
# How Climate Change May Effect the U.S. Economy

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SUMMARY

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There is general consensus within the scientific community that human activities have increased greenhouse gas concentrations in the atmosphere and that the increased concentrations have contributed to a rise in global average temperatures. The United Nations' Intergovernmental Panel on Climate Change recently assessed, "Overall adverse economic impacts attributable to climate change, including slow-onset and extreme weather events, have been increasingly identified."

Two of the main avenues through which climate change can affect GDP in the short and long terms are productivity and investment effects. Productivity is a key determinant in long-term economic growth—as productivity increases, economies can produce more goods and services with the same level of resources, which in turn tends to increase well-being and income. Business investment is also a determinant of long-term growth insofar as it contributes to the domestic capital stock, which is directly related to the economy's overall productive capacity. Research suggests that climate change could negatively impact productivity and business investment, as rising temperatures and heat waves could result in lower output per worker. Declines in productivity and production could decrease businesses' incentive to invest, particularly in a scenario in which physical capital is routinely damaged or destroyed due to the effects of extreme weather events to a point where further investment becomes unattractive. Climate change can also bring some benefits (such as fewer extreme cold events) and opportunities (opening of Arctic shipping lanes), although the net effects of climate change on the economy are generally expected to be increasingly adverse and widespread on net.

Climate change—notably the projected increase in certain extreme weather events—is also expected to affect the overall economy through its impacts on specific sectors, such as housing, infrastructure, and agriculture. Nearly one-third of the U.S. housing stock could be at high risk of climate-change-induced hazards, and billions of dollars of property are vulnerable to complete destruction or being rendered unusable by flooding risk alone. Transportation infrastructure, which supports the production and movement of goods and services, could be damaged with climate change. While transportation systems are typically designed to withstand certain magnitudes of extreme weather events, an increase in the frequency and severity of extreme weather events would increase the residual risk. Heat waves, heavy precipitation, and other storms can additionally cause delays and disruptions on roads, public transit systems, airports, and the like, adding to the costs of production and interfering with consumption.

There are several considerations to take into account when analyzing research on the economic effects of climate change. One is that economic projection is an imprecise science and entails a degree of uncertainty, and uncertainty may increase over long time horizons. This research becomes more complicated when based on climate modeling results, which are often based on scenarios that may or may not be associated with likelihoods of occurrence or reflect future conditions. Additionally, there is no consensus on the best way to model the economic effects of climate change. Several different methodologies and types of modeling are used to estimate the impacts of various climate change scenarios on economic indicators such as GDP and personal income. Differing methods can make it difficult to compare results across studies. Currently, this field of study into the economic effects of climate change is relatively small compared to other types of economic or climate-related research. The relative dearth of studies makes it challenging to reach specific "mainstream" conclusions about economic impacts. Nonetheless, the large majority of existing studies tend to find that climate change impacts to longer-term economic output—either economy-wide or in impacted sectors—is likely to be negative and increasingly so, although the magnitude of these effects is not widely agreed upon.

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# Introduction

While certain aspects of climate science are debated within the scientific community, there is a high level of agreement on several points, including that human activities have increased greenhouse gas (GHG) concentrations in the atmosphere and that the increased concentrations are the primary drivers of the discernible rise in global average temperature since the mid-20th century.[1] According to the latest climate change scientific assessment of the Intergovernmental Panel on Climate Change (IPCC):[2]

> The scale of recent changes across the climate system as a whole and the present state of many aspects of the climate system are unprecedented over many centuries to many thousands of years.[3]
>
> Climate change is already affecting every inhabited region across the globe with human influence contributing to many observed changes in weather and climate extremes.[4]
>
> Future emissions cause future additional warming, with total warming dominated by past and future $CO_2$ emissions.[5]
>
> Global warming of 1.5°C and 2°C will be exceeded during the 21st century unless deep reductions in $CO_2$ and other greenhouse gas emissions occur in the coming decades.[6]
>
> All regions are projected to experience further increases in hot climatic impact-drivers (CIDs) and decreases in cold CIDs.[7]
>
> Many changes in the climate system become larger in direct relation to increasing global warming. They include increases in the frequency and intensity of hot extremes, marine heatwaves, and heavy precipitation, agricultural and ecological droughts in some regions, and proportion of intense tropical cyclones, as well as reductions in Arctic sea ice, snow cover and permafrost.[8]
>
> With every additional increment of global warming, changes in extremes continue to become larger. For example, every additional 0.5°C of global warming causes clearly discernible increases in the intensity and frequency of hot extremes, including heatwaves (*very likely*), and heavy precipitation (*high confidence*), as well as agricultural and ecological droughts in some regions (*high confidence*).[9]

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[1] For a more detailed discussion of climate science, points of agreement, and contentions within the climate science community, see CRS Report R45086, *Evolving Assessments of Human and Natural Contributions to Climate Change*, by Jane A. Leggett; and CRS Report R43229, *Climate Change Science: Key Points*, by Jane A. Leggett. For the attribution assessment, see V. Masson-Delmotte et al., *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, 2021, https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_Full_Report.pdf.

[2] The IPCC is organized by national governments affiliated with the United Nations and relies on volunteer expertise from thousands of scientists to assess for policymakers the science, impacts, and policy options related to climate change. The assessments require expert, public, and government reviews before release. For the latest assessment of climate change science see Masson-Delmotte et al., *Climate Change 2021*.

[3] Masson-Delmotte et al., *Climate Change 2021*, p. SPM-9.

[4] Masson-Delmotte et al., *Climate Change 2021*, p. SPM-10.

[5] Masson-Delmotte et al., *Climate Change 2021*, p. SPM-16.

[6] Masson-Delmotte et al., *Climate Change 2021*, p. SPM-17.

[7] Masson-Delmotte et al., *Climate Change 2021*, p. SPM-32.

[8] Masson-Delmotte et al., *Climate Change 2021*, p. SPM-19.

[9] Masson-Delmotte et al., *Climate Change 2021*, p. SPM-19.

> Many regions are projected to experience an increase in the probability of compound events with higher global warming (*high confidence*).[10]
>
> If global warming increases, some compound extreme events with low likelihood in past and current climate will become more frequent, and there will be a higher likelihood that events with increased intensities, durations and/or spatial extents unprecedented in the observational record will occur.[11]

Even under the lowest GHG emission scenarios considered by the IPCC—including some with immediate, deep, and rapid reductions of GHG emissions—global average temperatures are expected to continue to rise through mid-century. Climate changes are expected to continue unless deep GHG reductions occur in coming decades. Climate modeling indicates increases in climatic impacts related to heat and decreases in climate impacts related to cold temperatures, with changes in extreme weather with every increment of temperature increase.

While economic activity affects climate change, so too does climate change affect economic activity. Economic activity can be affected in the short and long terms by climate change. Of note, while no single extreme weather event can necessarily be attributed to climate change, scientific and statistical analyses can estimate the effects of climate change on the change of likelihoods of single extreme events and on extreme events overall. Given the scientific consensus about the relationship between climate change and trends in extreme weather events, this report includes the overall economic impact of extreme weather events as part of the economic effects of climate change.

The effects of climate change on the economy include both positive and negative components and involve estimation uncertainties, and research estimates vary. The research community generally agrees that long-term economic effects are likely, on balance, to be increasingly negative and widespread—and catastrophic for some locations—although the magnitude of effects is a continuing area of research. In particular, evidence suggests that human preparation and adaptation to anticipated changes *can* reduce adverse impacts and capture opportunities, but the degree, comprehensiveness, and ancillary consequences of adaptation are challenging to predict.[12] (Adaptation is not within the scope of this report and will not be further discussed.)

