The Budgetary Effects of Climate Change and Their Potential Influence on Legislation

Recommendations for a Model of the Federal Budget
About This Report

Climate change will induce increasingly severe and frequent hazards, such as heat waves, wildfires, droughts, and floods. In turn, these hazards lead to increased spending in such areas as disaster relief, health care, and insurance programs. Climate change will also likely lead to a net reduction in revenue by affecting productivity, labor hours, and total labor force. The combination of these factors results in a substantial net loss to the federal budget because of climate change. However, these losses are currently underrepresented by the methodology used to quantify the costs and benefits of climate policy. This report examines the ways that climate change and climate change mitigation policy affect the federal budget. In this report, we recommend ways to improve the modeling of such effects and provide an overview of a budget model that can be used to score legislation.

This report is intended for modelers seeking to capture important relationships between climate, federal policy, and the economy. Our goal is to inform the eventual development of such a model. In particular, the analysis presented here might be useful for analysts involved in budget modeling at policy research organizations, such as the Congressional Budget Office (CBO), the Office of Management and Budget, and other policymakers involved with scoring legislation.

RAND Education and Labor

This study was undertaken by RAND Education and Labor, a division of the RAND Corporation that conducts research on early childhood through postsecondary education programs, workforce development, and programs and policies affecting workers, entrepreneurship, and financial literacy and decisionmaking.

More information about RAND can be found at www.rand.org. Questions about this report should be directed to price@rand.org and kathryne@rand.org, and questions about RAND Education and Labor should be directed to educationandlabor@rand.org.

Funding

Funding for this research was provided by the Nick and Leslie Hanauer Foundation.

Acknowledgments

This work benefited from helpful conversations with members of the CBO, the First Street Foundation, Perry Beider, and Philip Joyce. We would also like to thank our peer reviewers, Christine Eibner at the RAND Corporation and Marc Hafstead at Resources for the Future, for their time and thoughtful feedback.
Summary

What Is at Stake?

As temperatures rise globally, driving an increasing number of expensive natural disasters, U.S. policymakers will need to consider climate change mitigation policies. Such policies could significantly lower climate change–related costs and even generate net economic benefits but would require shifting trillions of investment dollars among U.S. regions and economic sectors that will have their own respective objectives.

However, budgetary analysis only assesses the costs to the federal budget from policies (i.e., how a policy affects discretionary and mandatory spending and revenues) without incorporating its potential nonfiscal benefits (e.g., reductions in mortality from cleaner air). While most federal agencies perform cost-benefit analyses (CBAs) for proposed policies, the underlying assumption for budgetary analysis is that other lawmakers will lay out the potential benefits of policies while the costs are quantified and communicated as scores. This methodology gives an incomplete picture of the impacts of policy and can bias against phenomena that operate outside the conventional ten- or 30-year budget horizon, such as climate change. Such agencies as the Congressional Budget Office (CBO) and the Office of Management and Budget (OMB) have shown a strong commitment to understanding the impacts of climate change in their budget estimates. However, both agencies are constrained by time, resources available, and congressional mandates. Therefore, gaps remain in this area of research. Budget analysis at academic institutions (e.g., the Penn Wharton Budget Model, which was developed by researchers at the University of Pennsylvania) also fails to account for benefits from climate change policy.

The goal of this research is to discuss the necessary characteristics of a model or set of models that can be used to incorporate the costs and benefits of climate change and climate change mitigation policy. Therefore, this analysis can be used for model scoping. Additionally, we hope to illustrate the importance of considering longer periods of analysis than the ten- or 30-year period that is conventionally used in budget projections and offer methods to contend with the uncertainty that such long timescales induce.

This report describes the key considerations for the development of a model that (1) captures the major interrelationships between climate change, the economy, and policy; (2) explores the range of probable trajectories for key climate hazards; and (3) tests different assumptions related to beliefs about key policy parameters (e.g., responses from other countries or technological advancement related to efficiency). We have included sufficient technical detail that this report should be of interest to modelers seeking to design and develop a fiscal model that incorporates climate change implications.

Our Approach

We conducted several reviews of the literature, with each highlighted in a different chapter. Primary sources for the Chapter 2 review, which focused on the impact of climate change on federal spending and revenue at the baseline, included recent reports from CBO, OMB, the U.S. Environmental Protection Agency (EPA), and several prominent climate-economy academic studies. Chapter 3 discusses the economic and environmental impacts of different climate change mitigation policies. The Chapter 3 literature review is more comprehensive and includes recent studies in several climate change mitigation policy domains. Chapter 4 covers some

---

1 Here, we are specifically referring to policies focused on mitigating and adapting to climate change. Other policies (e.g., health, housing) will be affected by climate change but fall outside the scope of this report.
main sources of uncertainty that complicate modeling the climate-economic system. Because of the broad range of topics contained in this chapter, we based our recommendations on several sparser reviews of the literature. Additionally, we demonstrate the importance of the discount rate and the timescale of analysis using results from a highly stylized climate-economic model.

Findings

- Climate change will have a substantial impact on federal spending and revenue. For example, increases in extreme heat will increase morbidity and mortality. In turn, this will affect labor hours, productivity, and the overall workforce. Such health impacts will increase spending in health care programs at the same time as revenue decreases, leading to net losses overall.
- The projected impact of climate change on revenue depends on how climate change damage is modeled and quantified. Climate-economic models offer various methods to calculate damage.
- Climate change mitigation policies will introduce both opportunities and risks to different sectors. For example, a policy that subsidizes renewable energy can promote new employment in the renewable energy sector but lead to job losses in the fossil fuel industry. Depending on the timing and intensity of the implementation, such a policy can lead to stranded assets and overall economic losses. The net impacts are also highly dependent on investor expectations. Belief in the success of a mitigation policy can trigger new investments into the renewable energy sector, thus amplifying its ability to reduce emissions.
- The environmental and economic impacts of climate change mitigation policies are highly dependent on characteristics that vary across the population, such as income and hazard-risk. Current models do a poor job of representing differences across the target population.
- The efficacy of climate change mitigation policies also depends on where relevant technologies are on the technology-adoption curve.
- Considering a ten-year timescale for scoring federal legislation only captures a small fraction of the benefits of a climate change mitigation policy. (In our analysis, this timescale captures only 0.5 percent to 4.5 percent of benefits.) However, when using longer timescales in the analysis, many other uncertain factors can change the impact of a policy, such as the level of international cooperation and the speed of technological innovation.
- The environmental and economic impacts of climate change differ from many other economic and physical systems because extremes are more likely and are higher in magnitude than in other naturally occurring events. The economic impacts of climate change are typically modeled using equilibrium models, but these models are not well suited to representing these characteristics. Heavy tails are also not suited to traditional metrics that are used in CBA. Using the mean of a heavy-tailed distribution of impacts can underrepresent both the risks and opportunities of a policy.

---

2 Stranded assets are resources that can no longer be used because of some factor (legal or otherwise) that prematurely ends their economic life.

3 For example, doubling an average person’s height (for example, 5 feet 6 inches) would immediately put them outside the realm of what is biologically possible. In contrast, doubling the potential temperature increase in response to a greenhouse gas emissions change is potentially possible.
Recommendations

Any model or set of models used to represent the federal budget will be highly influential in shaping future policy decisions and will affect the quality of life of people both in the United States and around the world. We therefore recommend that all assumptions and their implications in such a model are made transparent and accessible. Here, we outline the modeling decisions that will help to best represent the impact of climate change and climate change policy on the federal budget. First, the model must link the physical and human systems so that the decisions made in the economic system lead to changes in emissions and subsequent changes in temperature. Modeling emissions requires both a detailed representation of energy technologies and quantification of higher-level macroeconomic feedbacks. We therefore recommend that a bottom-up energy model be coupled to a macroeconomic model of the economy in addition to a climate model. Importantly, many such models, called Integrated Assessment Models, are based on a framework that does a poor job of modeling nonlinearities and tipping points in the complex coupled human-Earth system. A model used to quantify risks in this system must be able to quantify the impacts of extremes, including compounding and cascading risks.

As mentioned previously, the modeled impacts of policies are dependent on regional and demographic characteristics. A model of the federal budget must be able to represent these distributional characteristics. Finally, we would like to stress the importance of considering longer timescales for evaluating climate change mitigation policies to capture most of the benefits that would be associated with such policies. To address the high levels of uncertainty in longer timescales, we recommend modeling multiple baselines to craft policies that are robust to the range of plausible circumstances.

---

4 The human-Earth system refers to the inextricably linked human and natural systems. These systems are coupled, meaning that outputs from one system feed into and alter the other system (one-directional coupling), where these changes then affect the initial system (bidirectional coupling).
# Contents

About This Report ........................................................................................................ iii
Summary ....................................................................................................................... v
Figures and Tables ...................................................................................................... xi

**CHAPTER 1**

Introduction .................................................................................................................. 1
Scope of the Challenge ................................................................................................. 1
Poor Understanding of Relationship Between Economy, Climate Change, and Policy .................................................................................................................. 2
Previous and Ongoing Work on Climate Change by the Congressional Budget Office and Office of Management and Budget ............................................................................................ 3
Limitations .................................................................................................................. 4
Organization of the Report ............................................................................................ 4

**CHAPTER 2**

The Budgetary Effects of Climate Change .............................................................. 7
Effects of Climate Change on Mandatory Spending ................................................. 7
Effects of Climate Change on Discretionary Spending ............................................ 14
Effects of Climate Change on Revenue ................................................................ 16

Key Modeling Points ...................................................................................................... 18

**CHAPTER 3**

The Economic, Environmental, and Social Effects of Climate Change Mitigation Policies .................................................................................................................. 21
Treatment of Carbon Pricing in This Chapter ......................................................... 22
Measuring the Impact of Regulations ........................................................................ 23
Measuring the Impact of Fiscal Policy on Behavior Change and Technology Adoption .................................................................................................................. 27
The Budgetary Risks of Climate Change Mitigation Policies ................................ 29

Key Modeling Points ...................................................................................................... 30

**CHAPTER 4**

Baseline and Timescale Considerations for Climate and Fiscal Models ................. 33
Considerations for Long-Term Policy Analysis ......................................................... 33
Scenarios for Policy Evaluation .................................................................................. 36
Tail Risks .................................................................................................................... 42

Key Modeling Points ...................................................................................................... 44

**CHAPTER 5**

Conclusion ................................................................................................................... 47
Recommendations for a Budget Model ....................................................................... 47
Recommendations for Model Use for Budget Analysts and Other Modelers .......... 48
Future Work ............................................................................................................... 49
APPENDIXES
A. Expanded Framework for Policy-Climate Model .......................................................... 51
B. Supplemental Information on the Congressional Budget Office ................................. 53
C. Supplemental Information on Climate Change Mitigation Policy Impacts ................... 55

Abbreviations .................................................................................................................. 63
References ..................................................................................................................... 65
Figures and Tables

Figures

1. Interactions Between Policy, the Economy, and the Climate ............................................. 2
2. Example Pathways of Budgetary Impact Because of Increases in Extreme Heat ..................... 18
3. Electric Power Markets in the United States ........................................................................... 28
4. Percentage of Present Value Net Benefits as a Function of the Time Horizon ......................... 36
4.2. Transforming the Shared Socioeconomic Pathways to the Subnational Level Using the Factor-Actor-Sector Framework .......................................................................................... 39
4.3. Tails of Common Distributions ......................................................................................... 43
A. Interactions Between Federal Policy, the Climate, and Both the U.S. and Global Economy ....... 51
C. Technology Adoption “S-Curve” with Sources of Support and Funding ................................. 56
C.2. Expenditures by Tax Credit Type ....................................................................................... 57
C.3. History of the Production Tax Credit with Historic Annual Wind Capacity Additions and History of the Investment Tax Credit with Historic Annual Photovoltaic Capacity Additions in the United States .......................................................................................... 59

Tables

2. Current State of Work, Gaps, and Recommendations ............................................................ 19
3. Types of Climate Change Mitigation Policies ........................................................................... 22
3.2. Benefits Assessed in the Power Regulation–Based Climate Change Mitigation Policy Literature ........................................................................................................................................ 24
3.3. Current State of Work, Gaps, and Recommendations ........................................................ 24
4. Sample of Possible Dimensions and Values for U.S.-Centric Scenario Development Related to International Effects ........................................................................................................... 40
4.2. Current State of Work, Gaps, and Recommendations ........................................................ 45
CHAPTER 1

Introduction

Scope of the Challenge

While many of the hazards associated with climate change have been theorized and predicted for decades, we are increasingly seeing the real-world consequences—with potentially staggering public price tags attached. Record-breaking heat waves, droughts, and floods that affect tens of millions of Americans each year are costing the federal government billions of dollars. Furthermore, the federal government spends billions of dollars each year on protection, prevention, and mitigation efforts associated with climate hazards. Similarly, efforts to decarbonize energy, transportation, construction, agriculture, and other sectors will require substantial federal spending amounting to trillions of dollars. Decarbonization in the United States and worldwide could significantly lower the costs of climate change while generating net economic benefits but would require shifting the investment of trillions of dollars among U.S. regions and economic sectors (Shukla et al., 2022).

Given the scope and scale of the economic effects of climate change, it is important that policymakers engaged in planning and budgeting understand the costs associated with climate hazards and transitioning to a sustainable economic system. However, both the economy and climate are complex systems, which make estimating the effects of climate change on the economy, and vice versa, a nontrivial endeavor. Climate change affects the economy and society through direct hazards, such as floods and fires; through efforts to protect, prevent, and mitigate against these hazards, such as hardening buildings or changing land use patterns; and through efforts to reduce greenhouse gas (GHG) emissions, such as electrifying transportation and buildings. Beyond the macroeconomic considerations, climate change raises significant challenges to equity because the responsibility for and implications of GHG emissions are spread unequally, both geographically and across generations. Because climate change–related hazards and responses will increase over the coming decades, any forward-looking, comprehensive budgetary analysis must include climate implications. Similarly, any analysis of climate policies must capture the economic and budgetary effects to produce meaningful forecasts.

Figure 1.1 provides a schematic of how federal policy interacts with the economy, which, in turn, affects the climate. As described above, climate change influences hazards that effect economic activity, economic activity can result in emissions that drive climate change, and the federal government can influence these relationships through policy, regulation, spending, and taxation. Additionally, there are some direct emissions from federal activities (e.g., fuel burned in a federally owned vehicle), though we will not discuss this channel in detail in this report. Impacts in these systems feed back to each other in an iterative fashion through time. A framework for global interactions is discussed in Appendix A.

This report describes the complex relationships between the climate and the federal budget and the factors that models of these relationships should include to inform policymakers as they consider future climate mitigation and adaptation policies.
Poor Understanding of Relationship Between Economy, Climate Change, and Policy

The relationships between the economy, climate change, and federal mitigation and adaptation policies are extremely complex and only partially understood. Additionally, the deep uncertainty around many key parts of the interrelated systems requires assumptions to be made when scoring the budget effects of climate policies. Experts and stakeholders might not know or agree on many of the conceptual models that describe the system of interest (e.g., the climate), the probability distributions used to represent uncertainty about inputs to the system (e.g., the temperature change per doubling of the carbon dioxide $[\text{CO}_2]$ concentration), and how to weigh and value alternative outcomes (e.g., comparing the costs of mitigation with avoided damages in future generations) (New, Reckien, and Viner, 2022). Such uncertainties arise from numerous factors, including complex and cascading risks and the potential for breaching physical, biological, and social tipping points (Ara Begum et al., 2022). Because the consequences of climate change and its accompanying responses will unfold over decades to millennia, assumptions about how to value the costs experienced in the future can drive the results of analysis. For all these reasons, commonly used methods, such as cost-benefit analyses (CBAs), are not adequate for addressing climate change.

Given the complexity, uncertainty, and growing importance of the relationships between climate change and the economy, it is important that policymakers have access to robust policy-analysis tools. In this report, we describe the key considerations for the development of a model that (1) captures the key interrelationships between climate change, the economy, and policy; (2) explores the range of probable trajectories for key climate hazards; and (3) tests different assumptions related to beliefs about key policy parameters (e.g., responses from other countries or technological advancement related to efficiency). The goal of this research is to provide a roadmap for a model that can adequately represent the costs and benefits of climate change policy and appropriate methods of employing the model to inform budget analyses with dynamic scoring. These recommendations are not limited to any agency in particular and might fall outside the constraints imposed by congressional mandates or executive orders. In such cases, we clarify where revisions to mandates would be required.
Previous and Ongoing Work on Climate Change by the Congressional Budget Office and Office of Management and Budget

Because the Congressional Budget Office (CBO) and Office of Management and Budget (OMB) are key federal offices responsible for studying and modeling fiscal policy, it is important to understand their existing work on the interactions between climate change and the budget. However, it is also important to acknowledge that CBO and OMB have limitations in their mandates that restrict the scope of their analyses.

In recent years, CBO has added the effects of climate change into its long-term budget outlooks through reductions in Total Factor Productivity. The calculation of these reductions follows a five-step procedure. First, CBO uses different econometric estimates of the economic impact of changes in temperature and precipitation along with different climate projections to yield a series of estimates of economic impact in 2050. Second, CBO combines these estimates with a single climate projection and a weighted average of the economic impact of climate change. Third, CBO estimates the damages from the increasing frequency and severity of hurricanes based on their past estimates (CBO, 2016). Fourth, the effects of damages from hurricanes and hydroclimatic variables are summed together, and finally, CBO ensures that the effects of climate change are not double counted by adjusting the damage estimates according to climate impacts already in the baseline. In addition to adjusting the long-term baseline to include the damages from climate change, in a volume detailing policy options, CBO has evaluated the budgetary impacts of wildfires and the estimated reductions to the deficit from a $25 per ton tax on GHG emissions to reduce the deficit (CBO, 2022f). Additional information on the organization, mission, and methods used by CBO is given in Appendix B.

OMB has also recently started considering the impact of climate change on the federal budget in an official capacity. In April 2022, OMB released a white paper that quantified the damages from climate change on crop insurance, wildfire suppression, health, and coastal disasters (OMB, 2022). OMB also included a climate risk scenario based on the 95th percentile scenario developed by the Network for Greening the Financial System (NGFS) that projects a 4.5 percent loss in gross domestic product (GDP) over the next 25 years (Bertram et al., 2020). In April 2022, OMB released a white paper in collaboration with the Council of Economic Advisers that discussed the necessity of climate-macroeconomic analysis for the federal government, provided an overview of previous work that has integrated the physical risks of climate change on the economy along with the risks associated with the transition to a greener economy, and cataloged the datasets and models that are available to use for climate-macroeconomic analyses (OMB, 2022). Both agencies are tasked with providing the federal government with the capabilities to run climate-macroeconomic simulations through Executive Order 14030 (2021). To help the Council of Economic Advisers and OMB with their analysis, the National Academy of Sciences introduced an Interagency Technical Working Group (ITWG) on climate and the macroeconomy.

CBO and OMB have both shown a strong commitment to understanding the impacts of climate change on their budget estimates. However, both agencies are constrained by what is required of them by Congress and the executive branch, respectively, and must complete these requirements given the time and resources available. For example, CBO is tasked with providing scores for every piece of legislation that passes through congressional committees, meaning that they must conduct hundreds of estimates each year. While the no-policy baselines (i.e., the modeled scenario of spending and revenue in the absence of the policy) of these scores account for the effects of climate change using the five-step process outlined earlier, CBO notes that it has no basis for estimating the future savings of investments in climate change adaptation and mitigation.

---

1 CBO uses the average of effects from two emission scenarios from the middle and high end of the range across climate models. Weights are based on the projections and the precision of the estimates from the source study. See Chapter 4 for further explanation of these scenarios.
The Budgetary Effects of Climate Change and Their Potential Influence on Legislation

(i.e., CBO lacks the necessary inputs and information needed to accomplish this task). That is, the scores of proposed legislation do not incorporate the avoided damages that climate policies could offer. Instead, only the direct monetary costs are included.

