

Working Paper Series
Congressional Budget Office
Washington, D.C.

CBO's Projection of the Effect of Climate Change on U.S. Economic Output

Evan Herrnstadt
Congressional Budget Office
evan.herrnstadt@cbo.gov

Terry Dinan
Congressional Budget Office
terry.dinan@cbo.gov

Working Paper 2020-06

September 2020

To enhance the transparency of the work of the Congressional Budget Office and to encourage external review of that work, CBO's working paper series includes papers that provide technical descriptions of official CBO analyses as well as papers that represent independent research by CBO analysts. Papers in this series are available at <http://go.usa.gov/xUzd7>.

This work benefited from the guidance of Joseph Kile. Christine Browne was the editor. Mark Doms and Jeffrey Kling reviewed the document. Helpful comments were provided by Sebastien Gay, John Kitchen, John McClelland, Robert Shackleton, and Jeffrey Werling of CBO. Pranav Bhandarkar provided excellent research assistance. Useful input was also received from Tatyana Deryugina of the University of Illinois, Trevor Hauser of the Rhodium Group, Solomon Hsiang of the University of California-Berkeley, Derek Lemoine of the University of Arizona, Pierre Mérel of the University of California-Davis, Kamiar Mohaddes of the University of Cambridge, John Reilly of the Massachusetts Institute of Technology, James Stock of Harvard University, and David Wilcox of the Peterson Institute for International Economics.

Abstract

As part of its long-term economic forecast, the Congressional Budget Office projects the effect of climate change on the growth of U.S. real gross domestic product (GDP). CBO projects that climate change will, on net, reduce average annual real GDP growth by 0.03 percentage points from 2020 to 2050, relative to growth that would occur under the climatic conditions that prevailed at the end of the 20th century.

That annual growth differential accumulates to a 1.0 percent reduction in the projected level of real GDP in 2050. Of that 1.0 percent reduction, one-third reflects a continuation of the effect of climate change on real GDP growth in recent years, and two-thirds reflects expected increases in that effect in the future.

This paper describes how CBO constructed its projection, how the projected effect should be interpreted, limitations of the analysis, and the central climate-change scenario that CBO used. It also places CBO's projection in context by comparing it with two widely discussed estimates of the net damage to the United States from climate change. Finally, it notes the many sources of uncertainty underlying the projection.

Keywords: climate change, economic growth

JEL Classification: Q54

Contents

| | |
|--|----|
| Introduction..... | 1 |
| CBO’s Projection of the Effect of Climate Change on Real GDP | 2 |
| Interpreting the Projection | 5 |
| CBO’s Methodology..... | 7 |
| CBO’s Central Climate-Change Scenario | 11 |
| Uncertainty..... | 11 |
| Estimates of Net U.S. Damage by Two Other Research Teams..... | 12 |

Introduction

The Congressional Budget Office produces long-term economic forecasts to serve as a basis for its projections of the federal budget in coming decades. Among the many factors CBO takes into account in producing those long-term forecasts is the effect of climate change on growth in real (inflation-adjusted) U.S. gross domestic product (GDP). As part of its most recent long-term forecast, released on September 21, 2020, CBO projected that the effects of climate change will, on net, reduce the growth rate of U.S. real GDP from 2020 to 2050.¹ This working paper is being published in part because lawmakers have expressed interest in having CBO provide more information about how it analyzes the effects of climate change.²

To construct its projection of the effect of climate change on GDP, CBO draws upon a wide variety of recent research that models the relationships among greenhouse gas concentrations; global climate conditions; temperature, precipitation, hurricane activity, and sea level in various U.S. regions; and macroeconomic outcomes. CBO's projection is primarily driven by the effect on output of changes in temperature and precipitation, which is estimated using reduced-form econometric models that do not enumerate the specific pathways through which that effect occurs. The rest of the projected effect is driven by changes in the magnitude of hurricane damage. In that case, the agency relies on the results of a structural macroeconomic model that translates changes in expected hurricane damage into effects on overall output.

CBO's projection of the effect of climate change on U.S. real GDP growth is a central projection, which means that it represents the middle of a wide range of potential outcomes. Consistent with the best available research, CBO's approach allows for both positive and negative effects of climate change; however, it does not incorporate every possible effect of climate change on GDP. The projection is subject to a great deal of uncertainty.

This year's report on CBO's long-term budget projections differs from previous reports in two ways with regard to the effect of climate change. First, the agency changed the way it forecasts the size of that effect. CBO reviews and updates its estimation methods every year, and this year, in light of new information from recent academic research, the agency focused on its methods for projecting the effects of climate change on real GDP growth. Second, in past analyses, CBO incorporated the effect of climate change into its economic projections by carrying forward trends in economic measures that are influenced by climate change, but the agency did not separately report the size of that effect. This year, the agency is reporting that effect separately.

¹ Congressional Budget Office, *The 2020 Long-Term Budget Outlook* (September 2020), www.cbo.gov/publication/56516.

² See, for example, Congressional Budget Office, *Answers to Questions for the Record Following a Hearing on The Budget and Economic Outlook: 2019 to 2029 Conducted by the Senate Committee on the Budget* (March 19, 2019), www.cbo.gov/publication/54991.

Although this projection is useful for assessing the effects of climate change on the economy and the federal budget, it is not a comprehensive measure of the effects of climate change on well-being. For example, changes in GDP do not capture changes in mortality due to increases in heat-related deaths and decreases in cold-weather-related deaths.

Some studies have attempted to enumerate the projected effects of climate change on measures of specific market and nonmarket outcomes. Such analyses are not directly comparable to CBO's projection of the effect of climate change on GDP, but they provide additional context. Therefore, this working paper reports some estimates by others of future net damage due to climate change and discusses how and why they differ from CBO's projection.