As summarized by the latest IPCC impacts, adaptation, and vulnerability assessment:

> Overall adverse economic impacts attributable to climate change, including slow-onset and extreme weather events, have been increasingly identified (*medium confidence*). Some positive economic effects have been identified in regions that have benefited from lower energy demand as well as comparative advantages in agricultural markets and tourism (*high confidence*). Economic damages from climate change have been detected in climate-exposed sectors, with regional effects to agriculture, forestry, fishery, energy, and tourism (*high confidence*), and through outdoor labour productivity (*high confidence*). Some extreme weather events, such as tropical cyclones, have reduced economic growth in the short-term (*high confidence*). Non-climatic factors including some patterns of settlement, and siting of infrastructure have contributed to the exposure of more assets to extreme

[10] Masson-Delmotte et al., *Climate Change 2021*, p. SPM-33.

[11] Masson-Delmotte et al., *Climate Change 2021*, p. SPM-35.

[12] For a literature review of adaptation effectiveness, see Bonnie Jean Owen, "Evaluating Effectiveness in Climate Change Adaptation and Socially-Engaged Climate Research," University of Arizona, PhD dissertation, 2019, https://repository.arizona.edu/handle/10150/634331. For a prospective analysis of how adaptation may decrease future impacts on U.S. infrastructure, see, for example, James E. Neumann et al., "Climate Effects on US Infrastructure: The Economics of Adaptation for Rail, Roads, and Coastal Development," *Climatic Change*, vol. 167, no. 3 (August 19, 2021).

> climate hazards increasing the magnitude of the losses (*high confidence*). Individual livelihoods have been affected through changes in agricultural productivity, impacts on human health and food security, destruction of homes and infrastructure, and loss of property and income, with adverse effects on gender and social equity (*high confidence*).[13]

This report begins with a discussion of potential mechanisms through which climate change could affect the economy, including productivity, business investment, and sector impacts. It then examines some of the research into the economic effects of climate change as well as the limitations of such research. This report does not review the scientific evidence on climate change and takes the science as accepted by national governments.[14] Rather, its purpose is to discuss the ways in which climate change may impact the U.S. economy.[15] The report does not review research on how policies to mitigate climate change would affect the economy. Rather, the report reviews research on the economic effects of climate change given specific climate outcomes. The research reviewed is intended to provide "what if" scenarios rather than a "best guess" of future outcomes.

# How May Climate Change Impact the U.S. Economy?

This section discusses some of the avenues through which climate change affects economic activity and gross domestic product (GDP). While later sections in this report describe the methodology used to estimate possible economic effects of climate change and summarize specific studies, this section will conceptually describe certain mechanisms through which climate change may effect economic outcomes. It is not necessarily a straight line from climate change to changes in overall economic activity (often measured by GDP). Rather, climate change more directly affects various inputs used to generate overall economic output, and there may be many variables—including the implementation of policies—that intervene between potential and actual effects.

Two of the main avenues through which climate change can affect GDP in the short and long terms are through effects on productivity and investment. Climate change may also affect the overall economy through its impacts on specific sectors—such as housing, infrastructure, and agriculture—if they are sufficiently large and lasting.

## Short-Term vs. Long-Term Impacts

As will be described in subsequent sections, climate change may have differing effects on the economy in the short and long terms. In the short term, any extreme weather events made more frequent or severe by climate change may result in positive, negative, or no changes to output, depending on the extent to which business activity is disrupted and rebuilding efforts of pre-

[13] Hans-O. Pörtner et al., *Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, February 27, 2022, https://report.ipcc.ch/ar6wg2/pdf/IPCC_AR6_WGII_FinalDraft_FullReport.pdf. The version of the report cited here is a final draft and subject to final edits and therefore may differ from future versions.

[14] See CRS Report R43229, *Climate Change Science: Key Points*, by Jane A. Leggett. For the most recent IPCC scientific assessment of climate change, see Masson-Delmotte et al., *Climate Change 2021*.

[15] For more information on this topic, see CRS In Focus IF11156, *Projected Economic Impacts of Climate Change*, by Jane A. Leggett.

existing structures takes place.[16] Other manifestations of climate change, such as temperature change, may also affect the economy in the short term in ambiguous ways. For example, warmer temperatures may boost crop production in some cases but not others (see "Agriculture" for more information).

Given the literature and research developments at this point, economists generally agree that the long-term economic effects of climate change are likely to be increasingly negative on balance. Absent deep GHG mitigation, research generally indicates that output is likely to be negatively impacted by climate change over the medium to long run. The overall negative impact would likely be due to decreasing incentives for businesses to invest, as well as to decelerating or decreasing productivity growth (as described below). The magnitude of any future impacts is uncertain and debated.[17] Of note, if the long-term productivity growth rate (as opposed to a temporary shift in the level) changes as a result of climate change, the long-term *growth rate* of GDP may also be affected, leading to an ongoing accumulation of losses.[18]

## Productivity

Productivity measures how efficiently inputs are producing outputs in an economy. In other words, productivity is the ratio of the amount of land, labor, capital, energy, etc., that is used to produce goods and services to the amount of goods and services produced. Productivity is a key determinant of long-term economic growth. As productivity increases, economies can produce more goods and services with the same level of resources, which in turn tends to lead to increased income and well-being. There are two common measures of productivity: labor productivity and total factor productivity.[19] Labor productivity measures the amount of hours worked relative to the amount of output in an economy, while total factor productivity considers not only labor but also other factors of production such as land and capital.

The effect climate change has on productivity is not easily measured. However, some economists have postulated that climate change might negatively affect productivity. According to several studies, rising average temperatures and extreme heat are associated with lower labor productivity, although the extent to which productivity is affected varies across studies.[20] This

[16] The destruction of physical capital is not directly included in subsequent measures of GDP. For more information about the effect of natural disasters on measures of GDP, see Bureau of Economic Analysis (BEA), "How Are GDP and Related Income Measures of the National Accounts Affected by a Disaster?," December 5, 2005, https://www.bea.gov/help/faq/55.

[17] U.S. Global Change Research Program, *Fourth National Climate Assessment Volume II: Impacts, Risks, and Adaptation in the United States*, 2018 (revised March 2021), p. 4, https://nca2018.globalchange.gov/downloads/NCA4_2018_FullReport.pdf (hereinafter NCA4); and CRS In Focus IF11156, *Projected Economic Impacts of Climate Change*, by Jane A. Leggett.

[18] One-time increases in productivity would cause one-time increases in GDP, resulting in temporary GDP growth but then a return to the previous GDP growth rate. However, if productivity continues to grow, this would cause GDP to continue to growth as well, increasing its growth rate.

[19] Relevant to GHG emissions and their mitigation is energy productivity, more typically called energy efficiency at the scale of a particular technology or activity, and energy intensity at the scale of an economy—typically measured as the energy consumed (or sometimes supplied) per unit of GDP. GHG control policies would generally increase energy productivity but, in many cases, at a cost. An examination of the potential impacts GHG control policies is beyond the scope of this report, however.

[20] For example, according to a working paper from the National Bureau of Economic Research, productivity on any one day declines about 1.7% for every 1° increase in average temperature above 15°C (about 59°F). The paper does not address potential productivity increases of rising minimum (winter) temperatures. The IPCC's *Fifth Assessment Report*, published in 2014, cites estimates that suggest global labor productivity could decrease during the hottest months of the year to 60% of its average in 2100 and less than 40% in 2200 under a scenario in which global mean temperatures rise

occurs because workers exposed to extreme heat would be expected to see their output decline. Studies frequently do not, however, examine or report the potential productivity benefits of rising minimum temperatures and extreme cold events, so the balance between heat and cold effects is uncertain.

