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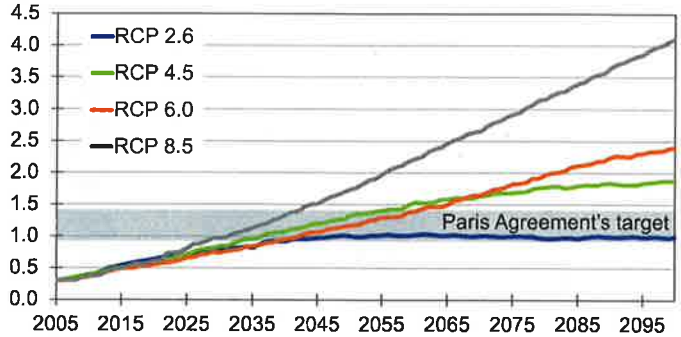
The Economic Implications of Climate Change

Introduction

In the absence of global pollution mitigation, anthropogenic emission of carbon dioxide into the Earth's atmosphere will raise global temperatures. Rising temperatures and shifting precipitation patterns will affect agricultural production and universally hurt worker health and productivity. More frequent and intense extreme weather events will increasingly disrupt and damage critical infrastructure and property. And sea-level rise will threaten coastal communities and island nations.

Chart 1: Temperatures Will Rise

Projected mean global temp. increases relative to 1986-2005, °C



Sources: IPCC, Moody's Analytics

spearheaded by the Integrated Assessment Model Consortium. The IAMC is a collection of IAM groups, four of which were responsible for publishing the predecessors to today's globally used climate scenarios.

The IAMC is the IPCC's main point of contact. It collaborates with other members of the scientific research community: IAV, CM, technology and engineering communities. Following a stakeholder convention that was initiated by the IPCC in 2007, it took two years of collaboration for this mélange of stakeholders to produce their end result: a set of climate scenarios known as Representative Concentration Pathways.

RCPs are climate scenarios that provide varying trajectories for greenhouse gas emissions. The scientific community named the scenarios based on the concept of radiative forcing, which is the difference between the energy from the sun absorbed by the Earth and the energy the Earth radiates back to space. Positive radiative forcing occurs when the Earth absorbs more energy on net. The greenhouse effect is the scientific principle that describes how an increasing concentration of greenhouse gases leads to positive radiative forcing. In its fifth assessment report released in 2014, the IPCC identified four RCP scenarios that were crafted by members of the scientific community. These scenarios are the international standard for climate change research.

In contrast to its predecessors, the RCP scenarios do not begin with a set of assumptions on economic, demographic, technological or policy factors to produce the associated emissions and temperature trajectories. Rather, they work in reverse, targeting CO_2-equivalent emissions. This framework implicitly acknowledges that there are many factors that determine emission quantities, and the projected CO_2-equivalent concentrations can be achieved in different ways. It also allows researchers to test the effect of different assumptions—technology, population growth, public policy—on emissions trajectories. In this regard, the RCP scenarios are much more flexible than their predecessors.

Because the RCP scenarios are essentially emissions scenarios, they do not offer an explicit trajectory for temperature fluctuations. Different climate models produce different temperature trajectories given the same emissions trajectories.[4] Moreover, the same models can also be used to produce different scenarios, resulting in different temperature trajectories.[5] The IPCC reports the mean temperature trajectories produced by different models as a deviation from the base period of 1986-2005. This is slightly different from the Paris Agreement's target, which expresses temperature change relative to pre-industrial levels (See Chart 1).

Given the hundreds of climate models in existence, the scientific community rallied behind a gatekeeper to regulate historical data and provide a framework for coordinated climate change experiments. This gatekeeper is the Coupled Model Intercomparison Project. CMIP is supported and maintained by the Lawrence Livermore National Laboratory in the San Francisco Bay Area. CMIP models are a critical component of the IPCC's Fifth Assessment Report, AR5, which introduced the four finalized RCP scenarios. Each RCP was designed using a unique IAM component of the CMIP model family:

- RCP 2.6. Radiative forcing value in the year 2100 is 2.6 watts/meter^2. CO_2-equivalent atmospheric concentration reaches 421 parts per million.[6] Mean global temperature increases by 1°C over the base period.
- RCP 4.5. Radiative forcing value in the year 2100 is 4.5 W/m^2. CO_2-equivalent atmospheric concentration reaches 538 parts per million.[7] Mean global temperature increases by 1.9°C over the base period.
- RCP 6.0. Radiative forcing value in the year 2100 is 6.0 W/m^2. CO_2-equivalent atmospheric concentration reaches 670 parts per million.[8] Mean global temperature increases by 2.4°C over the base period.
- RCP 8.5. Radiative forcing value in the year 2100 is 8.5 W/m^2. CO_2-equivalent atmospheric concentration reaches 936 parts per million.[9] Mean global temperature increases by 4.1°C over the base period.