CBO's Projection of the Effect of Climate Change on Real GDP

Climate change has a variety of effects on economic activity in the United States, some of which are positive and some of which are negative. For example, changes in temperature and precipitation (weather) patterns may increase agricultural productivity in some regions and decrease it in others. Similarly, changes in weather patterns may increase or decrease the productivity and supply of workers (particularly outdoor workers). Climate change is expected to increase sea temperatures and melt ice sheets; together, those changes are expected to exacerbate damage from hurricanes by increasing the frequency of major hurricanes (Category 3 and higher) and making storm surges more severe. An increase in hurricane damage to buildings, infrastructure, or other capital could dampen future economic growth in the United States.

CBO projects that the effects of climate change, taken together, will reduce the growth rate of real GDP from 2020 to 2050 by an average of 0.03 percentage points, relative to the growth rate that would be projected under benchmark climate conditions during a period near the end of the 20th century with 1995 as its midpoint (see Table 1). That 0.03 percentage-point difference in annual growth accumulates over the 30-year projection period to a 1.0 percent reduction in the projected level of real GDP in 2050.

The 0.03 percentage-point reduction in the GDP growth rate that CBO projects reflects both the continuation of the recent effect of climate change on the GDP growth rate and the impact of expected increases in that effect in the future. On its own, the continued recent effect of climate change on the growth rate would reduce the average real GDP growth rate from 2020 to 2050 by 0.01 percentage points, relative to GDP growth under the benchmark climate, lowering the level of real GDP in 2050 by 0.4 percent. The agency had already accounted for that effect in its forecast but now expects that the negative effect on the GDP growth rate over the next 30 years will be larger than implied by the effect of climate on economic outcomes over the past 25 years. Specifically, CBO projects that the increasing effect of climate change on the growth rate will reduce the average real GDP growth rate by another 0.02 percentage points, reducing the level of real GDP in 2050 by an additional 0.6 percent. That additional effect is incorporated into the forecast as an adjustment to CBO's projection of growth in nonfarm business total factor

productivity (TFP). In *The 2020 Long-Term Budget Outlook*, CBO projects that the increasing effect of climate change will reduce average TFP growth by 0.01 percentage point over the next decade and 0.03 percentage points from 2030 to 2050.³

³ See Appendix A of Congressional Budget Office, *The 2020 Long-Term Budget Outlook* (September 2020), www.cbo.gov/publication/56516.

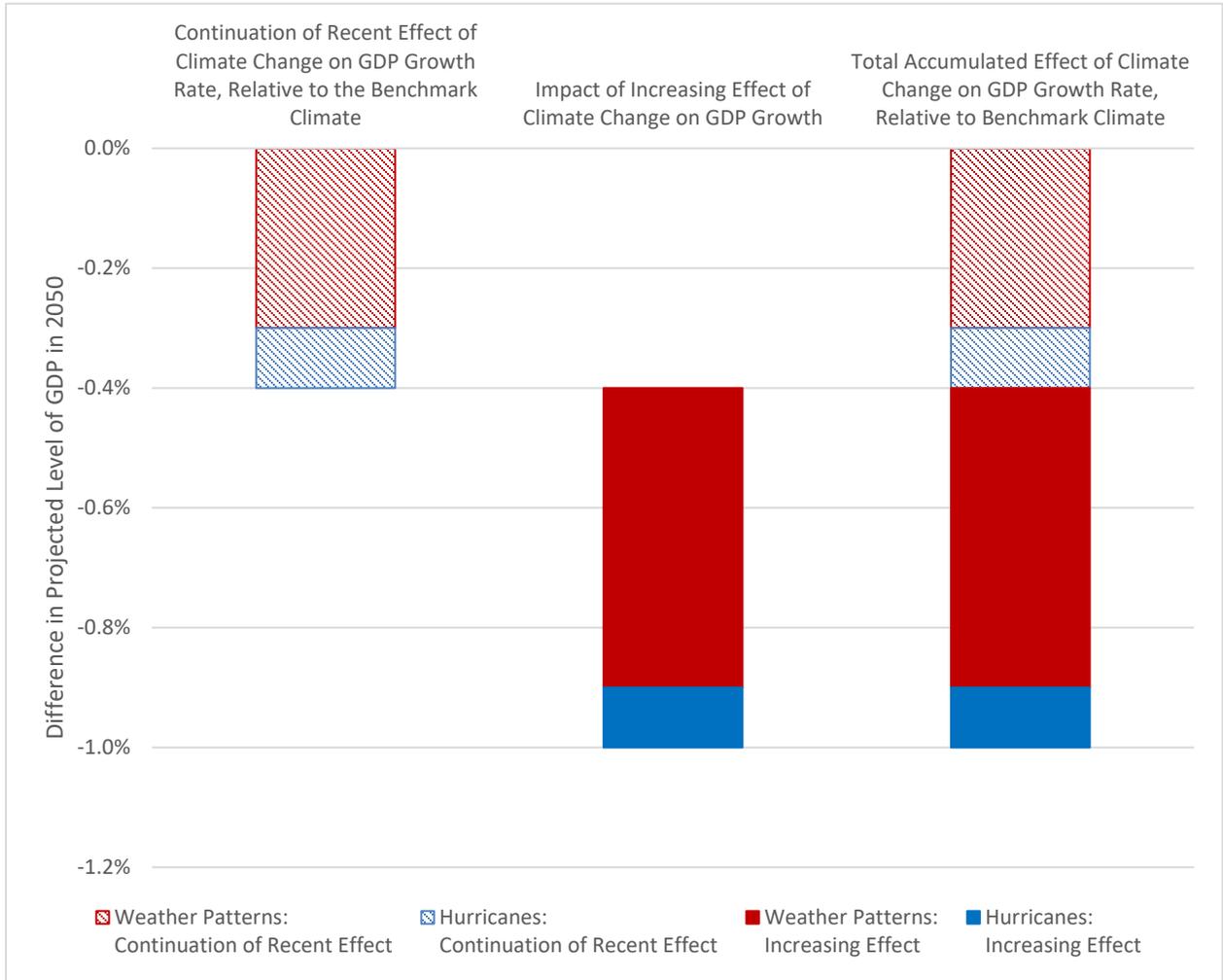
Table 1. How Climatic Conditions in Different Periods Affect CBO’s Projection of Real GDP Growth