In terms of its uses in agriculture and forestry, land can also become less productive as a result of rising average temperatures (or more productive in the case of relatively cool areas, such as when growing seasons lengthen). Scientists expect rising global temperatures overall to increase precipitation but also its variability in many locations. The effects of changing precipitation on productivity would depend strongly on its timing (e.g., during a growing season), its variability and predictability, and its intensity (of precipitation or lack thereof, as drought). The net effect of changing precipitation is uncertain and would vary by location, with summer drying in the U.S. Midwest and increasing summer rainfall in the Northeast, for example.[21] Generally, climate change, including extreme weather events, is likely to "increasingly disrupt agricultural productivity in the United States."[22] This will be discussed in more detail in the "Agriculture" section.

The effects of rising average temperature are likely to affect productivity differently across different sectors, regions, and countries. For example, a country that specializes in labor-intensive production may see greater decreases in labor productivity during extreme heat, as a worker doing physical labor outdoors is more likely to be affected than is an office worker on a hot day. One of the largest potential contributors to productivity loss is extreme heat. The United States is likely to see smaller productivity losses than other countries do as a result of this phenomenon, because most of the United States has a temperate climate and its workforce is relatively less concentrated in outdoor labor-intensive industries.[23]

## Business Investment

Business investment refers to spending by private businesses and nonprofits on physical capital—long-lasting assets used to produce goods and services. An increased stock of physical capital increases the capacity of businesses to produce goods and services and can therefore affect the greater economy. In the short term, an increase in business investment directly increases the

3.4°C by 2100 and 6.2°C by 2200 relative to 1861-1960 averages. The EPA's *Climate Change and Vulnerability Report* from September 2021 finds that for weather-exposed workers in the United States, climate-driven increases in high-temperature days will result in an average of 14 lost labor hours per year for temperature increases of 2°C (relative to 1986-2005 temperatures) and 34 hours per year for increases of 4°C. See Tatyana Deryugina and Solomon M. Hsiang, *Does the Environment Still Matter? Daily Temperature and Income in the United States*, National Bureau of Economic Research, Working Paper no. 20750, December 2014, https://www.nber.org/papers/w20750; Kirk R. Smith et al., *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects*, IPCC, 2014, p. 736, https://www.ipcc.ch/site/assets/uploads/2018/02/WGIIAR5-PartA_FINAL.pdf; and U.S. Environmental Protection Agency (EPA), *Climate Change and Social Vulnerability in the United States: A Focus on Six Impacts*, September 2021, https://www.epa.gov/system/files/documents/2021-09/climate-vulnerability_september-2021_508.pdf. Of note, these studies and statements are generally considering only the effects of increasing high temperatures and frequently omit the effects—typically benefits—of rising minimum temperatures.

[21] IPCC, WGI Interactive Atlas: Regional information (Advanced); accessed January 18, 2022, https://interactive-atlas.ipcc.ch/regional-information#eyJ ... n19.

[22] NCA4, p. 29.

[23] Even still, one study predicts that the United States could lose up to $100 billion annually as a result of climate-induced labor productivity losses. For a sense of scale, U.S. real GDP was over $19 trillion in the third quarter of 2021. See Atlantic Council, "Extreme Heat: The Economic and Social Consequences for the United States," August 2021, https://www.atlanticcouncil.org/wp-content/uploads/2021/08/Extreme-Heat-Report-2021.pdf.

current level of GDP, because physical capital is itself produced and sold. In the long term, economic growth generally depends on growth in the economy's productive capacity (rather than swings in supply and demand), and a larger physical capital stock increases the economy's overall productive capacity, allowing more goods and services to be produced with the same level of labor and other resources. In turn, faster economic growth generally translates into faster income growth and improved living standards.[24]

The effect of climate change on average investment over a longer period is of particular concern due to its connection with long-run economic growth. (Over short time periods, business investment in any given year may fluctuate significantly as a result of extreme weather events, but this effect would be transitory—and potentially positive—in a time period in which damaged or destroyed physical capital was replaced.) The logic behind this concern is that if climate change causes declines in production, income, and productivity, it will lower businesses' incentive to invest, thereby lowering the investment rate. There is, as of yet, not clear evidence that longer-term trends in business investment have been altered significantly by climate change, as research to try to quantify this potential effect is limited and results vary.[25]

## Regional Impacts

The United States is a large country that spans several climate regions. Along with differences in populations, economic structures, and other factors, climate change will likely affect differentially the economies of separate regions. The magnitude of the climate change effects in each separate region is likely to vary as well, in part due to anticipation, preparation, and adaptation (which incur their own costs and returns). Climate change can also provide benefits to some regions or sectors. For example, earlier starts to and generally longer growing seasons are projected to increase crop yields in some regions.[26] The loss of sea ice may also prove beneficial to trade, at least in the short term, because of increased access to certain shipping passages during the year.[27] With information and adaptation, producers are also expected to be able to avoid some potential

[24] For more information on business investment and the economy, see CRS In Focus IF11020, *Introduction to U.S. Economy: Business Investment*, by Lida R. Weinstock.

[25] While research is limited, some studies have attempted to estimate the change in business investment as a result of climate change. For example, the authors of a recent study stated, "In computing the economic path that optimises this century's global consumption under unmitigated climate change, we find a 22% income reduction compared to an economy unaffected by climate change. Hereof 40% are losses due to growth effects of which 48% result from a reduced incentive to invest under climate damages." In other words, a little more than 4% of income losses would be the result of reduced investment. In this particular study the authors use an economic growth model, known as the DICE-2013R model, to estimate the response of investment activity to climate change to a high GHG emissions scenario (the IPCC's RCP6.0 and RCP8.5). This type of model uses an intertemporal framework to analyze optimal investment decisions. Whether to invest or not is framed as a trade-off between present-day consumption and future consumption. Investment will limit current consumption but may enable more consumption in the future. The results of this model therefore do not predict what *will* happen but rather what *could* happen if optimal investment decisions are made under specific conditions such as the one in which future GHG emissions increase at a pace well above the trajectories under current policies. See Sven N. Willner, Nicole Glanemann, and Anders Levermann, "Investment Incentive Reduced by Climate Damages Can Be Restored by Optimal Policy," *Nature*, vol. 12, no. 3254 (May 31, 2021), https://www.nature.com/articles/s41467-021-23547-5. For more information on the DICE-2013R model, see William Nordhaus and Paul Sztorc, *DICE 2013R: Introduction and User's Manual*, October 2013, http://www.econ.yale.edu/~nordhaus/homepage/homepage/documents/DICE_Manual_100413r1.pdf.

[26] NCA4, p. 952.

[27] David Herring, "Are There Positive Benefits from Global Warming?," National Oceanic and Atmospheric Administration, September 27, 2021, https://www.climate.gov/news-features/climate-qa/are-there-positive-benefits-global-warming.

losses and to seek opportunities. The benefits should be netted with costs to estimate the overall net economic impact of climate change.

All of this is to say that not all climate changes impact the economy in the same way or over the same time horizon, and therefore, some regions of the United States may feel the effects of climate change more negatively and acutely than other regions do. The same logic applies not only within the United States but throughout the world. Other countries may be more or less impacted by climate change than the United States is. In a global economy, the impacts to other countries will likely matter for the United States, especially in terms of trade, demands for assistance and disaster relief, pressures on migration, etc.

## Sector Impacts

Climate change can impact the economy via many avenues, including how it impacts different economic sectors. This section delves into some of the sectors most likely to see significant impacts from climate change. The list of sectors is not all inclusive but rather a subset used to illustrate how impacts to a specific sector could potentially impact the overall domestic economy.

