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Chapter 9

Opportunities for Better Managing Weather Risk in the Changing Climate

Global temperatures as high as those in recent years are unprecedented in the time span of human civilization and have likely not been seen in at least the last 125,000 years of Earth's history (Gulev et al. 2021). Many nations, including the United States, are working ambitiously to limit the impact of climate change by reining in greenhouse gas emissions and harnessing the opportunities of the clean energy transition. However, given the time it takes to transform the global energy system and for the climate to respond, the climate will continue changing at least until global greenhouse gas emissions fall to zero. In the coming decades, more intense and frequent weather extremes and the uncertainty of the changing climate will present a range of economic and financial risks to the U.S. economy and will confront the Federal Government with related fiscal challenges. Physical climate risks can be managed by anticipating and planning for coming changes in climate, a process known as adaptation. Adaptation presents opportunities to lower climate change costs over the long-term while also building resilience to natural hazards and weather risks today.

The design of climate adaptation policies must recognize that actors across the United States, including individuals and businesses and all levels of government, already face incentives to adapt to climate change. But they also face informational, financial, and legal constraints that may limit their ability to adapt. Targeting adaptation policies to alleviate these constraints and address related market failures should be most effective in supporting private action.

The Federal role in climate change adaptation is complicated by the complex, nested governance structure of relevant policy areas. Many important areas that are relevant to adaptation, from land use planning and zoning to the regulation of insurance markets, are governed at the State or local level. The Federal Government, however, has a strong interest in advancing reforms in these areas to address climate change because of its role in managing risks across the United States, from credit and insurance provision to disaster response and recovery to social safety net programs.

The risks that climate change poses are multidimensional, regionally specific, and vary based on underlying socioeconomic vulnerabilities. Adaptation policies need to be targeted to particular settings and therefore will need to be both varied and complex. This chapter proposes four overarching objectives for structuring further Federal adaptation efforts:

- Producing and disseminating knowledge about climate risk
- Long-term planning for the climate transition
- Ensuring accurate pricing of climate risks
- Protecting the vulnerable.

The United States has joined nations around the world in acting to reduce greenhouse gas emissions. If fully implemented, national pledges may limit global warming to 3.6°F (2°C; Meinshausen et al. 2022), achieving a primary goal of the Paris Agreement (United Nations Climate Change, n.d.). The steeply falling costs of low-carbon technologies and the increasingly ambitious climate policies of many countries are bending the global emissions curve, rendering worst-case outcomes of 8–10°F of warming by the end of the century increasingly unlikely (Hausfather and Moore 2022). The United States has implemented major domestic legislation to achieve its own goals to reduce emissions to 50–52 percent below 2005 levels by 2030 and to reach net-zero emissions by 2050. In particular, the August 2022 Inflation Reduction Act and the November 2021 Bipartisan Infrastructure Law together make $430 billion in investments in American infrastructure, with a focus on the climate challenges facing our Nation (U.S. Department of Energy 2022).

However, even given the ambitious action to rein in emissions that will be required to meet these national commitments, the climate will

continue changing for the foreseeable future, for two main reasons. First, it will take decades to completely transform the global energy system, which currently relies heavily on greenhouse-gas-generating fossil fuels. Second, the climate system will take years to respond to changes in emissions. At present, temperatures across the lower 48 States are about 1.8°F above their level in 1900 (Vose et al. 2017, 185); even if all nations meet their emission reduction goals, global warming will at least double by 2100. (Meinshausen et al. 2022).

The effects of global warming are already apparent across the United States, in the form of more extreme heat and longer heat waves (National Oceanic and Atmospheric Administration, n.d.; Lipton et al. 2018; Gutiérrez et al. 2021, p. 2004); more extreme rainfall events and associated flooding (U.S. Environmental Protection Agency 2021; Davenport, Burke, and Diffenbaugh 2021); more frequent and intense droughts driving huge wildfires (Williams, Cook, and Smerdon 2022; Borunda 2021; Burke et al. 2021); and higher sea levels driving coastal flooding and worse storm surges (Hino et al. 2019; Marder 2020). Among the events that have been formally linked to climate change in recent years are the ongoing drought in California (Diffenbaugh, Swain, and Touma 2015); exceptionally dry conditions in the Southwest (Park Williams, Cook, and Smerdon 2022); extreme heat in the Pacific Northwest (Bercos-Hickey et al. 2022); flooding in the mid-Atlantic (Winter et al. 2020); major western wildfires (Yu et al. 2021); the damage caused by Hurricane Harvey, which inundated Houston in 2017 (Frame et al. 2020; World Weather Attribution 2017); and severe, rain-induced flooding in Louisiana in 2016 (van der Wiel et al. 2017).

Fluctuating weather conditions have always presented challenges. The inherent variability of the atmospheric system means that specific weather conditions cannot be predicted—even in principle—beyond a 7- to 10-day predictability horizon. In a stable climate, however, the *probability* of different weather conditions can be accurately estimated. A stable climate allows actors to understand the risks of weather-dependent outcomes and to plan accordingly, in designing infrastructure, allocating investments, and adjusting daily routines and habits. For example, statistical methods currently used to design infrastructure assume a stable and unchanging climate, where the probability of extreme weather over the lifetime of the infrastructure remains constant at historical values (Milly et al. 2018).

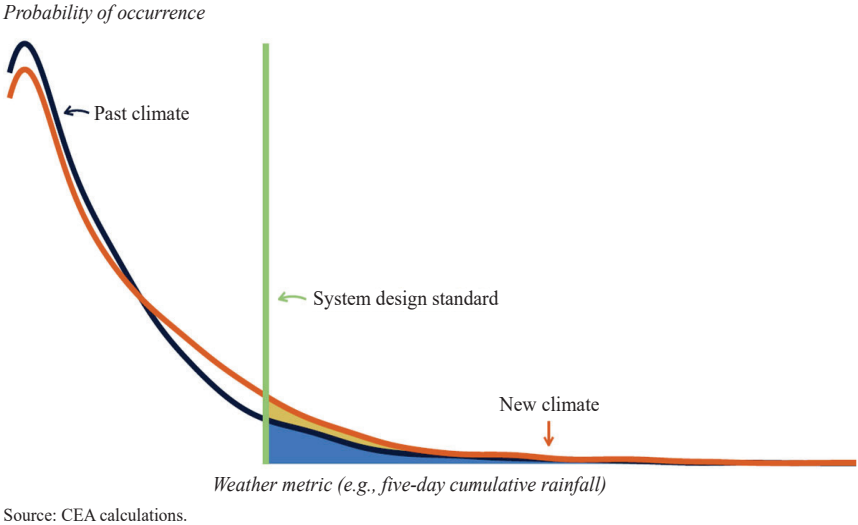
With the human-induced climate change of today, however, it is no longer possible to assume that the future will be like the past and to use unadjusted past experience as a guide for the future. Decisions made using only historical weather records will become increasingly inaccurate and costly as weather patterns change (Milly et al. 2018; Electric Power Research Institute 2022). Weather variability occurring in the context of the

changing climate will result in repeated experiences of historically unprecedented weather conditions (Fisher, Sippel, and Knutti 2021).

Even small changes in average climate conditions can produce large changes in the probability of previously rare weather events. Social, financial, and infrastructural systems that manage these risks typically have certain tolerances, with steeply increasing costs when these thresholds are exceeded. For instance, construction is often designed to standards based on historical weather conditions, such as a 1-in-100-years rain event, and conditions exceeding these design thresholds can produce dangerous conditions that have high economic and social costs (American Society of Civil Engineers 2018, 239). A shifting climate can quickly render these standards obsolete. In the example shown in figure 9-1 using an illustrative climate distribution, the mean changes by just under 20 percent, but the probability of an extreme event (the area of the distribution to the right of the green line) increases by about 80 percent.

Modern societies have been and continue to be ordered for a climate that no longer exists; therefore, the projected rapid changes in the climate system will pose major, evolving risks for economic, social, infrastructural, and governance systems in coming decades. Recognizing and planning for these risks—a process that is often called adaptation—can reduce costs, improve stability, and protect the most vulnerable people and communities. Because climate change touches many aspects of economic production and societal well-being, adaptation policies need to be equally broad, ranging

Figure 9-1. Small Changes in Climate Can Greatly Increase the Probability of Extreme Weather Events



Source: CEA calculations.

from the provision of decision-relevant climate information to the regulation of insurance markets to improved building codes and zoning. Box 9-1 describes some of the ongoing investments being made by the Biden-Harris Administration to build resilience while reducing and managing the costs of a changing climate.