In order to streamline the construction of economic scenarios, Moody's Analytics used the mean global temperature increases for each RCP scenario as reported by the IPCC in AR5 (see Table 1).

Of the four scenarios, it is highly unlikely that RCPs 8.5, 6.0 or even 4.5 will fall within or under the Paris Agreement's warming targets. The only scenario that is likely to fall between 1.5°C and 2°C of warming relative to pre-industrial levels is RCP 2.6. The IPCC estimates that at the current rate of greenhouse gas emissions, reaching a warming path within the range of the RCP 2.6 scenario will require large and immediate mitigation efforts.[10]

4 The majority of these models are highly sophisticated and typically rely upon high computing power and geospatial datasets.

5 The IPCC AR5 database comprises 31 models and 1,184 scenarios.

6 Produced using the IMAGE Integrated Assessment Model.

7 Produced using the GCAM Integrated Assessment Model.

8 Produced using the AIM Integrated Assessment Model.

9 Produced using the MESSAGE Integrated Assessment Model.

10 UNEP (2018). The Emissions Gap Report 2018. United Nations Environment Program, Nairobi http://wedocs.unep.org/bitstream/handle/20.500.11822/26895/EGR2018_Full-Report_EN.pdf?sequence=1&isAllowed=y

of more-developed nations that rely more on services. As a result, the temperature effects on labor productivity vary widely between countries.

Fourth, higher temperatures, higher atmospheric concentrations of CO_2, and changes in precipitation patterns will directly impact global crop yields. The changes will not be uniform across regions and crops, however. Growing seasons will lengthen in colder climates and shorten in hotter ones. The relative importance of temperature and water stress for crop productivity can be assessed using models, making adjustments for different crops in each region.[16] Without adaptation, agricultural productivity will decrease in more regions than it will increase, especially as the increase in average global temperature rises.

Fifth, tourism and income flows between countries will be directly impacted by changes in climate. Climate is one of the main drivers of international tourism, and tourism revenue is a fundamental pillar of the economy in many countries.[17] Changes in climate will lengthen the tourism season in some regions while reducing it in others. It will likely shift tourism toward higher altitudes and latitudes, increasing visitors in colder countries and reducing travelers in warmer countries. Some people may also choose to forgo international trips in favor of staying closer to home if their local climate improves. This could result in sizable redistributions of income among various countries as flows of tourism spending change.

And sixth, changes in climate will also have substantial effects on household energy demand. Variations in temperature alter energy needs. Warmer temperatures increase energy demand for cooling in the summer while decreasing the demand for heating in the winter. Warmer temperatures will increase demand for electricity for air conditioners, and reduce demand for natural gas, oil and wood for heating. But because more energy is used across the globe to heat spaces than is used to cool them, rising temperatures will on net result in weaker energy demand. Changes in demand will have significant implications for energy prices as well as investment in infrastructure.

Methodology

Moody's Analytics created economic scenarios for the countries in its global model consistent with the four internationally recognized RCP scenarios. In this section, we describe the complex, multistep process that we undertook to do so.

The process begins with quantifying the six impact channels. To do so, we relied on the work of Roberto Roson and Martina Sartori, economists who published a working paper in affiliation with the World Bank in 2016.[18] Roson and Sartori summarize the results from a series of meta-analyses that establish a connection between temperature rise and economic implications by impact channel. Roson and Sartori provide central values of climate change impacts by making interdisciplinary assessments of various of studies with different approaches and methodologies. The beauty of the Roson and Sartori work is that they synthesized the research of academic economists and linked the impact channels to temperature fluctuations for all of the world's major countries.

Moody's Analytics translated these linkages to the four international RCP scenarios. To do so, we first created quarterly temperature paths for each RCP scenario to match the Moody's Analytics global model's quarterly periodicity. We then constructed time series of overlays to key economic variables in the Moody's Analytics global model. These variables act as levers in the global model that can be pulled to craft economic scenarios. Real intermediate net exports are the lever for the tourism channel.[19] Oil prices are the lever for the energy channel. Real consumption is the lever for the sea-level rise channel. And because human health effects, heat stress, and agricultural changes all affect productivity, they were combined into a shock to real potential productivity, which is the final lever.