The impacts described in the following sections are distilled only to certain industries, and the potential effects on the economy are described assuming no further additional mitigation, adaptation, or economic and policy changes. In reality, however, it is likely that declines in certain categories of spending will result in increases in other categories of spending and that less investment in one higher-risk region or sector may lead to greater investment in other regions or sectors. Therefore, in the longer run, any aggregate effects considered in this section may be exaggerated. For example, if jobs in a particular sector are lost, total employment does not necessarily decline if those workers find jobs in a different, growing sector.[28] Additionally, the effects of climate change are likely to be strongly distributional, meaning that where some sectors see losses as a result of climate change, others may see gains. For this reason, it is not possible to look at impacts on select sectors and map them directly onto economy-wide GDP or employment.

### Housing

The housing market plays an important role in the U.S. economy.[29] At the aggregate level, housing accounts for a significant portion of all economic activity, and changes in the housing market can have broader effects on the economy. According to the Federal Reserve, the market value of owner-occupied real estate rose to $33.4 trillion in the second quarter of 2021, up from $29.9 trillion a year previously and $17.4 trillion a decade previously.[30] This amount is approximately 1.5 times the size of annual GDP in 2020.[31] At an individual level, about 64% of housing units are owner-occupied,[32] and these homes can be a substantial source of household

[28] Or, as businesses adapt to changing conditions, jobs may change with uncertain effects on overall employment and wages. For example, one study of ski resorts in Utah found that owners are diversifying the recreational opportunities they offer, although there are likely barriers, such as costs, to complete adaptation. Emily J. Wilkins et al., "Climate Change and Utah Ski Resorts: Impacts, Perceptions, and Adaptation Strategies," *Mountain Research and Development*, vol. 41, no. 3 (September 2021), p. R12, https://doi.org/10.1659/MRD-JOURNAL-D-20-00065.1.

[29] For more information, see CRS In Focus IF11327, *Introduction to U.S. Economy: Housing Market*, by Lida R. Weinstock.

[30] Federal Reserve, *Z.1 Financial Accounts of the United States: Flow of Funds, Balance Sheets, and Integrated Macroeconomic Accounts*, Second Quarter 2021, https://www.federalreserve.gov/releases/z1/20210923/z1.pdf.

[31] BEA, *Gross Domestic Product (Third Estimate), Corporate Profits (Revised Estimate), and GDP by Industry, First Quarter 2021*, June 24, 2021, p. 11, https://www.bea.gov/sites/default/files/2021-06/gdp1q21_3rd_1.pdf.

[32] U.S. Census Bureau, *American Community Survey*, Table DP04: Selected Housing Characteristics, 2019,

wealth for those who own them. As of the end of the first quarter of 2021 owner-occupied real estate accounted for more than a quarter of households' net worth.[33] Total spending in the housing market, including residential investment and housing services, directly contribute to GDP, and housing prices can affect consumer spending through wealth effects.

Given the value of the U.S. housing stock, even in a scenario in which only high-risk homes[34] are affected by climate change via extreme weather events (it is not necessarily likely or predictable that all of these homes would be affected during a set period of time), climate change could still potentially translate to trillions of dollars of damage over the long term that would be borne by homeowners, insurers, and the government. A significantly damaged or destroyed housing stock could affect longer-term housing prices in affected locations, though it may increase prices in other locations where housing may be priced lower—or, to the extent that damage was uninsured, this would decrease the wealth of the owners of climate-change-affected houses. To a certain extent, climate-change-induced damage to property could cause competing forces on residential investment. If homes are damaged and rebuilt (assuming they were originally built in a previous year), that rebuilding will increase GDP in the form of increased residential investment. However, if housing prices fall in a location as a result of risk, construction spending might fall as builders' profits fall, resulting in lowered residential investment.

## Infrastructure

Physical infrastructure generally refers to long-lasting structures or systems that facilitate economic activity. Economists generally agree that infrastructure is critical to economic well-being, enabling private businesses and individuals to produce and consume goods and services in a more efficient manner. For example, a new bridge may greatly shorten travel distances for truck drivers, allowing them to deliver goods to consumers more quickly and at a lower cost. For businesses, infrastructure can help lower fixed costs of production, especially transportation costs, which are often a central determinant of where businesses are located. For households, a wide variety of final goods and services are provided through infrastructure services, such as water, energy, and telecommunications. Infrastructure tends to benefit the economy overall, as it allows more goods and services to be produced with the same level of inputs, fostering long-term economic growth.[35]

Infrastructure is at risk of damage—and, to some extent, has already been damaged—by the effects of extreme weather events associated with climate change, including, but not limited to, sea level rise, flooding, and extreme heat. As with other sectors, climate change is likely to impact

https://data.census.gov/cedsci/table?q=dp04&d=ACS%201-Year%20Estimates%20Data%20Profiles&tid=ACSDP1Y2019.DP04&hidePreview=false.

[33] Federal Reserve, *Z.1 Financial Accounts of the United States*, p. 9.

[34] According to CoreLogic's *2020 Climate Change Catastrophe Report*, most homes in the United States have some risk of climate-change-induced hazard events, and nearly one-third of the U.S. housing stock (about 35 million homes) is considered to be at high risk. The study defines *risk* based on the sum of the average annual loss for earthquake, wildfire, inland flood, severe convective storm, winter storm, hurricane/tropical storm coastal surge, and hurricane/tropical storm hazards for 105 million residential structures across the United States. These values are then considered in conjunction with reconstruction cost values to determine a risk ranking for structures. See Saumi Shokraee et al., *2020 Climate Change Catastrophe Report*, CoreLogic, January 28, 2021, https://www.corelogic.com/downloadable-docs/2020-climate-change-catastrophe-report-17-ctr-0121-00.pdf; CoreLogic, "Risk Redefined: CoreLogic Climate Change Catastrophe Report Emphasizes Need to Address Increasing Frequency of Hazard Events," January 27, 2021, https://www.corelogic.com/press-releases/risk-redefined-corelogic-climate-change-catastrophe-report-emphasizes-need-to-address-increasing-frequency-of-hazard-events/; and NCA4, p. 339.

[35] For more information, see CRS Report R46826, *Infrastructure and the Economy*, by Lida R. Weinstock.

infrastructure in different regions and localities to varying extents. In the case of infrastructure, urban, suburban, and rural areas tend to have differing systems of infrastructure and therefore are prone to different kinds of risks. Urban populations can be particularly at risk, as many systems of infrastructure tend to be interrelated in urban areas. For example, water treatment and public transportation may run off the same electrical grid.[36]

One of the types of infrastructure most at risk of being impacted by climate change is transportation.[37] While transportation systems are typically designed to withstand extreme weather events based on historical norms, a projected increase in frequency and severity of some extreme weather events, such as extreme heat, may make existing transportation infrastructure potentially more at risk of damage. The risk to infrastructure from climate change, while not necessarily calculable, may change incentives for both private and public infrastructure investment, including which types of infrastructure to invest in. Higher temperatures can cause damage to pavement[38] and rail tracks. Heat waves, heavy precipitation, and other storms can also cause delays and other disruption on roads, public transit systems, and airports, to name a few, potentially decreasing productivity in the economy.[39] On the other hand, fewer winter ice and storms could result in cost savings and improved mobility in certain areas.[40]

Should existing infrastructure—particularly transportation infrastructure—become less efficient, this could result in the less efficient production and consumption of goods and services throughout the economy, thereby hindering economic growth.[41]

## Agriculture

The agriculture industry—including farming, forestry, fishing, and related activities—had a gross output of over $500 billion in the first quarter of 2021.[42] In the same quarter, the value added of the agriculture industry to the economy amounted to 1.0% of GDP.[43] Certain studies suggest climate change could cause productivity losses in this sector, resulting in slower sector growth than would be realized without climate change.[44]

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[36] U.S. Global Change Research Program, *Third National Climate Assessment Report Findings: Infrastructure*, 2014, https://nca2014.globalchange.gov/highlights/report-findings/infrastructure.

