rather than the CMIP5 models used in the AR5.

- Recent research has greatly improved the ability to attribute specific events (West Coast wildfires, German floods, etc.) to climate change.

- The August 9 report reviews the potential for irreversible changes to the Earth's climate. The report estimates the time to reverse changes in a stringent mitigation scenario. In some cases, changes may be reversed within a few years or a decade or two. In other cases, it may take centuries to reverse the changes.

- The report also contains an extensive discussion of tipping points, defined as points at which physical changes jump discretely from a smooth process to a highly nonlinear and unpredictable process. Tipping points are associated with rapid acceleration in climate change.

There is much more valuable information in the August 9 report, but the overall message is that the pace of climate change has exceeded previous expectations and the changes over the remainder of this century are likely to be greater than projected in AR5. In addition, continuing research and the new generation of CMIP models have increased confidence in the IPCC projections.

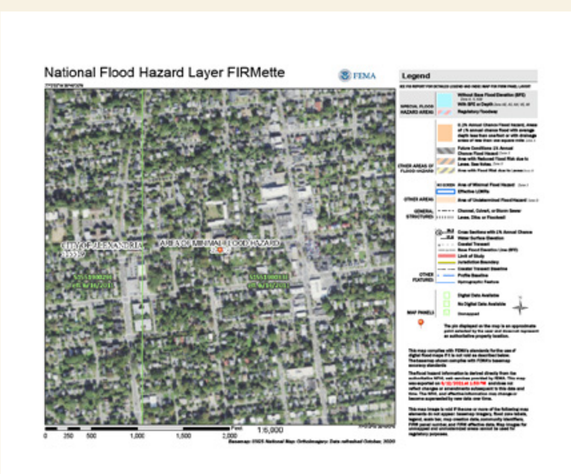
Appendix B: Flood Risk Scores

The availability of indicators of climate risk affects the ability to measure and manage the impact of climate change on housing and housing finance. Modelers, risk managers, insurance companies, regulators, investors and government planners all need this information. And, in fact, many risk scores are available.

But these indicators differ in the types of information they provide, the length of history available, and the ease of incorporating them in risk models. At present, use of these scores is still in a formative stage and best practice is undefined. While there is not space to cover all the risk scores currently available, looking at a few of them may make it easier to understand the challenges the housing and housing finance industries face in quantifying climate risk.

Flood risk is the greatest weather risk, in dollar terms, currently facing the U.S. Accordingly, indicators of flood risk have been available longer than indicators of other weather risks.

Perhaps the most familiar indicator of flood risk is the FEMA flood zone designation. FEMA produces flood maps[69] that categorize areas as low to moderate risk (zones labeled B, C and X), high risk (zones whose labels start with A and, for coastal risk, V) and undetermined risk (D). FEMA provides a variety of tools for leveraging the flood maps (https://www.fema.gov/flood-maps/products-tools).



69. See https://www.fema.gov/flood-maps for more details.

Homeowners can visit FEMA's flood map service center (https://msc.fema.gov/portal/home) to look up the FEMA designation for the area surrounding a home they may be considering purchasing. Entering my home address produces this picture of my Alexandria, VA neighborhood. This area is classified as Zone X and the picture is unshaded, an indication of minimal flood hazard (outside the 500-year floodplain).

This web site also provides the full Flood Insurance Rate Map (FIRM) for the selected area (see picture on the next page). The shaded areas adjacent to the Potomac River are classified as high risk (Zone AE).