The time series of overlays are weighted averages of the impact channels per degree of warming, with the weights being the global mean temperature increases in the RCP scenarios, assuming a linear impact. For example, if a temperature increase is 1.4°C in a given quarter of an RCP scenario, we added 60% of the impact estimate for 1° of change to 40% of the 2° estimate to determine the change in the impact channel relative to the baseline in that quarter. This method is used for the tourism and human health effects channels.

The process above is also used when calculating the productivity impact caused by heat stress and changes in agricultural productivity, but because these are largely sector-specific shocks we must also account for the industrial composition of a country. For agricultural productivity, once we have a time series of calculated deviations from the baseline, we then multiply those by the agricultural share of each particular economy. Once a time series of impacts has been calculated for each sector—agriculture, manufacturing and services—we then multiply that series by the size of that sector relative to the size of the overall economy. After calculating a time series for the three channels through which climate change impacts productivity, and adjusting them to account for their relevant industrial share, these impact channels are aggregated into a single time series overlay for real potential productivity.

Forecasting industrial shares

It thus becomes critically important for us to forecast country industrial shares. To do this, we used historical data from The World Bank, which measures the share of GDP of

16 Porter, J.R., L. Xie, A.J. Challinor, K. Cochrane, S.M. Howden, M.M. Iqbal, D.B. Lobell, and M.I. Travasso, 2014: Food security and food production systems. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Field, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L. White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 485-533.

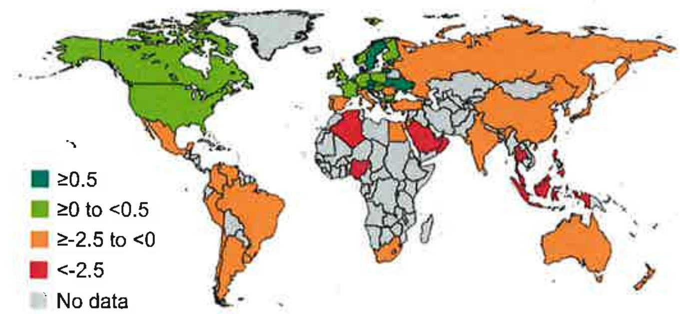
17 Roson, Roberto, and Martina Sartori. "Estimation of Climate Change Damage Functions for 140 Regions in the GTAP9 Database." Policy Research Working Paper 7728. World Bank Group. June 2016.

18 https://jgea.org/resources/jgea/ojs/index.php/jgea/article/view/31

19 This variable does not exist for a select group of countries in the global model, including the United States, Germany and Canada. For those countries, real imports and/or real exports are the levers.

Chart 4: Some Winners, More Losers

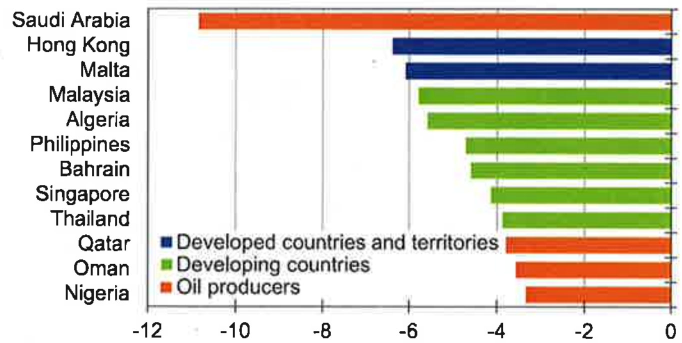
GDP % deviation from baseline in 2048, RCP 8.5



Source: Moody's Analytics

Chart 5: Climate Change Hurts Nations

Real GDP, % change, RCP 8.5, 2048



Sources: World Bank, Moody's Analytics

ever, the economic logic still follows. As sea levels rise, and destroyed land cuts rents, weaker income growth results in weaker consumer spending.

Oil prices

When temperatures rise, household electricity demand in hot countries rises and household demand for energy from oil products falls dramatically, especially in cold countries. The net result is a decline in energy demand that is accounted for in the Moody's Analytics global model by a decline in oil prices. As with sea-level rise, this is mainly because of the model's structure.