[37] For more information about the impacts of climate change on surface transportation infrastructure and recent policy actions in this area, see CRS In Focus IF11921, *Surface Transportation and Climate Change: Provisions in the Infrastructure Investment and Jobs Act (P.L. 117-58)*, by William J. Mallett.

[38] The EPA estimates that "climate change-driven changes in temperature and precipitation are projected to result in significant impacts to U.S. roads. Discounted, reactive adaptation costs (rehabilitation measures) are estimated at $230 billion through 2100 under RCP8.5 and $150 billion under RCP4.5, on average." See EPA, *Multi-Model Framework for Quantitative Sectoral Impacts Analysis: A Technical Report for the Fourth National Climate Assessment*, May 2017, https://www.epa.gov/sites/default/files/2021-03/documents/ciraii_technicalreportfornca4_final_with_updates_11062018.pdf.

[39] EPA, "Climate Impacts on Transportation," January 19, 2017, https://19january2017snapshot.epa.gov/climate-impacts/climate-impacts-transportation_.html.

[40] EPA, "Climate Impacts on Transportation."

[41] For more information on how infrastructure affects economic growth, see CRS Report R46826, *Infrastructure and the Economy*, by Lida R. Weinstock.

[42] BEA, *Industry Economic Accounts Data, Gross Output by Industry*, https://apps.bea.gov/iTable/iTable.cfm?reqid=150&step=2&isuri=1&categories=gdpxind.

[43] BEA, *Industry Economic Accounts Data, Value Added by Industry*, https://apps.bea.gov/iTable/iTable.cfm?reqid=150&step=2&isuri=1&categories=gdpxind.

[44] One recent estimate suggests that global agricultural productivity (using 1961 as a baseline), despite growing in absolute terms, is 21% lower than it might otherwise have been due to the effects of climate change. This is only one

Crop-based agriculture depends heavily on climate conditions, and therefore climate change is likely to significantly affect the agriculture sector even though producers have been adept at managing weather variability.[45] The frequency of certain climate-change-induced extreme events such as droughts or flooding can disrupt crop growth and significantly damage yields, leading to less overall crop production. In some regions, a warming climate and increased amounts of carbon dioxide are projected to improve yields of some crops in some locations—assuming other environmental conditions necessary for crop growth are met—but result in yield declines for others. However, the net effects across the United States are uncertain.[46] Furthermore, as regional climates change, where specific crops are farmed may change. Regions that were once hospitable to a certain crop may become inhospitable and vice versa. As such, there may be winners and losers as crops are redistributed across regions.[47]

Livestock and fisheries could also be negatively impacted by climate change. Warming temperatures, drought, and heat waves may all affect the health and viability of livestock. Water temperature change and acidification caused by increased atmospheric carbon dioxide could harm fish and aquatic ecosystems alike. Livestock often accounts for over $100 billion in cash receipts in the United States annually, and fisheries contribute around $1.5 billion to GDP annually.[48] (The magnitude or likelihood of effects on these industries is uncertain, and the above statistics are meant only to provide a sense of the size of these industries, not provide estimates of potential losses.)

Climate change that decreases the productivity of the agricultural sector could also carry costs for the economy, depending on the extent to which overall productivity is affected. As of 2019, there were 2.6 million direct on-farm jobs.[49] If climate change decreases agricultural productivity, profits could decrease and jobs could be lost, although many of those workers would likely relocate to different regions or take jobs in different industries. Additionally, farmworkers in

example and other studies show varying results. As such, this point is only meant to be illustrative of how agricultural productivity may be affected by climate change and is not a definitive result of what will happen. See Ariel Ortiz-Bobea et al., "Anthropogenic Climate Change Has Slowed Global Agricultural Productivity Growth," *Nature*, vol. 11, no. 306-312 (April 1, 2021), https://www.nature.com/articles/s41558-021-01000-1. For a wider range of research, see NCA4, p. 393.

[45] For a more detailed discussion of agriculture and climate change, see the section "Primer on Climate Change, Agriculture, and Forestry" in CRS Report R46454, *Climate Change Adaptation: U.S. Department of Agriculture*, coordinated by Genevieve K. Croft.

[46] NCA4, Chapter 10: Agriculture and Rural Communities.

[47] *The Economist*, "Climate Change Will Alter Where Many Crops Are Grown," August 28, 2021, https://www.economist.com/international/2021/08/28/climate-change-will-alter-where-many-crops-are-grown. A recent field study experiment suggests that there may be global crop yield losses as a result of climate change. The study concludes that "yield losses in response to a global mean warming level of 1.5K, as aimed for in the Paris Agreement, would still be substantial, ranging from 2% to 7% across the main producing countries." The study focuses on corn, wheat, soybeans, and rice. The United States is one of the top five producers of corn, wheat, and soybeans and produces roughly 50% of the global supply of corn, 40% of soy, and 20% of wheat. Of note, this is only one experiment and therefore the results may not be representative of the entire field of study and should be interpreted with caution. See Xuhui Wang et al., "Emergent Constraint on Crop Yield Response to Warmer Temperature from Field Experiments," *Nature*, vol. 3, (June 29, 2020), p. 912, https://www.nature.com/articles/s41893-020-0569-7; and U.S. Department of Agriculture, *Climate Change and Agriculture in the United States: Effects and Adaptation*, February 2013, https://www.usda.gov/sites/default/files/documents/CC%20and%20Agriculture%20Report%20(02-04-2013)b.pdf.

[48] EPA, "Climate Impacts on Agriculture and Food Supply," January 19, 2017, https://19january2017snapshot.epa.gov/climate-impacts/climate-impacts-agriculture-and-food-supply_.html.

[49] Economic Research Service, *Ag and Food Sectors and the Economy*, 2021, https://www.ers.usda.gov/data-products/ag-and-food-statistics-charting-the-essentials/ag-and-food-sectors-and-the-economy/#:~:text=In%202019%2C%2022.2%20million%20full,1.3%20percent%20of%20U.S.%20employment.

warm climates are particularly prone to decreased productivity (and risks of mortality) as a result of increasing temperatures and extreme heat events, which could negatively impact the agriculture sector in the longer term, as discussed in the "Productivity" section.

# Methodology for Estimating Economic Impact

While identifying mechanisms through which climate could affect the economy are useful for understanding potential causes and effects, estimates of the magnitudes of the effects could be helpful to policymakers and other stakeholders seeking to weigh the potential benefits and costs of alternative policy choices. Economists have developed and are practiced in a number of techniques and tools to make economic projections. However, the uncertainties that are inherent in making economic projections may be particularly challenging when making climate change projections.

Economic projections involve estimating potential future economic conditions, typically over months to a few years. In this discipline, economists build "models" that attempt to approximate but simplify how vastly complicated economies at the regional, national, or even global level function and how they are affected by key variables. These variables can include any number of factors that could affect economic outcomes, including the size of the labor force, the size of the capital stock, how productive a unit of labor or capital stock is, price levels, interest rates, and asset values, among many others. Typically, uncertainty in the assumptions increases the further out in time the analysis projects. Despite the assumptions and simplifications of these models, economic forecasting is nonetheless a useful tool for policymakers, business organizations, and other stakeholders. It is arguably the best available tool to estimate possible future economic conditions when making policy or business decisions.

Economic projections are not perfect predictors. Projecting economic conditions is an imprecise science and entails a degree of uncertainty, especially in the long term. Economists have various statistical techniques and methods for addressing the challenges of economic modeling, but a degree of uncertainty remains in the results.[50] Further contributing to differences in results are differences in methodology across studies, which will be discussed in more detail in the next section.