| Period Used in Analysis | Year(s) | Role in CBO’s Projection |
|-------------------------------------|----------------|---|
| Midpoint Year for Benchmark Climate | 1995 | Climate change is measured in relation to a specific benchmark climate. Multiple studies have measured changes in climate relative to periods that span multiple decades and share a midpoint of 1995. CBO compared its projections of real GDP growth with a hypothetical projection of what real GDP growth would be if the future climate were the same as during this period. |
| Reference Period | 1995 to 2019 | CBO used historical data from this period to determine the recent effect of climate change on growth in real GDP. Previously, CBO incorporated the effect of climate change into its forecast by carrying forward trends from this reference period in economic measures that are influenced by climate change. |
| Projection Period | 2020 to 2050 | CBO projected real GDP growth rates over this period for its 2020 long-term budget outlook. Those growth rates include an adjustment that reflects expected increases in the effect of climate change on GDP growth in the future; that adjustment is incorporated into CBO’s long-run forecast as a reduction in nonfarm business total factor productivity. |

Source: Congressional Budget Office.

GDP = gross domestic product.

Figure 1. How Climate Change Is Expected to Change the Level of Real GDP in 2050
 Percentage of Real GDP



Source: Congressional Budget Office.

Differences in the projected level of real GDP in 2050 reflect accumulated differences in the projected real GDP growth rate from 2020 to 2050.

GDP = gross domestic product.

Interpreting the Projection

CBO’s projection reflects many different types of effects of climate change on GDP: positive and negative, direct and indirect, and immediate and gradual. However, the projection does not fully capture all ways that climate might affect GDP. The agency’s projection of climate effects is in the middle of a wide range of possible outcomes, and the eventual effect of climate change

on GDP may be larger or smaller than projected. Moreover, climate change will have effects on people's well-being that are not measured in GDP.

Some aspects of climate change would affect GDP in a relatively direct manner and would occur immediately. For example, if a farmer's crop yield was lower in a year because of extreme heat, that farmer's contribution to GDP would also be smaller. If a farmer's yield was higher because a cold-weather region experienced a longer-than-usual growing season, that farmer's contribution to GDP would be larger. Similarly, if extreme heat made construction workers less productive and reduced the number of jobs they could complete in a season, that would reduce their contribution to GDP. If a reduction in extreme cold allowed them to work a longer season, that would increase their contribution to GDP.

Other aspects of climate change would have more complicated and indirect effects that might affect GDP over an extended period. For example, suppose that increases in hurricane damage induced by climate change included the destruction of \$50 million worth of factory equipment. Because the value of that stock of equipment is not counted in the current production of goods and services, that \$50 million worth of damage would not count as a reduction in GDP. Instead, the \$50 million of damage would affect future GDP in three ways.

First, the factory would not be able to produce at its pre-hurricane level, and GDP would be reduced to the extent that other U.S. factories could not make up that missing output. Second, if the owner of the factory replaced the \$50 million of destroyed equipment, that investment would be included in GDP in the year the new equipment was purchased. Third, the economy's capital stock would be smaller going forward, either because the owner did not replace the destroyed equipment or because replacing the equipment crowded out other investments that would have taken place in the absence of climate change. The smaller capital stock would result in less production, which would decrease GDP in the future. The cumulative loss of GDP could thus exceed the \$50 million worth of initial damage.

Although CBO's projection captures those types of direct and indirect effects, it does not fully capture all aspects of climate change that could affect GDP, and the agency cannot determine whether the net effect of those uncaptured aspects is positive or negative. For example, the agency's projection does not fully account for potential effects on the U.S. economy from migration, social upheaval, and reduced economic performance in other countries due to climate change. Those international spillovers could have negative effects on U.S. GDP (for example, a reduction in demand for U.S. exports) or positive effects on U.S. GDP (for example, an increase in labor supply due to higher immigration rates). In addition, CBO's projection does not capture all the effects on GDP of sea-level rise (it captures the effects of storm-surge damage but not the effects of inundation) or all the effects of investments made to adapt to the changing climate. Expenditures on such adaptations, such as sea walls, air conditioning, or irrigation systems, may boost GDP in the year that the spending occurs. However, investing in such measures could also

crowd out other productive investment and reduce GDP in the future. Even investing in more climate-resilient versions of existing capital could increase costs without enhancing productivity. Furthermore, CBO’s projection does not fully capture all the costs associated with adjusting to a new climate, such as people moving away from regions of the country that have become uncomfortably hot or toward regions that have become more temperate.

Finally, GDP is not a measure of overall well-being. It does not reflect, for example, the changes in people’s comfort because of milder winters and hotter summers; the risks and living constraints associated with increases in asthma due to higher temperatures; the increases in the number of premature deaths due to heat or tropical diseases, or decreases in the number of premature deaths from cold weather; or the potential disproportionate effects on disadvantaged communities if they are less able to adapt to climate change.