To calculate the change in oil prices, Moody's Analytics first produced a baseline forecast for global oil demand through 2100 and alternative trajectories for oil demand for each of the RCP scenarios using the Roson and Sartori estimates. We then used our satellite models of oil prices to translate the demand trajectories into oil price add factors that were subsequently applied to the global model.

Lineup

The overlay time series for real net exports, real potential productivity, nominal oil price, and real consumption were calculated by comparing the temperature changes in the RCP scenarios to the average temperature in the 1986-2005 baseline period.

To ensure a clean transition from history to forecast, the overlay time series were lined up to history. This ensures that in the first quarter for which Moody's Analytics makes a forecast for any variable in any country, the climate change impact is isolated to the change in temperature from the last quarter of history to the first quarter of forecast. Indeed, the effect of climate change on historical data has already occurred. The method of implementation was different for different channels.

For the tourism impact channel, we subtracted the last historical value of the overlay time series from the first quarter of the forecast. The resulting time series was then added to net exports to determine net exports' final path.

For productivity, we calculated a baseline overlay that resulted from the change in each country's industrial structure and subtracted that from the productivity overlay in each RCP. We applied this percentage difference to the baseline forecast for real productivity growth.

For sea-level rise, to account for cumulative impacts, the impact from the first historical period (2005Q1) was subtracted from the entire impact series. The overlay was then calculated by subtracting the prior quarter's value from each quarter.

Results

Once the exogenous paths for the key economic variables were calculated for each country under each scenario, Moody's Analytics used them to shock the model. The result is four economic scenarios that are consistent with the four RCP scenarios that are the international benchmark for climate change analysis. We provide quarterly forecasts through 2048 for all variables and all countries in the Moody's Analytics global model. This analysis reveals that some countries are significantly exposed to rising temperatures while others, particularly in Northern Hemisphere climates, are well insulated (see Chart 4).

Losers

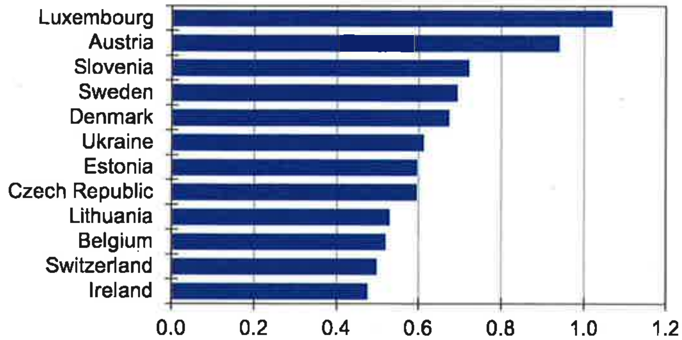
A handful of nations are severely affected by climate change. There are two groups of countries that are most negatively affected: countries in hot climates, particularly those that are emerging economies such as Malaysia, Algeria, the Philippines, and Thailand, and oil producers such as Saudi Arabia, Qatar and Oman (see Chart 5). The first group is being hurt by the tourism and productivity channels. Rising global temperatures put the tourism sectors of these countries at a greater disadvantage. Singapore, for instance, suffers a decline of nearly 2% of GDP by 2048 in the RCP 8.5 scenario (see Chart 6).[21]

Productivity declines in these countries are steep as well. Many of the most negatively affected countries are emerging market economies. As such, their share of outdoor workers is greater than in most advanced economies, and they are more vulnerable to the heat stress impact channel. Moreover, their industrial composition is tilted more towards agriculture, which maximizes the stress from the agricultural productivity channel.

21 In contrast, Sweden is much colder country and thus the biggest "winner" from the tourism channel as warmer temperatures prolong warm seasons and boost tourism.