The remainder of this section discusses some of the challenges facing economic analysis.

## Challenges of Economic Analysis

- **Assumptions.** In general, economic models necessarily make simplifying assumptions and cannot account for all variables. The assumptions made in a model can cause more uncertainty for long-term than short-term forecasting as the range of changes that may occur in an economy widens over time.
- **Shocks.** Economic models are usually not able to predict random future events, but these events often have significant implications for the economy.[51] For

[50] For example, see Neil R. Ericsson, *Economic Forecasting in Theory and Practice: An Interview with David F. Hendry*, Board of Governors of the Federal Reserve System, November 2016, pp. 1-2, https://www.federalreserve.gov/econresdata/ifdp/2016/files/ifdp1184.pdf; and Masayuki Morikawa, "The Accuracy of Long-Term Growth Forecasts by Economic Researchers," *VoxEU*, February 10, 2020, https://voxeu.org/article/accuracy-long-term-growth-forecasts-economics-researchers.

[51] Cornell University, "Introduction to Time-Series Regression," http://node101.psych.cornell.edu/Darlington/series/series1.htm.

example, economic forecasts did not predict the COVID-19 pandemic, which resulted in a recession and served as the impetus for significant fiscal and monetary policy changes.[52] Depending on the shock, long-term trends in economic series may or may not be permanently altered, and this is usually apparent only in hindsight.[53] Nonetheless, advances in climate change modeling include "stochastic" processes or are able to estimate the effects of hypothesized shocks to understand the potential implications of, say, extreme weather events or a series of them on economic conditions.

- **Structural change**. Economies change structurally over time.[54] Structural changes—changes that affect the way the economy functions—can happen quickly but often occur relatively slowly. Changes in technology, the composition of the labor force, or demographics, for example, may result in the parameters of a model becoming inaccurate over time.[55] Long-term models may be particularly ill-equipped to deal with this limitation given the likelihood that there may be more (or more significant) structural changes to the economy in the longer term than the shorter term.[56] Further, these structural changes could interact with climate change. For example, new technology might increase or reduce the energy and carbon intensity of economic production. Because climate change is necessarily a process that evolves over decades, and the likelihood that effective GHG mitigation policies may radically alter certain economic systems, modeling may not capture the potential for unforeseen structural changes.
- **Data.** Measurement challenges can affect the precision or accuracy of the data used to build and test models. This is illustrated by the fact that as part of the data collection and calculation process in the United States, statistical agencies often provide revised estimates. For example, the Bureau of Economic Analysis provides three estimates of GDP over time as more source data and revised data become available.[57] Such revisions tend to be fairly insignificant, although the definitions and manner of data collection and calculation of certain economic series have also changed, causing significant breaks in data and necessitating unexpected data revisions in some cases.[58] Many agencies also do longer-term

[52] As an example of how significantly unforeseen events such as the pandemic can affect economic conditions, prior to the pandemic in January 2020 the Congressional Budget Office forecasted real GDP to grow by 2.5% in the second quarter of 2020. In actuality, real GDP fell by 31.2% in the second quarter of 2020. See Congressional Budget Office, "Budget and Economic Data," https://www.cbo.gov/data/budget-economic-data.

[53] For example, see Francesco Furlanetto et al., *Estimating Hysteresis Effects*, Federal Reserve Bank of Atlanta, November 2021, https://www.atlantafed.org/-/media/documents/research/publications/wp/2021/11/08/24-estimating-hysteresis-effects.pdf.

[54] Daron Acemoglu, *Advanced Economic Growth: Lecture 19: Structural Change*, Massachusetts Institute of Technology, November 12, 2007, https://economics.mit.edu/files/1953.

[55] J. H. Stock, "Time Series: Economic Forecasting," *International Encyclopedia of the Social and Behavioral Sciences*, 2001, p. 15723, https://scholar.harvard.edu/files/stock/files/time_series_economic_forecasting.pdf.

[56] Bin Chen and Yongmiao Hong, "Testing for Smooth Structural Changes in Time Series Models via Nonparametric Regression," *Econometrica: Journal of the Econometric Society*, vol. 80, no. 3 (May 2012), p. 1157, https://www.jstor.org/stable/41493847?seq=1#metadata_info_tab_contents.

[57] BEA, "Glossary: Advanced Estimate," https://www.bea.gov/help/glossary/advance-estimate.

[58] Itzhak Yanovitsky and Arthur VanLear, "Time Series Analysis: Traditional and Contemporary Approaches," in *The SAGE Sourcebook of Advanced Data Analysis Methods for Communication Research* (Thousand Oaks, CA: Sage Publications, 2007), p. 96, https://us.sagepub.com/sites/default/files/upm-assets/23658_book_item_23658.pdf.

benchmark revisions, which can significantly impact data.[59] Models can be and often are updated to reflect data revisions, but at any given point in time, the most recent data incorporated may still be subject to revision, and any definitional change in a series can cause a break in the data.[60] Data changes and revisions can be problematic for any economic model but may be of particular import to longer-term models, such as those used to estimate the effects of climate change, because the data is less and less likely to be accurate the more time passes.

- **Lack of a control.** Generally, scientific research tends to employ control groups—that is, a group that does not receive a particular treatment and therefore can be compared with the experimental group to determine which effects are actually a result of the treatment. While theoretical constructions can be used for the purposes of research, in reality it is not possible to, for example, observe how the economy responds to a new policy while also simultaneously observing the same economy without the policy. Likewise, conditions are typically the result of many factors, making it difficult in empirical studies to isolate the specific effects of climate change.[61]

# Selected Government Reports on Economic Impacts of Climate Change

The literature surrounding the economic impacts of climate change is varied. There are several different methodologies and types of modeling used to estimate the impacts of various climate change scenarios on economic indicators such as GDP and personal income. Some models are broad, and others are sector or region specific. Baseline and alternate scenarios of climate change vary across studies. Indeed, the types of climate conditions studied vary from temperature change to precipitation change to extreme weather shocks and beyond. In sum, it can be difficult, and at times inadvisable, to compare the results of different studies. Further, as discussed in the previous section, any single result is likely to have a high degree of uncertainty due the challenges and limitations of both economic and climate modeling. The methodology and scope of each individual study should be considered when analyzing research. Despite challenges in this field, research into the economic effects of climate change can provide valuable insights into how systems may work, which factors may be more or less important in outcomes, and how specific assumptions may alter the type and magnitude of outcomes.

## Selected Research

**Table 1** below shows a few government-sponsored reports published on the impacts of climate change. For the purposes of this literature review, the selection of research is limited to studies published since 2015 by government or intergovernmental agencies, whether original research,

[59] For example, see BEA, "Information on Updates to the National Economic Accounts," 2021, https://www.bea.gov/information-updates-national-economic-accounts.

[60] For example, the Federal Reserve changed the composition of the M1 money stock, causing a break in the data. Federal Reserve Board of Governors, "Technical Q&As: Money Stock Measures—H.6 Release," https://www.federalreserve.gov/releases/h6/h6_technical_qa.htm.

[61] World Health Organization, *Climate Change and Human Health: Risks and Responses*, 2003, p. 61, https://www.who.int/globalchange/publications/climchange.pdf.

reviews of other research, or independent research published under the auspices of an agency.[62] By limiting the discussion to only these sources, the following research designs and results could fall within a smaller range than would the literature as a whole, because the authors come from organizations that may have similar missions, stakeholders, and cultures. However, because these organizations are widely recognized to be authoritative sources of research and their results are generally representative of conventional studies and not producing outlier results, these studies serve as a good set of illustrative reports.

While this report focuses on domestic economic effects of climate change, some of these studies additionally focus on global economic effects. As such, global estimates are likely different than they would be for the United States alone, as some foreign countries are more vulnerable and some are less vulnerable than the United States is to climate risk.