As part of its ongoing effort to assess methodologies of incorporating climate risks into macroeconomic planning for the federal budget, OMB recommended the use of models with the following attributes: output macroeconomically relevant variables, represent U.S. climate policies, incorporate additional information on climate damages, operate at a subnational level, represent capital and labor frictions, and be open-source and peer-reviewed (OMB Circular A-4, 2023).

The goal of this research is to provide recommendations for a model that can be used to assess the effects of climate change on the federal budget for both the baseline economic outlooks and when scoring legislation. Both CBO and OMB produce budget projections at ten-year (both agencies), 25-year (OMB) and 30-year (CBO) time frames. However, we hope to illustrate the importance of considering longer periods of analysis and offer methods to contend with the uncertainty that such long timescales induce. This work should add to the discussion about changing the framework of federal budgetary analysis so that it is compatible with the best available science.

Limitations

This report should be viewed as an overview of the relevant considerations when building a model to quantify the budgetary effects of climate change rather than a comprehensive review of any of the literature discussed herein. We prioritized researching policies that were judged to have significant macroeconomic implications. While we endeavored to produce a thorough review of the relevant literature, given the volume and pace of climate research, we might have missed some relevant analysis either because of its recentness or because the search did not include the appropriate parameters. The primary data collection and analysis for this work was completed by February 2023, though a few documents were added after that point.

Because our focus is on U.S. federal policy, there might be relevant mechanisms that were considered out of scope. Additionally, not every conceivable climate change mitigation policy is discussed because of the large number of possible interventions.

Organization of the Report

The next two chapters of this report describe the scope of what a model of climate and fiscal policy should include to inform policymakers. Chapter 2 discusses the pathways through which climate change affects the federal budget in the absence of major mitigation policies, providing more detail on pathways with higher-magnitude effects (climate–U.S. economy–federal government pathway in Figure 1.1). The climate affects the economy through different hazards, such as droughts, storms, and heat waves. The hazards can affect the economy by damaging capital (e.g., storms damaging coastal infrastructure) and by affecting the labor force (e.g., extreme heat adding to morbidity and reduced productivity). Chapter 3 provides an overview of climate change mitigation policies and their economic and environmental implications (climate–U.S. economy–federal government pathway in Figure 1.1). For example, increases in investment in renewable energy technologies will influence the economy by shifting employment toward renewable energy sectors. Once these changes have been made in the employment and energy mixes, there will be a subsequent reduction in emis-

---

2 CBO explains this in its response to how efforts to adapt to and mitigate climate change would affect the budget on its Frequently Asked Questions page. The response can be found at CBO, undated-b.
sions that will influence the climate system. Both chapters provide an overview of the model characteristics necessary to represent policy-economy-climate interactions and discuss how the associated impacts are being modeled. The pathways in Figure 1.1 are highly uncertain and require long timescales to be modeled. In Chapter 4, we describe the key design elements required for a model to usefully inform policy. Specifically, Chapter 4 addresses three interrelated areas where current modeling approaches are lacking: the use of multiple base cases for policy evaluation, the treatment of extreme tail risks, and the appropriate treatment of long timescales. Finally, Chapter 5 concludes and offers recommendations for the budget model and how this model might be incorporated into budgetary analysis. There are also three appendixes that present an expanded version of Figure 1.1 that includes global implications of U.S. policy, information on the methodology used by CBO, and additional information on the impact of climate change mitigation policies.
CHAPTER 2

The Budgetary Effects of Climate Change

This chapter provides an overview of the relevant literature on the budgetary effects of climate change on mandatory and discretionary spending, discusses the methodological approaches that are used to quantify the effects of climate change on revenue, and lists several important sources of uncertainty that should be considered when conducting this type of analysis. The overview of spending is limited to programs that make up the highest proportion of spending in the budget: health care, Social Security, income security, disaster aid, and defense. We also discuss the effects of climate change on other insurance programs.

We conducted the literature review for this chapter by examining CBO’s and OMB’s recent reports on climate change, reading some of the studies cited therein, and reviewing other studies for pathways that were neglected or underrepresented by those reports. To identify literature on underrepresented pathways, we used combinations of keywords such as “climate hazards,” “mandatory spending,” “discretionary spending,” and “revenue” in Google Scholar. We found additional studies through the citations within the reports returned in our Google Scholar searches. We also used the artificial intelligence tool Elicit, which takes a user-provided research question and returns a summary of relevant articles from the Semantic Scholar database.

Effects of Climate Change on Mandatory Spending

Federal spending mandated by existing laws (i.e., mandatory spending) includes entitlement programs and programs that make payments to individuals, businesses, and state and local governments. The amount spent on these mandatory programs depends on various eligibility thresholds and formulas. While an act of Congress can amend spending on these programs, nearly all long-run budget forecasts assume mandatory spending grows at a constant rate or share of overall spending. The following subsections are ordered according to their proportionate cost to the federal government.

Effects on Health Care Spending

Mandatory health care programs—such as Medicare, Medicaid,¹ and federal employee health care benefits funds—make up a significant portion of the federal budget. In fiscal year (FY) 2022, Medicare made up 16 percent of total federal spending, and other health care–related programs made up 12 percent (USASpending.gov, undated). These numbers are broadly consistent with pre-coronavirus disease 2019 (COVID-19) era spending patterns as well.

Health care spending programs will likely grow over the next century due to climate change because of more frequent hurricanes, wildfire, and heat waves. There is an extensive literature on the health impacts of these climate change hazards. These studies use a variety of methods, including panel data models

¹ Medicaid is primarily funded by the federal government but is funded at the state level as well.
The Budgetary Effects of Climate Change and Their Potential Influence on Legislation

The Budgetary Effects of Climate Change and Their Potential Influence on Legislation

(Deryugina, 2017), case studies (Patz et al., 2000), and integrated climate-computable general equilibrium (CGE) models (OMB, 2022; Hsiang et al., 2017). The National Climate Assessment provides a review of the literature and concludes that climate change is likely to increase morbidity and mortality risks in the United States because of increased heat waves, floods and storms, air pollution, food- and water-borne diseases, and vector- and rodent-borne diseases (Reidmiller et al., 2017). Extreme weather events can also disrupt the ability to provide health care by interrupting critical public health and health care systems, which can affect health outcomes years after the event (Bell et al., 2018).

The literature finds that, in general, the health impacts of climate change are not evenly distributed across the population. Vulnerable subpopulations include children and the elderly, those with underlying health conditions, and those living in specific geographic regions that are highly exposed to climate hazards (i.e., hurricane exposure on the Gulf Coast and extreme heat in the Southwest) (Reidmiller et al., 2017).\(^2\) Climate change might also improve health outcomes in some regions. For instance, warming temperatures in cool regions might reduce morbidity and mortality by reducing extreme cold. However, Hsiang et al. (2017) constructs a dose-response function for heat and mortality using Bayesian meta-analysis and estimates that rising mortality in hot locations (e.g., the Southwest United States) more than offsets the decline in mortality in cooler regions, resulting in a net increase in climate-related mortality across the country. The authors distinguish outdoor laborers in fields such as construction, mining, agriculture, and manufacturing as high-risk in contrast to workers who are not predominantly exposed to outdoor temperatures.

Several studies have modeled the impacts of climate change on local and federal health care budgetary expenses. For instance, Deryugina (2017) uses historical hurricane tracks and data on government non-disaster transfers to individuals and finds that hurricanes increase public medical payments for several years following the storm’s impact. Other studies find that changes in climate variables can have near immediate impacts on health care use. For instance, Reidmiller et al. (2017) finds that an additional day of wildfire smoke increases same-day Medicare inpatient and outpatient spending by 0.6 percent and 2.8 percent, respectively.

OMB (2022) uses the U.S. Environmental Protection Agency’s (EPA’s) Framework for Evaluating Damages and Impacts (FrEDI) to calculate the sectoral impact of longer-term temperature changes and applies these estimates to a model of health care spending (EPA, 2021). The analysis finds that federal health care spending is expected to increase in the range of $824 million to $22 billion by the end of the century because of increased morbidity and mortality from extreme temperatures and lower air quality under different scenarios of future warming.

In a 2020 working paper, Barrage (2020) estimates the impact of extreme heat on public health care expenditures at the county level, finding that an additional extreme heat day (greater than 35°C) increases the annual public health care expenditure by up to 0.45 percent, conditional on the county’s baseline climate. Then, using a dynamic general equilibrium climate-economy model (the Climate Optimization Model of the Economy and Taxation [COMET]), the study finds that a 2.5°C warming by 2050 scenario would increase total national public health care expenditures by 0.41 percent because of extreme heat (Barrage, 2020).\(^3\) Barrage (2020) also uses the COMET model to estimate the overall impact of climate change on the federal budget, incorporating the extreme heat impact on health care spending along with the impact of other climate hazards on other spending programs and revenue. The study finds that climate change is projected to increase spending on the services the government provides (e.g., health care, wildfire suppression support,

---

\(^2\) It is also important to note that Medicare and Medicaid provide coverage for nearly all the elderly in the United States and a large number of children. Thus, federal health spending is likely to be acutely affected by climate change.

\(^3\) According to the Centers for Medicare & Medicaid Services, the National Health Expenditure in 2021 was $4.3 trillion, and the federal government’s share of that was 34 percent. So, 0.41 percent of federal health care spending would be about $6 billion in 2021 dollars.
hurricane direct response aid) by 1.45 percent and income support programs by 0.3 percent by 2050 in a high emissions scenario. Health care costs account for the majority of the projected cost increase.

Modeling the Impacts of Climate Change on Health Care Spending

Modeling the impacts of climate change on federal health care expenditures requires detailed data on climate hazard intensities and frequencies (historical and projections into the future) and historical health care outcomes. One open-source tool that merges these types of data and allows users to calculate the economic costs of climate change is FrEDI (EPA, 2021). The tool allows users to estimate the total morbidity costs—including the costs of hospitalizations and loss of productivity—under a variety of climate scenarios. The federal government will not be responsible for the total costs of morbidity because of climate change because some costs will be borne by individuals and businesses. Payer-share ratio data is available from the Medical Expenditure Panel Survey and show the source of health care expenditures paid by private insurance, public funds, and by individuals out-of-pocket. Assuming constant payer-shares into the future, the portion of total morbidity costs paid by federal programs can be estimated from FrEDI’s output by applying the federal government’s current share of total health care expenditures. This process of estimating the impacts of climate change on federal health care costs is used in OMB’s analysis of climate change’s impact on the federal budget (OMB, 2022).

One way these approaches could be modified is by allowing for greater substitutability between outdoor labor and capital. If technological advancements augment or replace human labor in outdoor work that is highly exposed to climate risk, future health care costs might not rise as much. Detailed occupation-level task data from the U.S. Department of Labor could provide insights into how many workers are currently exposed to climate drivers that negatively affect health outcomes because of a significant component of outdoor work in their daily jobs. Testing the impact of potential changes in worker exposure on model predictions of health care costs could expose areas where additional research is required to fully understand the future impacts of climate change on federal health care spending.

Effects on Social Security

Social Security made up 14.3 percent of FY 2022 federal budgetary spending. The program, which provides retirement, disability, and survivor benefits, is expected to grow as the U.S. population ages over the coming decades (CBO, 2022e). Climate change might put additional stress on the program. Not only is climate change expected to worsen health outcomes for vulnerable populations, including senior citizens (Reidmiller et al., 2017), but it might also increase unemployment. For instance, the International Labor Organization estimates that the heat stress could cost the United States nearly 400,000 (full-time equivalent) jobs by 2030, mostly because of reduced working hours and lost labor productivity in outdoor work, such as construction and farming (International Labor Organization, 2019). Empirical evidence has found a link between unemployment and benefit claiming: During economic downturns, workers are more likely to claim retirement benefits earlier (Coile and Levine, 2011) or to claim disability benefits more frequently than they otherwise would (Autor and Duggan, 2003). Given the results in these studies, the impact of climate change on employment might add to the strain on the Social Security program if younger workers claim retirement benefits earlier because of additional negative employment outcomes.

The existing literature has paid little attention to the potential impact of climate change on the Social Security program. A 2016 OMB assessment of the impact of climate change on the federal budget does not discuss the impact of climate change on Social Security (OMB, 2016). CBO reports that Social Security costs are expected to grow if people retire earlier or disability rates increase in response to climate change (CBO, undated-a). However, the report does not provide an estimate of how much the program is expected to change over the next century. Changes in mortality that arise from climate change will also affect the
Old-Age, Survivors, and Disability Insurance program. At the same time, increased morbidity and illness because of climate change might increase the use of disability insurance. The overall net effect of climate change on the program is unclear because this subject has not been adequately studied. CBO’s assessment of the impact of climate change on economic output does not address Social Security (CBO, 2021). CBO’s assessment of the impact of climate change on economic output also does not address that, under its current trajectory, the Social Security program is facing long-term financing shortfalls, which could result in reductions in scheduled benefits (Social Security Administration, undated; Huber, 2022).

Modeling the Impacts of Climate Change on Social Security
While the literature has yet to focus on Social Security, its large share of the federal budget means that Social Security must be addressed when forecasting the potential impact of climate change on the budget. Modeling the impact of climate change on Social Security might require new methods and approaches to better understand the interaction between the aging U.S. population, internal migration, and exposure to climate hazards. For instance, population-aging forecasts can be used to estimate the overall growth of program expenditures. The challenges that the aging population creates for the Social Security program has been documented in the literature (Reznik, Shoffner, and Weaver, 2005/2006). Forecasting the difference in regional and national aging profiles for scenarios with and without climate change would allow for an analysis of climate exposure of those using Social Security. For instance, the aging population in Florida is likely to become more exposed to hurricanes as these storms intensify over the next century. Depending on the interaction between a climate hazard and morbidity and mortality, the relationship between climate change and Social Security expenses could be positive or negative.

Effects on Income Security and Means-Tested Programs
The federal government provides several income security programs. In FY 2022, these various income security programs made up 9.7 percent of federal expenditures, making them the fifth largest source of federal spending (USASpending.gov, undated). The individual programs that fall under the income security umbrella range from programs designed to provide food and nutrition assistance, housing assistance, unemployment insurance, and supplemental security income, as well as tax credits, such as the Child Tax Credit and the Earned Income Tax Credit. Many of these programs are designed to help low-income households with expenses, and many are means-tested, which means that they are available only to individuals and families with income or assets below specified limits.

The impact of climate change on income security programs will likely depend on their varying requirements and thresholds, as well as the intensive and extensive margin of program utilization. For example, an intensification of climate hazards leading to higher unemployment rates could result in increased use of income security programs as more workers become eligible for benefits (the extensive margin). Conversely, the benefits of certain programs are contingent on worker income, so a negative climate shock causing a decline in wages could lead to an increase in program spending among existing program users (the intensive margin).

The various eligibility thresholds used across federal income security programs imply that analyzing the impact of climate change on income security programs requires a detailed analysis at the individual program level. However, changes in labor productivity, employment, and wages are all likely to play a role in determining the overall impact. While little research assesses the potential impact of climate change on the use of these income security programs, many studies provide evidence of a link between climate hazards and labor market outcomes. For instance, Belasen and Polacheck (2009) point out that hurricanes can cause a negative shock to labor supply in affected regions as workers move (temporarily or permanently) out of the area. On the one hand, the negative labor supply shock may push up wages, even if labor demand remains
constant. Labor demand in affected regions may grow as regions rebuild, which increases demand for workers to fill new jobs in reconstruction, and firms try to fill vacancies resulting from workers moving out of the region (Belasen and Polachek, 2009). On the other hand, labor demand might fall if employers move out of the affected region. In an empirical exercise, Belasen and Polacheck (2009) find that hurricanes have opposing effects on labor supply and labor demand. The authors find that employment falls in affected regions while wages rise. However, in neighboring unaffected regions, wages fall, and employment remains relatively unchanged. The authors note that these findings can help policymakers assess unemployment insurance eligibility issues. Similar results are found by Groen, Kutzbach, and Polivka (2020).

The research findings of Belasen and Polacheck (2009) and Groen, Kutzbach, and Polivka (2020) provide insight into the intricate relationship between climate change and labor market outcomes and their potential impact on spending for income security programs. Notably, the effects of climate change on employment and wages have implications for income security programs, making it challenging to anticipate their impact with certainty.

To illustrate, consider the impact of hurricanes. In regions affected by hurricanes, a decrease in employment could result in a higher number of workers qualifying for income security programs. However, an increase in wages could result in a decrease in the benefits to which workers are entitled. Furthermore, although income support spending would decline because of the benefits from rising wages overshadowing the effects of falling employment, a decrease in wages in neighboring regions could lead to an increase in benefits for workers in areas near the affected region. The impact of climate change on income is expected to vary widely across the nation: Some regions are subject to hurricanes, while others are subject to wildfire, and different types of disasters will have different impacts on income, which makes it difficult to predict their overall effect on income security programs.

Other studies focus on how climate hazards affect worker productivity. Declining labor productivity could have far-reaching impacts on the economy. Without adaptation, climate-induced disruptions to work activities might reduce industrial capacity, leading to lower output and job losses. For instance, the National Climate Assessment notes that over 500 million labor hours could be lost due to extreme heat in the U.S. Southeast by 2090 (Carter et al., 2018). This loss would negatively affect the industrial activity, worker earnings, and local poverty incidence. As a result, productivity declines from climate change might result in an increased use of federal income support programs.

Studies in this literature consistently find that climate hazards reduce worker productivity and thus reduce wages (Reidmiller et al., 2017). For instance, Behrer et al. (2021) finds that one additional hot day (temperatures above 90°F) reduces annual payroll by 0.04 percent. This is equivalent to 2.1 percent of average weekly earnings for workers. The authors also find the impact of extreme heat on wages is smaller in wealthier areas, suggesting that extreme heat might worsen economic inequality. While Behrer et al. (2021) states that they are unable to identify a specific mechanism driving this result, the finding is consistent with hot temperatures making working conditions uncomfortable. Cachon, Gallino, and Olivares (2012) finds extreme heat can reduce labor productivity even in indoor settings. The study finds that a week with six or more extremely hot days (above 90°F) reduces production in U.S. automobile manufacturing plants by 8 percent, on average, and that lost production does not appear to be recovered weeks after the event. Hsiang et al. (2017) estimates that total labor hours supplied declines by 0.1 percent per degree of warming for workers who work indoors and 0.5 percent per degree of warming for workers directly exposed to weather in their line of work.

Other research establishes a negative relationship between climate hazards and overall economic output, suggesting that climate change might influence economic opportunities for workers while it negatively affects national economic activity. For example, Hsiang and Jina (2014) finds that hurricanes reduce long-run GDP, years after they make landfall. This suggests that climate change might permanently alter economic growth.
trajectories. The authors attribute this change to the continued destruction of productive capital and the inability to fully recover after successive storms.

Overall, the existing research suggests that climate change might increase demand for income security programs in some situations. However, as discussed previously, the relationship between labor supply, wages, and income security program use is complicated. Climate change's impact on program spending will likely depend on the interaction between climate hazards and the intensive and extensive margin of program use. While some evidence suggests that climate change might increase program spending, the literature is mostly silent on the extent to which this might drive up the federal costs of providing income security. One exception is the recent report on climate change by CBO, which states that unemployment insurance costs will likely grow as climate change displaces workers in local labor markets and reduces economic growth across the country (Beider, 2021). While the report does not discuss potential mechanisms, the loss of labor productivity and long-term effect on economic growth might cause firms to restrict hiring, resulting in higher unemployment rates and greater use of unemployment insurance.