Economic Principles of Adaptation Policy and Planning

The economic principles that support adaptation planning for climate change are both different from, and more varied than, those underpinning the reduction of greenhouse gas emissions, typically referred to as mitigation. Mitigation is a classic example of a public good. The costs of emissions accrue to people all around the world and will last far into the future. Because the market prices of fossil fuels do not incorporate these large social costs, climate change can be understood as a global externality—what Nicholas Stern has termed "the greatest market failure the world has ever seen" (Stern 2006). Private markets have little incentive to provide emissions reduction in the absence of government action. Moreover, because the benefits of reducing emissions accrue globally and are not captured within the borders of a single country, nations must cooperate to address the climate challenge (Nordhaus 2019). Aligning the incentives of private actors and nations throughout the world to account for the climatic effects of fossil fuels requires coordinated action.

In contrast, many adaptation decisions are private goods, in that both the costs and benefits are largely internalized by the decisionmaker (Mendelsohn 2000; Kahn 2021; Kolstad and Moore 2020). For adaptation, communities, households, and businesses all have their own motivations for responding to and planning for climate risks. Examples include a homeowner investing in reinforced windows to defend against stronger storms, a farmer choosing what crops to grow in response to changing drought conditions, and a business adjusting suppliers to reduce weather-related disruptions that are shifting due to climate change. Though there are public goods problems and other market failures related to adaptation (discussed in detail later in the chapter), they are varied, specific, localized, and very different from the global externality problem that characterizes mitigation.

Indeed, there is already evidence that private actors are starting to consider emerging climate risks in their decisions. For example, recent research suggests that both the risks of sea-level rise and the productivity effects of extreme heat are reflected in property and agricultural land prices (Keys and Mulder 2020; Bernstein, Gustafson, and Lewis 2019; Baldauf, Garlappi, and Yannelis 2020; Severen, Costello, and Deschênes 2018). Climate risk premiums are also showing up in longer-term corporate and municipal bonds (Painter 2020; Acharya et al. 2022; Goldsmith-Pinkham, Gustafson,

Box 9-1. Adaptation and Resilience Investments of the Biden-Harris Administration

The 2021 Bipartisan Infrastructure Law (BIL) and the 2022 Inflation Reduction Act (IRA) both contain a number of provisions to build resilience to natural disasters and adapt social and economic systems to reduce the costs of climate change. The Biden-Harris Administration is in the process of implementing these laws, making historic investments in climate change resilience. The BIL in particular provides $50 billion for adaptive investments such as support for energy-efficiency improvements in low-income households, grants to states and territories for resiliency projects and flood mitigation, dedicated funding to improve resiliency of transportation systems, and funding for wildfire defense and coastal adaptation (White House 2022g, 2022h; U.S. Department of Transportation 2022; U.S. Department of Commerce 2022). Resiliency provisions within the IRA include tax credits and rebates for improving home energy efficiency and funding for addressing droughts and improving water infrastructure (White House 2022i).

Beyond the investments provided by the BIL and IRA, the United States is pursuing a multipronged adaptation strategy that includes: inter-agency coordination on climate extremes, building codes and climate-related financial risks; the provision of climate data tools such as the Climate Mapping for Resilience and Adaptation portal; and building resilience into Federal procurement (UN Framework Convention on Climate Change 2021; Climate Mapping for Resilience and Adaptation, n.d.). Principal agencies are now required to develop and implement Climate Adaptation and Resilience plans and report annually on implementation and progress under the plans (White House 2022j). Several programs target assistance to groups that may be particularly vulnerable such as low-income and Tribal communities (White House 2022g, 2022h).

These historic investments are laying the foundation that will be required for building adaption and resilience in the United States. This chapter describes both the broad economic principles that underlie adaptation policy generally and that could support future work building on this foundation. For instance, spending on adaptation and resilience projects will be most effective when coupled with reforms to zoning, building codes and infrastructure standards (mostly governed at the State and local level; see figure 9-3), as well as clear communication of strategic priorities for the management of climate risks at all levels of government.

and Lewis 2021). There is also evidence that property market adjustments are concentrated in regions where more people report believing in climate change, which suggests continuing pricing frictions in areas where there is greater skepticism about climate change (Barrage and Furst 2019; Bernstein, Gustafson, and Lewis 2019; Baldauf, Garlappi, and Yannelis 2020; Severen, Costello, and Deschênes 2018).

The importance of private incentives in shaping climate action has implications for the design of adaptation policy. First, effective adaptation policy will recognize that individuals, households, businesses, and communities will act in response to the shifting climate. But these actions will be defined by legal, informational, and financial constraints, along with the sometimes-distorted or perverse incentives that these actors face. Government action that targets constraints and market failures that impede adaptation should be most effective in supporting and enabling private action rather than crowding out actions that would have occurred anyway. Examples of these constraints and market failures, as well as policies that can address them, are discussed in detail later in the chapter.

Second, government policies and programs already play a role in determining how the costs of weather-related hazards are distributed through society, a role that will likely grow in importance as climate change effects worsen. Individuals with more wealth and a higher income are better able to avoid, prepare for, and recover from weather-related shocks. This means that, in the absence of counteracting policies, climate change costs will likely be disproportionately borne by the poor and marginalized. Programs of public lending, insurance, grants, and welfare can be designed to reallocate some of these risks and thus reduce the regressive nature of climate change costs. However, the existing disaster response and social support system is composed of legacy programs that were designed in a pre–climate change era and thus may not be adequate for addressing climate change. Programs are distributed across multiple agencies and levels of government, often with burdensome applications or complex requirements, making their net distributive effect difficult to determine (Mach et al. 2019; Howell and Elliott 2019). In fact, there is evidence that postdisaster aid can exacerbate rather than mitigate preexisting inequalities (Billings, Gallagher, and Ricketts 2022). Comprehensive reevaluation and reform of the system composed of these interacting support programs, building on the ongoing adaptation work within the Biden-Harris Administration (box 9-1), will be required to ensure that the system is able to protect the vulnerable as climate change damage grows.

The next sections first review new evidence on the economic costs and financial risks that climate change poses to the United States and to Federal finances and then outline the role that a Federal adaptation strategy could play in managing and reducing physical climate risk.

The Economic Costs and Financial Risks of Climate Change in the United States

Shifting climate patterns are producing a wide array of risks affecting the well-being of American communities. Earlier research on climate change economics assumed that higher-income countries like the United States would be able to manage the effects of changing weather conditions relatively easily because of the small share of clearly exposed sectors of the economy, such as agriculture and forestry, and the assumption that adjusting to climate change would be straightforward (Mendelsohn, Nordhaus, and Shaw 1994; Nordhaus 1991, 930). However, this assessment needs to be reconsidered in light of new economic evidence and the increasing intensity and frequency of extreme weather events across the United States that can be formally attributed to climate change (Seneviratne et al. 2021).

The Costs of Climate Change for the United States' Well-Being and Prosperity

Weather variability has a range of effects within the United States. For example, studies have shown that very hot temperatures have adverse effects—including increasing premature mortality and worsening of the health of newborn babies (Deschênes and Greenstone 2011; Deschênes, Greenstone, and Guryan 2009; Barreca and Schaller 2020); decreasing crop yields (Schlenker and Roberts 2009); adversely affecting mental health (Burke et al. 2018); lowering the labor supply in exposed industries (Graff Zivin and Neidell 2014); increasing violence (Mukherjee and Sanders 2021); and reducing students' ability to learn (Park et al. 2020). These effects are not borne equally across geographic regions or economic sectors within the United States, and they are felt most acutely among disadvantaged groups with a high vulnerability to natural hazards (box 9-2).

Climate models predict that extreme heat will become more frequent and intense as climate change continues (IPCC 2021). Today, in many parts of the United States, the heat wave season is nearly three times longer than in the 1960s; in the summer of 2022 alone, 400 U.S. locations broke their monthly temperature records (Lipton et al. 2018; Stevens and Samenow 2022; U.S. Global Change Research Program 2018, figure 1.2b). There is some evidence that people, businesses, and communities can adjust to hotter temperatures over time—for instance, by changing the timing of outdoor activities (Graff Zivin and Neidell 2014; Dundas and von Haefen 2020) or by using more energy for cooling (Auffhammer 2022; Deschênes and Greenstone 2011). But these adaptations are costly, do not eliminate climate change costs, and may reduce the quality of life (Deschênes 2022).