CBO’s Methodology

CBO drew upon a broad range of recent research to construct its projection of the effect of climate change on U.S. GDP. That research employed both “top-down” and “bottom-up” approaches to estimate the effects of climate change on economic outcomes.

- Top-down approaches estimate the historical relationship between conditions that are affected by climate change and overall economic outcomes without enumerating the channels underlying those relationships. For example, a top-down analysis might relate a state’s historical temperature patterns to changes in that state’s overall output without identifying the specific kinds of economic activities that were affected. Those historical relationships could then be combined with future projections of temperature to project future effects of climate change on state-level output.
- Bottom-up approaches seek to understand the relationship between conditions that are influenced by climate change (such as temperature, frequencies of various categories of hurricanes, and sea-level rise) and specific economic outcomes (such as labor supply, hurricane damage, or premature mortality). Although bottom-up approaches do not directly estimate how climate change would affect overall output, the economic effects that they do estimate can be incorporated into economic models to determine effects on overall output.

CBO’s approach to projecting the effect of climate change on U.S. GDP entailed the following steps (see Figure 2). (This paper provides an overview of the approach; CBO will release a follow-up working paper outlining the technical details of its projection.)

Step 1. Obtain Projections of Changes in U.S. Climatic Conditions Through 2050. CBO drew on a range of projections for temperature, precipitation, hurricane frequency, and sea level for specific regions, such as states or counties. Climate scientists developed those detailed

climate projections by scaling down projections from numerous atmospheric-ocean coupled general circulation models (AOGCMs), which are global in scale.⁴

Step 2. Project Effect of Changes in Weather Patterns on U.S. GDP Growth. To project the effect of changing weather patterns on GDP, CBO compiled four recent top-down studies that used reduced-form econometric methods to estimate the historical relationship between weather and output for individual states, counties, or metropolitan statistical areas.⁵ CBO then applied those historical relationships between weather and output to the projections of future U.S. regional weather patterns; the results were summed across regions to produce several projections of the overall effect of climate-change-induced changes in weather on the future growth rate of U.S. GDP.⁶ To combine those various projections, CBO performed a random-effects meta-analysis, which effectively averages estimates in a way that accounts for their relative precision and similarity.⁷ The result of this analysis was CBO’s projection of the effect of climate-change-induced changes in weather (relative to the benchmark climate) on the growth rate of U.S. GDP.

Step 3. Project Effect of Changes in Hurricane Damage on U.S. GDP Growth. To project the effect of climate-change-induced increases in hurricane damage on GDP growth, CBO used a bottom-up projection of changes in expected hurricane damage that the agency published in 2016.⁸ That projection was based on projections of changes in sea levels along the eastern U.S.

⁴ See, for example, D. J. Rasmussen, Malte Meinshausen, and Robert E. Kopp, “Probability-Weighted Ensembles of U.S. County-Level Climate Projections for Climate Risk Analysis,” *Journal of Applied Meteorology and Climatology*, vol. 55 (October 2016), pp. 2301–2322, <https://doi.org/10.1175/JAMC-D-15-0302.1>.

⁵ The four studies are Matthew E. Kahn and others, *Long-Term Macroeconomic Effects of Climate Change: A Cross-Country Analysis*, Working Paper No. 26167 (National Bureau of Economic Research, August 2019), www.nber.org/papers/w26167; Marshall Burke and Vincent Tanutama, *Climatic Constraints on Aggregate Economic Growth*, Working Paper No. 25779 (National Bureau of Economic Research, April 2019), www.nber.org/papers/w25779; Riccardo Colacito, Bridget Hoffmann, and Toan Phan, “Temperature and Growth: A Panel Analysis of the United States,” *Journal of Money, Credit, and Banking*, vol. 51, nos. 2–3 (March–April 2019), pp. 313–368, <https://doi.org/10.1111/jmcb.12574>; and Tatyana Deryugina and Solomon Hsiang, *The Marginal Product of Climate*, Working Paper No. 24072 (National Bureau of Economic Research, November 2017), www.nber.org/papers/w24072. Only two of those studies explicitly modeled the potential effects of adaptation; to better account for those effects, CBO adjusted the historical relationships from the two studies that did not.

⁶ Although the four studies focused on regional changes in temperature and precipitation, the estimated effects on GDP growth would also capture some other expected effects of climate change (for example, floods, wildfires, trade flows, or migration) to the extent that they have historically correlated with regional changes in temperature and precipitation.

⁷ Random-effects meta-analyses have been used by other researchers to summarize multiple estimates in the context of climate-change economics. See, for example, Solomon Hsiang and others, “Estimating Economic Damage From Climate Change in the United States,” *Science*, vol. 356, no. 6345 (2017), pp. 1362–1369, <https://doi.org/10.1126/science.aal4369>; and Marshall Burke, Solomon Hsiang, and Edward Miguel, “Quantifying the Influence of Climate on Human Conflict,” *Science*, vol. 341, no. 1235367 (2013), pp. 1–14, <https://doi.org/10.1126/science.1235367>.

⁸ See Congressional Budget Office, *Potential Increases in Hurricane Damage in the United States: Implications for the Federal Budget* (June 2016), www.cbo.gov/publication/51518.

