EFFECTS & COSTS OF CLIMATE CHANGE

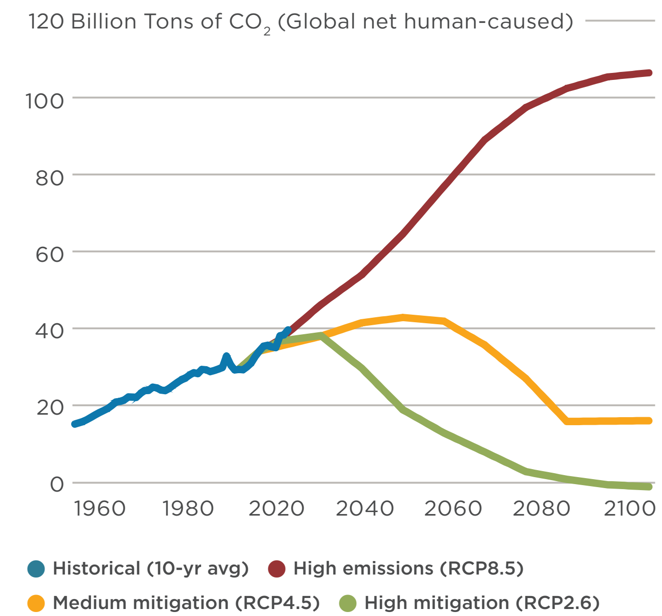
Climate Change & the U.S. Economic Future

Amir Jina, Assistant Professor, Harris School of Public Policy

The science of climate change poses four unique challenges for policymakers. First, the causes and the consequences of climate change are global. The main climate change culprit, CO_2, disperses throughout the atmosphere so emissions from anywhere can lead to consequences everywhere. Second, it is a long-term problem. Many of the gases that cause climate change will remain in the atmosphere and affect the climate for hundreds or thousands of years. Actions taken to reduce those emissions will provide benefits, but on a much longer timeframe than a typical election cycle. Third, as the science of climate change advances, it is apparent that there is potential for irreversible impacts. A point may arrive after which reducing emissions will not be sufficient to prevent or reverse many of the worst effects of climate change. Finally, while much is known about the causes and likely trajectory of climate change in the coming century, researchers are still racing to learn where certain impacts will be felt, how severely, and over what timeframe. Together, these four scientific issues suggest that the climate challenge will demand not one policy solution, but many.

FIGURE 1 - CHAPTER IN A CHART

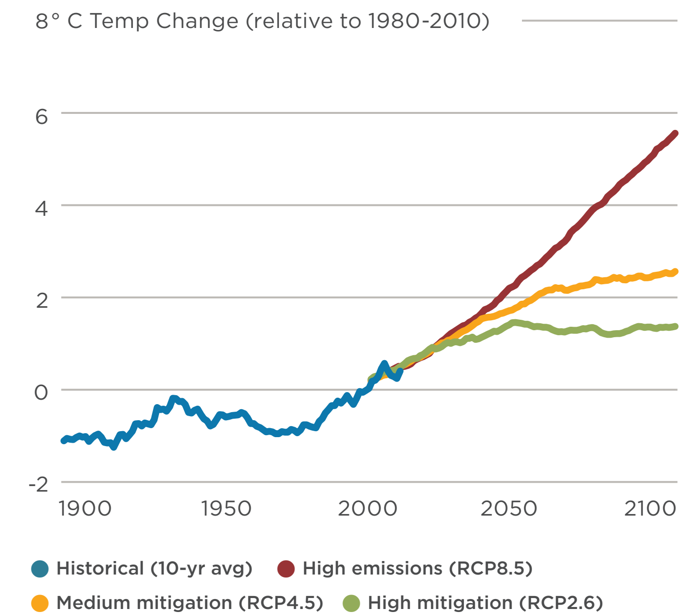
Historical and Projected Emissions of Human-Caused CO_2



Source: IPCC (2014).

FIGURE 2

Historical and Projected Temperatures for the United States



Source: Houser, et al. (2015).