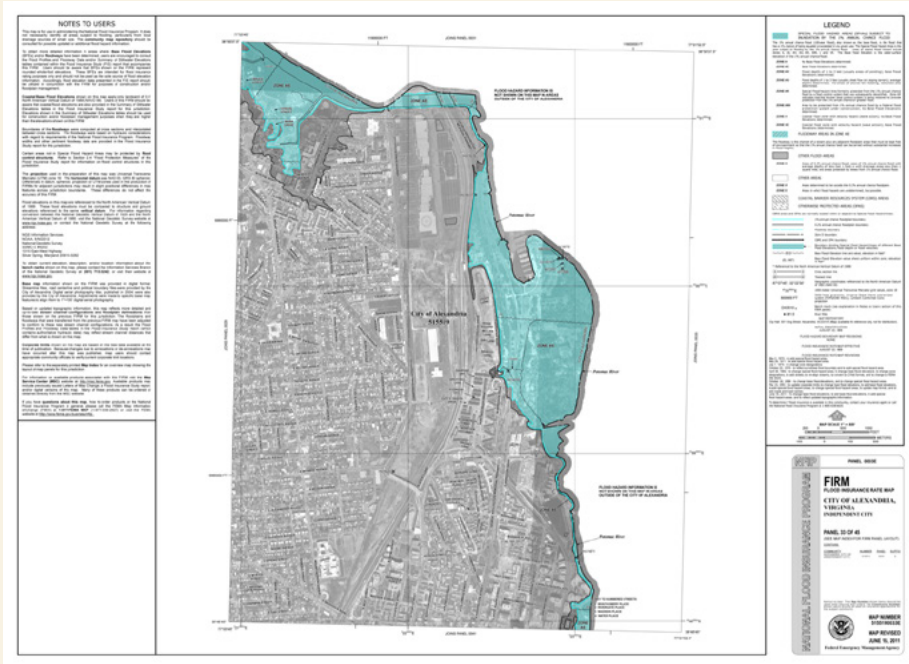
As noted in previous sections, FEMA has faced challenges keeping flood maps up to date, and many critics have questioned the accuracy of some FEMA maps. In addition, the FEMA maps do not capture what can be significant house-to-house variation in flood risk within a single zone.

Other organizations have offered what they believe to be improvements on the information provided by FEMA. One such organization is the First Street Foundation,[70] a research and technology group that has developed its own flood risk model.[71] First Street estimates that FEMA's SFHAs underestimate the number of homes facing significant flood risks by almost 70 percent.[72] Property-level assessments of flood risk are available for free at the foundation's FloodFactor web site (https://floodfactor.com/).

70. https://firststreet.org/

71. A technical description of the model is available at https://assets.firststreet.org/uploads/2020/06/FSF_Flood_Model_Technical_Documentation.pdf.

72. See https://www.washingtonpost.com/weather/2020/06/29/flood-risk-climate-change/ for a summary of First Street's results. The full First Street report is available at https://assets.firststreet.org/uploads/2020/06/first_street_foundation__first_national_flood_risk_assessment.pdf. The First Street estimates are centered on IPCC's RCP4.5 projection which is characterized as an intermediate scenario.



Using my home address again, FloodFactor returns results that are different and more detailed than those returned by FEMA. First, FloodFactor returns a score based on a 10-point scale, where a score of 1 indicates minimal flood risk and a score of 10 indicates extreme flood risk. My address is rated as a 6 (major flood risk) on the FloodFactor scale. The web site also displays a timeline of the cumulative probability of a flood of different magnitudes. For instance, FloodFactor estimates a 41 percent probability of a flood greater than 1 inch at my address within 15 years. FloodFactor expects $103 in annual flood damage to my property and $1,500 of damage over the next 15 years.

Other organizations rate multiple climate-related risks. One example is RiskFootprint™ (https://riskfootprint.com/), a service created by Coastal Risk Consulting, LLC (CRC), a climate adaptation and technology consulting company.[73] CRC's address-level reports include FEMA's flood zone classification; estimates of pluvial (rainfall) and fluvial (riverine) flood risk along with identification of poor drainage on and near the target address; the risk of tidal and storm-surge-related flooding; and ratings of risks from wind, tornados, wildfires, earthquakes, extreme heat, and drought.

As a courtesy, CRC provided me the 10-page residential report for my home address. The cover page includes a dashboard summary of current and future risks at my address and in the surrounding neighborhood and a satellite photo of the property with the legal boundaries shaded in red.