Modeling the Impacts of Climate Change on Income Security Programs
To model the effect of climate change on income security programs, it is necessary to estimate how it will affect various factors, such as labor supply, employment, wages, and worker productivity. Additionally, it is crucial to examine how climate change could alter the eligibility criteria for these programs. For example, as explained in Box 2.1, there are various ways in which climate change could affect the usage and expenditure of the Supplemental Nutrition Assistance Program (SNAP). Although climate change's impact on the labor market could affect most income security programs, predicting the extent of changes in program spending is difficult. Furthermore, research shows that climate change's impact on economic activity might

---

**BOX 2.1**

**Climate Change and the Supplemental Nutrition Assistance Program**

SNAP is the largest federal food assistance program and one of the largest means-tested programs in the United States (Landers et al., 2021). In FY 2022, SNAP provided benefits to 12 percent of U.S. households, according to estimates from the Center on Budget and Policy Priorities (Center on Budget and Policy Priorities, 2023).

To be eligible for SNAP benefits, individuals or household must meet specific criteria. For instance, the following are some important criteria:

- The household’s gross monthly income must be at or below 130 percent of the federal poverty level. The federal poverty level used in this calculation depends on the family size.
- The household must have limited resources, such as money in a bank account. These limits vary by state and by household size.
- The household might need to meet work requirements, including not voluntarily reducing hours or leaving a job or participating in employment and training programs if required by the state.

Climate change could affect the use of SNAP in various ways. For example, in regions where heat waves are intensifying, individuals might lose employment or wages (Reidmiller et al., 2017), making more households eligible for SNAP benefits. Conversely, in other regions, such as the Northwest, warmer temperatures could improve economic conditions and reduce the number of eligible households (Hsiang et al., 2017). Additionally, as climate change affects global crop production and food prices, the benefits provided by SNAP might need to increase to ensure eligible households can purchase nutritious food (Brown et al., 2015). SNAP usage has also been shown to increase after hurricanes and therefore will likely be used more as hurricanes intensify because of climate change (Food Research & Action Center, undated).
vary by region (Hsiang et al., 2017). Coupled with the fact that U.S. states have discretion in designing and implementing eligibility thresholds for some income security programs, regional differences in the impact of climate change necessitate assessing subsequent changes in program spending at a regional level. These regional-level impacts should then be aggregated to the national level to better understand the overall impact on federal program spending.

**Effects on Crop, Flood, and Mortgage Insurance**

Various federal insurance programs, which typically reimburse private insurance providers for administrative costs or subsidize premiums paid by policyholders, or both, have been studied extensively in the climate change literature. This section discusses the potential impact of climate change on three such programs: crop insurance, flood insurance, and mortgage insurance. These programs are funded with mandatory federal spending, but their current share of the federal budget is relatively small. For instance, Federal Crop Insurance—one of the larger insurance programs—made up 0.5 percent of FY 2022 federal budgetary expenditures (USASpending.gov, undated).

Nonetheless, the literature suggests that the size of these programs is expected to grow over the next century because of climate change. For instance, OMB (2016) estimates that the federal costs of subsidizing crop insurance for farmers could increase by billions of dollars per year because of the effects of climate change. Across five climate models, OMB finds that crop insurance subsidies are likely to increase by over 60 percent for soybeans, almost 40 percent for corn, and roughly 10 percent for wheat by 2080, assuming the average portion of total premiums paid for by the government does not change from its current level. These changes account for shifting fertility zones that might cause crops to become more viable in new regions. In its assessment of climate change’s impact on the federal budget, CBO finds that the costs of agricultural support programs will likely increase, even while growing seasons expand in some locations (Beider, 2021). The report states that drought, floods, crop diseases, and pests are expected to grow or intensify (or both) over the next century, resulting in greater agricultural loss and increasing federal insurance expenses.

The costs of other forms of federally backed insurance are also expected to grow. For instance, the National Flood Insurance Program (NFIP) will likely see an increase in claims due to climate change’s impact on coastal flooding, inland flooding, and hurricane storm surge (CBO, 2016). The infrastructure consulting firm AECOM estimates that the average NFIP loss cost would increase by 50–90 percent by 2100, primarily because of climate change (AECOM, 2013). However, as noted in the OMB (2016) report, recent changes to the NFIP could reduce the estimated impact on the program. Specifically, NFIP’s pricing methodology has changed and is expected to result in nearly 25 percent of NFIP policyholders seeing premiums decrease (U.S. Department of Homeland Security, 2021).

Mortgage insurance programs might also see increased expenditures under climate change. CBO notes that Freddie Mac and Fannie Mae, which provide mortgage guarantees valued at $16 trillion (Colman, 2020), could see increased default risks and losses as wildfires and floods threaten residential properties. Estimates of how much these government-backed mortgage costs might grow are not provided by CBO (2021) and were not evaluated in OMB (2016), which suggests that this is another area of the literature where further analysis is required.

---

4 Barrage (2020) uses results from OMB (2016) and estimates that crop insurance costs will increase by 14 percent per 1°C of warming.
Modeling the Effects of Climate Change on Crop, Flood, and Mortgage Insurance

While crop and flood insurance has been analyzed, the impact of climate change on mortgage insurance markets is relatively understudied. Modeling the change in Fannie Mae and Freddie Mac expenditures that result from climate change could involve evaluating trends in the housing market to determine the growth in exposure of these lending programs to climate risks. Additionally, if insurance rates that adjust for growing climate risks incentivize population migration away from highly exposed regions (though there is limited evidence of this occurring), the financial burden of climate change on the federal mortgage guarantees would be mitigated in the long run.

Effects of Climate Change on Discretionary Spending

Discretionary spending refers to spending programs funded yearly by Congress through the appropriations process. In FY 2021, discretionary spending comprised 23 percent of overall federal spending (CBO, 2022c; National Priorities Project, undated). The plurality of discretionary spending is related to national defense, but other programs include early childhood education programs, housing programs, food assistance, and job training. Because the amount of funding for discretionary programs varies yearly based on congressional priorities, modeling the impact of climate change on discretionary spending must rely on assumptions about the share of funding received by programs, the potential creation of new programs, and inflation rates. CBO’s method for forecasting discretionary spending time paths assumes current appropriations extend into the future, while accounting for overall budgetary caps and automatic reductions put in place by the Budgetary Control Act of 2011 (CBO, undated-a).

Within discretionary spending, we focus on defense spending because it makes up the largest share of discretionary expenditures. Additionally, we discuss the impact of climate change on federal disaster relief programs. While the overall budget share of federal disaster relief is small—only 0.5 percent of federal spending in FY 2022 (USASpending.gov, undated)—it is particularly relevant to climate change because this spending is a direct response to climate drivers.

Effects on Defense Spending

Defense spending accounted for 13.1 percent of the federal budget in FY 2022, making it the second largest spending category after health care. Defense spending is the largest component of discretionary spending, making up over 46 percent of discretionary spending in FY 2021 (USASpending.gov, undated). Climate change has multiple implications for national security and will likely change federal spending on defense. For instance, climate hazards, such as hurricanes and floods have resulted in billions of dollars of damage to U.S. Department of Defense (DoD) installations (Feima and Werrell, 2022). International geopolitical instability driven by drought, extreme heat, and other climate hazards increases external threats to U.S. security (Allen and Jones, 2021); such instability might also increase discretionary spending on national defense.

Several studies have estimated the impact of climate hazards on damage to DoD assets and installations. The literature suggests that climate change will likely increase the costs of rebuilding after hurricanes, floods, and wildfires (Baldwin, 2021; Gade et al., 2020). For instance, Gade et al. (2020) develops a DoD Climate Assessment Tool and uses it to evaluate the exposure of DoD assets to various climate hazards, both within the United States and globally. The tool allows users to assess the vulnerability of various DoD installations, providing flood mapping analyses and hurricane exposure based on incidence and future climate projections. Gade et al. (2020) finds that climate change exposure is growing across many installations and across warming scenarios. For example, Hurricanes Florence and Michael in 2018 caused $3.6 billion and $4.7 billion in damage to DoD installations, respectively (Eversden, 2021).
Modeling the Impacts of Climate Change on Defense Spending

A 2023 RAND report devises a new method of quantifying the climate impacts on DoD installations (Narayanan et al., 2023). The method relies on geospatial data from DoD on the position of assets within installations. These files contain data on asset class (building, wharf, road and bridge, etc.) as well as the asset’s value and physical footprint. These data are compatible with the Federal Emergency Management Agency (FEMA) simulation-based software Hazus. Once loaded into Hazus, the DoD installation data can be used to simulate the damage costs of hurricanes, storm surge, and inland flooding. Combined with forecasts of hazard intensification from climate change, the resulting damage estimates can be appropriately scaled to capture the implications of climate change–related damage at DoD installations. The report analyzes several climate drivers and potential resilience options, finding that resilience begins to provide net benefits (over rebuilding) as climate drivers become more frequent and more intense but that the net benefits vary across installations. For example, analysis suggests that six feet of building floodproofing on all installation buildings could provide positive net benefits under current flooding probabilities at Naval Station Norfolk but would require flooding to become 18 times more frequent to provide positive net benefits at Naval Weapons Station Yorktown. While research points to a strong statistical relationship between climate and geopolitical instability and violence (Hsiang, Burke, and Miguel, 2013), no study has attempted to quantify this potential impact of climate change on defense spending. This may be due to the difficulty assigning specific mechanisms, as climate influences several factors that are likely to contribute to instability and violence.

Effects on Nondefense Spending

Outside of defense-related spending, discretionary spending includes several education, health, transportation and economic development, and research programs. Discretionary spending also includes federal assistance to states following natural disasters. While these programs are relatively small compared to defense spending, together, these programs comprised 53 percent of total discretionary spending in FY 2021 according to data from USA Spending (USASpending.gov, undated). While our focus is on larger spending programs, an immediate impact of climate change on nondefense discretionary spending is through federally funded disaster aid following hurricanes, flooding, and wildfires. These climate hazards are expected to intensify over the coming century (Reidmiller et al., 2017), which will likely put increased pressure on federal aid programs. Disaster-related programs receive appropriations spending yearly. The amount of funding, how the funding should be allocated, and conditions on how aid funding can be spent vary on a case-by-case basis (CBO, 2016). FEMA disaster relief funds have accounted for 45 percent of all hurricane-related discretionary spending over the past 15 years, and the bulk of this spending has come in the form of public assistance aid (CBO, 2016).

CBO has estimated the potential impact of hurricane damage on the federal aid response using statespecific estimates of hurricane exposure. These exposure measures are based on estimates of the distribution of hurricane frequencies and sea-level rise over the next century (CBO, 2016). Using historical data, CBO’s method involves creating a damage function that relates hurricane intensity to physical damage. Then, the damage function is applied to simulated potential future hurricane frequencies and state-level sea-level rise scenarios. To determine the cost to the federal government, CBO assumes that federal spending remains at 60 percent of the total hurricane damage. While CBO does not address other climate hazards, a similar approach can be taken to understand the impact of flooding and wildfires on federal disaster aid.

According to CBO analysis of the FEMA Disaster Relief Fund, appropriations in the past few years have been higher than ever before except for the appropriations for Hurricane Katrina in 2005. See CBO, 2022d.
Apart from federal disaster aid, climate change might alter the demand for other government services provided with discretionary spending. While outside the scope of this report, federal programs that support transportation, energy, housing, and education will likely be affected by climate change. For instance, Hurricanes Katrina and Rita increased federal spending on emergency aid for displaced students (U.S. Government Accountability Office, 2011). Hurricane intensification under climate change might increase demand for federal aid to students and schools while households adjust to the physical damage caused by these storms.

Modeling the Effects of Climate Change on Federally Funded Disaster Aid

While the CBO has developed methods for projecting future federal disaster aid spending in response to hurricanes, the impact of other climate drivers is less studied. For instance, using the CBO methods, a similar analysis could be conducted analyzing how wildfire intensification under climate change might influence disaster aid spending. Incorporating estimates from a climate-economic model with subnational resolution would also provide a more comprehensive evaluation of the potentially exposed population in any region. For example, a climate-economic model could account for broader changes in macroeconomic activity, regional economic opportunities, and local climate conditions that influence migration decisions. By incorporating federal disaster aid into a climate-economic model, the model can account for how populations respond to economic and climate conditions when choosing where to live, thereby affecting the projected change in federal disaster aid expenditures because the underlying population exposed to a given climate driver would respond dynamically.

Effects of Climate Change on Revenue

The vast majority of federal revenue comes from individual income and payroll taxes. In 2022, receipts from income taxes totaled 10.5 percent of GDP, payroll taxes totaled 5.9 percent, corporate income taxes totaled 1.7 percent, and receipts from other sources totaled 1.4 percent of GDP (CBO, 2023a). These values are subject to change depending on changes to U.S. tax law and the strength of tax collection, among other factors. For the purposes of this analysis, we will assume that the proportions of revenue sources stay constant and that revenues will primarily be affected through changes in GDP.

The following subsection provides an overview of how climate-economic modeling is typically conducted and gives the benefits and drawbacks of the common approaches. Because of numerous uncertainties in conventional climate-economic modeling, including human behavioral adaptations, the second subsection addresses how these uncertainties can influence modeling projections. Finally, the financial system and private firms will have a substantial role to play in the economic impacts of climate change. The final subsection will discuss the economic risks involved in the transition to a greener economy.

Modeled Effects on Gross Domestic Product: Market-Based Approaches

If climate change does not abate, it will cause revenue losses if there is less taxable output. The reported impacts of climate change on GDP vary widely and are highly dependent on the method of analysis (e.g., macroeconomic or sector-level), such key inputs as the climate sensitivity or the discount rate (see Chapter 4), and whether adaptations or system thresholds are included in the analysis. Broadly speaking, macroeconomic

---

6 CBO has published some analysis on the historical costs of wildfires but has not yet published on the methods for projecting the federal costs of wildfires (CBO, 2022c).

7 According to a 2022 report from OMB, a high warming scenario that reduced GDP by 10 percent by the end of the century could result in a loss of federal revenue of approximately 7 percent (OMB, 2022).
analyses (also referred to as *top-down models*) tend to report smaller losses in GDP than microeconomic or sector-level analyses (also referred to as *bottom-up models*), while studies that consider nonlinearities in the human-Earth system show the largest losses overall (Burke, Hsiang, and Miguel, 2015). Unless otherwise noted, all climate-economic assessments project climate change to cause net losses to the economy. As the values of these losses are highly variable and dependent on a myriad of input assumptions, we will focus on providing an overview of the types of models, their strengths and weaknesses, and their general characteristics that lead to higher or lower damages.

**Aggregated Models of the Macroeconomy (Top-Down)**

Top-down models of the economy provide an aggregated representation of market mechanisms. These types of models can capture the feedbacks among welfare, economic growth, and employment and are therefore able to model adaptations to exogenous shocks, reducing their overall impact. By representing the economy as a system of equations, researchers can assess the persistence and long-term effects of climate shocks through different economic channels. Piontek et al. (2019) stress test a macroeconomic Ramsey-type growth model using one-time unanticipated shocks and anticipated recurring shocks to understand their respective effects on output, capital, labor, and labor productivity. They find that while climate shocks through different channels may have the same immediate effect on GDP, the persistence of the impacts is a crucial factor in determining the cumulative impacts of the shock. For example, a shock to labor productivity (e.g., from a lasting trend in more extreme heat days) will have a much longer persistence than the economic shock observed from an acute natural disaster (Piontek et al., 2019). Their analysis also points to the importance of assessing the impact of climate change on economic growth in addition to one-time shocks to GDP.

Simple integrated assessment models (IAMS)—such as the Dynamic Integrated Climate-Economy (DICE) model, the Climate Framework for Uncertainty, Negotiation, and Distribution (FUND),⁸ and the Policy Analysis of the Greenhouse Effect (PAGE)—rely on macroeconomic growth equations and damage functions that relate hydroclimatic changes (such as increases in temperature) to economic damages. These models are typically used in an optimization framework so that costs of abatement are equal to damages from climate change. They are commonly criticized for their disproportionate influence on policy analysis with respect to their simplistic structure and the sensitivity of their output to highly uncertain parameters and methodological choices (Pindyck, 2013).

CGE models (e.g., REMIND, MESSAGE, IGSM) are a category of more complex top-down IAMS that model the economy by solving for the optimal vector of prices in all markets where supply is equal to demand. Because all markets are cleared simultaneously, CGE models can represent secondary and tertiary market responses to exogenous shocks.⁹ As with other neoclassical economic models, CGE models generally assume agents (households and representative firms) are rational, have access to perfect information, and take actions to maximize utility. Because they rely on homogeneous agents or only a few classes of agents, these models cannot capture the variability in the underlying population and are not well suited to modeling population distributions or inequality. Critics of traditional neoclassical models point to their restrictive assumptions and instead advocate for approaches that allow agents to differ in their objectives and beliefs and to take adaptive actions in response to outcomes created by the cumulation of each agent’s decisions (Arthur, 2021).

---

⁸ The FUND model projects net gains to the global economy from 2°C of warming. These gains are primarily because of additional arable land from increased warming in northern climates.

⁹ REMIND = Regional Model of Investment and Development; MESSAGE = Model for Energy Supply Strategy Alternatives and their General Environment Impact; IGMS = Integrated Global System Model.
Sector Level Models (Bottom-Up)

Sector-level, or bottom-up, models provide a more detailed representation of technologies than top-down models and are generally focused on representing specific sectors through physics-based rather than economic-based approaches. The distinction between top-down and bottom-up models is typically made according to the intent and scope of the model. While most CGE models attempt to capture the economy as a whole, sector-specific models, such as power systems models, use physically based constraints to model a specific system. Power system models are often used to quantify the emissions from specific energy sources (see Chapter 3) and can be linked to other sector-specific models to assess the impact of those emissions.

Hsiang et al. (2017) conduct a sector-level analysis to examine the effects of climate change on agricultural production, coastal damages, energy expenditures, labor supply, crime, and mortality. The authors calculate energy expenditures using the National Energy Modeling System (NEMS) forced with different weather realizations, cyclone exposures using analytical wind field models alongside a database of coastal properties maintained by Risk Management Solutions, and the remaining sectoral impacts by generating dose-response functions from a Bayesian meta-analysis. The authors found that at temperature increases above 2.5°C, increases in mortality induced the largest losses to GDP followed by losses in the supply of labor (Hsiang et al., 2017). Health impacts generate the largest damages to overall GDP from climate change. Hotter temperatures place high-risk workers in danger of heat-induced mortality, can shorten the number of hours spent working outside, and reduce the productivity of working hours (see Figure 2.1). Hotter temperatures also increase the frequency and severity of wildfires and the resulting particulate matter (PM) in the atmosphere that contributes to respiratory illness.

Key Modeling Points

In both spending and revenue categories, the economic damage from climate change is estimated to be the highest in the health sector. Extreme heat will affect productivity, labor hours, and overall morbidity and mortality. It is therefore necessary to model key inputs to these metrics, such as age and income in different geographic regions. This is necessary to determine the number of people covered by major spending programs and to estimate the health risks associated with increasing temperature and levels of pollutants in the atmosphere. The magnitude of uncertainties in changes in spending and revenue associated with climate change impacts in the health sector overshadow the economic consequences of many other sectoral risks, such as agriculture or transportation. Thus, while an ideal model would capture the interplay between all

**FIGURE 2.1**

Example Pathways of Budgetary Impact Because of Increases in Extreme Heat

<table>
<thead>
<tr>
<th>Climate hazard</th>
<th>First-order impact</th>
<th>Macroeconomic impact</th>
<th>Budgetary impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extreme heat</td>
<td>Morbidity and mortality</td>
<td>Total outdoor labor hours</td>
<td>Decrease in revenue</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Productivity</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Increase in spending</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Increase in spending</td>
</tr>
</tbody>
</table>
sectors affected, it is most practical to first focus on reducing uncertainties in the sectors with the highest-magnitude impacts.

Projections of emissions at the subnational level can be obtained through power system models that represent the energy system using a bottom-up approach. However, solely modeling the energy system through technologies will miss dynamics that occur in the broader macroeconomy, such as substitutions between labor, capital, and energy. It is therefore advantageous to couple a bottom-up energy model with a macroeconomic model (see Table 2.1). Specifically, using an agent-based macroeconomic model would better capture distributional effects in the economy.