Chart 10: ...But Some Will Still Benefit

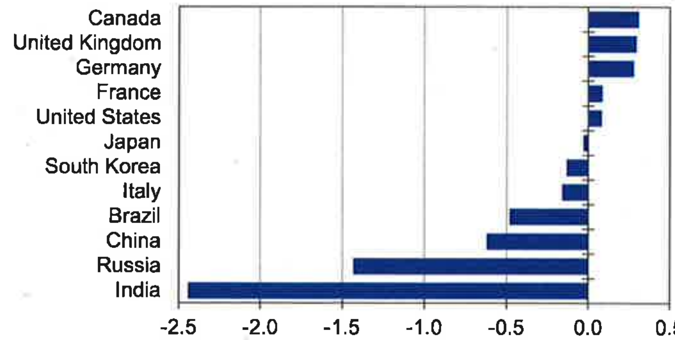
Real GDP, % change, RCP 8.5, 2048



Sources: World Bank, Moody's Analytics

Chart 11: Large Economies, Little Changed

Real GDP, % change, RCP 8.5, 2048



Sources: World Bank, Moody's Analytics

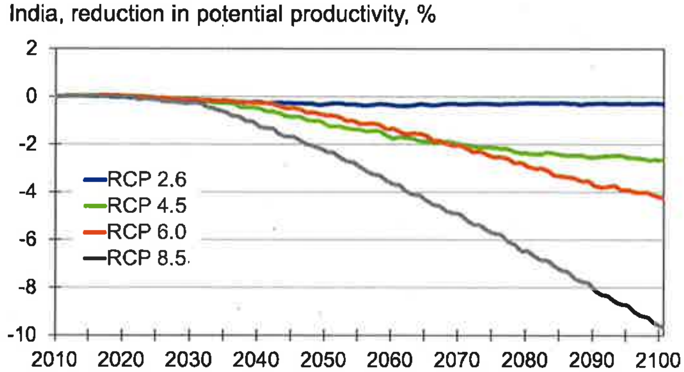
as Northern Europe (see Chart 10). Luxembourg, Austria, Slovenia, Sweden and Denmark top the list of countries with the largest deviation from baseline GDP in the RCP 8.5 scenario by 2048. These advanced countries suffer less from heat stress, are not major oil producers, and benefit from the tourism impact channel.

Everyone else

Of the world's 12 largest economies, all of the industrialized ones feature GDP changes of 0.5% or less in RCP 8.5 by 2048. Canada, the U.K., Germany, France and the U.S. feature very modest increases while Japan, South Korea and Italy feature very modest declines (see Chart 11). The oil price shock played an instrumental role in mitigating the declines in productivity that follow from rising global temperatures. Indeed, France and the U.S. would have been net losers were it not for lower oil prices.

Chart 12: Climate Stress Compounds

India, reduction in potential productivity, %



Sources: World Bank, Moody's Analytics

Brazil, Russia, India, China and South Africa, however, fare worse. Brazil and China decline by roughly 0.5% of GDP. While lower oil prices are a great help to the Brazilian economy, the negative effects from less tourism and lower productivity are too much to overcome. China actually benefits from a rise in tourism and agricultural productivity, along with lower oil prices, but negative heat stress and health effects are more severe. Russia also benefits from increased tourism and agriculture, but the oil price decline more than offsets these positives.

Of the world's 12 largest economies, India is hurt the most. Given India's lower share of service industry employment, the country suffers greatly from the heat stress impact channel. This is the most significant impact channel weighing on India's GDP growth. Agricultural productivity also falls, and the hit from human health effects is roughly equivalent to the hit from agriculture. Lower oil prices are not nearly enough to offset the economic damage. India's real GDP is 2.5% lower in RCP 8.5 by 2048.

Implications

There are five major takeaways from our climate change scenarios. The first is that the physical costs of climate change compound slowly over time. The degree of economic damage from these six channels is tied directly to the global mean temperature increase, and the temperature increase compounds slowly over time. This analysis reveals no acute effects of climate change that could cause recessions. The only source of acute effects would emanate from a heightened occurrence and severity of natural disasters, and those are not covered in the scope of this work.

The second takeaway is that the more draconian effects of climate change are not felt until 2030 and beyond (see Chart 12). And they do not become especially pronounced until the second part of the century. Until around 2030, the tangible effects of climate change will mostly be felt by the increased incidence and severity of natural disasters, which are not covered in this work.

Third, the heterogeneous effects of climate change create different incentives and disincentives for countries to adopt public policies to regulate greenhouse gas emissions. There is less of an incentive for advanced Northern European countries to adopt policies that mitigate greenhouse gas emissions, while there is a much greater incentive for the emerging economies of Southeast Asia to do so.

Fourth, climate change carries vast geopolitical risk. International immigration is not assumed in any of these four scenarios, but it is a major risk. Slower economic growth in the most affected countries could prompt residents of those countries to relocate. If the degree of emigration is large enough, it could put strain on certain countries that are

Table 2: Deviation in Real GDP From Baseline in 2048Q4, % (Cont.)