Box 9-2. Climate Change Will Most Likely Interact with and Exacerbate Existing Inequalities

The effects of climate change are not evenly distributed across the U.S. population by income, race, or ethnicity. Lower-income communities have fewer resources to prepare for or respond to extreme weather events, leaving them more vulnerable to their effects. For instance, residents of lower-income communities are less likely to evacuate away from the path of hurricanes and tend to live in more vulnerable structures, leaving them at a higher risk of mortality or injury (Deng et al. 2021; Fothergill and Peek 2022). Low-income Americans are less able to adjust their activities to avoid exposure to wildfire-induced air pollution or to adjust air-conditioning in response to extreme heat (Burke et al. 2022; Cong et al. 2022). They are more likely to work in industries such as agriculture and construction that are highly exposed to dangerously high temperatures (U.S. Environmental Protection Agency 2021). Major natural disasters are more likely to lead to financial hardships, such as debt defaults and bankruptcies in low-income and minority communities (Billings, Gallagher, and Ricketts 2022; Jerch, Kahn, and Lin 2022).

Injustices throughout U.S. history mean that these effects are also strongly differentiated by race. For instance, because of forced relocation away from their tribal homelands, many Native American people live on marginal lands that are highly susceptible to wildfires, extreme heat, and droughts (Farrell et al. 2021). Minority and low-income areas within cities, including formerly redlined neighborhoods, are substantially hotter than wealthier, whiter, and nonredlined areas (Hoffman, Shandas, and Pendleton 2020; Benz and Burney 2021); Black and Hispanic students are more likely to attend schools without air-conditioning (Park et al. 2020); and minority communities are more likely to be affected by expected increases in extreme heat and coastal flooding due to climate change (U.S. Environmental Protection Agency 2021; Wing et al. 2022).

Wealth and assets allow households to avoid, prepare for, respond to, and recover from weather-related shocks, leaving minority populations that lack these assets more exposed to intensifying weather extremes. Minority populations, particularly African Americans, were barred from accessing avenues for wealth accumulation for centuries—for instance, through discriminatory home-lending practices that persisted through much of the 20th century—leading to stark disparities today in wealth and assets by race and ethnic group; the median wealth of white households is almost eight times that of Black households (Rothstein 2017; Derenoncourt et al. 2022; Cook 2014; Bhutta et al. 2020).

Moreover, disadvantaged and racial minority communities have generally received less financial assistance after disasters than affluent white communities (National Advisory Council 2020), partly because some of this aid is tied to property ownership, from which minorities have

been historically excluded. The Biden-Harris Administration is working to address these inequities. The Federal Emergency Management Agency (FEMA) has committed to establishing an equitable and fair distribution of Federal aid and assistance and to increase access for underserved populations (U.S. Department of Homeland Security 2022). In response to past inequities, the U.S. Environmental Protection Agency recently created the Office of Environmental Justice and External Civil Rights, which seeks to coordinate and prioritize environmental justice within the agency and in its partnerships with other Federal agencies (U.S. Environmental Protection Agency, n.d.). More generally, the Biden-Harris Administration is working to direct 40 percent of the benefits of climate and clean energy investments to disadvantaged communities. Several programs in the IRA and BIL, most notably the $27 billion Greenhouse Gas Reduction Fund, also target those communities (U.S. Environmental Protection Agency 2022; White House, n.d.).

Beyond extreme heat, climate change is associated with a host of other costly events. About one-third of the cost of major flood events since 1988, totaling $79 billion, has been attributed to climate change (Davenport, Burke, and Diffenbaugh 2021). The western United States is currently having the worst drought in at least 1,200 years, requiring costly cutbacks in water use and endangering the functioning of the Lake Meade and Lake Powell reservoirs (Wheeler et al. 2022; Park Williams, Cook, and Smerdon 2022; Borunda 2021). California and the Pacific Northwest have suffered devastating wildfires that blanketed cities under thick smoke, undermining decades of air quality gains driven by the Clean Air Act and forcing preemptive blackouts to avoid igniting wildfires, temporarily cutting off power to millions of customers (Burke et al. 2022; Childs et al. 2022; Goss et al. 2020; Chediak 2019). Hurricane Ian struck Florida in September 2022, causing a coastal storm surge of up to 18 feet and widespread inland flooding; it will end up being one of the costliest storms on record, with losses to residential and commercial property estimated at between $36 billion and $62 billion (CoreLogic 2022; Paquette and Kornfield 2022).

Unprecedented extreme events are exposing the weaknesses of aging U.S. infrastructure, which was designed to operate in different climate conditions. Multiple infrastructural systems gradually built over many decades—including electricity grids, dams and irrigation systems, coastal and riverine defenses, roads and railways, and ports—will need to be quickly redesigned, retrofitted, or rebuilt to maintain their functionality in the changing climate. And this investment in climate resilience will need to be made while also addressing the estimated $2.6 trillion in deferred infrastructure investments

required over the next 10 years just to restore existing infrastructure to working order. These costs will likely be borne by cities, States, and the Federal government, along with specific infrastructure user groups such as electric utility customers or irrigation district members (American Society of Civil Engineers 2021).

The complexity of global supply chains means that extreme weather events around the world can ripple through international trade networks, to affect American producers and consumers (Woetzel et al. 2020a). Pankratz and Schiller (2022) show how disruption from extreme heat and flooding in supplier locations is transmitted through supply chains to affect the revenues of customer firms. As climate change intensifies, the chances of major disruptive weather events occurring simultaneously in multiple regions will increase, causing larger and more systemic threats to supply chains. The summer of 2022 saw major heat and drought events in the United States, Europe, and China disrupt global production, which prevented the transporting of agricultural products along rivers and shut down electricity generation for car and electronics factories, and thus exacerbated supply chain challenges (Ahmedzade et al. 2022; Bradsher and Dong 2022; Plume 2022).

Crop failures and other effects of climate change could also exacerbate volatile conditions in fragile nation-states, leading to instability and conflict—with spillover effects to the United States via migration and escalation of local conflicts into national security concerns (Missirian and Schlenker 2017; Benveniste, Oppenheimer, and Fleurbaey 2020; Mach et al. 2019; White House 2015a). Studies have suggested that both the conflict in Syria and the flows of migrants from Central America have been exacerbated by climate-related stressors (Ash and Obradovich 2019; Kelley et al. 2015; Lustgarten 2020). Recent massive flooding in Pakistan led to the inundation of one-third of the country by floodwaters, internal displacement of 33 million people, massive disruption of the agricultural sector, and a sovereign debt downgrade (Lu 2022; Fitch Ratings 2022). By shifting where nonhuman species live and how they interact with humans, climate change could even increase the risks of zoonotic disease spillovers (Carlson et al. 2022).

There is some evidence that climate change could also affect macroeconomic growth. Empirical investigations of the causal relationship between temperature fluctuations and gross domestic product (GDP) generally find negative effects from hotter temperatures, particularly in poor and hot countries, with some indications that this heat depresses growth rates (Dell, Jones, and Olken 2012; Burke, Hsiang, and Miguel 2015; Bastien-Olvera, Granella, and Moore 2022). According to modeling and simulation studies of the macroeconomy, negative effects of climate change on growth greatly increase both the magnitude and uncertainty of aggregate climate costs (Moore and Diaz 2015; Newell, Prest, and Sexton 2021), but little is currently understood about the mechanisms connecting weather shocks and

long-term climate trends to macroeconomic variables. Plausible mechanisms include faster depreciation of the capital stock resulting from more intense extremes (Hallegatte, Hourcade, and Dumas 2007; Otto et al. 2023), effects to productivity growth (Ortiz-Bobea et al. 2021), or effects on the labor force that either depress the supply of labor or slow the accumulation of human capital via effects on learning (Graff Zivin and Neidell 2014; Park et al. 2020). Improving empirical evidence and modeling capabilities in this area should be a high priority for future research.

Because climate change affects many aspects of well-being, including those not traded in traditional markets, the costs of climate change and losses of other natural capital are mismeasured by GDP (Coyle 2015; Brunetti et al. 2021; Svartzman et al. 2021; NGFS-INSPIRE 2022). For example, production that emits climate-change-causing greenhouse gases adds to GDP, and so too do expenditures to adapt to climate damage or reduce emissions. Meanwhile, many important services that nature provides, including reducing risks to health and protection from climate-driven extreme weather events, are not reflected in GDP or are misattributed. Examples include the role urban trees play in providing shade and lowering heat extremes or the value of intact wetlands in reducing coastal storm damage. A more complete accounting system than GDP that tracks national wealth—the stock of multiple forms of capital that produce flows of both market and nonmarket benefits—could provide clearer macroeconomic information on climate change than exclusive reliance on GDP (Agarwala and Coyle 2021; Dasgupta 2021). Including natural capital in measures of wealth would help track climate change costs and nature loss in ways that complement GDP and fill in important blind spots. This is why the Biden-Harris Administration has begun the process of rigorously measuring natural capital in a way that could inform a more complete picture of economic progress and climate change costs (White House 2022c).