**Table 1. Selected Reports on the Economic Impacts Under Certain Assumed Scenarios**

| Report | Year of Publication | Sponsoring Agency | Scenarios Tested |
|---|---|---|---|
| Climate Change Impacts and Risk Analysis | 2017 | U.S. Environmental Protection Agency | RCP 8.5[b] and RCP 4.5[c] |
| Fourth National Climate Assessment Volume II: Impacts, Risks, and Adaptation in the United States | 2018 | U.S. Global Change Research Program[a] | Drawing on a suite of analyses with a focus on the IPCC's RCP 8.5 and 4.5 |
| Climate Change 2022: Impacts, Adaptation, and Vulnerability, Chapter 14: North America | 2022 | Intergovernmental Panel on Climate Change | A suite of scenarios including RCP 2.6, 4.5, 6.0 and 8.5[d] |
| Long-Term Macroeconomic Effects of Climate Change: A Cross Country Analysis | 2019 | International Monetary Fund Working Paper | RCP 8.5 and RCP 2.6 |
| The Economic Consequences of Climate Change | 2015 | Organisation for Economic Co-operation and Development | RCP 8.5 |

**Source:** See below sections for more information on these studies.

**Notes:**

a. The U.S. Global Change Research Program is a federal program, mandated by Congress, that includes 13 member agencies such as the U.S. Environmental Protection Agency and the U.S. Department of Agriculture.

[62] For a selection of some of the nongovernmental academic research on this subject, see Dale W. Jorgenson et al., "U.S. Market Consequences of Global Climate Change," *Pew Center on Global Climate Change*, April 2004, https://research.fit.edu/media/site-specific/researchfitedu/coast-climate-adaptation-library/united-states/national/us—pew-climate-center—c2es-reports/Jorgenson-et-al.-2004.-Economy—CC.pdf; Robert S. Pindyck, "Climate Change Policy: What Do the Models Tell Us?," *Journal of Economic Literature*, vol. 51, no. 3 (September 2013), pp. 860-872, https://www.aeaweb.org/articles?id=10.1257/jel.51.3.860; Robert S. Pindyck, *What We Know and Don't Know About Climate Change, and Implications for Policy*, National Bureau of Economic Research, Working Paper no. 27304, June 2020, https://www.nber.org/papers/w27304; Nicholas Stern, *The Economics of Climate Change: The Stern Review* (Cambridge, U.K.: Cambridge University Press, 2007), https://www.lse.ac.uk/granthaminstitute/publication/the-economics-of-climate-change-the-stern-review/; and William D. Nordhaus, "To Slow or Not to Slow: The Economics of the Greenhouse Effect," *Economic Journal*, vol. 101, no. 407 (July 1991), pp. 920-937, https://www.jstor.org/stable/2233864?seq=1#metadata_info_tab_contents.

b. RCPs, or representative concentration pathways, are what-if scenarios based on alternative assumptions and relationships among socio-economic, technological, environmental, and atmospheric/climate relationships, with associated ranges of temperature and other climate results for each scenario from many independent climate models. RCP 8.5 represents a pathway of increasing emissions with no mitigation efforts and is considered by many to be well above currently enacted policies and technology trends.

c. RCP 4.5 represents a pathway of slowly declining GHG emissions with current and increasing mitigation efforts.

d. RCP 2.6 represents a pathway of strongly declining GHG emissions, and RCP 6.0 represents a pathway of stabilizing emissions.

e. For discussion of the two principal studies of economic impacts in the United States cited in the NCA4, see CRS In Focus IF11156, *Projected Economic Impacts of Climate Change*, by Jane A. Leggett.

## Environmental Protection Agency, *Multi-Model Framework for Quantitative Sectoral Impacts Analysis: Climate Change Impacts and Risk Analysis*

As part of a technical report for the U.S. Global Change Research Program's Fourth National Climate Assessment, the U.S. Environmental Protection Agency, in collaboration with several other federal agencies, completed a Climate Change Impacts and Risk Analysis project.[63] The authors model various impacts of climate change in the United States under RCP 4.5 and 8.5 scenarios. The report generally concludes that "annual damages are projected to increase over time and are generally larger under RCP8.5 compared to RCP4.5."[64] Of particular note to the discussion of U.S. economic effects is the report's discussion of labor effects. Importantly, the following findings are only a few among many and, therefore, are not representative of the report's findings as a whole. To determine the effects of climate change on labor, the researchers use dose-response functions for the relationship between temperature and labor.[65] These estimates measure short-term responses and do not account for adaptation or other structural changes. The cost of losses is estimated using average wages in 2005, as reported by the Bureau of Labor Statistics, and adjusted to the future using projected changes in GDP per capita. Under these assumptions and the very high RCP 8.5 scenario, over $160 billion could be lost in U.S. wages per year by 2090 owing to the effects of extreme heat on working conditions. Under RCP 4.5, the losses were halved to $80 billion.[66] For a sense of scale, as of the fourth quarter of 2021, total wages and salaries totaled roughly $10.8 trillion in the United States.[67]

## U.S. Global Change Research Program, *Fourth National Climate Assessment Volume II: Impacts, Risks, and Adaptation in the United States*

No less than every four years, the U.S. Global Change Research Program is required to deliver a report to Congress and the President that assesses the published literature on climate changes and

[63] EPA, *Multi-Model Framework for Quantitative Sectoral Impacts Analysis: A Technical Report for the Fourth National Climate Assessment*, May 2017, https://www.epa.gov/sites/default/files/2021-03/documents/ciraii_technicalreportfornca4_final_with_updates_11062018.pdf.

[64] EPA, *Multi-Model Framework for Quantitative Sectoral Impacts Analysis*, p. 4.

[65] Joshua Graff Zivin and Matthew Neidell, "Temperature and the Allocation of Time: Implications for Climate Change," *Journal of Labor Economics*, vol. 32, no. 1 (January 2014), pp. 1-26, https://www.jstor.org/stable/pdf/10.1086/671766.pdf.

[66] EPA, *Multi-Model Framework for Quantitative Sectoral Impacts Analysis*, p. 54.

[67] BEA, "National Income and Product Accounts, Table 2.2B. Wages and Salaries by Industry," https://apps.bea.gov/iTable/iTable.cfm?reqid=19&step=2#reqid=19&step=2&isuri=1&1921=survey.

their observed and projected impacts.[68] The most recent report,[69] the *Fourth National Climate Assessment*, uses the Coupled Model Intercomparison Project Phase 5 for its climate change scenarios.[70] The report summarizes U.S. research findings on economic impacts as follows: "Without substantial and sustained global mitigation and regional adaptation efforts, climate change is expected to cause growing losses to American infrastructure and property and impede the rate of economic growth over this century."[71]

### IPCC, *Climate Change 2022: Impacts, Adaptation, and Vulnerability, Chapter 14: North America*

As part of the Working Group II contribution to the IPCC's *Sixth Assessment Report*, there is a chapter devoted to the impacts, adaptation, and vulnerability to climate change in North America.[72] The authors note that since the fifth assessment report, research into climate impacts for the United States has significantly expanded and that, despite differences in magnitude owing to approach, assumptions, and expectations, the new studies "show substantial projected economic damages across North America by the end of the century, especially for warming greater than 4ºC." The authors further cite that:

> For the U.S., reductions in mortality, energy expenditures and improvements in agricultural yields are projected to result in net gains in the North and Pacific Northwest whereas in the South, higher heat-related mortality, increases in energy expenditures, SLR and storm surge are projected to result in economic losses by the end of the century. No region in the U.S. is expected to avoid some level of adverse effects.[73]

### Kahn et al., *Long-Term Macroeconomic Effects of Climate Change: A Cross Country Analysis*

In this working paper,[74] the authors attempt to develop a multi-country stochastic growth model with climate effects that links deviations in historical norms in precipitation and temperature to changes in labor productivity, investment, and real output per capita. The study includes 174 countries over the period from 1960 to 2014. Results indicate that a persistent 0.01°C annual increase in temperature above its historical norm could reduce real GDP per capita growth by

[68] The U.S. Global Change Research Program is a federal program, mandated by Congress, that includes 13 member agencies such as the EPA and the U.S. Department of Agriculture.