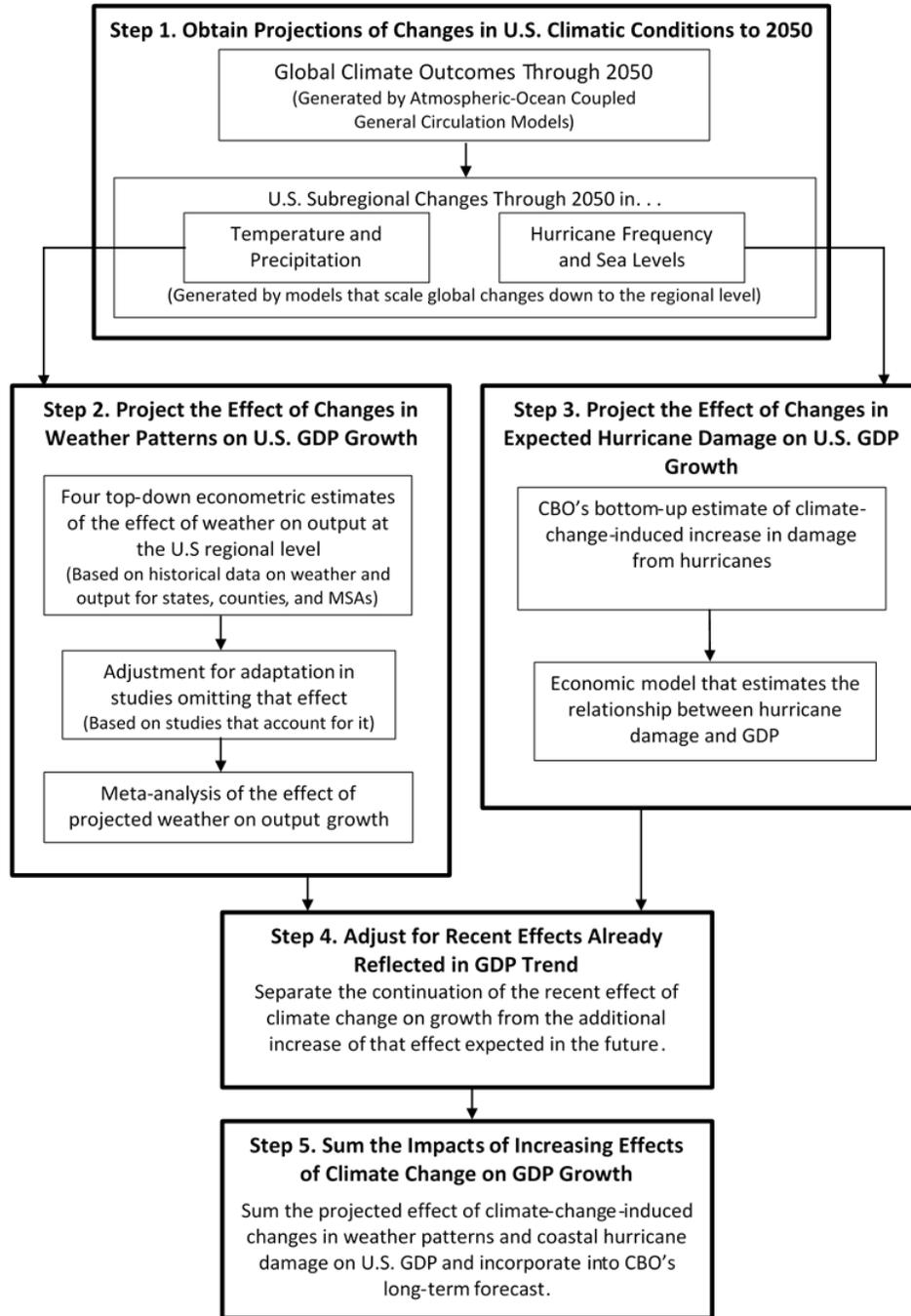
coastline and projections of changes in the frequency and intensity of hurricanes making landfall in the United States. It also accounted for the potential increase in damage due to the interaction of climate change and coastal development. Because changes in hurricane damage do not translate one-for-one into changes in GDP in the same year, CBO applied its projection of the increase in expected damage to the results from a structural macroeconomic model that traces out the effect of hurricane damage in one year on GDP in future years.⁹ The final result is CBO's projection of the effect of climate-change-induced increases in expected hurricane damage on the level of U.S. GDP in 2050, which implies an average effect on the projected growth rate of GDP from 2020 to 2050.

Step 4. Adjust for Effects Already Reflected in GDP Trends. CBO's long-term economic projection already incorporates some recent effects of climate change on GDP growth. Therefore, the projections from Steps 2 and 3 were adjusted to avoid double counting those effects in the overall projection of GDP growth rates. That adjustment left only the projected increases in the effect of changes in weather and hurricane damage on GDP growth.

Step 5. Sum the Impacts of Increasing Effects of Climate Change on GDP Growth. CBO summed the projected impacts on GDP growth of the increasing effects of changes in weather patterns and changes in hurricane damage. That total was incorporated into the agency's long-run growth projection, which, as noted, already includes some recent effects of climate change on GDP growth. The impact of the increasing effects of climate change on the growth rate accumulated through the projection window, yielding the projected effect on the level of GDP in 2050.

⁹ Solomon Hsiang and others, "Estimating Economic Damage From Climate Change in the United States," *Science*, vol. 356, no. 6345 (2017), pp. 1362–1369, <https://doi.org/10.1126/science.aal4369>.

Figure 2. Flow of the Model for Projecting the Effect of Climate Change on U.S. GDP Growth



Source: Congressional Budget Office.

GDP = gross domestic product; MSA = metropolitan statistical area.

CBO's Central Climate-Change Scenario

CBO's projection is based on climate-change projections made by a set of AOGCMs for selected representative concentration pathways (RCPs), which were developed for the Intergovernmental Panel on Climate Change's (IPCC's) Fifth Assessment Report of 2014.¹⁰ Each RCP describes a different projected time path for atmospheric concentrations of greenhouse gases.