The second page is a "thank you" letter from CRC to the customer with a link to the firm's resiliency advisory service. Pages 3-7 provide a combination of visual and qualitative information about various types of flood risk (pluvial, poor drainage areas, fluvial, sea level rise, storm surge and FEMA flood zone classification); current risks from wind, tornados, wildfires and earthquakes; FEMA's community rating and NRI community resilience rating; and future risks from extreme heat, extreme rainfall and drought. The last three pages provide definitions, explanations of methodology and links to data sources.

Like First Street Foundation, RiskFootprint™ estimates that many properties in locations rated low risk by FEMA (flood zone X) are nonetheless at high risk of flooding. In contrast to First Street's aggregate estimate of the difference between their identification and FEMA's identification of flood risk, RiskFootprint™ provides individual examples of properties in FEMA X zones where other indicators suggest significant flood risk.

FEMA recently introduced a National Risk Index (NRI)[74] that combines information on 18 types of natural hazard[75] with information on social and community resilience to produce combined estimated annual loss from all 18 hazards at the

73. CRC is a for-profit company offering risk information and adaptation consulting to residential and business clients. A residential report for a single address costs $99, but a sample report can be viewed here: https://riskfootprint.com/wp-content/uploads/2020/10/CRCRiskFootprint-SAMPLE-REPORT-Campana-Avenue-Coral-Gables-Florida-33156.pdf. RiskFootprint™ does not provide property-level expected damage estimates, but it does offer advisory services on strategies for resilience and mitigation. Full disclosure: I am a member of CRC's Advisory Board.

74. An interactive map and data download tool are available at https://hazards.geoplatform.gov/portal/apps/MapSeries/index.html?appid=ddf915a24fb24dc8863eed96bc3345f8. Technical documentation is available at https://www.fema.gov/sites/default/files/documents/fema_national-risk-index_technical-documentation.pdf.

75. The 18 natural hazards included in the NRI are avalanche, coastal flooding, cold waves, drought, earthquake, hail, heat wave, hurricane, ice storm, landslide, lightning, riverine flooding, strong wind, tornado, tsunami, volcanic activity, wildfire, and winter weather.

census tract and county level. FEMA's NRI is intended for use by planners and emergency manages at local, regional, state and federal levels.

There are many other organizations offering climate-related risk estimates.[76] It can be difficult to assess the relative strengths and weaknesses of this plethora of risk scores, especially since the scores aim to predict the probability of a distant event. In many cases, these alternative scores draw on similar raw data, assumptions and component models: FEMA flood maps, climate measurements from the National Oceanic and Atmospheric Administration, topographical information from the United States Geological Survey, the four IPCC projections (RCPs), fluvial and pluvial models from Fathom, coupled-environmental models from the World Climate Research Programme's Coupled-Model Intercomparison Project (CMIP), and a host of similar sources. Each organization has developed its own methods for using these information sources to create climate risk indicators. Some of these methods are open source while others are proprietary.

How might firms in the housing and housing finance industries leverage these types of risk indicators in their modeling and risk management?

Lenders already consult the FEMA flood maps to determine whether loans destined for the GSEs or a federal financing program will require NFIP insurance. Some portfolio lenders may also use the FEMA maps as an input to their loan approval process.

If modelers at the GSEs and other large housing finance firms are going to incorporate these types of indicators in their mortgage default and other risk models, they will need the ability to rapidly process indicators on hundreds of thousands of properties. Clearly, they will not be typing individual addresses into input fields on web sites and transcribing the results.

Several organizations do offer the ability to download large amounts of property-level data. The remaining challenge is estimating the relationship between these climate risk indicators and the probability of mortgage default or some other phenomenon of interest. Apparently, some firms have proprietary models that convert raw risk indicators into estimates of financial impacts and some large lenders and investors appear to be reviewing and possibly using that information.

76. For instance, *Moody's* is a major investor in Four Twenty Seven (https://427mt.com/), Munich Re offers GRESB, and the list goes on and on. Not to mention the dozens of research groups in government, international organizations, and universities around the world. In addition to risk scores, the organizations may offer insurance, advisory services, assistance with ESG and other services depending on their business model.

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