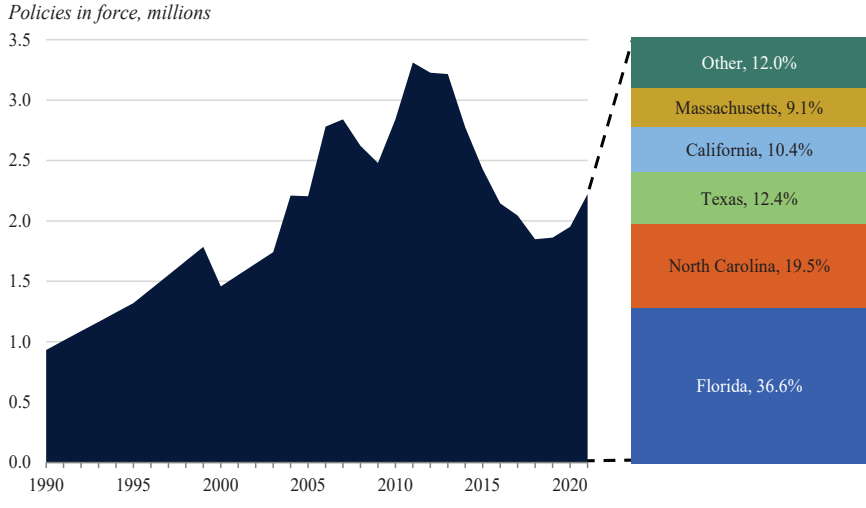
Climate Change and Financial Stability

Climate change risks have historically been unpriced in private markets, but as these risks become increasingly apparent and investors become more cognizant of the threat, price adjustments for exposed assets would be expected. Property and long-lived physical infrastructure are particularly exposed, and risk becoming stranded as climate conditions shift beyond their design standard, thus causing investments to underperform or fail altogether. There is substantial evidence that *current* natural hazard risks are undercapitalized in property markets, a setting that could produce sudden price shocks in response to new information that reveals underlying risks to buyers (Bakkensen and Barrage 2022; Baldauf, Garlappi, and Yannelis 2020; Hino and Burke 2021; Gibson and Mullins 2020).

Certain financial instruments—such as insurance contracts, catastrophe bonds, and mortgages—that directly or indirectly price weather-related risks are also highly exposed to climate change. Rapid changes in asset prices or reassessments of the risks in response to a shifting climate could produce volatility and cascading instability in financial markets if not anticipated by regulators. Because of the interaction of long-lived investments and direct exposure to weather extremes, property insurance against catastrophic natural hazards is at the forefront of climate change risk exposure and is already showing signs of strain in several states (box 9-3).

Governments have typically stepped in to provide coverage when private insurers pull out from particularly risky areas or hazards. More than 95 percent of flood policies in the United States are insured through the Federal National Flood Insurance Program (NFIP), and the number of policies in State-run insurance plans has more than doubled since 1990 (Kousky et al. 2018). Figure 9-2 shows the long-run growth in State-run disaster insurance plans combined with a sharp rise following major hurricane strikes in 2004 and 2005, after which the largest insurance companies pulled out of Florida (Leefeldt 2022). Although the State was able to move policies off its rolls and back into the private market in the 2012–15 period, Florida's public insurer, Florida Citizens, is once again the largest property insurer in

Figure 9-2. Count of Policies under U.S. Residual Property Insurance Market, 1990–2021, with Geographic Breakdown for 2021



Sources: Insurance Information Institute, n.d.; Citizens Property Insurance Corporation of Florida, n.d.
Note: Data are linearly interpolated for the years 1991–94, 1996–98, and 2001–2. Policies from North Carolina are included only for 2011 (2.2 percent of total policies in that year) and later.

Box 9-3. Disaster Insurance in the Changing Climate: Challenges and Opportunities for Reform

Even in the absence of climate change, weather-related extremes—such as flooding, hurricanes, and wildfires—pose particular challenges to the insurance industry. Losses due to natural disasters are highly concentrated in space and time, leaving insurers financially vulnerable to a major weather event (Wagner 2020). Moreover, the distribution of losses from these events is "thick-tailed," a statistical property meaning that expected losses are heavily influenced by extremely rare events, the risks of which are difficult to quantify and price (Conte and Kelly 2018; Kousky 2022, 38–42). In the face of these challenges, insurers must limit exposure by either exiting from or limiting activity in certain markets or by purchasing reinsurance, which raises costs.

For these reasons, even without climate change, natural disasters hover on the edge of insurability. Without reforms to improve the functioning of insurance markets and reduce the costs of extremes (for instance through zoning changes and building code improvements), climate change could well make many more hazards uninsurable as the frequency and intensity of extremes increase. Climate change increases uncertainty, particularly in the tails of the distribution that drive expected losses, and raises the risk of completely unprecedented events for which there is no historical analog (figure 9-1). In the absence of high-quality, trusted information on quickly evolving climate risks, ambiguity in how to price extreme weather risks could lead insurers to leave certain markets altogether. Major insurers have already stopped offering hurricane wind coverage along the Gulf Coast and are increasingly exiting high fire-risk areas in California (Sadasivam 2020; Elliott 2022; Schuppe 2022; Querolo and Sullivan 2019). Moreover, the increasing likelihood that multiple catastrophic events could occur concurrently could raise costs or limit the availability of reinsurance.

A lack of access to insurance makes extreme events more costly because it slows economic recovery in affected communities and raises the probability of cascading financial hardships, such as mortgage defaults and debt delinquencies (Billings, Gallagher, and Ricketts 2022; Kousky 2019; Kousky, Palim, and Pan 2020; Otto et al. 2023). Therefore, reforms to address challenges in hazard insurance markets should be a high priority for adaptation policy. A major issue in the U.S. disaster insurance system is that although climate change presents a systemic threat that simultaneously raises the risk of multiple perils (wind, fires, and floods) across the United States, hazards are insured on a peril-by-peril basis and are regulated at the State level. Alternative models—such as those used in France, Spain, and New Zealand—instead create broad, diversified risk pools by mandating comprehensive, multiperil catastrophe insurance while also providing an

explicit public reinsurance backstop that limits the exposure of private insurers (Kousky 2022, 53–55). These kinds of reforms will likely be increasingly important to stabilize insurance markets and expand access in the face of climate change.

the State after seeing a 48 percent growth in policies during 2022 (Florida Citizens 2023; Insurance Journal 2022). Other sharp growth in State insurance rolls in recent years has come from California, where wildfire risk has led private insurers to pull out and the number of policies on the State's FAIR plan to increase by over 80 percent since 2018 (State of California 2018; Insurance Information Institute, n.d.–a). These programs strain government finances because premiums generally do not cover payouts, meaning that losses are covered with general tax revenue or debt issuance (Hartwig and Wilkinson 2016).

Even with these implicit public subsidies that effectively transfer risks to general State and Federal taxpayers, the penetration of natural hazard insurance is low; for instance, only one-third of homes within FEMA-defined 100-year flood zones have flood insurance while fewer than 3 percent outside these flood zones have it, despite still being at risk of flooding (Evan et al. 2020). Increased risks of delinquencies and defaults after disasters can have subsequent implications for property and mortgage markets, particularly in the absence of insurance (Kousky 2019; Billings, Gallagher, and Ricketts 2022; Kousky, Palim, and Pan 2020). Sastry (2022) suggests that mortgage lenders respond to the availability of federally backed flood insurance by requiring higher down payments when public insurance is either limited or not required, changing the demographics of eligible home buyers.

Climate-change-driven weather extremes can have subsequent effects on State and municipal finances through several pathways beyond public insurance plans. First, responding to climate change places additional burdens on local budgets, which could cause serious financial hardships, particularly in communities with smaller budgets. The need to either rebuild damaged infrastructure after disasters or upgrade existing infrastructure to prepare for climate change raises the cost burden for cities, States, and Tribes. Second, repeated occurrences of climate extremes can threaten the property tax base and cause a decrease in revenues. For instance, the McKinsey Global Institute has estimated that an extreme storm surge event in 2050 would cause damage equivalent to 10 percent of the total market value of properties in Miami–Dade County and as much as 30 percent in Lee County, which was recently inundated by 18 feet of storm surge

from Hurricane Ian (Woetzel et al. 2020b; Paquette and Kornfield 2022). Residential real estate construction has been an important driver of growth in some U.S. coastal communities, and declines in response to emerging climate risks could have serious implications for local economies, employment, and tax revenue (Brunetti et al. 2022).