In addition to the recommendations provided previously, a successful climate-economy model should represent the risk associated with transitioning to a greener economy along with the physical risks discussed in this chapter. These risks are discussed further in the following chapter.

### TABLE 2.1
**Current State of Work, Gaps, and Recommendations**

<table>
<thead>
<tr>
<th>Action</th>
<th>Current State of Work and Gaps</th>
<th>Recommendations for Modelers</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Use a climate-economic model for baseline budget projections.</td>
<td>CBO quantifies economic damages from changes in temperature and precipitation based on a Bayesian meta-analysis of damage functions as well as damages from hurricanes to calculate reductions in Total Factor Productivity from climate change.</td>
<td>Use a climate-economic model (preferably a top-down macroeconomic model coupled to a bottom-up physics-based energy system model) to quantify the changes to federal spending and revenue across different sectors because of climate change.</td>
</tr>
<tr>
<td>• Represent distributional (geographic, economic, sectoral demographic) information when projecting future health impacts of climate change.</td>
<td>CBO does not model damages to specific sectors (e.g., health).</td>
<td>To capture the variable effects of climate change across the population, the model should operate at a subnational resolution; take inputs on geographic location, age, and income; and output metrics that affect morbidity and mortality estimates (thus influencing health care and income security spending as well as revenues), such as emissions and pollutant concentrations.</td>
</tr>
<tr>
<td>• OMB modeled the impacts of climate change on federal spending on health care, crop insurance, disaster relief because of coastal storms, and flood risk at federal facilities but does not include this analysis into budget projections. However, since OMB uses a structural econometric model grounded in macroeconomic theory to generate its budget forecasts, climate change impacts influence projections to the extent they have affected economic productivity in the past.</td>
<td>OMB modeled the impacts of climate change on federal spending on health care, crop insurance, disaster relief because of coastal storms, and flood risk at federal facilities but does not include this analysis into budget projections.</td>
<td>OMB is researching climate-economic models to use in budget projections.</td>
</tr>
</tbody>
</table>
The Economic, Environmental, and Social Effects of Climate Change Mitigation Policies

As described in Chapter 2, the economy and climate are dynamic systems in which changes in the climate affect the economy and vice versa. This chapter explores how federal outlays to mitigate climate change (i.e., climate change mitigation policies) affect emissions, employment, water use, energy consumption, and other outcomes that concern policymakers. In Figure 1.1, the pathways discussed in this chapter can be seen by moving from left to right: the federal government proposes some climate change mitigation policies and budgets that will affect spending and taxation in different ways. These changes will affect the economy (e.g., through employment) and result in reductions in emissions over time, which will ultimately affect the climate. Because the direct monetary costs of these policies are included in budgetary analyses, this chapter instead focuses on the indirect and nonfiscal benefits that would ultimately feed back into the federal budget.

Climate change mitigation policies ultimately aim to reduce GHG emissions that contribute to climate change by influencing and managing activities that typically emit or sequester these gases. Approaches might reduce the amount of carbon emitted per unit of energy consumed by changing the mix of energy sources or reduce the amount of energy used per dollar of GDP (Popp, 2010). Climate change mitigation policies are likely to aim at one or more of the highest contributing economic sectors, including the transportation (27.3 percent), electric power (24.9 percent), industry (23.9 percent), agriculture (10.7 percent), commercial (7.1 percent), and residential (6.1 percent) sectors (EPA, 2022).1

While all policies—including those not developed with climate change mitigation in mind—are likely to affect GHG emissions, this chapter focuses on policies specifically designed for climate change mitigation. It should be noted that the CBO currently assesses monetary benefits and costs in terms of tax revenue and expenditures of mitigation policies, respectively. Expenditures include administrative costs, as well as those to fund grants, loans, incentives, contracts, and the programs themselves. For example, the CBO and Joint Committee on Taxation estimate the total cost of the Inflation Reduction Act (IRA) to be $392 billion over ten years, with $121 billion attributed to direct federal spending and $271 billion attributed to incentives and subsidies (CBO, 2022a, as cited by Bistline, Mehrotra, and Wolfram, 2023). The Electric Power Research Institute has also modeled the bill, estimating the incentives portion will cost $780 billion by 2031 (Bistline, Mehrotra, and Wolfram, 2023), which demonstrates how model results can vary by almost a factor of three and that actual costs will depend on their uptake. However, most budgetary analysis of the IRA does not account for the indirect and nonfiscal benefits. The more successful the incentive-based bill is in terms of household and firm participation, the more important understanding nonfiscal and indirect fiscal benefits will become.

The literature we focus on includes both existing and proposed climate mitigation policies. In light of recent policy direction, we focus on approaches to climate mitigation policy that include regulations and standards and technology subsidies with some treatment of carbon pricing across both (summarized in

---

1 The reported proportions are based on U.S. data and might differ in other countries.
Table 3.1). First, on carbon pricing, we discuss interactions between carbon pricing and other mitigation policy as it emerges in the literature. Second, on regulatory policies, we center on impacts from standards in the power sector, expanding on different impacts and how they are measured, including outcomes for emissions, health, jobs, household energy expenditures, and water use. And third, on subsidies and incentives, we focus on their role in transitioning sectors to cleaner, low-to-no carbon technologies and how tax incentives in particular have been evaluated for research and development (R&D), power generation, and the transportation sector (see Appendix C). Overall, evaluations of regulatory policies tend to measure GHG emissions and health outcomes compared with evaluations of incentives and subsidies, which focus more on behavior change and technology adoption. This is partly because regulation and standards more directly aim to address emissions, while the immediate goals of incentives and subsidies are to change a behavior among actors that is expected to change emissions. Our approach follows a traditional literature review in that we select search terms along two sets of literature: In one, we searched for literature that evaluated recently proposed or adopted climate change mitigation policies (e.g., IRA, Build Back Better Act, Clean Energy Standard Act), and, in the other, we searched for well-cited scientific articles assessing climate change mitigation strategies more generally (e.g., comparing empirical results across different scenarios). Among the literature found, we focused on studies that helped us understand how climate change mitigation policies might be evaluated and how modeling approaches might be used.

Treatment of Carbon Pricing in This Chapter

*Carbon pricing* applies a direct monetary value on each ton of carbon emitted. In an ideal setting (at least to economists), the carbon price would be equated to the social damages caused by an additional ton of emissions (because of rising sea levels, crop loss because of changing rainfall patterns, health care costs associated with wildfires and heat waves, etc.). This is often referred to as the *social cost of carbon* (SCC). This estimate, however, is highly uncertain and varies considerably across modeling approaches: Most active carbon pricing programs and various carbon pricing proposals over the past few years are not directly tied to estimates of the SCC. The two main carbon pricing policy instruments are a carbon tax and a cap-and-trade system, often

---

**TABLE 3.1**

<table>
<thead>
<tr>
<th>Policy</th>
<th>Description</th>
<th>Examples We Describe in This Chapter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon pricing</td>
<td>Applies a direct monetary value on the amount of carbon emitted</td>
<td>Emissions trading system (ETS) and carbon tax</td>
</tr>
<tr>
<td>Regulation and intensity standard</td>
<td>Requires meeting a target on the overall emissions intensity or a minimum share of low- and zero-carbon electricity sources</td>
<td>Clean energy standard (CES) or renewable portfolio standard (RPS)</td>
</tr>
<tr>
<td>Subsidizing and incentivizing clean technology</td>
<td>Reduces the cost of developing or adopting a clean technology by giving money in the form of subsidies or reducing tax liability through tax incentives</td>
<td>R&amp;D grants and tax credits, production tax credit (PTC), investment tax credit (ITC), 45Q tax credit, plug-in electric drive vehicle tax credit, alternative motor vehicle tax credit</td>
</tr>
</tbody>
</table>

---

2 In 2022, the EPA released its latest estimate of the SCC of $190 per ton of CO₂. Meanwhile, the carbon allowance prices in the Californian cap-and-trade program have been below $35 per ton for the past decade, and the northeastern states’ Regional Greenhouse Gas Initiative had an all-time high allowance clearing price of $13.90 per ton recorded in June 2022.
referred to in this context as an ETS. A carbon tax sets a tax rate on carbon emissions, or the carbon content of fossil fuels being used, and directly affects the budget. An ETS places a cap on the total level of emissions allowed and distributes allowances across a set of producers, which can then be traded to maintain that total level. The ETS might or might not have a significant budget effect depending on how the allowances are allocated to firms (i.e., auctions or free allocation). An important difference in these instruments is that the latter sets a known reduction target when it sets a cap, while reductions for the former are dependent on firm response to the tax. A hybrid approach could look like a carbon tax scheme that accepts emissions reductions for lower tax liability or sets the tax rate based on the level of emissions or ceiling for its allowances (Hafstead and Williams, 2020). In the United States, carbon pricing does not exist at the national level. However, a few states have introduced their own schemes: A collection of northeastern states have participated in the Regional Greenhouse Gas Initiative (a cap-and-trade program on power plant emissions since 2009); California has had an economy-wide cap-and-trade program since 2013; Washington State formally implemented its own economy-wide cap-and-trade program in 2023; and New York State is also pursuing an economy-wide cap-and-trade as part of its Climate Leadership and Community Protection Act.

Within the following subsections, we discuss the interactions of carbon pricing with other climate mitigation policies. Carbon pricing usually increases the effect of another mitigation policy, decreases the cost of legislation by increasing revenue, and can help sustain mitigation activities after a mitigation policy expires. However, sometimes its effect can be mixed, depending on the context. For example, Popp (2006) finds that a carbon tax achieves 95 percent of the welfare gains of a policy that combines R&D subsidies, while R&D subsidies without a carbon tax only achieve 11 percent of the welfare gains of the combined policy. At the same time, a carbon price could spur demand for renewable energy among actors to the point that R&D subsidies might not be necessary to influence firm behavior (Donohoo-Vallett et al., 2017). Carbon pricing can also have important distributional effects on impacts (Goulder et al., 2019).

Measuring the Impact of Regulations

Regulatory policies are standards, regulations, and monitoring and enforcement processes that can be developed with a top-down command-and-control approach or a market-based approach. These policies can set operations standards, emissions standards, or renewable share requirements on energy producers and consumers and are typically applied at the sectoral level.

In this section, we focus on how the impacts from regulatory policies aimed at the power sector are measured to exemplify how sectoral-level regulations are measured. Considered to have the highest proportion of GHG emissions historically, the power sector promises significant opportunity for economy-wide decarbonization when coupled with electrification activities for the transportation and building sectors. A CES is a market-based, technology-neutral, and performance-based policy that has been proposed over decades. While, at the time of this writing, there is no federal-level policy for CES, 30 states, Washington, D.C., and two territories have active renewable or clean energy requirements as of August 2021. Together with power tax credits, which we discuss later in the chapter, these policies have been the most important drivers of renewable energy capacity additions (Hart and Noll, 2019). A CES sets a target that requires a percentage of retail electricity sales to come from low- and zero-carbon electricity sources. CESs are similar to RPSs but allow a wider array of sources, including nuclear power and fossil fuel generators with carbon capture and storage. The standards require a certain amount of clean energy to be used over time, replacing dirty energy sources. This is done by creating a market for clean energy credits. CES structures can differ in whether credits can be given or the extent to which power plants use carbon capture and storage or biomass. The Clean Energy Standard Act of 2019 proposed to provide a partial credit to such GHG emitting power plants based on life cycle GHG emissions. CESs can also have enforcement mechanisms, such as Alternative Compliance
Payments, which require payment if the target is not met. It is important to consider these details when evaluating the impact of the policy.

First, we will discuss modeling approaches that are used in the literature to estimate the GHG emissions reduction potential of existing and proposed CESs. Additionally, we will discuss how researchers assess CES policies’ other benefits and impacts beyond GHG emissions. Studies vary in the levels of information they include on these other benefits, but they generally use a similar framework to evaluate them. We will provide more information on some of these benefits that have been reported in the literature. Table 3.2 gives an overview of what benefits have been assessed per regulatory policy type.

**Approaches to Measuring the Effect of Power Sector Regulation**

Studies estimate a wide variety of benefits from proposed or implemented power sector decarbonization policies in environmental and economic terms. While some benefits represent societal net benefits, other impacts are resource transfers between the market participants. For example, GHG emission reductions are estimated as economy-wide net benefits, while job creation and economic development will come at the expense of job losses in more carbon-intensive sectors. A wide variety of integrated models that estimate these benefits are derived from policy-driven changes in the electricity sector and cascading impacts on other sectors. Generally, power sector optimization models (including both capacity expansion and production-cost dispatch models) are used to determine which resources must be built to meet demand and minimize the

### TABLE 3.2

<table>
<thead>
<tr>
<th>Policy</th>
<th>GHG Reduction</th>
<th>Health Benefits</th>
<th>Job Creation</th>
<th>Energy Price and Consumption</th>
<th>Water Conservation</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>RPS</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>Barbose et al., 2016</td>
</tr>
<tr>
<td>CES</td>
<td>x</td>
<td></td>
<td>x</td>
<td></td>
<td></td>
<td>Picciano, Rennert, and Shawhan, 2019</td>
</tr>
<tr>
<td>CES and carbon tax</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td>EIA, 2012</td>
</tr>
<tr>
<td>CES and other policiesa</td>
<td>x</td>
<td></td>
<td>x</td>
<td></td>
<td></td>
<td>Marsters et al., 2021</td>
</tr>
<tr>
<td>Distributional impactb</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Stock and Stuart, 2021</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Shawhan, Witkin, and Funke, 2022</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Hennessy et al., 2022</td>
</tr>
</tbody>
</table>

*a Other policies include transmission macrogrid, organized wholesale market, and utility-led decarbonization.

b This is not a policy, but the article discusses an approach to assess distributional impact between balancing authorities.
system cost. The most widely sourced models include NEMS,3 E4ST,4 ReEDS,5 REPEAT,6 and Energy Policy Simulator (EPS).7 Each model differs by spatial and temporal resolution, technical details, and the application of modules to capture varying impacts.

Greenhouse Gas and Climate Change Damage Reduction Benefit

Within the literature, the most frequently reported benefit of climate change mitigation policy is GHG emissions reduction. GHG reductions are presented as the difference between a baseline and the policy scenario. The Annual Energy Outlook by the Energy Information Administration (EIA) is the most widely used baseline scenario; however, the Rhodium Group produces its U.S. Greenhouse Gas Emissions Outlook every year and uses that outlook as its baseline.8 Some analyses within the literature address uncertainties in technology-cost projections, the extension of tax credits, fuel prices, and future demand with transportation and building electrification by using the low and high sensitivity scenarios.

Once the GHG reduction is identified, most studies use the SCC to estimate the monetary value of avoided climate change damages.

Air Pollution Emissions and Human Health Benefits

Reducing GHG emissions through mitigation policies has additional benefits through reductions in local air pollution associated with the burning of fossil fuels. Air pollutants, such as sulfur dioxide (SO₂), nitrogen oxides (NOₓ), PM, CO₂, and mercury (Hg) from fossil fuel combustion, contribute to adverse health outcomes (EPA, 2023). Much epidemiological research finds that exposure to air pollution has a causal association with increased mortality and morbidity (Dockery et al., 1993; Krewski et al., 2009; Lepeule et al., 2012). For example, EPA reports that the Clean Power Plan would provide health benefits estimated to be between $14 billion and $34 billion in 2030 based on reduced premature mortality (EPA, 2015). The health benefit from air pollution reductions often has a higher monetary value than other benefits from reducing fossil fuel combustion, including climate benefits.

Most studies use a similar approach for evaluating the health benefits of mitigation policies although they use different models or different concentration-response relationships. In general, the approach involves three steps. First, the lowest cost-power generation from a power sector optimization tool and an emissions factor for each type of power plant are used to calculate annual emissions (tons per year). Second, reduced-

---

3 NEMSs are developed and maintained by EIA. NEMS is an integrated model of the U.S. energy system linked to a macro-economic model.
4 The Engineering, Economic, and Environmental Electricity Simulation Tool (E4ST) is developed by researchers at Resources for the Future, Cornell University, Arizona State University, and Rensselaer Polytechnic Institute. E4ST is a power sector modeling software that projects the effects of policies, regulations, power infrastructure additions, demand changes, etc.
5 The Regional Energy Deployment System (ReEDS) is developed by the National Renewable Energy Laboratory (NREL). The ReEDS model is designed to simulate electricity sector investment decisions based on system constraints and demands for energy and ancillary services.
6 REPEAT is developed by the Princeton ZERO Lab (with Jesse D. Jenkins as the principal investigator), in partnership with Evolved Energy Research and Erin Mayfield (Dartmouth College). The REPEAT Project employs a suite of geospatial planning and analysis tools coupled with detailed macro-energy system optimization models.
7 The EPS is developed by Energy Innovation LLC as part of its Energy Policy Solutions project. The EPS allows the user to control a large variety of policies that affect energy use and emissions in every major sector of the economy, including transportation, electricity supply, buildings, industry, agriculture, and land use.
8 Both EIA and Rhodium use the NEMS model.
complexity air quality models (RCMs) are used to convert emissions (in tons) to ambient air concentrations (in parts per million). A concentration-response function is then used to estimate health impacts on premature deaths (most common) and reduced morbidity. Commonly used RCMs include APX (Muller and Mendelsohn, 2006), EASIUR (Heo, Adams, and Gao, 2016), and InMAP (Tessum, Hill, and Marshall, 2017). Differences between those models include geographic resolution, inclusion of morbidity benefits, complexity, and usability. RCMs’ much lower computational intensity allows for greater spatial coverage and a larger number of model-runs to understand the sensitivity of the results to different assumptions. However, there are large uncertainties surrounding how air pollutants migrate and the ultimate exposure of different populations to that air pollution. Some studies use multiple model outputs or report outcomes from a different approach, such as EPA’s benefit-per-ton, as a sensitivity analysis. Third, studies evaluate the monetized health benefits of avoided premature deaths by using the value of a statistical life (VSL). The most widely used VSL value is over $10 million (EPA, 2014). Changing the VSL or calculating the economic value of mortality in a different way (considering age, for instance) would result in markedly different results. Thus, it is beneficial for a model to output multiple metrics (e.g., avoided deaths and fiscal impacts) to avoid the uncertainty involved in monetizing different metrics.

Regulatory Impacts on Job Creation and Economic Development

New expansions of electricity generation and infrastructure can create new employment opportunities. Researchers often use Jobs and Economic Development Impacts (JEDI), NREL’s tool to estimate the number of new jobs created as well as the increase in earnings, output, and GDP. JEDI divides these impacts into three categories: onsite, supply chain, and induced. However, the tool does not account for jobs in fossil fuel industry that are lost because fossil fuel–based power plants are retired. In fact, renewable energy typically requires fewer operations and maintenance labor hours than fossil fuel–based power plants, so the net impact on jobs might actually be negative (Barbose et al., 2016). This is a clear example of a trade-off between different sectors: Climate change mitigation policies might benefit some groups while disadvantaging others. Currently, most models do a poor job of representing these trade-offs.

Regulatory Impacts on Energy Consumption and Price Changes

Estimating regulatory impacts on energy prices and household expenditures on energy is a complex and nuanced procedure. Wholesale electricity prices can be simulated by using a power sector optimization model, such as a production-cost dispatch model, that uses assumptions about future demand, technology prices, fuel prices, and available resources. As the cost of renewable energy goes down, the supply curve can shift and reduce the wholesale market clearing prices. However, price changes from the wholesale market differ from societal net benefits because regulation-induced price reductions represent a transfer of wealth from producers to consumers (Felder, 2011). The impact on retail bills and household expenditures is even harder to estimate because of complex regulatory processes, which update the retail rate of power utilities within different time frames. Additionally, not all demand is exposed to wholesale spot market prices because utilities might enter into a long-term power purchase agreement to avoid market price volatility (Barbose et al., 2016). Most

---

9 APX = Air Pollution Emission Experiment and Policy Analysis Model; EASIUR = Estimating Air pollution Social Impact Using Regression; InMAP = Intervention Model for Air Pollution.