CBO's projection of the effects of weather on GDP used RCP 4.5 and RCP 8.5, which the IPCC describes as consistent with relatively low and high levels of emissions in the absence of climate policy, respectively.¹¹ To capture a middle-case scenario, CBO estimated the effects of weather on output for the median projected 2050 global average temperature change relative to the 1981–2010 average for RCP 4.5 (1.2°C) and for RCP 8.5 (1.6°C). CBO then averaged the two estimates.¹²

For hurricane damage, CBO's projection was based on the agency's 2016 report *Potential Increases in Hurricane Damage in the United States: Implications for the Federal Budget*. In that analysis, the projected change in hurricane intensity was based on draws from distributions of potential outcomes under RCPs 4.5 and 8.5, and the projection of changes in sea levels was based on draws from distributions of potential outcomes under those two RCP scenarios as well as RCP 2.6, the lowest-emissions scenario that the IPCC considered.¹³

Uncertainty

CBO's central projection reflects the middle of a range of widely varying potential outcomes.¹⁴ Although CBO's projection draws upon the most recent literature and models, it is highly

¹⁰ The set of projections comes from D. J. Rasmussen, Malte Meinshausen, and Robert E. Kopp, "Probability-Weighted Ensembles of U.S. County-Level Climate Projections for Climate Risk Analysis," *Journal of Applied Meteorology and Climatology*, vol. 55 (October 2016), pp. 2301–2322, <https://doi.org/10.1175/JAMC-D-15-0302.1>.

¹¹ See Table 4 of Detlef P. van Vuuren and others, "The Representative Concentration Pathways: An Overview," *Climatic Change*, vol. 109 (2011), pp. 5–31, <https://doi.org/10.1007/s10584-011-0148-z>.

¹² The average of the median RCP 4.5 and RCP 8.5 scenarios is close to the median climate projection from a recent paper that modeled future global energy use and economic activity. See Figures 6 and 7 of Erik Landry and others, *MIT Scenarios for Assessing Climate-Related Financial Risk*, Report 339 (MIT Joint Program on the Science and Policy of Global Change, December 2019), <https://globalchange.mit.edu/publication/17392>.

¹³ CBO's projection of the effect of climate change on real GDP growth incorporates the results of the agency's 2016 report on expected hurricane damage through 2075. For the purposes of that report, CBO drew from a distribution of sea-level projections for RCPs 8.5, 4.5, and 2.6, implicitly placing equal weight on each scenario. Compared with temperature and precipitation, sea levels respond relatively slowly to changes in emissions; they are therefore less sensitive to differences in emissions scenarios over the next few decades. See Congressional Budget Office, *Potential Increases in Hurricane Damage in the United States: Implications for the Federal Budget* (June 2016), www.cbo.gov/publication/51518.

¹⁴ CBO will publish a working paper that provides more detail about the methodology underlying its projection.

uncertain for numerous reasons. Some of those reasons relate to inherent uncertainty about the future, including the following:

- Uncertainty about how changes in underlying economic factors, such as changes in population, per capita income, energy use, and technology, will affect future greenhouse gas emissions.
- Uncertainty associated with projecting the diffusion of greenhouse gas emissions from the atmosphere into the oceans and biosphere; translating concentrations of greenhouse gases into changes in global climatic conditions, such as global temperatures, sea surface temperatures, and sea-level rise; and translating those conditions into changes in U.S. regional temperatures, precipitation patterns, hurricane frequencies, and sea levels.
- Uncertainty about the effects of climate change on the rest of the world and the resulting changes to the U.S. economy.
- Uncertainty associated with interactions between future climate change and economic growth. For example, the consequences of future climate-induced changes in hurricane frequencies and sea levels would be enhanced by coastal development.

Other sources of uncertainty relate to CBO's modeling approach, including the following:

- Uncertainty in the estimates of the historical relationship between regional weather and regional output.
- Uncertainty about how closely those estimated historical relationships will map to the effects of future climate-determined weather patterns on future U.S. output, including uncertainty about the effects of adaptation and interactive effects that may arise as different regions simultaneously experience (and adapt to) changes in weather.
- Uncertainty about the persistence of effects of damage, such as GDP losses from damage to capital.

Estimates of Net U.S. Damage by Two Other Research Teams

CBO's projection of the effect of climate change on the level of real GDP in 2050 (that is, on the production of goods and services in that year) is complementary, but not directly comparable, to two recent estimates of climate-change-related damage in the United States through the end of the century. The studies that produced those estimates, by Hsiang and colleagues and by the Environmental Protection Agency (EPA), used bottom-up approaches to estimate the net climate-change-related damage (reflecting both positive and negative effects) associated with a variety of sources, including agricultural yields, labor productivity, energy use, coastal damage,

and temperature-related premature mortality.¹⁵ They then assigned a monetary value to the estimated damage resulting from those sources (including assigning a statistical value of life to premature deaths). Drawing in part on those two studies, the Congressionally mandated Fourth National Climate Assessment, published in 2018, reported that “with continued growth in emissions at historic rates, annual losses in some economic sectors are projected to reach hundreds of billions of dollars by the end of the century.”¹⁶

Unlike CBO, neither Hsiang and colleagues nor EPA estimated changes in GDP. The estimated value of damage in their studies may be compared to GDP to provide a sense of scale; for example, Hsiang and colleagues reported their estimate of overall damage in that manner. However, the two studies differed in how they treated future economic conditions, which complicates comparisons. EPA explicitly incorporated projected future population and economic growth into its estimate of damage, allowing its projections to be compared to projected future GDP. Hsiang and colleagues did not; instead, their estimate reflected the damage that would occur if future climate conditions were imposed on the 2011 U.S. economy—for example, holding the size of the agriculture sector at its 2011 level—and was expressed as a share of 2011 GDP.¹⁷