Several researchers have found evidence that the municipal bond market is beginning to account for these risks in its pricing of loans to municipalities. Bonds for cities and towns in areas exposed to sea-level rise carry a premium, with significantly larger effects on longer-maturing bonds, implying that investors expect either a decline in cash flow or increasing volatility in exposed cities (Painter 2020; Goldsmith-Pinkham, Gustafson, and Lewis 2021). Acharya and others (2022) find evidence for the pricing of extreme heat in municipal and corporate bonds, beginning in about 2013–15, and also larger effects on longer-term bonds. Higher borrowing costs strain municipal finances and make it even more challenging for cities to finance disaster reconstruction or adaptive infrastructure investments without either raising taxes or diverting resources from other public services. In areas with local declines in tax revenue and rising climate change costs, municipal bankruptcies may be increasingly likely. Jerch, Kahn, and Lin (2023) find evidence that hurricane strikes decrease tax revenues and raise the risk of municipal default over the following decade, with the largest effects being felt in disadvantaged communities. In addition to losses to creditors, bankruptcy costs are borne by current and future residents in the form of higher taxes and service fees (Chapman, Lu, and Timmerhoff 2020).

The Federal Fiscal Implications of Physical Climate Risk

Climate change affects the Federal fiscal outlook via numerous pathways. On the revenue side, it threatens economic output, leading to a lower tax base. One estimate by the White House's Office of Management and Budget (White House 2022b) suggests that the Federal Government could see 7.1 percent lower annual tax revenue by 2100 as a result of the adverse effect of climate change on macroeconomic growth. Though some of this could be offset by increasing taxes on income or capital, Barrage (2020) points out that the distortionary effects of these revenue-raising mechanisms can be substantial, increasing climate change costs by up to about 30 percent. Ongoing research within the Biden-Harris Administration is expanding the capacity of the Federal Government to integrate the modeling of both the physical and transition risks of climate change into macroeconomic forecasting in order to better explain and plan for these effects (White House 2022f).

On the expenditure side, many Federal operations are being affected by the changing climate. Though these effects are too extensive to enumerate in detail here, this section briefly reviews four primary pathways by which

the Federal Government is exposed to physical climate risk: risk assumption, the operation and financing of climate-exposed assets, the provision of national public goods, and social safety net programs.

Risk Assumption

By fully or partially assuming certain types of risk, the Federal Government is able to attract private investment and support production across broad sections of the economy. One of the most significant examples of this is the Federal role in housing: Through the government-sponsored enterprises (GSEs)—Fannie Mae and Freddie Mac, which are privately owned but federally chartered and are currently in conservatorship—and Federal agencies (e.g., the Department of Housing and Urban Development, Ginnie Mae, and the Department of Veterans Affairs), the Federal Government guarantees mortgages and securities backed by mortgages. Together, the GSEs and Ginnie Mae accounted for more than 65 percent ($7.7 trillion) of total outstanding mortgage debt in 2022 (Urban Institute 2022). The growing damage from hurricanes, storm surges, and wildfires has implications for defaults, recoveries, and other key cost drivers—and, by extension, for Federal loss exposure (Kousky, Palim, and Pan 2020; Rossi 2020; Woetzel et al. 2020b). There is evidence that private lenders are shifting climate-exposed loans into the GSEs, which may bear a substantial share of the increasing climate risk in the absence of policies that manage Federal exposure (Ouazad and Kahn 2022).

In addition to its support for the housing finance system, the Federal Government also directly assumes risk through various insurance programs. Flooding is the most frequent and most costly natural disaster in the United States, and the Federal Government underwrites essentially all home flood insurance policies via the NFIP (Federal Emergency Management Agency 2010; Kousky et al. 2018; Federal Insurance and Mitigation Administration 2022). Climate change will increase costs from flooding due to both more intense rainfall and higher sea levels, which worsen flooding from storm surges and slow drainage in low-lying coastal areas. The NFIP is already at risk of financial insolvency; it has a debt to the Treasury of $18.1 billion, despite the fact that Congress canceled $17 billion of its debt in 2017 (Federal Emergency Management Agency, n.d.; Environmental Law Institute 2022, 702). Without fundamental reforms of the U.S. disaster insurance system and of the Federal Government's role in managing these risks (box 9-3), these losses will continue to grow (White House 2022b).

Climate-Exposed Assets

The Federal Government owns and operates critical climate-sensitive infrastructure, most significantly dams, irrigation systems, and major flood

defenses such as river and coastal levees, along with buildings, military installations, and other physical assets that may be at risk from climate change (White House 2022b; U.S. Department of Defense 2021a). These assets were built over many decades at substantial cost and are now critical foundations for communities and regional economies across the United States.

The Bureau of Reclamation (2022) is the Nation's largest wholesale water supplier, operating 338 reservoirs and maintaining 487 dams that supply water to about 10 percent of U.S. residents, as well as supplying hydropower and water for agricultural irrigation. The functioning of some of these systems will be challenged by the changing hydroclimate, which is already bringing both more intense rainfall and more droughts, including the persistent megadrought currently hitting western States (Kao et al. 2022). The Central Valley Project, which supplies water to cities and farmers in California, has slashed its water deliveries to cities and has completely cut water to many farmers in 4 of the last 10 years (James 2022). The project's long-term operation is further threatened by sea-level rise, which will increase the salinity of the California Delta and eventually render its water unfit for drinking and irrigation (State of California 2018; Fleenor et al. 2008). Water levels in Lake Meade and Lake Powell reservoirs are close to the critical threshold, below which they will cease to produce electricity (Wheeler et al. 2022). The costs of either maintaining water and power services from Federal facilities in the changing climate or decommissioning projects and finding alternative solutions for dependent communities has not been fully estimated.

The U.S. Army Corps of Engineers (n.d.) is tasked with building certain public infrastructure projects that manage the risks of flooding, including riverine and coastal levees and flood control dams throughout the country. More intense rainfall events, higher sea levels, and stronger storms are expected to increase the costs of maintaining existing flood protection and expanding it to newly at-risk areas. The costs resulting from climate change for Federal flood control could be extremely high. Future expenditures will depend on high-level strategic decisions that have yet to be made regarding what role flood protection infrastructure will play in managing growing coastal and inland flood risks. For example, the Corps of Engineers has released a feasibility study for a plan to protect the New York metropolitan area from coastal storms. This plan—which includes storm surge barriers, floodwalls, levees, seawalls, and other measures—would cost upward of $52 billion, with 65 percent borne by the Federal Government (New York District 2022).

The Provision of National Public Goods

A central function of the Federal Government is to provide national public goods, most critically national defense, which accounted for about 45 percent of Federal discretionary spending in 2021 (CBO 2022a). Climate change poses threats to U.S. national security, which raises questions about its implications for defense spending and the Federal budget (U.S. Government Accountability Office 2022; National Intelligence Council 2021). The Department of Defense has identified climate change as a factor in national security planning and as an urgent and growing threat to U.S. security (White House 2015b; Department of Defense 2021b). Climate change effects are expected to increase global tensions, as nations compete for scarcer resources—threatening health and human rights and triggering conflict and mass migration (White House 2022e).

A second aspect of Federal public goods provision that is substantively affected by climate change is the stewardship of natural resources, public lands, and biodiversity. By altering the climatic environment to which ecosystems are adapted, climate change threatens to degrade ecosystem functioning and species survival (U.S. Global Change Research Program 2018). The additional costs of managing public lands in this rapidly shifting environment are not fully known. An example of costs that have been partially quantified are annual Federal wildland fire suppression expenditures, which, on average, have more than tripled since 1989, partly driven by intense, climate-change-driven droughts in the West (CBO 2022b). Moore and others (2022) estimate that direct spending on biodiversity conservation via the Endangered Species Act could increase by 75 percent (roughly $34 billion) by 2100, as unmitigated climate change pushes an estimated one in six species toward extinction (Urban 2015).

The Programs of the Social Safety Net

The various Federal programs known as the social safety net provide benefits and assistance to maintain a minimum level of well-being for the U.S. population. Climate change could increase the burden on these programs through a number of pathways, most notably health-related expenditures and assistance for disaster response and recovery.