10 The value of $10 million was calculated using the U.S. dollar’s 2020 currency value.

11 JEDI models estimate the economic impacts of constructing and operating power generation and biofuel plants at the local and state levels. The tool includes biofuels, coal, conventional hydropower, concentrating solar power, geothermal, international, marine and hydrokinetic power, natural gas, petroleum, photovoltaics (PVs), transmission line, and wind.
studies do not account for these complexities when estimating how changes in energy prices affect consumers. However, Barbose et al. (2016) discusses a framework that captures how some of these complexities in policy implementation affect retail bills. Some studies also look at how government subsidies for renewable energy, such as PTCs or ITCs, can affect who pays for the costs of reducing carbon emissions: Sometimes the burden falls on the general public instead of just the customers of power utilities. As subsidies lower the cost of renewables, the cost burden of decarbonization can shift from utility ratepayers to general taxpayers.

Models of changes in electricity and natural gas consumption typically use a market-equilibrium approach. Some studies use a simple demand elasticity rate or an inverse supply curve to model how price changes affect energy-demand changes. EIA’s NEMS model incorporates a general market equilibrium of supply and demand and includes international activities (EIA, 2019).

**Impact of Regulation on Water Use**

Fossil fuel power plants are heavy water users, primarily because of thermal plant cooling. Barbose et al. (2016) discusses the benefits of increasing renewable energy production for reducing water withdrawals and consumption. The study uses the water intensity rates of power plant water calculated by Macknick et al. (2012) to estimate differences between water use at the baseline and in the policy scenario.

**Geographic Distributinal Impacts of Regulatory Policies**

Regional differences in physical infrastructure, energy demand, supply resource mix, and interregional interconnectivity are important to consider when assessing climate policy impacts. Models with more granular resolution and more precise representation of the physical system will provide insights on distributional impacts. Most studies at least perform regional assessment based on the Federal Energy Regulatory Commission’s (FERC’s) electric power market segment (shown in Figure 3.1).

Some studies report total U.S. impacts by aggregating regional outputs. However, others report distributional or geographical impacts that depend on both the reported impact and the model’s resolution. In general, reported impacts on health benefits and job creations were more granular than other impacts, such as GHG emissions or price changes. There are a variety of distributional impacts yet to be considered in the regulation literature, including across different regions, states, counties, and even neighborhoods. The literature tends to focus on added benefits but does not explore sectors displaced by policies, avoided damages, or wealth transfers between producers and consumers. Furthermore, the literature does not measure net social impacts, such as job creation, energy prices and household expenditures, and economic growth.

**Measuring the Impact of Fiscal Policy on Behavior Change and Technology Adoption**

Private actors, such as individuals, investors, and firms, are prone to pursue activities that give them a direct return on their investment. When the public sector identifies a new technology whose uptake is expected to benefit other individuals, firms, or society-at-large, a tax incentive or subsidy can help create a return to

---

12 A demand elasticity of –0.4 percent is used in Picciano, Rennert, and Shawhan (2019), and the implied inverse elasticity curve for natural gas supply is derived by Barbose et al. (2016).

13 Water withdrawals are the amount of water removed or diverted from a water source, while water consumption is the amount of water that is removed from the immediate water environment by processes such as evaporation, transpiration, or incorporation in a product.
incentivize its uptake even when the benefits are hard for private actors to capture. Recent policy developments in the United States recognize that U.S. climate mitigation goals require that these actors dramatically shift how they choose to consume and produce energy through fiscal policies, including tax credits and subsidies. An example of such a policy is the 2022 IRA, which makes available more than $271 billion as part of its budget over ten years for tax credits and subsidies alone (CBO, 2022a, as cited by Bistline, Mehrotra, and Wolfram, 2023). These incentives and subsidies include grants, tax credits, and other financial policy tools funded by the government to promote research, development, and the adoption of new carbon-reducing technologies across a variety of economic sectors.

The goals of climate mitigation tax incentives and subsidies are to reduce emissions indirectly by first reducing technology costs to affect technology adoption among individuals, firms, and investors. In turn, climate change mitigation is expected to improve environmental quality, ensure more favorable health outcomes, and lower household spending. Most existing studies stop at the evaluation of the first-order impact of technology adoption, while a few studies explore the dynamics that could affect these higher order impacts. The literature on the impact of climate change mitigation incentives and subsidies is generally fragmented and limited, as studies tend to be specific to a technology and policy. Further, incentives in some sectors, such as transportation, are more researched than others, as are incentives for specific technologies within sectors, such as wind energy production in the power sector.

During summer 2022, Princeton University’s REPEAT project (Jenkins et al., 2022), Resources for the Future (Roy et al., 2022), the Energy Innovation’s EPS (Mahajan et al., 2022), and the Rhodium Group (Larsen...
et al., 2022) modeled the impacts of climate legislation, particularly the IRA, each treating tax incentives and subsidies differently. The preliminary report of the REPEAT project focuses on modeling direct emissions from the IRA, excluding incentives (Jenkins et al., 2022). The Resources for the Future paper focused on the power sector; it applies the organization’s Haiku Electricity Market Model to model scenarios with and without the extended incentives for zero-carbon power generation in the IRA and projects 44 percent more 2030 emissions reductions than the baseline scenario. The EPS uses a bottom-up system dynamics model to assess whether different technologies grow or decline as a result of policies. It then aggregates impacts on cash flows and pollutants at the sector and economy-wide scales (Energy Innovation, 2015).

Measuring Income-Based Distributional Impacts
Climate mitigation policies can also have distributional impacts if they are not adjusted and counteracted (Büchs, Bardsley, and Duwe, 2011), and the literature on tax incentives and subsidies addresses these impacts to some extent (Hardman et al., 2017). For example, a study on vehicle tax credits from the 2005 Energy Policy Act found that 90 percent of tax expenditures had been issued to the top income quintile of U.S. citizens (Borenstein and Davis, 2016). In response, the 2022 IRA introduced caps by household income and car prices to which the hybrid and electric vehicle tax credits could be applied. However, depending on a tax credit’s value and the number of years a credit can be carried over, these types of tax incentives can be more or less useful for different households. Lower income households often face lower net tax liabilities and might experience lower discount rates for future savings because of tax credits.

In addition, how and at what rate tax incentives and subsidies are used can vary depending on the region or state. For example, Roach (2015) finds that states with deregulated electricity markets were more responsive to the tax incentive than their regulated counterparts, claiming up to $464,450 more in federal benefits. In addition, characteristics of the regional electricity grid (e.g., the generation mix and timing of demand) can play a role in overall emissions impacts (Graff Zivin, Kotchen, and Mansur, 2014).

The Budgetary Risks of Climate Change Mitigation Policies
In this chapter, we have discussed the economic, environmental, and social impacts of climate change mitigation policies. These impacts will ultimately feed back into the federal budget and should therefore be included in budgetary analyses. This relationship is illustrated in Figure 1.1 in which we can see that changes in emissions will affect the climate system, which will contribute to hazards experienced by the economy. Thus, reductions in emissions will lead to fewer hazards and less impact on the economy. At the time of this writing, these avoided damages (e.g., the effects discussed in Chapter 2) are not incorporated in budgetary analyses (see Table 3.3). We recommend that decisionmakers broaden the scope of budgetary analysis to include the indirect and nonfiscal costs and benefits of climate change mitigation and adaptation policy. To adequately capture these effects, analysts would need to use a climate-economic model with the attributes discussed in the previous section. Such a model would also need to incorporate the risks associated with the uncertain path to decarbonization known as transition risk. Transition risk measures the risks and opportunities that arise from policies implemented to mitigate climate change, such as federal or state-level carbon pricing, low-carbon fuel standards, and EPA regulations. Transition risks include business-related risks from these policies and from changing investor expectations of future policies. Although these risks are an important consideration for investors and asset managers because they are associated with stranded assets and loss of income, climate-economic models typically do not represent these types of risks. These changes in the structure of the economy pose a non-negligible threat to revenue from climate change and therefore should be included in a model of the federal budget.
Although more effort has been dedicated to modeling the physical risks of climate change, there have been some recent advances made to understand climate transition risks. The Federal Reserve introduced a pilot study to assess the climate-risk management practices of major banking organizations (Board of Governors of the Federal Reserve System, 2023). The NGFS, which is a group of financial banks and supervisors, developed climate-economic scenarios based on high and low challenges to physical and transition risks. Transition risks are based on the timing of the implementation of mitigation policies. Later transitions (i.e., later implementation of mitigation policies) lead to disorderly transitions, while prompter implementation that is steadily ramped up over time leads to a more orderly transition associated with less transition risk (Bertram et al., 2020). However, other research has noted the importance of considering investors’ expectations and the financial system’s role in enabling or hampering an orderly transition. Battiston et al. (2021) introduces a framework in which the credibility of mitigation policies in an IAM inform investor expectations and thus investment decisions in energy technology. These investment decisions are then used as inputs in the relative prices of energy technology in the IAM.

Transition risks are especially important to consider at local levels (Raimi, Carley, and Konisky, 2022). A community that depends on its oil and gas sector could be heavily affected by a rapid divestment from the firms that serve as its economic foundation. The subsequent losses in employment and damages to the energy firms would reduce revenues from income and corporate taxes. Therefore, it is necessary to incorporate these risks in a model of the federal budget.

Generally, transition risks stem from uncertainty in future proposed policies, as well as the ability of the financial system and the population to adapt to them. The next chapter discusses the importance of representing uncertainty in budgetary analyses and the methodological changes required to adequately represent uncertainty about the climate change’s budgetary impact.

### Key Modeling Points

There are many ways in which fiscal and climate policies influence economic, environmental, and social outcomes. Models that explore the relationships between economic and climate outcomes will need to capture each of these distinct channels. While the modeling approaches that quantified the impacts described in this section are distinct, they have common properties as well as different assumptions—including data availability issues, modeling capabilities, and different representations—that lead to trade-offs in insight. Ideally, a model that explores federal climate and fiscal policies will offer a holistic view of policies and their outcomes, rely on rigorous empirical bases, and be easy to recalibrate to different scenarios, assumptions, and limi-
tions. Understanding the choices being made, trade-offs in uncertainty, and the insights that result is critical to modeling, as is finding the right balance for the question at hand.

Existing models for clean energy policy have an inherent trade-off between computing capabilities and precision in time and geographic scales. Brown and Botterud (2021) discuss three challenges on modeling clean energy systems. First, better representation of grid network and geographical coverage is needed to capture the spatiotemporal correlation between weather systems and the feasibility of power delivery. Second, large temporal coverage is required to account for interannual weather variability and changes in climate. Finally, fine temporal resolution is necessary to represent variable renewable generation and energy storage operation constraints (Brown and Botterud, 2021). Comparing power sector models, NREL's ReEDS is better at capturing geographic resolution with lower temporal resolution, while EIA's NEMS accounts for fine temporal resolution but has a limited representation of the transmission network. Without the right level of detail, a model can lose insight into important intermediary outputs (i.e., type of resources, the capacity needed to replace fossil fuel generation, the location of a power plant), which are then used to assess impacts on GHG emissions, health, jobs, energy price, and water.

Of course, higher spatial and temporal resolutions increase the computational and analytical burden of running models with these characteristics. This is necessary when the analysis requires accuracy, as is the case when the EPA undertakes a complex analysis for major air pollution. However, reduced-form models that can approximate these analyses have grown in availability in recent years and can be “reasonably comparable” to full-form models in terms of their estimates of the health-related benefits obtained from an air quality policy (Industrial Economics, 2019). Such models might be useful when comparing alternate scenarios.
Baseline and Timescale Considerations for Climate and Fiscal Models

In addition to the scoping elements described in Chapters 2 and 3, there are structural requirements related to the baseline and timescale that affect a model’s utility in estimating the effects of fiscal and climate policy. Climate change is often described as a “wicked problem” (Levin et al., 2012) because of the decadal to millennial timescales involved; deep uncertainties regarding both the impacts and the consequences of human actions (New, Reckien, and Viner, 2022); the potentially irreversible effects of those human actions; complex and cascading risks, including breaching physical, biological, and social tipping points (Ara Begum et al. 2022); profound questions of distributional justice within and among nations and between generations (Ara Begum et al., 2022); and a situation of polycentric governance in which no single jurisdiction or centralized authority has full control over solutions. Such attributes present significant challenges in assessing the budgetary impacts of climate change policies. In this chapter, we discuss three important and interrelated themes: the appropriate treatment of long timescales, the use of multiple base cases for policy evaluation, and the treatment of extreme tail risks, which are the risks caused by events that occur with low probability as determined by a probability density function (Weitzman, 2014).

This chapter covers a broader range of topics compared with the previous two, so we selected the literature we discuss through various processes. For most sections, the review focuses on previously known studies that are important to each topic and for our purposes. The section on scenarios for policy development, for example, starts with an examination of a special issue of the journal *Climatic Change*, which describes the theoretical framework used for the development of the socioeconomic scenarios currently used by the Intergovernmental Panel on Climate Change (IPCC) (Nakicenovic et al., 2014). We complemented these initial readings with studies that we identified through the special issue’s citations. We also conducted traditional literature reviews about methods for extending the SSP for national and subnational use and on stranded assets, focusing on frequently cited publications in prominent journals. Further, we use results from a highly stylized climate-economic model to demonstrate the importance of both the discount rate and the timescale of analysis.

Considerations for Long-Term Policy Analysis

Discounting

Actions taken today will affect costs and benefits experienced in future years. To take these future outcomes into consideration, economists and practitioners convert future streams of costs and benefits into their net present value (NPV). The NPV is calculated by applying a discount rate to cash flows in the future, such that \( NPV = \frac{C_t}{(1 + r)^t} \), where \( r \) is the discount rate and \( C_t \) is the net cash flow in the current period, \( t \). The discount rate is a highly contentious parameter when developing climate policy because of its ability to shape the results. For example, the interim discount rates under the first Biden administration followed the Obama
administration’s methodology, which used a 3 percent discount rate as its central estimate to develop the SCC. This, along with the inclusion of damages at the global level, led to an SCC of approximately $50/ton CO$_2$. In contrast, the Trump administration’s use of a 7 percent discount rate and its consideration of damages within national borders led to a SCC of only $1/ton CO$_2$. Additionally, leading climate scientists and economists have quantified the SCC using improvements in models, damage functions, and discounting and showed that the SCC was most sensitive to the discounting method used (Rennert et al., 2022). Because the SCC is used in CBAs of environmental policy, this decision has enormous implications.

In contrast to the previously used deterministic discount rates, the EPA’s recently proposed SCC of $190/ton CO$_2$ relies on a Ramsey-style discounting in which the discount rate is given by $r_t = \rho + \eta g_t$. Here, $\rho$ is the rate of pure time preference, $g$ is the average rate of consumption growth in time $t$, and $\eta$ describes the diminishing rate of consumption as wealth increases. The pure rate of time preference parameter, which describes how damages should be valued in the future, has been the source of considerable debate. Stern argues that it is unethical to discount future damages at all because future generations will be affected by the consequences of decisions they did not make (Stern, 2007). Meanwhile, such economists as Nordhaus believe the discount rate should be based on historically observed market interest rates (Nordhaus, 2007). However, it is worth noting that the social discount rate would only equal the market interest rate in a Pareto-optimal world (EPA, 2015). This means that the economy would be perfectly competitive, all agents had access to perfect information, and there were no taxes, distortions, or other market failures. GHG emissions are perhaps the most well-known example of a market failure in environmental economics. Absent a universal emissions tax, individuals do not have to pay for emissions that will cause damages to others. Such damages can affect different types of capital, including both built infrastructure and natural capital that comes in the form of forests, bodies of water, and other ecosystems that produce existential services to humanity. Over time, built infrastructure can be substituted by newer and improved technologies; however, damage to an ecosystem, such as an old-growth forest, cannot be replaced. This concern over the substitutability of capital must also be considered when damages affect a location that is essential for the cultural well-being of a community or a culture overall. For example, if sea-level rise forces an indigenous community to migrate from the land they have occupied for centuries, no amount of monetary or physical reparations can compensate them for the loss of their ancestral home. Therefore, the choice of a descriptive (based on empirical data) versus prescriptive (based on morals) approach to social discounting depends in part on the substitutability of the assets owned by those affected by the policy.

Another consideration to make when discounting the costs and benefits of a long-term policy is that uncertainty in economic growth rates will influence the discount rate used. Past literature on this subject has established that the uncertainty surrounding social discount rates leads to a certainty-equivalent discount rate that declines over time (Weitzman, 1998). Newell, Pizer, and Prest introduce a stochastic discounting rule that matches the term structure of long-term market interest rates to rates used in short-term CBA. The rule accounts for the correlation between damages and the discount rate while considering uncertainty in economic growth (Newell, Pizer, and Prest, 2022).

---

1 The CBO is not part of the executive branch, so changes in the administration’s preferred discount rate do not determine the rate used by the CBO. The CBO has used a 3 percent discount rate in recent publications, such as in CBO (2022d).
2 The new SCC estimates and associated methodology were proposed in November 2022.
3 Stern argues for a pure rate of time preference ($\rho$) of 0.1 percent. With the other parameters in the Ramsey equation, his recommended discount rate came to 1.4 percent.
Timescales

Conventionally, the time horizon of budgetary analysis is limited to ten years when scoring legislation. This ten-year time horizon could be justified in some cases because of uncertainty in longer-term estimates and discount rates, which reduces the salience of longer-term benefits and costs. However, neglecting to consider these uncertainties might seriously underestimate the budgetary impacts of any climate policy.

To suggest the extent to which alternative time horizons might underestimate the budgetary impacts of climate policies, we use the DICE model, which is a well-known and simple IAM, to calculate the present value net benefits from a carbon tax up to a certain time horizon and compare that value to the present value net benefits up to an asymptotic time horizon of approximately 300 years.

The discount rate is an existing input in DICE. To handle uncertainty about the long-term consequences of a policy, we assume that there is some annual probability that an event will occur that renders any further consequences of the policy negligible. Such an event might be a new policy that entirely supersedes the old one, a significant technological advance, or an economic shock. Therefore, we write the NPV of a policy as

\[ nPV = \sum_{t=0}^{\infty} (1 - p)^t \Delta(t) e^{-rt}, \]

where \( p \) is the annual probability that the further consequences of the policy become negligible, \( r \) is the discount rate, and \( \Delta(t) \) is the difference in gross economic product between the policy and no policy cases, as calculated by DICE in year \( t \). If we define a policy’s half-life \( \tau \) as the length of time before the policy has a 50 percent chance of having negligible further consequences, we can rewrite the policy’s NPV as

\[ nPV = \sum_{t=0}^{\infty} \Delta(t) e^{-\frac{r + \ln 2}{\tau} t}. \]

Figure 4.1 shows the results as a function of discount rate and policy half-life, using an optimal emissions-reduction policy for DICE. Such a policy generates a global mean temperature higher than that of the Paris Agreement. The \( y \)-axis of Figure 4.1 shows the percent of net benefits from the emissions-reduction policy achieved in a particular time frame (depicted by colors) using a 3 percent discount rate relative to the total benefits obtained from the policy over an asymptotic period of 300 years. The figure shows the results for a policy that persists indefinitely into the future (calculated as an infinite policy half-life as shown by the red line) and one whose influence decays into the future with a 30-year half-life (as shown by the blue line). The relative percent benefits rise as the discount rate increases because the net benefits at 30 years (i.e., the denominator) decrease as the discount rate increases. In other words, at a higher discount rate, the future is valued less, so more of the total benefit is captured in shorter time frames.