Estimates of Net Damage and Effects on GDP in 2050

In CBO’s analysis, the 1.0 percent reduction in the projected level of 2050 real GDP resulting from the effects of climate change is largely driven by top-down estimates of the effects of weather (see Table 2). That projected reduction in 2050 GDP is larger than the estimates of 2050 damage, reported as a share of GDP, found by the two bottom-up studies using a climate-change scenario similar to that used by CBO—though those results are not directly comparable.¹⁸ Specifically, the study by Hsiang and colleagues, which measured the effects of projected 2050 climate conditions on the 2011 economy, estimated that damage would amount to 0.7 percent of

¹⁵ See Solomon Hsiang and others, “Estimating Economic Damage from Climate Change in the United States,” *Science*, vol. 356, no. 6345 (2017), pp. 1362–1369, <https://doi.org/10.1126/science.aal4369>; and Environmental Protection Agency, *Multi-Model Framework for Quantitative Sectoral Impacts Analysis: A Technical Report for the Fourth National Climate Assessment*, EPA 430-R-17-001 (May 2017), <https://go.usa.gov/xGTs5>.

¹⁶ See Global Change Research Program, *National Climate Assessment, Volume II: Impacts, Risks, and Adaptation in the United States* (2008), p. 26, <https://nca2018.globalchange.gov/>.

¹⁷ To interpret Hsiang and colleagues’ estimate as a projection of future damages, one must implicitly assume that increases in damage scale to increases in GDP. For a given change in climate, to the extent that damage grows more slowly (or quickly) than GDP, that approach will overstate (or understate) future damage as a share of future GDP.

¹⁸ The results reported here from Hsiang and others are based on the projected temperature change in 2050 used in CBO’s analysis (1.2°C and 1.6°C). EPA’s results are the average of the median RCP 4.5 and RCP 8.5 estimates from Table 28.2 of the agency’s 2017 report, summed across categories of damage; the report does not note the average temperature change associated with each model outcome. Assuming that damage increases as the change in average temperature increases in each category, the two median estimates would correspond to temperature changes of 1.2°C and 1.7°C.

2011 GDP. The EPA study, which estimated damage in 2050 as a share of output in 2050, found that damage would amount to 0.5 percent of GDP.

The results of the two studies are conceptually different from CBO's result, in ways that could both increase and decrease their estimates of damage as a percentage of GDP relative to CBO's projection. Some elements of the two studies' results would tend to make their estimates of damage in 2050 (measured as a share of GDP) larger than CBO's projection of the decrease in the level of real GDP in that year. For example, the estimates of damage in 2050 include effects that would not lower GDP in that year, such as damage to capital; that damage would affect GDP in future years. In addition, the estimates of damage include certain nonmarket damages not included in GDP, such as premature mortality. Other elements of the two studies' results would tend to make their estimates smaller than CBO's projection. For example, neither estimate accounts for interactions between directly enumerated pathways (such as changes in the supply of outdoor labor and changes in crop yields) or for the effects of non-enumerated pathways. Further, the estimates provide snapshots of damage in a given year and do not account for lagged effects of past damage (such as capital destroyed by hurricanes, as discussed above). Taken together, those and other differences made the bottom-up estimates of net damage in 2050 smaller than CBO's projection of the net reduction in GDP in the same year.

Table 2.
CBO’s Projection of the Reduction in the Level of Real GDP and Two Bottom-Up Estimates of Damage From Climate Change

| Source of Projection of Economic Effects of Climate Change | Percentage Reduction in the Level of Real GDP in 2050 | Damage in 2050 as a Percentage of 2050 GDP | Damage in 2011 Under Climate Conditions Projected for 2050, as a Percentage of 2011 GDP |
|--|---|--|---|
| Congressional Budget Office | 1.0 | n.a. | n.a. |
| Environmental Protection Agency (2017) | n.a. | 0.5 ^a | n.a. |
| Hsiang and others (2017) | n.a. | n.a. | 0.7 ^b |

Source: Congressional Budget Office, using data from Solomon Hsiang and others, “Estimating Economic Damage From Climate Change in the United States,” *Science*, vol. 356, no. 6345 (2017), pp. 1362–1369, <https://doi.org/10.1126/science.aal4369>; and Environmental Protection Agency, *Multi-Model Framework for Quantitative Sectoral Impacts Analysis: A Technical Report for the Fourth National Climate Assessment*, EPA 430-R-17-001 (May 2017), <https://go.usa.gov/xGTs5>.

All estimates of damage and reductions in the level of GDP are net measures that include both positive and negative effects.

GDP = gross domestic product; n.a. = not applicable.

a. This estimate is based on the average of the median 2050 Representative Concentration Pathway (RCP) 4.5 damage estimate and the median 2050 RCP 8.5 damage estimate, summed across categories, as reported in EPA Table 28.2, and is relative to EPA’s 2050 gross domestic product estimate of approximately \$35 trillion in 2015 dollars.

b. The 0.7 percent result is obtained by averaging the damage estimated for the median RCP 4.5 (1.2°C) and median RCP 8.5 (1.6°C) temperature-change scenarios. See Figures 5A and 5B of Hsiang and others for details of the damage-temperature relationship.