The Changing Climate

The basic relationship between CO_2 and the global climate has been understood for more than a century, when scientists identified the gas as one of several in the atmosphere that retained heat and kept the planet habitable for humans.[1] To understand the consequences of this greenhouse effect as levels of CO_2 change, it is important to know not only what the trends of CO_2 have been in the past but also what they might be in the future. There is considerable uncertainty about what countries will do over the next 100 years, ranging from producing more emissions to gain the benefits of economic growth, to reducing emissions to limit the impacts of climate change. These alternate futures are captured in a set of scenarios, called Representative Concentration Pathways (RCPs) that correspond to different levels of radiative forcing, or warming, which could occur in the years to come.

Figure 1 shows both historic CO_2 emissions and the three future scenarios that are the subject of much of the research around the future climate. These range from a scenario of continued high emissions, spurred by a reliance on fossil fuels in a fast-growing global economy (RCP8.5), to a scenario of net zero emissions, where policymakers at all levels enact policies to remove carbon from the energy system, or at least prevent that carbon entering the atmosphere (RCP2.6).

Extended records about the climate paint a worrying picture of changes to date. Global average surface temperatures have risen by around 2°F since pre-industrial times and more than 1°F in the last few decades. (For scale, the global average temperature increase after the last ice age was about 11°F,[2] an increase that took place gradually over thousands of years rather than in just decades.) In fact, according to the instrumental record of temperatures stretching back to the 1880s maintained by the National Oceanic and Atmospheric Administration (NOAA),[3] nineteen of the twenty warmest years on record have occurred since the year 2000. The decade that has just ended is the warmest decade since records began. The

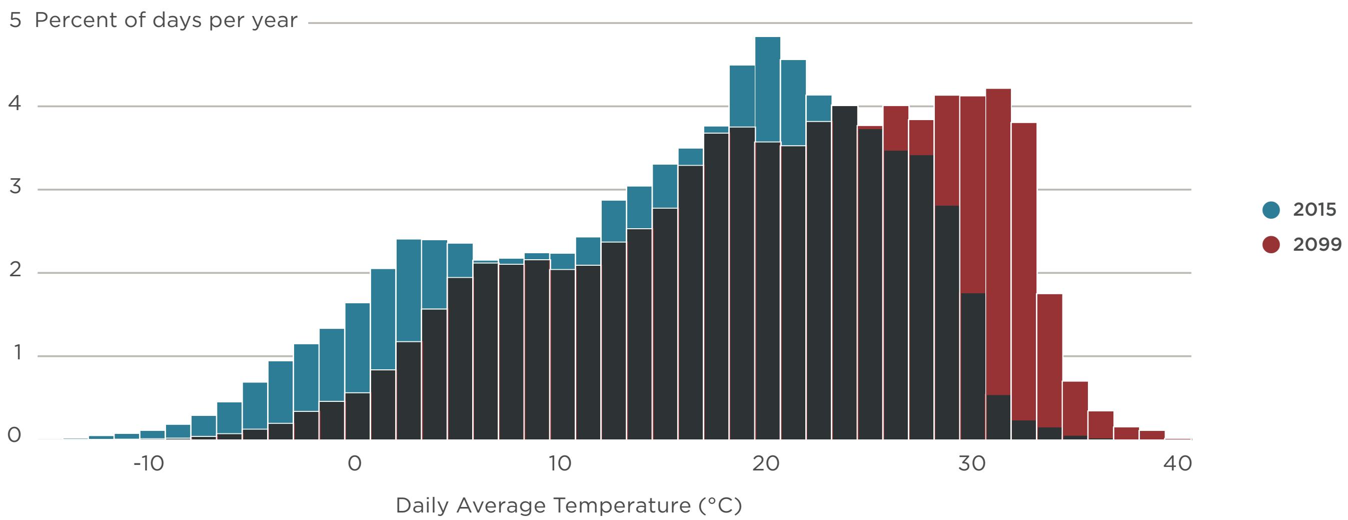
1 Arrhenius, "On the Influence of Carbonic Acid in the Air upon the Temperature of the Ground"; Foote, Circumstances Affecting the Heat of the Sun's Rays".