At a 3 percent discount rate, a ten-year time horizon only captures about 0.5 percent to 4.5 percent of the net benefits of the DICE optimal policy, depending on the policy half-life. Some commentators argue that much lower discount rates, on the order of 1 percent to 2 percent, are appropriate for considering climate change policy because of the significant potential for irreducible damages for future generations. With such low discount rates, even a 50-year time horizon captures no more than about 15 percent of present value net benefits, even with a 30-year policy half-life.

These rough calculations suggest that the budgetary implications of climate change need considerably longer time horizons to capture a significant fraction of the budgetary implications of GHG policies in a situation other than a very high discount rate and short policy half-life. This is echoed by the latest guidance from OMB, which suggests that the “time frame for . . . analysis should include a period before and after the date of compliance that is long enough to encompass all the important benefits and costs likely to result from the regulation” (OMB Circular A-4, 2023, p. 11).
Scenarios for Policy Evaluation

Policy evaluation generally requires some type of reference or base case against which to compare the effects of the policy in question. In some situations, the appropriate reference or base case might be obvious or inconsequential for the analysis, or both. But in many situations, the choice of a reference or base case might be uncertain and contested while being highly consequential to the results of the policy evaluation. This is often the case with climate change in which the effects of a policy unfold over a considerable period, and, in addition to the policy in question, many factors might significantly affect the outcomes of interest even over relatively short timescales (Jafino, Hallegatte, and Rozenberg, 2021; Whittington, 2022).

The climate community has often addressed this challenge by considering multiple scenarios so that policies can be evaluated against a variety of alternative base case assumptions. The IPCC Sixth Assessment report defines a scenario as “a plausible description of how the future may develop based on a coherent and internally consistent set of assumptions about key driving forces (e.g., rate of technological change [TC], prices) and relationships” and notes that “scenarios are neither predictions nor forecasts but are used to provide a view of the implications of developments and actions” (IPCC, 2022, p. 823). The scenario literature discusses three types of scenarios (Börjeson et al., 2006):

1. predictive (“What will happen?”)
2. explorative (“What might happen?”)
3. normative (“How might we reach our goals?”).

CBO uses scenarios, for instance, in its long-term budget outlooks. Additionally, in November 2022 Congress asked CBO to evaluate how economic uncertainties affected its budget estimates. This was accomplished by producing 100 simulations that take into account uncertainties in the unemployment rate, inflation, and interest rate. Using different uncertain parameters, these simulations can be used to robustly assess the budget impacts of climate policies. The climate change literature makes more extensive use of exploratory
scenarios by examining how a wide variety of assumptions regarding factors outside policymakers’ control might affect the outcomes of alternative policy choices. The Social Security Administration also has used exploratory scenarios in this sense (Paulson et al., 2007). Additionally, the latest OMB guidance recommends the use of discrete scenarios when uncertainties are large and cannot be adequately characterized by a probability distribution (OMB Circular A-4, 2023). However, to our knowledge, scenario analysis has not been applied to scoring legislation. Concerns may arise over multiple baselines leading to politicians cherry-picking scenarios based on their desired legislative outcome. While this concern is valid, including multiple scenarios would make the various potential paths transparent and strengthens the basis for substantive debate on the subject. That is, a politician who singles out a particular scenario would then have to offer their rationale for believing that scenario is more likely than the others.

To evaluate the budget impacts of climate policies over multiple scenarios, budget analysts should have a systematic approach to choosing a small number of relevant scenarios. The climate literature employs at least three approaches for choosing scenarios. An organization might (1) employ a standard set of scenarios that are widely used by many organizations, (2) begin with a standard set of scenarios and then adapt them to the particular needs of the organization, or (3) use analysis to identify a set of policy-relevant scenarios most useful for stress testing a particular policy. The first option is employed by the IPCC and U.S. National Climate Assessment through its RCPs and Shared Socioeconomic Pathways (SSPs). The second option is employed by some local or regional jurisdictions (Chakraborty and Sherman, 2020). The third option is employed by some natural resource and other infrastructure agencies in climate resilience and climate adaptation planning (Groves et al., 2020).

Option 1: Scenario Development
For decades, using an accepted set of multiple scenarios has been common practice in the study of climate change and the effects of climate policy. Over the years, climate scientists and policymakers have created a structured process to develop these scenarios.

The first global scenarios that were developed to provide estimates on all GHGs were published by the IPCC in 1992; they were intended to be used by researchers working with global circulation models to develop climate change scenarios. These scenarios and their use were evaluated in 1995 and were found to be pathbreaking, which quickly led to the development of a second, updated and expanded, set of scenarios. The second set of global scenarios would eventually be published in 2000 as the Special Report on Emissions Scenarios (SRES) and would serve as the basis for the Third and Fourth Assessment Reports of 2001 and 2007, respectively (Nakićenović et al., 2000). The SRES was used by diverse groups of stakeholders, including scientists, policymakers, and nongovernmental organizations, who benefited from a shared set of scenarios that allowed for comparisons across different fields, study types, and geographies. However, these scenarios explicitly avoided the inclusion of any policies that were intended to address climate change and were therefore of limited use once some degree of climate policy became part of the baseline. The sequential process that was followed to develop the SRES also led to long lags between the development of socioeconomic elements of the scenarios and the related climate projections. This lag made the socioeconomic elements slightly out-of-date by the time the climate projections were released and combined with other factors that limited their overall applicability for policy-relevant analysis.

The current climate change scenario framework was developed through a different process, in part, to address these limitations. The first component of this framework, the Representative Concentration Pathways (RCPs), was initially published in 2011 and was included as part of the IPCC’s Fifth Assessment Report (van Vuuren et al., 2011). The RCPs are named after the difference in radiative forcing entering and leaving the atmosphere and include potential future concentration levels of GHGs, aerosols, and other factors that can influence the atmosphere to trap additional heat. Although each RCP is based on an internally consistent
set of socioeconomic and demographic assumptions, these are not part of the RCPs themselves, which are strictly focused on the representation of a given level of radiative forcing. The RCPs were then used as inputs for the simultaneous but independent development of climate impact and socioeconomic scenarios based on the distinct futures represented by each of the RCPs. This parallel process shortened the time and cost of developing the scenario sets and produced a framework under which multiple socioeconomic narratives could be consistent with each RCP. In principle, this flexibility enables inputs for adaptation and mitigation-related analysis to be derived from the same set of scenarios and allows for the consideration of a broader range of possible futures and their implications, including futures that incorporate climate policy (Moss et al., 2008).

The SSPs, the socioeconomic component of this framework, were first published in 2014 and were included as part of the Sixth Assessment Report (O’Neill et al., 2014). The five narratives that make up the SSPs describe alternative pathways of socioeconomic development that the world might follow. Each pathway represents a combination of challenges to mitigation and adaptation that could be consistent with multiple RCP scenarios. The challenges to mitigation generally relate to higher emissions scenarios. The challenges to adaptation generally relate to increasing inequity and international fragmentation.

The SSP narratives have been extended to different geographic scales or sectors, or both, in many ways and places. Examples include participatory workshops with local and regional actors in the Barents region in northern Norway, Sweden, Finland, and Russia (Nilsson et al., 2017); expert elicitation methods to develop SSP narratives for the global forest sector (Daigneault et al., 2019); and the application of the factor-actor-sector (FAS) framework to construct subnational SSP storylines for the U.S. Southeast (Absar and Preston, 2015). Analogously, the RCPs are often used as part of more localized or otherwise nuanced climate modeling, including for purposes outside climate research and policy.

Option 2: Extending the Shared Socioeconomic Pathways for National and Subnational Use

The SSP–RSP framework was purposefully built to provide a platform for multiple modeling groups to use a consistent set of scenarios in their research but also allows for more customized scenarios to be used across different types of research and analysis. Each of the previously noted examples used a different approach to create national, subnational, and sectoral scenarios within that framework. Of these approaches, the FAS framework used by Absar and Preston stands out because it provides a systematic way to think through each component of the SSP and identify the most appropriate level of aggregation when extending the SSP. Under the FAS framework, a sector represents a subcomponent of a national or social system, an actor represents an individual or organization with the capacity to effect or influence change in the system, and a factor represents an element of the system around which there is particular interest (Kok, Rothman, and Patel, 2006). Once the appropriate level or levels of aggregation at which to consider each factor is determined and the actor and sector have been identified, national and subnational data and trends can be used to populate the respective scenarios and storylines, as shown in Figure 4.2. For example, Absar and Preston (2015) extended global population estimates from the SSP scenarios using national and then subnational population data to enable more detailed consideration at those levels. While the authors opted to use only published literature to fill in the information at the national and subnational levels, they note that combining a literature review with participatory stakeholder sessions could provide richer and more detailed information.

Table 4.1 presents a sample of possible dimensions and values related to how international cooperation and climate action affect and are affected by U.S. climate policy. To exemplify this relationship, we elaborate on one such dimension: the stranded asset risk to the United States. Although this particular risk is relevant to U.S. climate policy, our purpose here is to highlight the diversity of dimensions and interactions that must be considered when assessing the impacts of climate change. Considering the effects of inequality
would be necessary for adaptation-related analysis and yields a similar table. Another important consideration for both mitigation- and adaptation-related analysis is the effects of an environment-oriented world in which policies, technologies, and lifestyles lead to reduced environmental stresses versus an environmentally stressed world in which climate change affects environments and ecosystems that are already vulnerable (Rozenberg et al., 2014).

**Stranded assets** are “assets that have suffered from unanticipated or premature write-downs, devaluations, or conversion to liabilities” (Caldecott et al., 2021, p. 418), in this case because of climate change or related policy. Discounted global wealth losses from fossil fuel stranded assets alone were estimated to be $1 trillion–4 trillion, a loss comparable with the 2008 financial crisis. According to Mercure et al. (2018), regions with higher marginal costs of production will be especially hard hit, with the United States and Canada being at risk of losing almost all their oil and gas industry (Mercure et al., 2018). Critically, the study notes that the global energy transformation is already well underway, and significant fossil fuel asset stranding occurs whether policies to meet the 2°C goal of the Paris Agreement are adopted or not. The study also highlights that macroeconomic impacts on producer countries are primarily determined by fossil fuel consumption in the rest of the world, and no single country, no matter how large, can alter that trajectory. However, according to the study, U.S. climate policy will still have a substantial impact on fossil fuel asset stranding by determining how large the pool of assets at risk of becoming stranded grows, how much the country benefits from investment in low-carbon technology, and whether it “ends up importing this fuel from low-cost producers in the Middle East” (Mercure et al., 2018, p. 592). Hence, the stranded asset risk to the United States is highest when there is international climate action that would reduce demand for fossil fuels and there is no U.S. climate policy, which leads to more U.S. investment in assets that are eventually stranded, a continued dependency on imported fossil fuels, and the lost opportunity of decarbonization-related investment. Notably, each component that determines the risk of stranded fossil fuel assets to the United States is uncertain in both policy
### TABLE 4.1
Sample of Possible Dimensions and Values for U.S.-Centric Scenario Development Related to International Effects

<table>
<thead>
<tr>
<th></th>
<th>High International Cooperation</th>
<th>Low International Cooperation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>U.S. Climate Policy</td>
<td>No U.S. Climate Policy</td>
</tr>
<tr>
<td>2100 warming</td>
<td>Very low</td>
<td>Low</td>
</tr>
<tr>
<td>Climate damage</td>
<td>Very low</td>
<td>Low</td>
</tr>
<tr>
<td>CBAM risk to the United States</td>
<td>Very low</td>
<td>High</td>
</tr>
<tr>
<td>Stranded asset risk to the United States</td>
<td>High</td>
<td>Very high</td>
</tr>
<tr>
<td>Conflict multiplier effect</td>
<td>Very low</td>
<td>Low</td>
</tr>
<tr>
<td>International trade</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>Supply chain risk</td>
<td>Low</td>
<td>Medium</td>
</tr>
<tr>
<td>Cost of climate technology</td>
<td>Low</td>
<td>Medium</td>
</tr>
<tr>
<td>Diversity of climate technology</td>
<td>High</td>
<td>Medium</td>
</tr>
<tr>
<td>Rate of cost reduction</td>
<td>High</td>
<td>Medium</td>
</tr>
<tr>
<td>U.S. green jobs</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>U.S. green growth</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>International green jobs</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>International green growth</td>
<td>High</td>
<td>High</td>
</tr>
</tbody>
</table>

**NOTE:** CBAM = Carbon Border Adjustment Mechanism.
Baseline and Timescale Considerations for Climate and Fiscal Models

and no-policy futures. Therefore, any analysis that recognizes this risk must incorporate it in its scenario construction regardless of how the scenarios are constructed or whether policy to address it is foreseen or not.

Option 3: Scenarios That Illuminate Vulnerabilities

A relatively new option in the climate literature is to choose customized scenarios crafted to evaluate specific policies (Lempert, 2012). Often, this takes the form of a stress test, which subjects a proposed policy to deliberately intense testing to determine its breaking points (Borio, Drehmann, and Tsatsaronis, 2014). Analysts can identify such scenarios by running a simulation model over many sets of assumptions, represented by an experimental design over the input parameters to the model. Classification algorithms, such as the Patient Rule Induction Method (PRIM) or Classification and Regression Trees (CART), are then used to provide concise descriptions of those combinations of uncertainties that best distinguish futures in which a policy meets or misses its goals.

The government of Costa Rica employed this approach in assessing its National Decarbonization Plan (NDP). The plan sets the ambitious goal for the country to become carbon-neutral by 2050 and lays out a variety of policy and institutional reforms to achieve this goal. To evaluate this plan, RAND researchers and partners developed an integrated model that estimates the benefits and costs of implementing the NDP in all major sectors of the economy, informed by consultations with numerous government agencies, industries, and nongovernmental organizations (Groves et al., 2020). The researchers then used this model to evaluate the GHG reductions and net economic costs of the NDP over approximately 3,000 alternative futures, each consisting of a set of assumptions about future macroeconomic conditions, as well as many detailed assumptions (e.g., cost and effectiveness of various technologies). The analysis suggests that under most plausible assumptions about the future, the NDP would achieve or nearly achieve its GHG emission reduction goals and would do so at a net economic benefit. The researchers then employed classification algorithms on the database of 3,000 model runs to identify those future conditions in which the plan might not provide net benefits in one or more sectors. For example, these algorithms identified a concurrence of three conditions that explains around 85 percent of scenarios with positive net financial costs in the transport sector. Equally important, the study showed that under a subset of those conditions, financial costs in transport decarbonization could be avoided. The ability to look across a breadth of scenarios enabled not only insights into high-risk conditions, including thresholds to monitor, but also ways to modify planning to preserve net benefits under more stressing conditions. Conditions, thresholds, and sector-specific insights were reported as vulnerable scenarios to the government and local stakeholders who could plan accordingly. Developing similar capacities would strengthen modelers’ abilities to identify combinations of parameters most relevant for planning and evaluating specific policies. It would also make it possible to identify threshold values for these parameters (i.e., values at which the outcome of a proposed policy might change dramatically). Parameter ranges within which a proposed policy is effective across plausible futures (rather than the expected outcome of a specific set of values) can reduce the need to find consensus on specific parameters. Finally, developing these capacities would provide insights into policy modifications and contingency plans for guiding the response to poor policy performance under unforeseen circumstances.

This approach that chooses customized scenarios crafted to evaluate specific policies has also been used to evaluate the impacts of proposed policies on the federal budget under conditions of deep uncertainty. In 2007, Congress considered reauthorizing the Terrorism Risk Insurance Act (TRIA). A key question was whether the proposed legislation would save or cost the taxpayers money, which depended on assumptions about numerous factors that are hard to predict, including the likelihood of future terrorist attacks, the behavior of firms providing insurance, the behavior of firms purchasing insurance, and the willingness of future congresses to compensate uninsured property owners (Dixon et al., 2007).
To estimate the budgetary impacts of the proposed TRIA legislation, RAND researchers developed a computer model that projected the costs to taxpayers, the insurance industry, and commercial property owners given various assumptions about the size and type of any future terrorist attacks, the behavior of the insurance industry and its customers, and the willingness of future congresses to compensate property owners without insurance. The RAND team then ran the computer model over thousands of different combinations of parameters to explore the consequences of these various assumptions (Dixon et al., 2007).

Classification algorithms that were applied to the resulting database of thousands of model runs indicated that, of the 17 uncertain parameters considered, two most strongly differentiated the cases in which TRIA saved taxpayers money from those in which it did not. These parameters were the likelihood of a large terrorist attack and the amount that Congress compensates the uninsured. These two parameters represent the key driving forces of a scenario in which the taxpayer cost is lower when TRIA is reauthorized than when it is allowed to lapse. While the analysis did not definitively answer the question of whether the legislation would save or cost the taxpayers money, it did clearly demonstrate that over a very wide variety of plausible assumptions, the legislation saved the taxpayer money and clarified the relatively narrow range of conditions under which the legislation would impose a net cost on the taxpayer.

Budget analysts might use this approach to identify the key assumptions that differentiate futures in which proposed climate legislation resulted in a net benefit to the federal budget from futures in which the legislation resulted in a net cost.

**Tail Risks**

**Catastrophic Scenarios**

Modeling climate tipping points, in which a change in temperature triggers an event that causes a disproportionate change in outcomes, is one of the most challenging aspects of climate science and climate economics. Such events as the melting of the Greenland ice sheet, the dieback of the Amazon rainforest, the shutdown of the thermohaline circulation, or a shifting of the West African or Indian monsoon are irreversible in nature and would change the overall dynamics of global climate. Because of the positive feedbacks associated with these changes, crossing one tipping point increases the risks of crossing others and thus triggering cascading effects (Lenton et al., 2020). The thresholds of these events are highly uncertain as well, but recent work has found that these thresholds might be much closer than once believed (Armstrong McKay et al., 2022). Armstrong McKay et al. (2022) found that the central warming thresholds of several tipping points, including melting of the Greenland and West Antarctic ice sheets and abrupt thaw of boreal permafrost, are below even the Paris Agreement limit of 2°C.

The impacts of these physical risks, in turn, will propagate through teleconnections between human and natural systems to increase the likelihood of societal risk cascades, such as international conflict, a meltdown of the global financial system, and widespread disease or famine (Kemp et al., 2022). Such risks are underrepresented in the climate change literature but need to be studied in tandem with physical disruptions. However, the climate-economics literature has recently incorporated very stylized analyses of tipping points. Dietz et al. (2021) built a meta-analytic IAM that quantifies the economic damages of eight different tipping points in the climate system. The authors found that tipping points significantly increase the SCC and estimate a 10 percent chance of doubling the SCC (Dietz et al., 2021). However, the economic consequences of tipping points are highly uncertain. Damage functions are typically developed using historical observations, and therefore the lack of observations of extreme physical changes in the climate system leads to a high degree of uncertainty in the upper tail of climate change impacts.
Heavy-Tailed Impacts

Catastrophic scenarios might also be termed *tail events*, or events that would occur at the upper tail of a distribution of the impact of all events. These events are therefore rare by definition, although their exact probability and severity depend on the underlying distribution. Damages from climate change are a classic example of a heavy-tailed distribution. *Heavy tails* can be defined as tails that fall off slower than an exponential tail (see Figure 4.3). Put simply, this means that much of the impact is felt in only a handful of events. The distribution of individual income has a heavy tail because a small number of people own most of the wealth. In terms of climate impacts, this means that a high-impact catastrophic event is much more likely than would be expected under simpler modeling assumptions: Therefore, extreme events cannot be ruled out. As defined by the IPCC, climate risk depends on hazards, exposure, and vulnerability (Field et al., 2012). Climate hazards are determined by the rate of climate change and therefore depend on the climate sensitivity and the change in temperature per doubling of CO₂ emissions. The climate sensitivity is commonly thought of as a heavy-tailed distribution where the central tendency lies around 3°C. As already alluded to with the income example, vulnerability to climate hazards is also a heavy-tailed distribution. The compounding influence of two heavy-tailed distributions leads the climate risk distribution to have a fatter upper tail.