Federal health programs—namely, Medicare and Medicaid—represented 38 percent of total national health expenditures in 2021, or about $1.6 trillion (Centers for Medicare & Medicaid Services 2022). Several studies have estimated that health-related risks constitute the largest fraction of climate-change-related damage, with particularly severe effects on those over 65 years of age, who are much more likely to be treated through government programs (Rennert et al. 2022; Hsiang et al. 2017; Carleton et al. 2022). A White House study estimated annual Federal health care costs from

the effects of climate change on air quality, Valley Fever, southwestern dust, and wildfires by 2100 at between $835 million and $22 billion (White House 2022b). An additional unquantified, but likely much higher, cost would arise from hospitalizations resulting from extreme heat conditions, such as dehydration, renal failure, and stroke (Green et al. 2010; Wondmagegn et al. 2021).

Federal programs play a critical role in supporting communities affected by natural disasters. The Congressional Budget Office (CBO) estimates that the expected annual loss from hurricane winds and storm-related flooding is $56 billion, or 0.3 percent of 2019 GDP, with annual costs to the Federal budget of $18 billion through disaster assistance and NFIP claims (CBO 2019). However, Deryugina (2017) shows that disasters have far larger fiscal implications due to increases in social insurance payments—such as Medicaid, disability insurance, and income maintenance programs—which persist for 10 years after a storm hits. The Federal Government supports postdisaster response and recovery, not just through the immediate FEMA response but also through low-interest loans from the Small Business Administration and Community Development Block Grant Disaster Recovery funding from the Department of Housing and Urban Development to aid rebuilding disaster-affected communities (Howe et al. 2022, 700–704; U.S. Small Business Administration, n.d.).

Market Failures and Distortions That Slow Adaptive Adjustments and Policy Responses

As described above, shifting weather risks present incentives to private actors to adjust so as to reduce the negative effects of climate change and take advantage of any opportunities it offers. Indeed, there is evidence that these adjustments are already happening, in prices that seem to be starting to account for climate change risks (Keys and Mulder 2020; Bernstein, Gustafson, and Lewis 2019; Baldauf, Garlappi, and Yannelis 2020; Severen, Costello, and Deschênes 2018), as well as other evidence that households and local governments are altering practices in response to or in anticipation of the changing climate (Berrang-Ford et al. 2021).

Private adaptive adjustments occurring in the United States are subject to market imperfections—along with informational, institutional, legal, and financial constraints—that could limit or slow adaptation. Public adaptation policy should target these barriers to enable faster and more effective private action. This section reviews major market failures, imperfections, and distortions that are relevant to managing physical climate risks and describes the policy tools that can address them.

Imperfect Information on Physical Climate Risks

Adaptation to the changing climate requires incorporating information about how shifting weather patterns will alter the distribution of future weather risks. This is particularly important for decisions that are highly sensitive to climate change through long-lived investments or exposure to low-probability, high-consequence tail risks. A substantial body of literature indicates that individuals consistently underestimate or discount the probabilities of catastrophic events, a phenomenon that can lead to low rates of disaster insurance coverage and underinvestment in risk reduction (Wagner 2022; Bakkensen and Barrage 2022; Royal and Walls 2018). Information on climate risks that is of high quality and is trusted, decision-relevant, and widely disseminated is foundational for adaptation planning and is urgently needed. Yet it is now largely missing. Modeling tools used to understand the global climate system, termed general circulation models, are most accurate over large spatial scales and long time frames. Different, more fine-tuned tools are needed to make information on specific risks in particular places over short to medium time frames widely available to stakeholders making adaptation decisions (Fiedler et al. 2021; Pitman et al. 2022; American Society of Civil Engineers 2018, 7).

Governments already support a global network of satellites, in situ observing systems, weather stations, modeling facilities, and technical workforces that produce public weather forecasts. Similarly, as climate change information becomes an essential complement of weather data, governments will need to play a role in funding the production of and access to this essential public good to support climate-informed decisionmaking by many actors. This includes not just developing the ability of climate science to provide better information at the spatial and temporal scale at which decisions are made but also supporting the training of highly skilled workers who can translate and disseminate this information to the public and private actors seeking to use it (Fiedler et al. 2021; Kopp 2021). The Biden-Harris Administration has begun this work through development of the Climate Mapping for Resilience and Adaptation tool (CMRA, n.d.).

Information Asymmetries

Information asymmetries occur when one party in a transaction has more information than another, which can lead to price distortions and market failure (Akerlof 1970). In the climate risk context, information asymmetries could arise when buyers and sellers have varying knowledge about an asset's climate change exposure, such as a property's propensity to flood or wildfire risk. In this regard, Keenan and Bradt (2020) and Ouazad and Kahn (2022) find evidence of information asymmetries operating in coastal mortgage markets, with lenders shifting risks of flooding-exposed properties

onto Fannie Mae and Freddie Mac or to other lenders that have less knowledge of local risk exposure.

Mandatory disclosure laws are one tool governments can use to correct information asymmetries. These require parties to share particular types of information relevant to asset valuation. A proposed rule by the U.S. Securities and Exchange Commission (2022) would add climate-related risks to the required disclosures of publicly traded companies. Disclosure laws related to property transactions are governed at the State level and vary widely in the degree to which they require sellers to disclose climate-related risks (particularly flooding) to buyers (Hino and Burke 2021; Natural Resources Defense Council, n.d.). Only a handful of States—notably, Louisiana and Texas—have strong flood disclosure regulations to protect buyers, while 16 have no disclosure requirements at all (Federal Emergency Management Agency 2022).

Building codes and standards can be another way to protect buyers from information asymmetries in property markets. Details of building construction that determine how vulnerable a structure is to water, wind, and wildfire hazards can be highly technical and not easily understood by home buyers. This creates a market failure, if more resilient but also more expensive construction cannot command a premium because these qualities are not easily observable. By setting common minimum standards for all construction, governments can prevent a race to the bottom in building quality (White House 2022f).

Adverse selection in insurance markets—where buyers know more about their risk than providers, leading more risky individuals to opt into insurance at a given price—is another form of information asymmetry. There is some evidence of adverse selection operating in U.S. disaster insurance markets, where those with a lower flood risk (e.g., from an elevated house) are less likely to purchase coverage (Wagner 2022; Bradt, Kousky, and Wing 2021). In the absence of corrective policies, adverse selection can lead to an unraveling of insurance markets as insurers raise rates to cover the higher risk, driving lower-risk individuals from the marketplace and further concentrating insured risks. This market failure historically has been addressed through purchase mandates that solve the adverse selection problem by requiring everyone to participate in insurance markets thereby pooling the risk. Insurance mandates can also improve welfare in settings without adverse selection but where individuals systematically underestimate their exposure to a catastrophic loss (Wagner 2022).

Externalities and Public Goods

Although many adaptation actions are private goods that result from individual households and firms weighing their own costs and benefits, important

public adaptation goods will also be underprovided without government action (Mendelsohn 2000). Examples include building infrastructure for coastal protection; expanding the tree cover for urban cooling and other nature-based forms of climate adaptation; basic research relevant to adaptation, such as developing improved crop varieties; and the protection of species or ecosystems threatened by the changing climate. But unlike greenhouse gas mitigation, which is a global public good, many public adaptation benefits are more local and therefore may be best provided by State, Tribal, and local governments. The Federal Government may still have a role to play in coordinating, supplying information, and reducing transaction costs.

In addition to pure public goods, some private adaptations may involve externalities that require collective action by communities or higher levels of government. This is particularly the case for environmental goods and natural resource management, where preexisting inefficiencies related to the lack of established property rights can be exacerbated by climate change. Examples include the spillover effects of coastal protection onto neighbors, and the increasing drawing down of open-access aquifers to meet higher crop water requirements resulting from warmer temperatures (Beasley and Dundas 2021; Gopalakrishnan et al. 2017; Rosa et al. 2020). Threats to biodiversity are similarly characterized by market failures and problems of public good provision. Though habitat conversion, pollution, and invasive species are primary drivers of species endangerment, climate change further stresses threatened species and exacerbates these drivers (Tilman et al. 2017; Moore et al. 2022; Hashida et al. 2020). In these settings, reforms to more sustainably manage natural resources will have ancillary benefits in reducing climate damage and can be thought of as an important tool for managing climate risks.