[69] U.S. Global Change Research Program, *Fourth National Climate Assessment Volume II: Impacts, Risks, and Adaptation in the United States*, 2018 (revised March 2021), https://nca2018.globalchange.gov/downloads/NCA4_2018_FullReport.pdf (cited elsewhere as NCA4).

[70] Program for Climate Model Diagnosis and Intercomparison, "CMIP5—Coupled Model Intercomparison Project Phase 5—Overview," https://pcmdi.llnl.gov/mips/cmip5/.

[71] NCA4, p. 25.

[72] Jeffrey A. Hicke et al., "North America," in Pörtner et al., *Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, February 27, 2022, https://www.ipcc.ch/report/ar6/wg2/downloads/report/IPCC_AR6_WGII_FinalDraft_Chapter14.pdf.

[73] Hicke et al., "North America,", p. 14-68.

[74] Matthew E. Kahn et al., "Long-Term Macroeconomic Effects of Climate Change: A Cross Country Analysis," International Monetary Fund, Working Paper, vol. 19, no. 215 (October 2019), https://www.imf.org/-/media/Files/Publications/WP/2019/wpiea2019215-print-pdf.ashx. This article was later published in the peer-reviewed journal *Energy Economics*, vol. 104, no. 105624 (December 2021), https://www.sciencedirect.com/science/article/pii/S0140988321004898.

0.0586 percentage points per year in the long run (statistically significant at the 1% level) and that a persistent 0.01°C decrease below its historical norm reduces real GDP per capita growth by 0.0520 percentage points per year in the long run (statistically significant at the 5% level).

The authors additionally perform a counterfactual analysis for 2015-2100 and find that on an annual basis, if temperature were to increase by 0.01°C annually above its historical norm, global income growth would be lower by 0.0543 percentage points. Further, in the absence of GHG mitigation policies, a persistent increase in average global temperature by 0.04°C annually would reduce the level of global real GDP per capita by 7.22% by 2100 based on the stochastic growth model with climate assumptions. If the increase in global average temperatures were held to well below 2°C above the pre-industrial temperature—the Parties' collective aim for policies in the Paris Agreement[75]—the increase in average global temperature would be 0.01°C annually, and the global real GDP per capita loss would be 1.07% by 2100. Under this counterfactual, per capita GDP loss in the United States by 2100 would be between 0.98% and 2.84% for RCP2.6 and between 6.66% and 14.32% for RCP8.5.[76]

### Organisation for Economic Co-operation and Development (OECD), *The Economic Consequences of Climate Change*

In this research paper,[77] the authors combine two models—a sectoral and regional computable general equilibrium model and a large-scale integrated assessment model—to assess the impact of climate change on GDP around the world. The authors find that in 23 of 25 regions studied (including the United States), the net economic consequences of climate change would be negative for RCP8.5. Results indicate that, based on policies in place at the time of the publication of this report and in the absence of mitigation efforts from that point in time, the combined negative effect on projected global GDP annually could be between 1.0% and 3.3% by 2060. GDP may be negatively affected between 2% and 10% compared to a no-damage baseline scenario if temperature rise 4°C above pre-industrial levels by 2100.[78] With respect to the no-damage baseline, the authors additionally find that the percentage change in projected GDP in 2060 in the United States as a result of damages from climate change would be between 0% and -1%. Of note, this report uses RCP8.5, which assumes strong GHG emissions and does not purport to represent what is likely to happen in the future but only what could happen under a very high and increasing GHG emissions scenario.

## Questions of Measurement

Economists typically use aggregate measures of economic activity such as GDP, personal income, and the unemployment rate to determine the health of the economy. Despite certain shortcomings in these measures, economists generally believe them to be useful indicators when it comes to

[75] United Nations Framework Convention on Climate Change, "The Paris Agreement," https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement.

[76] See **Table 1** notes for an explanation of RPC2.6 and RPC8.5.

[77] OECD, *The Economic Consequences of Climate Change*, 2015, https://www.oecd-ilibrary.org/environment/the-economic-consequences-of-climate-change_9789264235410-en.

[78] The no-damage baseline is "a projection similar to the SSP2 standard scenario, but with revised socioeconomic drivers for population and economic growth. This 'naïve' no-damage baseline projection, while purely hypothetical, provides the appropriate reference point for the analysis. It is differentiated from the core projection in which climate change impacts affect the economy, while all other assumptions remain unchanged." In other words, the no-damage baseline assumes climate change will not affect the economy. OECD, *The Economic Consequences of Climate Change*, p. 46.

how policy or shocks affect Americans. However, given the likelihood of very disparate effects of climate change on different regions, industries, and individuals or groups of individuals, relying only on such aggregate measures could obscure some effects.

Further, there is debate as to whether aggregate economic measures such as GDP are good metrics of well-being or welfare.[79] For example, spending on climate adaptation, such as the construction of additional infrastructure, may increase GDP in any given year but does not necessarily make individuals better off than they would have been had the need for the better adapted infrastructure not arisen.

From a technical perspective, current GDP may not adequately measure current or future welfare. Components of GDP such as investment do not affect current welfare but rather future welfare, and thus current GDP may overstate the average welfare of citizens. On the other hand, current consumption, which may increase current welfare, may decrease future welfare, particularly when current consumption depletes natural resources.[80]

GDP growth and improving living standards are often highly correlated, and GDP is more easily measurable than welfare is, and thus it is often used as a proxy for quality of life. However, GDP does not inherently measure nonmarket costs (or benefits), including many negative *externalities* of the production process, such as pollution or loss of species. As defined by the OECD, "externalities refer to situations when the effect of production or consumption of goods and services imposes costs or benefits on others, which are not reflected in the prices charged for the goods and services being provided."[81] Of note, GDP also does not account for positive externalities that benefit society.[82]

All of this is not to say that economists should ignore the impacts of climate change on GDP. In fact, GDP may be a very telling metric, especially when it comes to longer-term impacts and some of the more gradual effects of climate change.

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[79] Some organizations, notably the OECD, have researched alternative metrics for well-being. The OECD Better Life Index rates member country well-being based on a series of metrics, including some more traditional metrics such as income and jobs but also less traditional metrics such as environment and life satisfaction. See OECD, *OECD Better Life Index*, https://www.oecdbetterlifeindex.org/#/11111111111.

[80] Peter S. Thorne, Chair, EPA Science Advisory Board, and Peter J. Wilcoxen, Chair, EPA Science Advisory Board Economy-Wide Modeling Panel, letter to the Honorable E. Scott Pruitt, Administrator, EPA, September 29, 2017, https://yosemite.epa.gov/sab/SABPRODUCT.NSF/0/4B3BAF6C9EA6F503852581AA0057D565/%24File/EPA-SAB-17-012.pdf.

[81] R. S. Khemani and D. M. Shapiro, *Glossary of Industrial Organisation Economics and Competition Law*, OECD, 1993, https://www.oecd.org/regreform/sectors/2376087.pdf.

[82] Amit Kapoor and Bibek Debroy, "GDP Is Not a Measure of Human Well-Being," *Harvard Business Review*, October 4, 2019, https://hbr.org/2019/10/gdp-is-not-a-measure-of-human-well-being.

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