Country	RCP 2.6	RCP 4.5	RCP 6.0	RCP 8.5
Cyprus	-1.30	-1.81	-1.53	-2.70
Kuwait	-0.81	-1.57	-1.25	-2.71
Nigeria	-0.05	-1.30	-0.57	-3.32
Oman	-0.46	-1.67	-0.98	-3.56
Qatar	-0.39	-1.73	-0.98	-3.79
Thailand	-0.81	-2.06	-1.47	-3.89
Singapore	-0.63	-2.04	-1.35	-4.15
Bahrain	-0.95	-2.26	-1.48	-4.61
Philippines	-0.87	-2.43	-1.67	-4.72
Algeria	-0.22	-1.73	-0.58	-5.60
Malaysia	-0.80	-3.04	-2.12	-5.80
Malta	-4.00	-4.79	-4.38	-6.10
Hong Kong Special Administrative Region of China	-2.77	-4.03	-3.17	-6.40
Saudi Arabia	-0.65	-4.04	-1.72	-10.85

Source: Moody's Analytics

receiving the immigrants. Already in the U.S., the issue of immigration has developed into one of significant political debate.

And fifth, this analysis does not delve into subnational economics, but the effects become far more dire in certain locations than across entire countries, particularly for the sea-level rise channel. The Environmental Protection Agency has done work to quantify the economic effects of sea-level rise and storm surge at the metropolitan level, and it estimates that in the Tampa area alone the damage could reach $90 billion by 2100.[22]

Limitations

It would be too simplistic to say that climate change does not hurt the U.S. The scope of our study was not comprehensive, and there are a number of factors that were not considered in this work. The foremost of these is the increasing frequency and severity of natural disasters. The year 2017 was the costliest on record for the U.S. Natural disasters created $300 billion worth of economic damage, including damaged homes, businesses, infrastructure and goods (see Chart 13). This amounted to 1.5% of U.S. GDP. Some of the damage was insured, but those losses create a liability for corporate profits and result in higher premiums paid by consumers. Some of the losses were offset by charity, and others by federal government aid. Every dollar that federal lawmakers appropriate for disaster relief is a dollar that could have otherwise been spent on Social Security, Medicare, national defense, or rebated as a tax cut. Natural disasters drain the federal government of resources and exacerbate the nation's fiscal situation.

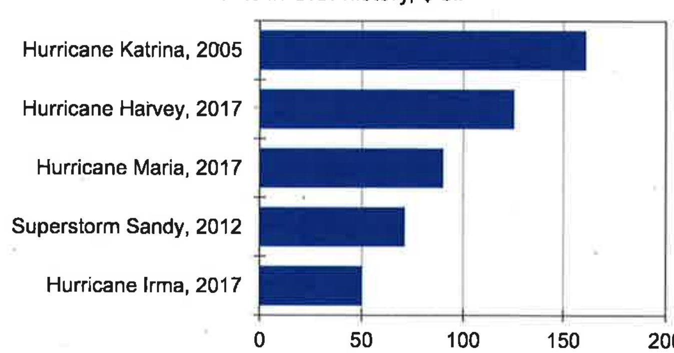
We plan on incorporating the increased cost of natural disasters in future analysis, but this is a very difficult exercise because we lack the counterfactual. It would be a flawed analysis to assume that the $300 billion of damage to the U.S. economy in 2017 was solely or not at all the result of climate change. We intend on disaggregating the effects of climate change from the economic damage of natural disasters in future work.

Our economic scenarios only go through 2048. Given that the distress compounds over time and is far more severe in the second half of the century, drawing binary conclusions from our 2048 scenario projections misses the mark. We intend to expand this analysis to 2100 as we conduct future work to be consistent with the time horizon most frequently examined in the climate change literature.

We also make no assumptions on the adaptation costs that would be accrued in order to achieve the RCP radiative forcing trajectories. The RCP trajectories can be achieved in many ways—slower population growth, slower economic growth, public policy, or technology. Through technological innovation, the private sector has dramatically altered the trajectory of greenhouse gas emissions in just the last 20 years. The advent of the shale revolution and the subsequent replacement of coal-fired power plants with natural gas combined-cycle plants helped the U.S. become the first na-

Chart 13: Disasters Are Costliest for U.S.

Costliest weather events in U.S. history, $ bil



Sources: NOAA, Moody's Analytics

22 https://www.epa.gov/cira/climate-action-benefits-coastal-property#findings

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