There are numerous statistical problems that arise under heavy tails, including the inflation of the variance of estimates of the mean and other moments, which render them unreliable (Taleb, 2022). This is a grave cause for concern because the sample mean, or expected value, is used in traditional CBA to make decisions. An extreme example of this concern is introduced by Weitzman (2009), who postulates that one cannot con-

---

4 Specifically, extreme outcomes are much more likely in systems with heavy-tailed distributions than if impacts are distributed according to a normal distribution. Because many models default to assumptions of normally distributed outcomes, this can lead to vast underestimation of the impacts (particularly, if outcomes are correlated).
duct a CBA of climate change impacts in the face of catastrophic events because the expected value could be infinite.\textsuperscript{5} Others have criticized this theory, arguing that it only holds under certain circumstances, although the instability of the expected value under heavy-tailed conditions remains an important problem (Ikefuji et al., 2015; Nordhaus, 2009).

This example of the deep structural uncertainty that is present in climate economics underscores the importance of using different approaches to make climate policy decisions. Other practitioners and researchers have noted the inadequacies of using a conventional expected utility approach to decisionmaking when dealing with heavy tails and instead advocate for approaches that minimize the expected value of the upper tail of a distribution (McInerney, Lempert, and Keller, 2012; Nazari et al., 2015). One such approach is the Conditional Value-at-Risk (CVaR). The CVaR quantifies the expected loss in the tail (specified by some threshold) of a distribution of utility. This is also known as the expected shortfall. The CVaR is useful in situations in which the upper tail of financial losses is heavy and unbounded. Therefore, in addition to reporting the central estimate of budgetary impacts, budget analysts could report such a measure as the CVaR to better communicate the potential for a policy to minimize risk.

In Mercure et al. (2021), the authors argue that in contexts subject to heavy-tailed uncertainty, the unknowable tail-risk precludes using the probability density function for risk analysis at all. Instead, they introduce the Risk Opportunity Analysis framework in which analysts use their understanding of the system in question to map out the pathway of compounding effects that leads to the highest benefits and highest risks because of the implementation of some policy (Mercure et al., 2021).

### Key Modeling Points

In this chapter, we have shown the importance of modeling decisions, such as the discount rate, the timescale of analysis, baseline scenario assumptions, and the approach used to aggregate distributional impacts. A model used to quantify the budgetary impacts of climate change must therefore be able to make different assumptions regarding these parameters. Table 4.2 provides an overview of the current state of work from budgetary agencies, as well as the following recommendations.

To begin, the baseline assumptions in budgetary analyses of climate change policies should support simulations spanning multiple decades to centuries to capture most of the benefits of a climate change mitigation policy. Given the necessary length of timescales in climate change analysis, an appropriate discount rate could be used to quantify the NPV of the avoided damages because of a policy at the beginning of the budget horizon when the policy is initially implemented, as is done for loan programs using accrual accounting (see Table 4.2 for more details).\textsuperscript{6} This way, the long-term benefits of a climate policy could be incorporated into the policy’s score while retaining the typical budget horizon for other costs. Of course, the quantification of avoided damages would be sensitive to the discount rate and to the deep uncertainty inherent in long-term socioeconomic and climatological projections. Thus, modelers should simulate many combinations of uncertain parameters in the baseline assumptions. These combinations might be designed around specific questions or might follow well-established scenarios that are used by many other organizations. Finally, given the known heavy-tailed behavior of impacts in the coupled human-Earth system, a model of this complex system must be able to represent some of the nonlinearities within and dependencies between systems. While this is no simple undertaking, progress has been made by modeling groups to build agent-based IAMs (e.g.,

---

\textsuperscript{5} This is commonly referred to as the dismal theorem.

\textsuperscript{6} Using accrual accounting rather than cash accounting for federal direct and guaranteed loans is required by the Federal Credit Reform Act of 1990. Thus, this change in methodology might require new legislation.
<table>
<thead>
<tr>
<th>Action</th>
<th>Current State of Work and Gaps</th>
<th>Recommendation for Modelers</th>
</tr>
</thead>
<tbody>
<tr>
<td>To score climate-related policies, use a discount rate that is appropriate for long timescales.</td>
<td>• CBO uses the rate of return for treasury securities as its discount rate; recently, this has been 3 percent. • OMB sets one rate for the social rate of time preference from the present through 30 years in the future. This rate is typically the real rate of return on long-term U.S. government debt, which averages about 1.7 percent.</td>
<td>The choice of a discount rate is ultimately a value judgment. Scores with long timescales should therefore be calculated using different rates, preferably endogenously through the Ramsey formula instead of using a single number.</td>
</tr>
<tr>
<td>Use long timescales for climate-related policies.</td>
<td>• CBO uses ten-year timescales for most scoring and 30-year timescales for long-term budget outlooks. • OMB uses ten-year timescales for most scoring and 25-year timescales for long-term budget outlooks.</td>
<td>Climate-related policies should have a 50–100-year timescale of analysis so that a large percentage of the available benefits of a mitigation policy may be captured.</td>
</tr>
<tr>
<td>Use multiple baseline scenarios to understand how uncertain parameters can influence the results.</td>
<td>• CBO has conducted uncertainty analyses using scenarios before but provides a central estimate when scoring legislation. • According to Circular A-4 (OMB Circular A-4, 2003), OMB recommends probabilistic analysis when there are large uncertainties with cascading effects. The updated draft Circular A-4 guidance (OMB Circular A-4, 2023) suggests discrete scenario analysis when the uncertainty is unquantifiable.</td>
<td>A central estimate of future costs and benefits under deep uncertainty is unreliable. Scores should be calculated using a subset of plausible scenarios that differ in their inputs. Lawmakers may then incorporate their respective levels of risk tolerance in the decisionmaking process.</td>
</tr>
<tr>
<td>Use a metric that captures the risk inherent in a policy.</td>
<td>• CBO uses a central estimate to provide its scoring and does not assess the risk of tail events. • The latest OMB guidance recommends reporting the central tendency as well as other characteristics of the distribution that reflect the extent of uncertainty when there are probabilistic distributions available.</td>
<td>The CVaR measures the tail risk of a policy. This could be reported in addition to the central estimate to give an indication of the risk involved and the variance of the estimates.</td>
</tr>
</tbody>
</table>

the Dystopian Schumpeter meeting Keynes model developed by Lamperti et al. [2018]). Varying the baseline assumptions in such a model would likely lead to a heavy-tailed distribution of scores, and simply reporting the central tendency of a heavy-tailed distribution is misleading because it does not communicate the extent of the risks. Therefore, the legislation scores that are designed to communicate budgetary impact (i.e., not to keep the budget on track) should include metrics that characterize the risk associated with a policy (e.g., the CVaR) in addition to point estimates for the central tendency.
Conclusion

Climate change will likely affect the federal budget substantially through the effects from physical risks (e.g., wildfires, droughts) on spending and revenue and from the transition risks associated with climate change mitigation policies. This report provides an overview of these effects and discusses the concepts that are crucial to model them. The decision-support literature makes clear that employing appropriate decision processes (e.g., exploratory rather than predictive scenarios) is at least as important as appropriate information products (e.g., relevant climate data) to informing effective climate-related decisions (National Research Council, 2009). This chapter thus provides recommendations both for a budget model that can address climate change and for how budget analysts might effectively use such a model.

Recommendations for a Budget Model

First and foremost, a model used to score legislation must be able to capture the effects of climate change. In Chapter 2, we described the different pathways through which climate change has affected and will continue to affect the federal budget. In particular, the health impacts will likely cause high increases in spending and decreases in revenue. A model developed to capture budgetary effects must therefore represent the health impacts of climate change as well as appropriate adaptations that can be made to mitigate those impacts (e.g., migration, job switching). Since these effects are distributed unevenly across geography and income levels, the model must operate at a subnational resolution.

Chapter 3 provided an overview of the impacts of certain climate change mitigation policies and described the models used to quantify these effects. To quantify the emissions reductions from a policy, it is necessary to use a model with technology-level resolution, or a bottom-up model. However, the ultimate effects of a policy will depend on the conditions and adaptations of the macroeconomy. The budget model should therefore incorporate both bottom-up and top-down modeling to ensure these effects are all represented. Additionally, the model should be able to report multiple metrics, including policy-induced emissions reductions (including both GHGs and non-GHGs, such as PM), changes in employment, implications for morbidity and mortality, and aggregated economic damages. Reporting multiple metrics removes a significant source of uncertainty that arises from attempts to monetize the impacts of climate change and climate change policy. Multiple metrics are also necessary to address equity and to avoid privileging some viewpoints over others (Ara Begum et al., 2022).

These recommendations have been implemented in other climate and energy economics studies; however, the models that are typically used in these studies rely on assumptions that are inconsistent with the complex nature of the coupled human-Earth system (Arthur, 2021). Dependencies and nonlinearities in this

---

1 In 2014, Senator Bernie Sanders (I-VT) introduced a bill that would require CBO to compute a “carbon score” of legislation in addition to its impact on the deficit. This bill was not passed by the House of Representatives or the Senate, though it is a good example of what reporting multiple metrics might look like. See U.S. Senate, 2014.
complex adaptive system can lead to risk cascades once certain thresholds are passed. A model that captures the linkages between the climate and human system should represent these dependencies and nonlinearities. Because interactions and feedbacks between systems are deeply uncertain, the analysis must be explicit about all assumptions and treat the myriad uncertainties appropriately.

Recommendations for Model Use for Budget Analysts and Other Modelers

Although our model-building recommendations provide a helpful foundation for climate policy analysis, it is equally if not more important to determine how the model will be used. Here, we offer several approaches that—either separately or in combination—could help budget analysts more effectively include climate change in their processes. In each case, we envision that analysts would provide the information obtained from this model in addition to their best estimate of the ten-year budgetary implications of a proposed policy. These recommendations are offered with respect to climate mitigation and adaptation policies, but similar analyses could be produced for other types of legislation.

As one approach, analysts could produce a longer time-horizon estimate of the budgetary impacts of climate-related legislation. In this report, we used a simple IAM to show the necessity of using timescales longer than a decade to capture more than a small fraction of the effects of climate policy. This analysis suggests that analysts should provide estimates of the budgetary implications of climate policies over longer timescales, for instance 50 to 100 years. Congress might use this information to balance near- and longer-term costs and benefits.

Most budgetary analysis does not currently consider longer timescales because of the high degree of uncertainty involved. Climate change compounds this uncertainty because of the deep structural uncertainties present in the coupled human and biophysical earth systems. Therefore, as a second approach, analysts could use scenarios to address the uncertainty inherent in climate change in general and in long timescale projections specifically.

Scenarios are a useful way to project a wide variety of plausible futures across the uncertainty space. We discussed three options for choosing appropriate scenarios in Chapter 4. First, analysts can rely on standard sets of scenarios, such as those used by the IPCC. This would enable easier communication between budget analysts, policymakers, and climate scientists. The second option is to customize the scenarios for the specific use case. In the context of budget modeling, such scenarios might focus on the subnational impacts of a climate change mitigation policy and levels of international cooperation or involvement in technological innovation. The third option is to use scenarios that stress-test proposed legislation. This can be accomplished by varying uncertainties in multiple dimensions and thereby developing hundreds or thousands of scenarios that can be used to check the sensitivity of the results to specific baseline assumptions. While this is arguably the most time- and resource-intensive option, this framework allows the analyst to develop scenarios that most effectively illuminate the strengths and weaknesses of particular legislation and provide the most information on potential improvements.

These options for choosing scenarios can be implemented separately or can build off one another: For example, users could construct detailed scenarios from a set of standard scenarios and use them to conduct stress tests. Once the scenarios are chosen, analysts could then supplement their preliminary estimates with estimates of the budgetary implications of climate policies across each of the scenarios. Decisionmakers might use this information to craft policy that is more robust over multiple scenarios.

In a third approach, budget analysts could use risk metrics, such as the CVaR, to report the probability and magnitude of the tail risk associated with each policy. For instance, analysts might find that, based on the
central estimate, a proposed piece of legislation has a small negative impact on the federal budget but would also reduce the risk of some low-probability, catastrophic outcome by some large amount. Congress might use such information to weigh the value of insuring against outcomes.

The implementation of some or all these recommendations by modelers will help policymakers to consider both the long-term implications and the inherent uncertainties embedded in climate policy decisions.

Future Work

Although we laid out the framework for a national budget model, international trade and the global nature of climate change require a global outlook (see Appendix A). Thus, future research should examine how to set the recommended model characteristics in a global context. Additionally, there are significant areas of uncertainty that remain to be explored. For example, there are still many competing schools of thought regarding how future damages should be discounted, which account for the role of ethics (Stern, 2007), global versus regional discount rates (Anthoff, Dennig, and Emmerling, 2021), and whether an expected utility-based framework is even appropriate given known inconsistencies in observed decisionmaking (Chambers and Melkonyan, 2017). The role of adaptation and its associated implications for the rate of learning (e.g., about the climate system, technological innovations) are also important considerations that were not discussed thoroughly in this report.

We hope that our model recommendations will contribute to the incorporation of climate change effects into models of the federal budget. Given the rapid pace of global change and the ever-diminishing window of averting catastrophic climate tipping points, budget modelers must use the lessons learned from the climate science, economic, and decisionmaking literatures so that policies are developed using the best information available.
Expanded Framework for Policy-Climate Model

This appendix extends the framework presented in Figure 1.1 for modeling policy and climate to include the global economy.

Global emissions play a significant role in climate change, and many of the effects of climate change will fall on other nations and the global economy. Therefore, while there are limits to the power of U.S. policies to influence climate change, this framework does point to an important set of considerations for future climate and fiscal models.

In addition to the connections portrayed in Figure A.1, federal policy and aid can influence the global economy, and the U.S. economy interacts with the global economy through trade, technology, migration, and aid. These additional linkages could be included in a large-scale model of policy and climate. However, given the additional complexity involved, we recommend first constructing a domestic model that follows the recommendations above and then expanding the scope to include global interactions.

FIGURE A.1
Interactions Between Federal Policy, the Climate, and Both the U.S. and Global Economy
Supplemental Information on the Congressional Budget Office

Background

The CBO is an independent, nonpartisan agency that was established by the Congressional Budget and Impoundment Control Act of 1974 to aid Congress in matters related to the federal budget (Public Law 93-344, 1974). Its status as an independent agency means that it is not overseen by the executive branch of the federal government. Rather, CBO uses processes that are specified by the Congressional Budget and Impoundment Control Act of 1974 or that were developed by CBO alongside congressional leadership and the House and Senate Budget Committees. Within the confines of what is required of CBO through statute (e.g., producing the annual Budget and Economic Outlook report and scoring each bill that passes through a congressional committee), analysts have the power to use whatever methods they deem are best suited to provide meaningful information. The CBO’s nonpartisan designation means that it does not offer policy recommendations, nor does it employ analysts based on political affiliation. A director of CBO is appointed every four years by the House Speaker and the President pro tempore of the Senate. In addition to the Office of the Director, CBO is composed of nine divisions: Budget Analysis; Financial Analysis; Labor, Income Security, and Long-Term Analysis; Macroeconomic Analysis; Management, Business, and Information Services; Microeconomic Studies; National Security; and Tax Analysis. These divisions are responsible for producing many products each year. Specifically, CBO produces scores of every piece of legislation that is approved by congressional committees except for the House Committee on Appropriations and Senate Committee on Appropriations (600–800 scores per year), baseline budget and economic forecasts (one updated throughout the year), long-term budget projections (one updated throughout the year), and reports and white papers related to major areas of federal policy (around 70 created throughout the year) (Kilroe, 2020).

The following sections describe the methodology behind each of these products.

Baseline Economic and Budget Forecasts

Every year, CBO produces ten-year projections of how the budget and the economy will evolve under existing legislation.

A small group of analysts rely on expert opinion (including other staff at CBO, CBO’s Panel of Economic Advisers, and other economists within and external to the federal government), economic events and data, and several economic models to generate the ten-year economic baseline. As a first step, the analysts determine the likely behavior of exogenous variables (i.e., those that will not be affected by macroeconomic interactions) over the ten-year horizon. These variables are then used as input into a large-scale macroeconomic model to yield estimates of GDP, unemployment, interest rates, inflation, etc. This process is validated against historical data and adjusted to add new data or projections from the analysts. The baseline is then reviewed by internal and external reviewers. The macro model includes stochastic (i.e., includes an error
term) and deterministic (i.e., identity) equations and is based on the premise that economic activity is determined by aggregate demand and aggregate supply. Exogenous variables (e.g., population, energy prices, foreign growth) and the outputs of other models (e.g., potential output from CBO’s Forecast Growth Model or the labor force participation rate from CBO’s Labor Force Participation Rate Model) are used as input to the macro model. The endogenous economic variables produced (e.g., inflation, consumer spending) are used in the construction of the budget baseline. Overall, the economic baseline is intended to reflect the center of the distribution of potential economic outcomes. More information on the economic baseline can be found in the CBO working paper series.1

The budget baseline relies on the economic baseline. It contains estimates of revenues and spending from every major source along with deficits and debt. The process for creating the budget baseline is similar to that of the economic baseline: Analysts consult experts internal and external to CBO, assess the accuracy of past projections and outside estimates, ensure consistency with current legislation, and add in new information where available. CBO produces revenue estimates by relying on the macroeconomic variables in the economic baseline and applying the appropriate tax rates for each taxable activity. Revenue sources are modeled differently depending on their characteristics. For example, individual income taxes and payroll taxes are modeled using a microsimulation model, whereas corporate income taxes and excise taxes are modeled using aggregate based models. The baseline for spending is constructed from nearly 3,000 subaccounts of discretionary and mandatory spending and net interest outlays. More information on the budgetary baseline can be found in the How CBO Prepares Baseline Budget Projections report (CBO, 2018).

Long-Term Budget Outlook

The Long-Term Budget Outlook extends the trends observed in the ten-year projection to a 30-year horizon. This is accomplished using OMB’s simplified model of the federal budget. The Long-Term Budget Outlook includes projections of alternative scenarios. For example, the 2024 Outlook contained three scenarios of GHG emissions depending on the climate change mitigation choices of other countries.

Cost Estimates

A large part of CBO’s mandate is to provide cost estimates for pieces of legislation that pass congressional committees. These cost estimates (or scores) are relative to the ten-year baseline and are given as point estimates that are intended to reflect the center of possible outcomes. Analysts use methods specifically tailored to the legislation at hand rather than relying on the same model for all scores. CBO includes estimates of how the piece of legislation would affect mandatory and discretionary spending and revenues and thus what the net impact on the deficit would be. The scores also include estimates of how federal mandates affect state, local, and tribal governments. Scoring is based on a set of guidelines to make the overall process consistent. More information on the scoring processes used by CBO can be found in its Budget Primer published in April 2023.2

---

1 Specifically, the methodology for producing the economic baseline is described in the working paper How CBO Produces Its 10-Year Economic Forecast. See Arnold, 2018.

2 CBO, 2023b.
APPENDIX C

Supplemental Information on Climate Change Mitigation Policy Impacts

In this appendix, we set up a framework for understanding the role of incentives and subsidies in diffusing new technologies, describe how tax expenditures on energy-related tax credits have changed over time, and summarize findings on the impacts of policies in different sectors, including R&D, power generation, and transportation across the literature.

The Role of Incentives and Subsidies in Technology Adoption and Use

In the long term, the incentive-based IRA is a technology policy that aims to significantly shift technology development and infrastructure investments to zero-carbon options by implementing tax incentives and subsidies across various actors in different sectors. Popp (2010) describes the interwoven stages of technology change as invention, innovation, and diffusion. Invention is the stage in which “an idea must be born” (Popp, 2010, p. 3), innovation is synonymous with R&D in which the idea is developed into something commercially viable, and diffusion is the stage of technology adoption. The invention stage can accommodate a new technology or new technology aim, such as an improved fuel economy for new vehicles. Ideally, as technologies are developed and diffused, relevant tax incentives and subsidies are used to initiate and motivate adoption, but they should be phased out as a self-sustaining market is established. Figure C.1 builds on Rogers, Singhal, and Quinlan’s technology adoption “S-curve” illustrating a stylized adoption trajectory for technology change from innovation to mainstream use (Rogers, Singhal, and Quinlan, 2014).