Credit Constraints

A number of adaptive actions require upfront capital investments that will pay off gradually. Examples range from homeowners installing air-conditioners to farmers adopting irrigation to manage increasing heat and droughts to major community projects to slow or prevent coastal erosion. If actors are unable to finance these investments at competitive interest rates, they will be underprovided relative to an optimal level, meaning that governments may play an important role in alleviating credit constraints to enable adaptation. Examples of relevant government programs include targeted subsidies for home efficiency upgrades such as certain provisions in the Bipartisan Infrastructure Law and the Inflation Reduction Act (box 9-1). This will be particularly compelling for populations that have been historically underserved by financial institutions and for financing adaptations

where there is a strong social interest in ensuring adaptation to alleviate climate-related risks.

Credit constraints do not just apply to individuals and business but may also limit the ability of States and municipalities to fund major public adaptation projects. Most States require voter approval for general obligation bonds backed by future tax revenues or have other constitutional limits on long-term debt issuance, constraints that do not apply to the Federal Government (Kiewiet and Szakaty 1996). The costs of major infrastructure projects to manage growing climate risks may be beyond the fiscal reach of many local governments, particularly if climate risks are simultaneously jeopardizing future tax revenue. Low-cost loans or grants from the Federal Government may therefore be important sources of financing for municipalities and States seeking to make major investments to reduce climate risks, a recent example being pilot grants for voluntary relocation of Tribal communities made by the U.S. Department of the Interior (2022).

Moral Hazard

"Moral hazard" refers to a phenomenon in insurance markets whereby access to insurance lowers incentives for risk-reducing or risk-avoiding behavior, increasing overall hazard costs. Settings with pervasive moral hazard can see higher insurance premiums or an unraveling of private insurance markets. Other programs that shift the costs of hazards—whether through subsidized insurance, publicly provided protection, or loan guarantees—can, unless carefully structured, also create moral hazard distortions. Annan and Schlenker (2015) estimate that the moral hazard associated with subsidized crop insurance has reduced the incentives of farmers to adapt to extreme heat and has led to a higher sensitivity to heat in insured crops. Baylis and Boomhower (2023) find that the implicit subsidy from public wildland fire fighting can reach 20 percent of home values in low-density, wildfire-prone areas. Similar indirect subsidies for building in flood-prone areas have likely led to more people and property in these risky areas (Panjwani 2022).

The moral hazard problem does not only apply to individuals; it can also apply to State and local governments. Many decisions relevant to reducing the costs of weather-related disasters—including zoning, building codes, and land-use management—are made at the State or local level (figure 9-3). State and local governments making these decisions see benefits in growth and tax revenues, but they are shielded from the full costs of risky development because of the Federal Government's assumption of disaster risk through the NFIP and disaster relief programs. Several States have seen rapid development in areas exposed to coastal flooding by sea-level rise, with local governments permitting two or three times more construction in these risky areas than in safer regions (Climate Central and Zillow 2018).

Reforming Federal programs and private insurance contracts to incentivize or require risk-reducing activities or to place a higher share of costs on those undertaking the risk (e.g., through higher deductibles) can help mitigate issues of moral hazard (Kousky 2022, 38).

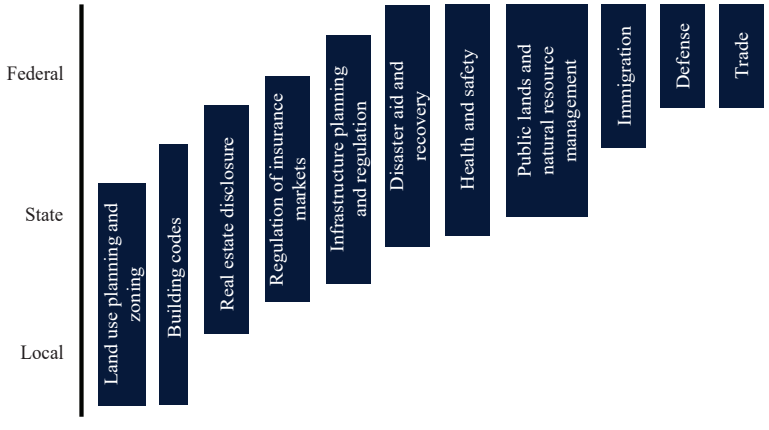
Four Potential Pillars of the Federal Adaptation Strategy and Major Policy Opportunities

Adaptation to climate change is characterized by complex governance across multiple scales, with relevant decisionmaking operating at the national, State, Tribal, and local levels (figure 9-3). Given the complex regulatory and planning processes relevant to managing climate risks and the local nature of many adaptation benefits, this nested governance structure may be appropriate (Dietz, Ostrom, and Stern 2003). Federal adaptation policy needs to be developed with an appreciation of the multilayered, complex regulatory systems that characterize adaptation-relevant policy areas. This final section outlines four broad, cross-cutting roles for further Federal adaptation efforts to support specific policymaking across these many issue areas, and it highlights major opportunities for action in each area.

Producing and Disseminating Knowledge about Climate Risk

As firms, local governments, and individuals increasingly seek to account for climate change in their planning and investments, actionable information will be a necessary input. From home buyers deciding where to move to local governments planning new stormwater drainage to businesses looking to disclose their climate risk exposure, actors across the economy will

Figure 9-3. Governance of Climate Risk Is Complex and Multiscale



Sources: Howe et al. (2002); CEA calculations.

require high-quality, trusted, and accessible climate impact information. This is essential "informational infrastructure"—technical information produced at high fixed costs but with broad applicability and value. Thanks to strong Federal support, the United States is a global leader in climate science. But the modeling tools used to understand the global climate system are not yet designed to deliver the decision-specific information needed by most stakeholders to manage climate risk (Fiedler et al. 2021; Pitman et al. 2022; ASCE 2018, 7).

Major opportunity: invest in the Federal capacity for catastrophic climate risk modeling. The U.S. government has an opportunity to lead the world in developing a high-performance public capability for catastrophic climate risk modeling. Managing evolving climate risks will require new scientific approaches that combine insights from climate models with other tools, such as statistical modeling and detailed engineering data to produce decision-relevant climate information tailored to the needs of stakeholders across the United States (Pitman et al. 2022). Catastrophe modeling is used in the insurance industry to understand the risks of extreme events, but it is done by just a few companies, is expensive to access, and can be difficult to evaluate (ModEx, n.d.). Given both the growing role of the public sector in absorbing climate risk and the need for many actors—ranging from State and local governments to homeowners to general businesses—to understand their exposure, information that is publicly available, credible, and from trusted sources is urgently needed. The U.S. government has the opportunity to build on its existing foundation of excellence in climate modeling and Earth system sciences to develop this critical capacity.

Long-Term Planning for the Climate Transition

Long-term, forward-looking planning that anticipates coming climate change is necessary to avoid unnecessary losses and destabilizing effects. Neumann and others (2021) estimate that proactive adaptations that anticipate future climate can reduce the costs of climate change for the United States' road, rail, and coastal infrastructure by a factor of between 3 and 6 by 2090, compared with purely reactive adaptation; Diaz (2016) finds a similar magnitude of savings for forward-looking adaptation for global coastal defenses.

The Federal Government, in a number of its capacities, from the Social Security Administration to the management of National Parks, has a particular role in the long-term stewardship of U.S. assets. It regularly makes decisions that will have consequences for decades if not centuries into the future. Planning across all affected Federal agencies should recognize the effects of climate change that are already apparent and are expected to intensify well into the future. Exposure to climate hazards should be incorporated

into an agency's enterprise risk management process. For example, the U.S. Department of Defense (2021b) is planning to integrate climate risk into all relevant hazard threat assessments.

In addition, high-level strategic planning will be essential to identify critical risks that climate change poses for agencies' missions, high-priority opportunities to address these risks, and the additional resources or legislative changes that may be required to realize these opportunities. Current and future climate change effects may necessitate difficult trade-offs involving many stakeholders with conflicting interests. Timely work to identify principles and priorities that will guide agencies will improve coordination, identify necessary reforms that may take a long time to implement, and ultimately lower costs and improve effectiveness, a motivation behind the ongoing agency climate adaptation planning process (box 9-1).

Clarity at the Federal level regarding priorities for funding public adaptation efforts is important for driving action by State and local governments. Estimated costs just for protection from sea-level rise are large, and are likely far beyond the means of many coastal communities (Diaz 2016). Other costs of responding to droughts, wildfires, and inland floods will further strain government budgets. As described above, Federal loans and grants will be essential to alleviate credit constraints for State and local governments, but these resources are necessarily limited. Establishing clear funding priorities and resolving uncertainty over which protection costs the Federal Government will finance can assist State and local actors in their own planning for the climate transition.