2 Tierney, et al, "Glacial Cooling and Climate Sensitivity Revisited".

3 NOAA National Centers for Environmental Information, "Climate at a Glance Global Time Series".

FIGURE 3

Population-Weighted Distribution of Daily Average Temperatures for the United States in 2015 and 2099 (RCP8.5)



Source: Author calculations using Global Meteorological Forcing Dataset (from Princeton University) for 2015, and Earth Exchange Global Daily Downscaled Projections (from NASA) for 2099.

historical record in Figure 2 shows the warming trend for the United States. It is worth noting that the United States is warming faster than the global average, as are many higher-latitude countries (i.e., countries further from the equator). Since the late 1970s, the United States has warmed between 0.29°F and 0.46°F per decade.

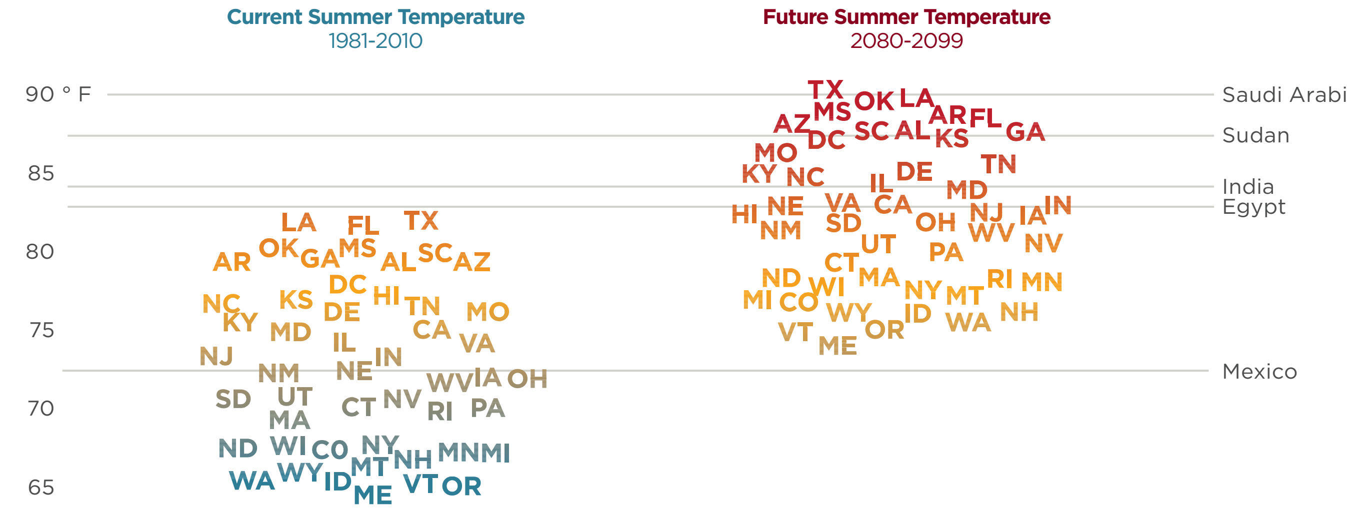
The question for policymakers is what these dramatic changes mean for the American people and the United States economy. Much of the science refers to global scales and far-off time horizons. Even expressing these findings for the whole of the United States provides an aggregate picture of climate change that may be difficult to apply in practice. With that said, however, scientists can make some concrete projections about local, relatively near-term changes to the U.S. climate and the consequences they may have for the economy.

Discussing climate change in terms of average temperature makes it hard to understand how much of a change Americans will actually feel. Figure 3 shows, for the whole of the United States, the change in the number of days at specific temperatures between 2015 and 2099. Higher bars mean more days at that temperature. It is clear, because the red bars have shifted to the right with respect to the blue bars, that the average temperature will be higher. It is also readily apparent that the extremely hot days, those with a daily average temperature above 95°F, will increase dramatically. Under a high emissions scenario, there may be seven times more of these days compared to the average from 1986-2005.