We introduce the S-curve in Figure C.1 for two reasons: (1) to demonstrate a framework of technology innovation and adoption and (2) to provide context for understanding how findings of our literature review may vary depending on when incentives and subsidies are introduced along a technology’s S-curve trajectory. Fiscal policy has historically played a major role in supporting innovation, particularly at its early phases.

As one moves along the adoption phase of the S-curve, the source of support and funding for technology development and production in Figure C.1 ideally changes. Early on, when there is an emphasis on the public sector and risk and cost trade-offs are high, tax incentives and subsidies provide a discount to early adopters that leads to initial sales that provide revenue for further iteration and scaling up of the new technology. As a technology attracts more adopters and moves into the takeoff phase, the sources of funding become more complex and more diverse. At the same time, the producers of the technology increasingly vary in approach and quality while learning and iterating continues until the best performing technology prevails. As the number of adopters increases and a technology’s reliability is proven between early and late adopters, a technology ideally achieves economies of scale by which it can eventually be sustained by profits; public funding can be phased out to pursue nonfiscal benefits elsewhere in the economy, such as supporting innovation in another technology.

A technology’s location on a S-curve is itself a factor to consider because it can lead to incentives and subsidies that are unique to that part of the curve. For example, if incentives and subsidies are applied too early
and a technology fails with early adopters, mainstream adopters will not be drawn to the market (Hart and Noll, 2019). If they are applied too late or for too long, the benefits might be accrued mostly by incumbents and prop up a market that eventually no longer generates new knowledge or innovation. Just as certain points of the curve are more appropriate for incentives and subsidies, other points are more appropriate for the evaluation of these policies, which might be affected by where in time along the curve the study is conducted. For example, although initial capital installation costs have fallen since 2005, solar PV capacity appears to steadily grow independent of the status of its relevant tax credits (Frazier, Marcy, and Cole, 2019; Hart and Noll, 2019).

### Public Sector Expenditures on Tax Incentives and Subsidies

Figure C.2 illustrates how tax expenditures for energy-related tax credits have changed since 1978. The majority of benefits went to fossil fuel–related investment until 2007, when renewable fuels, renewable technologies, and alternative-technology vehicles started to accrue more benefits. Notably, the Energy Policy Act of 1992 introduced important power generation tax credits for renewable fuel sources, and the 2005 Energy Policy Act introduced new tax credits for clean technologies, such as hybrid and plug-in electric vehicles. According to the Information Technology and Innovation Foundation, the PTC for renewables received the most spending at about $5 billion per year by 2019, followed by the tax incentives for fossil fuel–related investments (totaling just over $3 billion) and the ITC for renewables, which costs about $2.5 billion annually (Hart and Noll, 2019).
Impacts by Sectors

Research and Development for Clean Technologies

When the government identifies new and emerging technologies or ideas of technologies that could have spillover benefits for the public, it can offer incentives in the form of grants, investment, R&D tax credits, and demonstrations to encourage the prioritization of desired R&D activities and advance those technologies that are more attractive for firms, academic institutions, and other developer organizations. The IRA provides new funding for the Department of Energy’s Office of Clean Energy Demonstration and National Laboratory Infrastructure to support energy science and innovation. In addition, the 2022 Chips and Science Act authorized funding for new programs and initiatives to finance clean energy technologies across several federal agencies and regional programs (Public Law 117-167, 2022).

The expected spillover benefits include new knowledge and discoveries for society, less dependence on fossil fuel technologies, and an improved posture for the United States amid global competition and security threats, as well as potentially better health outcomes, job creation, stronger consumer protections, and improved economic outcomes for households in the long term as these technologies become cheaper and are increasingly adopted. These benefits are not easily owned and controlled by a given firm, hence the need for tax incentives and subsidies. The social rates of return for R&D have been calculated to be between 30 and 50 percent (Hart and Noll, 2019; Jaffe, 1986; Jones and Williams, 1998; Mansfield, 1996; Mansfield et al., 1977; Pakes, 1985; as cited by Popp, 2010), compared with calculated private marginal rates of return between 7 and 15 percent (Bazelon and Smetters, 1999; Hall, 1996; Jones and Williams, 1998; as cited by Popp, 2010). The U.S. government is in a position to consider the social returns and compensate for underinvestment by
private firms until long-term payoffs, greater certainty, and a finished product make it more appropriate for firms to take over (Popp, 2010).

Studies have found that R&D subsidies and incentives lead to an increased deployment of clean technologies (Acemoglu et al., 2012; Aghion et al., 2016; Donohoo-Vallett et al., 2017; Popp, 2006). These studies model different climate mitigation policy scenarios with and without different levels of R&D successes for developing clean energy technologies. With a focus on the power sector, a Department of Energy (Donohoo-Vallett et al., 2017) study compares NREL-developed Standard Scenarios (Cole et al., 2016; Sullivan et al., 2015), using the ReEDS and Distributed Generation Market Demand (dGEN) capacity-extension energy models. They find technologies enabled by R&D incentives and subsidies could lead to renewable energy generation becoming the largest source of electricity by 2050 under scenarios both with and without $10 per ton and $20 per ton carbon prices, respectively. However, delaying these R&D subsidies can also slow down sector transitions because the productivity gap between carbon-intensive and clean sectors is likely to grow with time if development and deployment of clean technologies continues to lag (Acemoglu et al., 2012; Acemoglu et al., 2016).

Power Generation

Earlier in this appendix, we discussed regulatory policies for the power sector, and here we discuss climate mitigating tax incentives for the power sector. These tax credits incentivize power generation from zero-carbon energy sources and apply to carbon capture, utilization, and storage for existing fossil fuel sources.

Power Production and Initial Investment Incentives

Power generation incentives first appeared in the United States in 1916 to stimulate oil and gas development a few years after the federal income tax was first introduced. Some version of these incentives still exist today (see Figure C.3). Since the 1970s, incentives for renewable energy sources have been attempted multiple times, but the first effective approach was introduced with the Energy Policy Act of 1992. The two main federal tax credits to take this approach are the PTC and the ITC. PTCs reduce taxes at specified rate (calculated at cents per kilowatt hour) for the first ten years of clean energy production. The ITC offers tax reductions for 30 percent of the initial capital expenditures in the same year as those expenditures (Upreti et al., 2016). Each of these tax credits can be claimed for many types of zero-carbon energy sources, but while PTCs are predominantly claimed by investors and owners of wind farms, ITCs are predominantly claimed by those in solar power generation.

Frazier, Marcy, and Cole (2019) evaluates PTC and ITC interactions using modeling techniques similar to those discussed under regulation, evaluating scenarios with and without tax credits to understand their effect. They consider the NEMS and ReEDS models, examining the case in which the full value of a credit is extended to the end of the projection period and the case in which an immediate tax expires in 2020. They find that, in both sets of scenarios, solar PV capacity steadily grows at an annual rate across all scenarios, including the reference scenario, though the annual rate of growth varies. Annual wind capacity additions fall following the expiration of the PTC, although wind prices become more competitive with high natural gas prices (Frazier, Marcy, and Cole, 2019). Figure C.3 illustrates the history of PTC authorizations and expirations of wind capacity and the history of ITC authorizations and expirations of solar power capacity. Since 1992, the wind PTC has been allowed to expire ten times. In a survey analysis, Barradale (2010) found that investment volatility in wind power generation is a result of uncertainty related to whether a PTC will be renewed when it expires and how power purchase agreements are negotiated—not necessarily the existence of the PTC itself. In other words, while investors wait for the PTC to be renewed, investment in wind declines, which creates boom and bust cycles that discourage long-term investment.
As power generation technologies mature along the adoption curve, a similar theme emerges: The types of technology prioritized by tax credits matter. While new wind development appears to be dependent on the PTC to keep prices down to 2 cents per kilowatt from 7 cents per kilowatt, since 2010, the costs of dominant crystalline silicon solar panels has decreased by 92 percent, and their energy productivity has increased by 40 percent (Hart and Noll, 2019). With decreased initial capital expenditures for solar installation, the value added by the 30 percent ITC has also decreased. The Information Technology and Innovation Foundation points out that there are opportunities for new technology in the renewable energy space, such as perovskites and quantum dots for solar panels, solar paint, and landfill coverings (Hart and Noll, 2019). In addition, other technologies that are still in the R&D phase are not yet eligible for the ITC or PTC and have not yet claimed the benefits of these tax credits. Distinct technologies can be affected differently by the same tax policies.

Carbon Capture, Utilization, and Storage Incentives

The incentive for carbon capture, utilization, and storage (CCUS) is known as 45Q, named for the section of the U.S. Internal Revenue Code that introduced a tax credit for carbon storage in 2008. The credit has since been expanded, at first in the Bipartisan Budget Act to include carbon monoxide (Public Law 115-123, 2018) and in the IRA to higher levels of credit. The original tax credit incentive promoted geological storage and carbon-enhanced oil recovery, in which carbon is reinjected into an oil field to stimulate more oil production. The expansions increased the incentive amounts, added a performance-basis, and made more industries eligible, including carbon conversion to concrete, plastics, and chemicals, as well as direct air capture.
the process of capturing carbon dioxide from ambient air concentrations. The credit can be realized for 12 years after the carbon capture equipment is placed and will be inflation-adjusted beginning in 2027, indexed to 2025.

The literature on 45Q is limited. Two studies find that the tax credit provides an economic opportunity for fossil fuel plants during the 12-year subsidy period, but its benefits are not necessarily sustained over the 40-year life cycle of a plant, which could mean that CCUS activities cease once the tax credit expires (Fan et al., 2019; Victor and Nichols, 2022). In terms of methods, Fan et al. (2019) applies delay real option theory to calculate a total investment value for CCUS projects under three policy scenarios and develops a decision framework to predict whether firms will deploy, continue, or halt CCUS activities. Victor and Nichols (2022) use MARKAL energy system modeling and determine that, to varying degrees,1 all five of their policy scenarios have a net positive result on tax expenditures. Adding a carbon tax makes CCUS more attractive before and after tax credits expire and increases tax revenues in all scenarios across both studies.

There is debate about how effective CCUS is in mitigating climate change. The additional equipment is not only expensive but also energy intensive, which in turn increases the fuel needs of eligible plants. In addition, translating the uptake of CCUS to higher-order impacts can be challenging because projects range maximally from 6 to 56 percent in net storage efficiency, and processes can reemit 0.43–0.94 kg CO₂ per kg of stored CO₂ (Farajzadeh et al., 2020). Furthermore, Victor and Nichols (2022) point out that there is a lack of available manmade carbon sources in places that make economic sense for sourcing and transporting carbon for CCUS, particularly outside the United States. These barriers must be overcome before CCUS becomes a ready and scalable solution to lower overall total CO₂ abatement costs in the future (Edenhofer et al., 2010; International Energy Agency, 2010; Martinsen et al., 2007; Winskel et al., 2009).

Transportation

The majority of emissions produced in the transportation sector come from internal combustion engines used in vehicles, planes, ships, etc. Reducing emissions in the transportation sector could rely on various approaches, including modifying urban planning and land use to limit commuting distances; increasing the use of public transportation; transitioning fuels and fuel economies for heavy-duty vehicles, such as cargo trucks, planes, and ships; and electrifying light-duty vehicles, such as sedans, SUVs, vans, and smaller trucks. The IRA builds on past approaches to provide tax incentives and subsidies for transitioning the transportation sector to cleaner technologies through vehicle purchase incentives to households and consumers, incentives to develop charging infrastructure, and fuel credits for low carbon fuels and sustainable aviation fuels. In this subsection, we focus on vehicle purchase incentives as an example.

Purchase incentives have historically included income tax credits, rebates, and sales tax waivers at the state, local, and federal level, and several studies demonstrate that these incentives have a significant effect on whether individuals purchase cleaner vehicles (Hardman et al., 2017). For example, Tal and Nicholas (2016) attribute about a 32.5 percent increase in plug-in electric vehicle sales to the existence of a federal incentive. Through survey analysis, Turrentine and Kurani (2007) conclude that this consumer behavior is more complex than an economically rational decision model accounts for. Individuals do not necessarily analyze their fuel costs in a systematic way and are more likely responding to immediate perceptions of rising gas prices, environmental issues, and several smaller policy design choices related to the purchase incentive than overall savings (Hardman et al., 2017; Tal and Nicholas, 2016; Turrentine and Kurani, 2007). In other words, how incentives are designed can influence technology adoption in important ways, as well as how that adoption affects higher-order impacts, such as reducing carbon emissions (discussed earlier in this section). These

---

1 MARKAL = Market Allocation numerical model.
design choices include transparency, ease of use, how immediately individuals receive benefits, and what vehicles the incentive can be applied to. In addition, when incentives are capped or made unavailable can have important implications for sales (Hardman et al., 2017).

As an example of one design choice, the closer to the point-of-sale an incentive is applied, the more likely more consumers will use it. In a study that used 2000–2006 data to compare waivers, income tax credits, and non-tax incentives (e.g., unrestricted access to carpool lanes, free parking, and administrative waivers) at the state level, Gallagher and Muehlegger (2011) found that a $1,000 income tax credit increases sales by 5 percent but that sales tax waivers also increase hybrid car sales relative to income tax credits tenfold. This is likely because each type of incentive differs in what level of effort is required to obtain it and at what point in time consumers can expect to see returns. Sales tax waivers can reduce the cost of a car immediately, while a rebate still requires some effort and wait for a refund. Income tax credits require even more foresight, level of effort, and an overall lag in returns.

Other incentive design choices can also translate into higher-order impacts, such as electric mile range, whether a car is secondhand, or how the car is used. Tax credits in the 2005 Energy Policy Act assigned different credit levels for varying battery capacities. For example, it correlated to greater sales of the Nissan Leaf compared with other makes and models (Tal and Nicholas, 2016). The 2022 IRA adds price caps for the value of the car and a new credit for buyers of secondhand cars. At the same time, few studies translate the impact of these purchases to higher-order benefits. For example, if the vehicle purchase being incentivized is not meant to serve a household as the primary vehicle, there is a chance that overall emissions will not actually be lowered for that household (Nunes, Woodley, and Rossetti, 2022). In addition, the energy mix of the grid being used to charge the vehicle can play a role in overall emissions reductions (Graff Zivin, Kotchen, and Mansur, 2014).
### Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>CBA</td>
<td>cost-benefit analysis</td>
</tr>
<tr>
<td>CBO</td>
<td>Congressional Budget Office</td>
</tr>
<tr>
<td>CCUS</td>
<td>carbon capture, utilization, and storage</td>
</tr>
<tr>
<td>CES</td>
<td>clean energy standard, clean electricity standard</td>
</tr>
<tr>
<td>CGE</td>
<td>computable general equilibrium</td>
</tr>
<tr>
<td>CO₂</td>
<td>carbon dioxide</td>
</tr>
<tr>
<td>CVaR</td>
<td>Conditional Value-at-Risk</td>
</tr>
<tr>
<td>DICE</td>
<td>Dynamic Integrated Climate-Economy</td>
</tr>
<tr>
<td>DoD</td>
<td>U.S. Department of Defense</td>
</tr>
<tr>
<td>EIA</td>
<td>Energy Information Administration</td>
</tr>
<tr>
<td>EPA</td>
<td>U.S. Environmental Protection Agency</td>
</tr>
<tr>
<td>EPS</td>
<td>Energy Policy Simulator</td>
</tr>
<tr>
<td>ETS</td>
<td>emissions trading system</td>
</tr>
<tr>
<td>FAS</td>
<td>factor-actor-sector</td>
</tr>
<tr>
<td>FEMA</td>
<td>Federal Emergency Management Agency</td>
</tr>
<tr>
<td>FERC</td>
<td>Federal Regulatory Commission</td>
</tr>
<tr>
<td>FrEDI</td>
<td>Framework for Evaluating Damages and Impacts</td>
</tr>
<tr>
<td>FY</td>
<td>fiscal year</td>
</tr>
<tr>
<td>GDP</td>
<td>gross domestic product</td>
</tr>
<tr>
<td>GHG</td>
<td>greenhouse gas</td>
</tr>
<tr>
<td>IAM</td>
<td>integrated assessment model</td>
</tr>
<tr>
<td>IPCC</td>
<td>Intergovernmental Panel on Climate Change</td>
</tr>
<tr>
<td>IRA</td>
<td>Inflation Reduction Act</td>
</tr>
<tr>
<td>ITC</td>
<td>investment tax credit</td>
</tr>
<tr>
<td>JEDI</td>
<td>Jobs and Economic Development Impacts</td>
</tr>
<tr>
<td>NDP</td>
<td>National Decarbonization Plan</td>
</tr>
<tr>
<td>NEMS</td>
<td>National Energy Modeling System</td>
</tr>
<tr>
<td>NFIP</td>
<td>National Flood Insurance Program</td>
</tr>
<tr>
<td>NGFS</td>
<td>Network for Greening the Financial System</td>
</tr>
<tr>
<td>NPV</td>
<td>net present value</td>
</tr>
<tr>
<td>NREL</td>
<td>National Renewable Energy Laboratory</td>
</tr>
<tr>
<td>OMB</td>
<td>Office of Management and Budget</td>
</tr>
<tr>
<td>PM</td>
<td>particulate matter</td>
</tr>
<tr>
<td>PTC</td>
<td>production tax credit</td>
</tr>
<tr>
<td>PV</td>
<td>photovoltaic</td>
</tr>
<tr>
<td>R&amp;D</td>
<td>research and development</td>
</tr>
<tr>
<td>RCM</td>
<td>reduced-complexity air quality model</td>
</tr>
<tr>
<td>RCP</td>
<td>Representative Concentration Pathway</td>
</tr>
<tr>
<td>Acronym</td>
<td>Full Form</td>
</tr>
<tr>
<td>---------</td>
<td>-----------</td>
</tr>
<tr>
<td>ReEDS</td>
<td>Regional Energy Deployment System</td>
</tr>
<tr>
<td>RPS</td>
<td>renewable portfolio standard</td>
</tr>
<tr>
<td>SCC</td>
<td>social cost of carbon</td>
</tr>
<tr>
<td>SNAP</td>
<td>Supplemental Nutrition Assistance Program</td>
</tr>
<tr>
<td>SRES</td>
<td>Special Report on Emissions Scenarios</td>
</tr>
<tr>
<td>SSP</td>
<td>Shared Socioeconomic Pathway</td>
</tr>
<tr>
<td>TRIA</td>
<td>Terrorism Risk Insurance Act</td>
</tr>
<tr>
<td>VSL</td>
<td>value of a statistical life</td>
</tr>
</tbody>
</table>
References


Beider, Perry, “Budgetary Effects of Climate Change and of Potential Legislative Responses to It,” Congressional Budget Office, April 2021.


CBO—See Congressional Budget Office.


Congressional Budget Office, Budgetary Effects of Climate Change and of Potential Legislative Responses to It, April 2021.

Congressional Budget Office, Estimated Budgetary Effects of H.R. 5376, the Inflation Reduction Act of 2022 as Amended in the Nature of a Substitute (ERN22335) and Posted on the Website of the Senate Majority Leader on July 27, 2022, 2022a.


EIA—See U.S. Energy Information Administration.


EPA—See U.S. Environmental Protection Agency.


FERC—See Federal Energy Regulatory Commission.


IPCC—See Intergovernmental Panel on Climate Change.


OMB—See Office of Management and Budget.


Social Security Administration, "A Summary of the 2022 Annual Reports,” webpage, undated. As of February 6, 2023: https://www.ssa.gov/oact/TRSUM/