Estimates of Net Damage in 2090

All three projections in Table 2 correspond to a central climate scenario in 2050, but studies often focus on projections closer to the end of the 21st century—for example, 2090. By that year,

there is even more uncertainty around the severity of climate change, the size of the economy, and the size of the population, which can lead to very different estimates (see Table 3). In addition, the amount of damage associated with the monetary value of premature mortality can account for a large fraction of the estimate; although that damage represents a real cost to society, most of it would not factor into GDP.¹⁹

For example, Hsiang and colleagues estimated that damage associated with the average of the median RCP 8.5 temperature increase (3.4°C) and RCP 4.5 temperature increase (2.1°C) for 2090 would amount to 1.7 percent of 2011 GDP, but if the value of premature mortality is excluded, their estimate decreases to 1.0 percent of the value of 2011 GDP. However, they also estimated that damage would amount to nearly 12 percent of 2011 GDP under a more severe 2090 climate scenario. About two-thirds of that projected effect represents the value of premature mortality; the remaining damage is equal to only 4 percent of 2011 GDP. That climate scenario, which reflects risks in the extreme tail of the distribution of potential climate-change outcomes, leads to a projected 8.1°C increase in global average temperature by 2090. By contrast, the least severe scenario in Hsiang and colleagues' study, associated with RCP 4.5 (a 0.9°C increase in temperature by 2090), results in damage that amounts to 0.4 percent of 2011 GDP, almost none of which is due to premature mortality.

Relative to Hsiang and colleagues, EPA reported a narrower range of outcomes. The average of EPA's median estimates of total damage under RCP 4.5 and median estimates of total damage under RCP 8.5 is 0.6 percent of 2090 GDP if the value of premature mortality is included and 0.4 percent of 2090 GDP if it is excluded. EPA's most severe climate scenario leads to only a 4.6°C projected increase in average global temperature by 2090 (as opposed to 8.1°C in Hsiang and others). Summing EPA's highest damage estimates across categories results in estimated damage amounting to 1.0 percent of 2090 GDP, or 0.6 percent of 2090 GDP if the value of premature mortality is excluded. Summing EPA's lowest damage estimates across categories results in estimated damage equal to 0.3 percent of 2090 GDP, or 0.2 percent of 2090 GDP if the value of premature mortality is excluded. For reference, EPA analyzed increases in average global temperature ranging from 1.2°C to 4.6°C by 2090 (as opposed to 0.9°C to 8.1°C under the RCP 4.5 and RCP 8.5 scenarios used by Hsiang and colleagues).

Overall, studies estimating U.S economic effects from climate change may report very large or very small magnitudes. Those differences may be driven by important differences in the time frame, climate-change projection, and method of reporting damage in the various studies.

¹⁹ Hsiang and colleagues used a value of statistical life (VSL) of \$9 million in 2019 dollars; EPA used a VSL of \$16.3 million in 2019 dollars for its 2090 projections. The difference in magnitude arises largely because EPA allowed VSL to increase over time as per capita income increases, consistent with the agency's own projections of economic growth and population. Because Hsiang and colleagues did not project growth in the economy or population, their VSL is the same for all their estimates.

Table 3.
End-of-Century Bottom-Up Estimates of Damage From Climate Change

| Source of Projection of Economic Effects of Climate Change | Damage | | Damage Excluding Monetary Value of Changes in Premature Mortality | |
|--|------------------------------------|---|---|---|
| | Damage as a Percentage of 2090 GDP | Damage in 2011 Under Climate Conditions Projected for 2090, as a Percentage of 2011 GDP | Damage as a Percentage of 2090 GDP | Damage in 2011 Under Climate Conditions Projected for 2090, as a Percentage of 2011 GDP |
| Average of Median Damage Under RCP 4.5 and Median Damage Under RCP 8.5 Median RCP 4.5 Temperature Change Modeled: EPA = 1.7°C, Hsiang and others = 1.6°C Median RCP 8.5 Temperature Change Modeled: EPA = 3.6°C, Hsiang and others = 3.4°C | | | | |
| EPA (2017) | 0.6 ^a | n.a. | 0.4 ^a | n.a. |
| Hsiang and others (2017) | n.a. | 1.7 | n.a. | 1.0 |
| Lowest Damage Reported Under RCP 4.5 Smallest RCP 4.5 Temperature Change Modeled: EPA = 1.2°C, Hsiang and others = 0.9°C | | | | |
| EPA (2017) | 0.3 ^b | n.a. | 0.2 ^b | n.a. |
| Hsiang and others (2017) | n.a. | 0.4 | n.a. | 0.4 |
| Highest Damage Reported Under RCP 8.5 Largest RCP 8.5 Temperature Change Modeled: EPA = 4.6 °C, Hsiang and others = 8.1°C | | | | |
| EPA (2017) | 1.0 ^c | n.a. | 0.6 ^c | n.a. |
| Hsiang and others (2017) | n.a. | 11.9 | n.a. | 4.0 |

Source: Congressional Budget Office, using data from Solomon Hsiang and others, “Estimating Economic Damage from Climate Change in the United States,” *Science*, vol. 356, no. 6345 (2017), pp. 1362–1369, <https://doi.org/10.1126/science.aal4369>; and Environmental Protection Agency, *Multi-Model Framework for Quantitative Sectoral Impacts Analysis: A Technical Report for the Fourth National Climate Assessment*, EPA 430-R-17-001 (May 2017), <https://go.usa.gov/xGTs5>.

All estimates of damage are net measures that include both positive and negative effects.

See Figures 5A and 5B of Hsiang and others for details of the damage-temperature relationship and Table 28.2 of EPA for damage estimates.

All EPA estimates are relative to its 2090 GDP estimate of approximately \$70 trillion in 2015 dollars.

GDP = gross domestic product; EPA = Environmental Protection Agency; n.a. = not applicable; RCP = representative concentration pathway.

- a. This estimate is based on the average of the median 2090 RCP 4.5 damage estimate and the median 2090 RCP 8.5 damage estimate summed across categories.
 - b. This estimate is based on the minimum 2090 damage estimate among RCP 4.5 climate outcomes summed across categories.
 - c. This estimate is based on the maximum 2090 damage estimate among RCP 8.5 climate outcomes summed across categories.
-