Not all areas of the United States will feel this increase in the same way or at the same rate, with currently colder states warming faster than currently hotter states. Some of these local changes will be dramatic. Figure 4 shows the average summer temperatures for each of the fifty states plus Washington, DC between 1981 and 2010, and how they could change by the end of the century under a high emissions scenario. The compression of the cloud shows that the differences between hot and cool states are shrinking even as all the states warm over time. Some of the coolest states, like Maine or Vermont, will warm to be similar to today's Illinois, Indiana, or Virginia, while those three states will warm to be hotter than the states that currently have the hottest summer temperatures: Florida, Texas, and Louisiana. Today's hottest states will far exceed their current summer temperatures; Texas and Louisiana, for example, will have summer temperatures at the end of the century similar to today's Sudan or Saudi Arabia. Nearly half of the states in the United States will have summer temperatures hotter than today's summers in India or Egypt.

FIGURE 4

State-Level Average Summer Temperatures, 1981-2010 and 2080-2099 (RCP8.5)



Note: States are indicated by two-letter abbreviations. Current (1981-2010) national average summer temperatures for selected countries are displayed for comparison on the side of the figure.

Source: Houser, et al., (2015).

Temperature rise is just one of the many environmental changes the United States can expect due to climate change. Changes are also expected in average precipitation levels, the frequency of extreme precipitation events, sea levels, and hurricane intensity, to name a few.[4] Nor are these changes far off into the future. Over the past twenty years compared to 1960-1980, the average American has experienced 20 percent more extremely hot days (>95°F) per year, and a nearly 70 percent increase in extreme precipitation events.[5] Hurricanes have also become more intense: in 2007-2017 compared to 1979-1989, while hurricanes of all intensity categories have become more frequent, the most extreme, Category 5, doubled in frequency.

The climate, in other words, is already changing.

Economic Impact

Understanding the damages due to climate change at both national and local scales is important for assessing the benefits that will accrue from any policy that limits climate change, as well as for informing policies to adapt. A recent increase in the volume of research into climate impacts has led to a new understanding of the relationship between climate and local economic outcomes, built on solid foundations in data. This has allowed researchers to empirically derive estimates of the climate's influence on multiple sectors of the U.S. economy, project them into the future under various carbon emissions scenarios in high spatial detail, and then sum across outcomes to give a comprehensive estimate of damages that vary spatially. A discussion of some of these outcomes follows, but it is important to note that they do not cover all of the potential damages of climate change. Rather, they are a subset of outcomes that are likely to be major drivers of costs.[6]

Before discussing the economic implications of climate change for the U.S. economy in the future, it is important to understand some general features of how the economy and the climate are related. First, climate damages are often non-linear, meaning they can increase dramatically after a threshold level of warming is reached. Second, people are most affected by increases in extremes—that is, adding more very hot days has a greater impact than an increase in the average annual temperature.

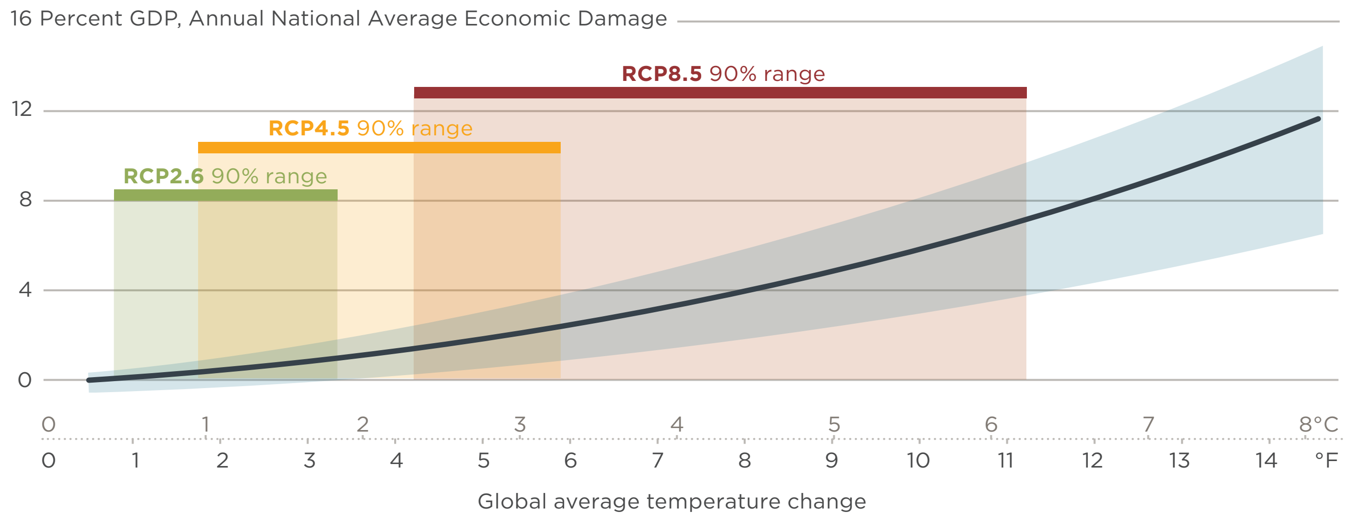
4 The Intergovernmental Panel on Climate Change (IPCC, 2014) and the Fourth National Climate Assessment (Hayhoe et al., 2017) contain excellent summaries of these changes regionally and globally.