Major opportunity: use access to Federal funds to incentivize subnational adaptive reforms. Many policies critical to building long-term resilience to natural disasters are controlled at the State or local level (figure 9-3). However, Federal funds flowing through States both directly and indirectly finance long-lived, climate-exposed infrastructure and development projects (CBO 2018). If physical climate risks are not fully integrated into agency enterprise risk management, these investments risk underperforming and becoming stranded. Similarly, decisions to convert land subject to wildfires or flooding to developed uses implicates the Federal Government via its various risk-absorbing functions, such as mortgage guarantees, flood insurance, and disaster management and response. Reforms to zoning, building codes, insurance markets, and residential disclosures can all have major benefits in reducing the costs of disasters.

Climate-relevant Federal investments can be tied to the enactment of adaptive reforms that will protect both affected communities and the Federal budget. For example, FEMA has proposed reforms of the NFIP to Congress that would, if enacted, condition participation in the program on the development of community-level flood disclosure requirements for property transactions (U.S. Department of Homeland Security 2022), while

provisions of the Bipartisan Infrastructure Law lower the non-Federal share of certain grants for transportation projects prioritized in a State's Resilience Improvement Plan (U.S. Department of Transportation 2022).

Ensuring the Accurate Pricing of Climate Risk

Provided that actionable and credible information on climate risk is available, prices would be expected to adjust, sending accurate signals to actors to reallocate investment and production in response to and in anticipation of the changing climate. However, market failures arising from information asymmetries or misaligned incentives can distort these signals and require a policy response. One role of the Federal adaptation strategy should be to identify and correct these market failures to enable stronger market signals that would guide adaptive decisions over the longer term. Specific market failures relevant to adaptation and policy tools to address them were discussed in the previous section; they include information provision, disclosure requirements, building standards, and insurance purchase mandates. An important example is the recent reform of pricing in the NFIP, termed Risk Rating 2.0, which prices policies based on individualized flood risk assessments while continuing to provide discounts for investments by individuals or communities that lower flood costs (CRS 2022).

Market mechanisms can play an important role in allocating resources efficiently and sending price signals to market actors on the scarcity of resources. In places where markets are missing or incomplete, climate-change-induced scarcity could exacerbate existing distortions—meaning that reforms to expand market access or establish property rights over common-pool resources could lower total costs, one example being the allocation of water use in California (Arellano-Gonzalez et al. 2021). Even in the absence of markets, using mechanisms such as auctions to allocate resources cost-effectively could be a useful strategy to manage scarcity under climate change (Hagerty and Leonard 2022).

Major opportunity: develop quality and transparency standards for climate data and the modeling used in market transactions. An important part of supporting the integration of physical climate risks into market prices will be oversight of the quality of climate information being used. Pricing climate risk requires the use of specialized modeling tools, and evaluating the quality of this information is a technical and highly specialized skill. Use of proprietary models of natural hazard risk that cannot be evaluated by the expert community as an input into significant regulatory decisions has caused tensions in the past, particularly in the insurance industry (Xu, Webb, and Evans 2019). Developing minimum standards and reporting requirements for the climate data used to inform significant investment decisions could help build trust, ensure quality, and enable broader adoption.

This is particularly important when insurance contracts are leveraged into more complex financial instruments, such as catastrophe bonds and other insurance-linked securities, or when used as input into scenario exercises central banks are beginning to use to evaluate climate risks to the financial system (Insurance Information Institute, n.d.–b; Braun and Kousky 2021; U.S. Federal Reserve 2023; Financial Stability Board 2022). Oversight and evaluation of the Earth system models used for significant economic or regulatory decisionmaking could be important in preventing natural disasters from triggering more systemic failures across the financial system.

Protecting the Vulnerable

Climate change is expected to increase weather-related hazards for many Americans, but its effects will not likely be felt equally (see box 9-2 above). Low-income and disadvantaged communities are both more exposed to climate effects (e.g., through working in industries exposed to extreme heat, such as agriculture and construction) and lack assets that can be drawn on to smooth the costs of weather-related disasters. In the absence of policies addressing the needs of low-income and marginalized communities, preexisting vulnerabilities—such as inadequate health care, poor-quality or overcrowded housing, and food insecurity—will likely interact with climate change effects to worsen inequalities. Addressing these underlying vulnerabilities and developing policies targeted at disadvantaged populations should be a critical part of an effective U.S. adaptation strategy, building on the robust set of existing programs within the Biden-Harris Administration targeted at low-income and disadvantaged communities (boxes 9-1 and 9-2).

As prices adjust to reflect changing climate risks, this could present challenges for low-income communities, for whom higher prices are particularly burdensome. For instance, low-income households are already less likely to have flood insurance and almost 9 percent of policyholders in FEMA-defined 100 year floodplains pay more than 5 percent of their income for flood insurance premiums and fees (U.S. Department of Homeland Security 2018). To the extent possible, rather than restricting price adjustments, which would blunt the incentive for private risk reduction and increase risks over the long term, policies should seek to address these adverse distributional effects via targeted lump sum transfers. More generally, policies that seek to accelerate income growth and increase access to wealth-building opportunities for the poorest Americans should be thought of as broadly adaptive. Although by no means the main goal of programs that may be primarily focused on educational opportunities, housing affordability, or poverty alleviation, by increasing resources available to the most vulnerable that can be drawn on to manage the effects of climate shocks,

they should lower overall vulnerability and decrease climate costs over the long term.

Major opportunity: develop criteria for public adaptation funding that reflect the social value of investments. Criteria for the prioritization and evaluation of public adaptation projects that accurately reflect the social benefits of these investments should be developed. Historically, public investments in flood defenses or community risk reductions have used the value of protected property as a key metric in evaluating project benefits (McGee 2021). However, inequality in property values and ownership in the United States reflects decades of exclusion of racial minorities from home-ownership and public investment (Rothstein 2017). Evaluating the benefits of climate protections solely using property values is unlikely to capture the full, multidimensional benefits of these projects and risks perpetuating these historical injustices and exacerbating differences in vulnerability (Martinich et al. 2013). Additional criteria that capture differential vulnerability and variations in the extent to which communities are able to self-insure and recover from damage could be developed to assess project outcomes.

Major opportunity: reenvisioning social insurance under climate change. The increasing frequency and intensity of climate-change-related disasters, along with the disruptions and dislocations required to adjust to changing conditions, will likely challenge the policies and programs that spread risks and protect the vulnerable as never before. Understanding the burden this will place on traditional social insurance programs in the United States and identifying reforms to strengthen the social safety net is essential in this era of climate change. In addition, a process for reimagining the public role in catastrophe management and social solidarity in the face of rising risks is also urgently needed. The United States' current approach—managing catastrophic perils in a piecemeal way with fiscally unstable public insurance programs—will only become more problematic as climate change continues. U.S. policymakers should seriously consider models from other countries, where governments act as backstop reinsurers, capping catastrophic losses in the private sector to crowd in private financing while also spreading the risk broadly through mandated natural disaster coverage (Kousky 2022, 53–56).

Conclusion

The United States is making historic investments that will transform the American energy system to address the challenge of climate change and meet President Biden's goal of halving U.S. greenhouse gas emissions by 2030. These investments are central to the global effort to rein in emissions and limit the effects of climate change.

Even with the massive shift already under way in global energy production, models show the climate will continue changing for decades (IPCC 2021; Meinshausen et al. 2022). Shifting weather patterns will likely subject communities to unprecedented extremes making the management of weather risks and natural disasters increasingly difficult. A large body of literature, as well as the mounting costs of climate-change-associated extreme events, shows that the U.S. economy is sensitive to the effects of climate change. Without forward-looking adaptive planning that anticipates changing conditions, climate costs will very likely keep growing, compounding risks to infrastructural, social, economic, and financial systems across the United States.

Managing the risks of climate change is a complex challenge across multiple policy areas, characterized by varying market failures and nested governance structures. However, the particular capacities, authorities, and interests of the Federal Government mean that it should play an essential role in leading adaptation policy development and structuring the responses of subnational and private actors to emerging climate risk. An effective Federal adaptation strategy includes producing and disseminating knowledge about climate risk, long-term planning for the climate transition, ensuring accurate pricing of climate risks, and protecting the vulnerable. Managing the risks and consequences of the warming planet, along with continued efforts to reduce greenhouse gas emissions, will allow the Nation to face the climate challenges of the 21st century.