5 Houser et al., 2015

6 This discussion is drawn largely from the results in Hsiang, Kopp, Jina, Rising, et al. (2017).

FIGURE 5

The Relationship between Annual Damages to the U.S. Economy (as a Percentage of Global GDP) and Increases in Global Mean Surface Temperatures



Note: Relationship is shown with the black line with the 5-95 percentile range shown in grey. Damages are shown for 2080-2099 for RCP2.6, RCP4.5, and RCP8.5. Damages increase with temperature. Shaded vertical regions show the 90 percent probability range for each of the three emissions scenarios considered.

Source: Hsiang, Kopp, Jina, Rising, et al., (2017).

Non-linearities may mean, for example, that increases of 1°F in places with a low average temperature may have a different impact than an increase of 1°F somewhere warmer. Mortality rates, for example, are higher during both very cold and very hot temperatures, so a 1°F increase in a warmer location might increase mortality, while a 1°F increase in a colder location might decrease mortality. Non-linearities may take other forms. Temperatures above a certain value may damage growth in some crops, for instance, but below the threshold no negative effect is seen.

These non-linearities lead to a few implications. Most importantly, a place's current average climate matters. For example, for certain types of climate damages, parts of the United States benefit from higher temperatures (for instance, northern areas benefit from experiencing fewer cold days) while other parts experience damages (for instance, southern parts only experience an increase in damaging hot temperatures without the offsetting benefit of a reduction in cold temperatures).

Just as climate damages can be calculated for mortality, so too can they be for labor productivity, energy demand, crime, agriculture, and coastal property. The local economic damages of climate change in the United States presented below consider both county-level and aggregate national-level damages to the U.S. economy due to warming and precipitation changes under high, medium, and low emissions scenarios. Aggregating damages across the country requires valuing each outcome using the best available data and summing up the dollar costs.[7]

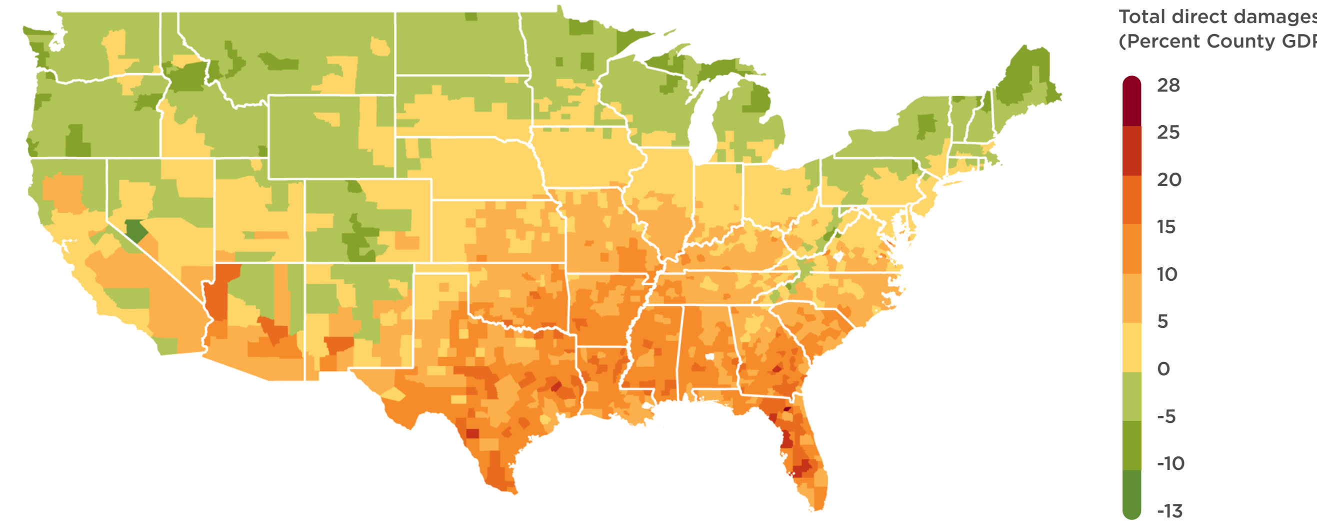
Figure 5 shows that the value of market and nonmarket damage across analyzed sectors—agriculture, crime, coastal storms, energy, human mortality, and labor—increases as global mean temperature rises. These damages are the sum of individual effects in individual sectors across the economy, accounting for all of the non-linearities discussed above. The damage curve gets steeper as temperatures increase, showing that damages get progressively worse as temperatures rise. Taken together, these effects could cost roughly 0.7 percent of gross domestic product per 1°F increase on average.

Overall, climate change will harm the U.S. economy, even with modest amounts of warming, and damages will increase non-linearly with temperature. About two-thirds of these damages will be due to changes in mortality. When weighing policies to reduce emissions, the implications of Figure 5 are important. For example, under an average expected change of temperature associated with the high emissions scenario (between 7°F and 8°F), the U.S. economy would stand to lose between about 2 percent and 5 percent of GDP annually by the end of the century due to impacts in the six sectors that were analyzed.

7 Authors use the U.S. Environmental Protection Agency Value of a Statistical Life to value mortality, daily wages from the Bureau of Labor Statistics for labor impacts, value of coastal property for coastal damages, crop prices for agricultural damages, best practice cost-of-crime estimates for crime impacts, and energy prices from the U.S. Energy Information Administration for energy costs.

FIGURE 6

Total Direct Damages for Counties in 2080-2099 (RCP8.5)



Note: Damages are summed across analyzed sectors: agriculture, crime, coastal storms, energy, human mortality, and labor. Median damages are shown. Damages are shown in shades of red and damages are normalized by local county incomes.

Source: Hsiang, Kopp, Jina, Rising, et al., (2017).

Climate Change & Inequality

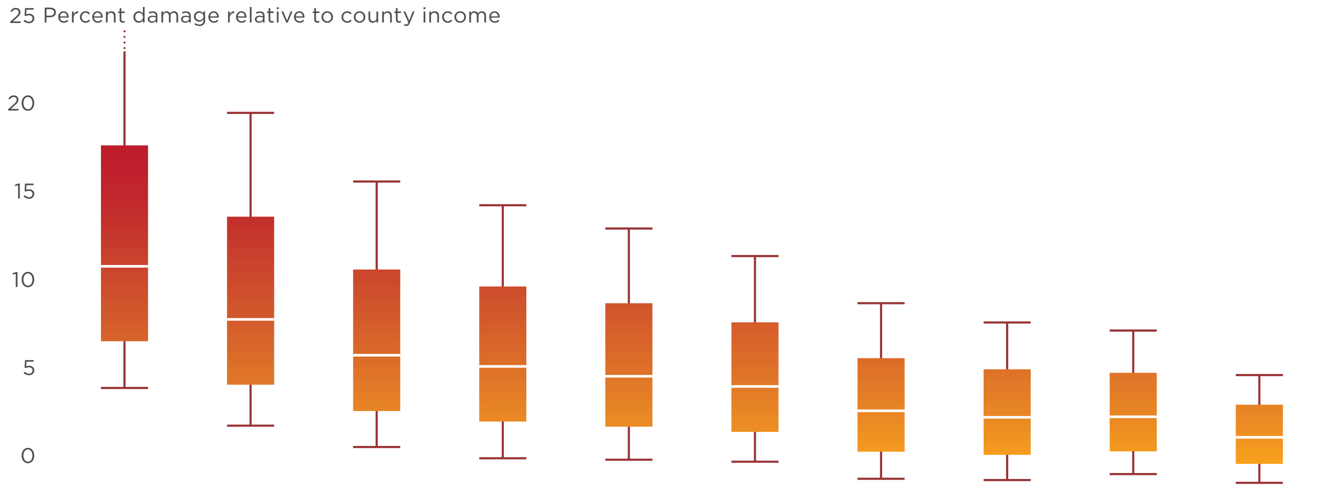
The aggregate picture masks substantial local differences in these impacts. Figure 6 shows damages at the county level as a proportion of that county's income level in 2080-2099 under a high emissions scenario. As expected, the colder, more northerly parts of the United States have much lower damages than the rest of the country. In southern, coastal states, meanwhile, there is an overall high negative impact, as they experience higher temperatures and exposure to enhanced coastal damages from storms and sea level rise.

Understanding the total damages expected in various locations, and the contributions made by energy, mortality, and other sectoral components, help to illustrate the adaptation challenge that the United States will face if it does not avoid the worst effects of climate change through mitigation. Adaptation policy at local levels will move expected damages off the trajectories that these results imply. What this map really shows is a future that can be avoided through either mitigation or adaptation. Neither policy choice is free, but doing nothing is also expensive. Economic assessments such as this provide information on the relative benefits of various climate policies in particular places.

The pattern of damages in Figure 6 also reveals another potential impact of climate change: an increase in inequality across the country. Figure 7 ranks counties by income level, and then plots damages in groups that gather together income deciles from poorest to wealthiest. The pattern of damages is strongly correlated with income levels, and the poorest counties suffer the largest damages. Indeed, the poorest third of counties are projected to experience damages of between 2 and 20 percent of county income under a high emissions scenario. This aspect of climate impacts in the United States has the potential to substantially widen the income gap between rich and poor parts of the country, saddling those areas that may already have fewer resources to adapt with larger damages.

FIGURE 7

Income Distribution of Impacts across U.S. Counties



Note: Counties are arranged into deciles of county-level production/income and aggregate impacts as a percent of income are averaged across deciles. Boxplots denote median (white line), "likely" range (17 percentile-83 percentile, box), and 5 percentile-95 percentile (whiskers).

Source: Author's calculation adapted from Hsiang et al., (2017).

Climate change will affect the American people in different ways. The national aggregate results imply that the economy will start to exhibit losses no matter what the level of warming. No part of the country will be insulated. A hurricane in Florida or Texas still requires federal assistance, and a Midwestern heatwave with negative effects on agriculture will affect food prices in other parts of the country.

These results also imply, however, that limiting CO_2 emissions now would significantly reduce the overall losses by the end of the century. The projected 1-4 percent annual GDP decline under a high emissions scenario would drop to 0.1-1.5 percent in a medium emissions scenario. The differences in damages across sectors, locations, and income levels help to highlight that the effects of climate change will not be the same for everyone. Different sectors of the economy will be harmed in different places, but mitigation and adaptation policies will help avoid these often substantial and costly damages. Perhaps most important to remember is that climate change has the potential to dramatically increase inequality. The benefits of climate change mitigation have the potential to not only improve the U.S. economy on average, but also to protect and support the most vulnerable Americans.

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FURTHER READING

Climate Change

Estimating Economic Damage From Climate Change In The United States

Science

Unmitigated climate change will make the United States poorer and more unequal, with the poorest third of U.S. counties projected to sustain economic damages costing as much as 20 percent of their income if warming proceeds unabated.

NBER

Valuing the Global Mortality Consequences of Climate Change Accounting for Adaptation Costs and Benefits

National Bureau of Economic Research

Continuing a high emissions trajectory increases average global temperatures by around 4.8°C (8.6°F), raising global mortality risk in the United States by ten deaths per 100,000—about on par with the current fatality rate from auto accidents.