Testimony of Oren M. Cass before the
House Committee on Science, Space, and Technology
May 16, 2018

Summary of Major Points

- Assumptions about how human society will adapt to climate change are central to our understanding of the challenges that the phenomenon presents and the costs that it will impose.
- This issue does not concern climate science but rather climate economics, which attempts to address the question of how the changes to our physical environment anticipated by climate science will affect human society via their influence on public health or infrastructure or the economy.
- In recent years, prominent studies that purport to forecast the cost of climate change have begun to rely on statistical analyses of the effects of temperature variation. These correlation-based, temperature-impact studies—"temperature studies"—start with present-day relationships between temperatures and outcomes such as mortality or economic growth. They extrapolate from those relationships a proportionally larger response to long-term projected climate warming and assign dollar values to the very large impacts that appear to emerge.
- The fallacies underlying this framework are (a) that the same responses detected for small, random variations in historical temperatures will manifest themselves proportionally in large, gradual, permanent future changes, and (b) that society will not change or adapt in any way to mitigate the effects.
- The GAO's 2017 report, "Climate Change: Information on Potential Economic Effects Could Help Guide Federal Efforts to Reduce Fiscal Exposure," derives the vast majority of its costs from such studies, accepting absurd forecasts like one created by EPA that finds Pittsburgh's extreme-heat mortality rising to 75 times the level experienced in Phoenix or Houston today.
- Another emerging line of research seeks to link rising temperatures directly to changing rates of economic growth, again leading to bizarre predictions like Iceland and Mongolia becoming the world's leading economies while India's economy begins rapidly contracting. The Federal Reserve Bank of Richmond has recently published a working paper that uses a similar methodology.
- Analyses that do not properly account for adaptation describe an alternative universe that does not exist; the estimates they produce are not plausible forecasts of future costs and should not be credited by policymakers.
- Instead, policymakers should focus on understanding what adaptation is likely to be necessary, in what circumstances it will be difficult, and how better public policy can create the information and incentives to facilitate its occurrence.

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Good morning Chairman Smith, Ranking Member Johnson, and Members of the Committee. Thank you for inviting me to participate in today's hearing.

My name is Oren Cass. I am a senior fellow at the Manhattan Institute for Policy Research where my work addresses environmental policy including the economics of climate change. This testimony focuses on the role that adaptation may play in the human response to climate change and the importance of accounting for such adaptation when conducting economic analyses of climate costs and when formulating climate policy. I addressed this topic recently in a Manhattan Institute report titled "Overheated: How Flawed Analyses Overestimate the Costs of Climate Change."[1]

My primary message to the committee is this: **The assumptions that we make about how human society will adapt to climate change are *central* to our understanding of the challenges that the phenomenon presents and the costs that it will impose.** Relative to most problems that we encounter in public policy, climate change is a gradual process; its most dangerous effects will appear on decades- and even centuries-long timescales. Yet analysts frequently analyze these effects as if they will happen *now*, without accounting for how our economy, society, and technology are likely to evolve independent of climate change and—especially—in response to climate change. **Analyses that do not properly account for adaptation describe an alternative universe that does not exist; the estimates they produce are not plausible forecasts of future costs and should not be credited by policymakers.**

Let me pause here to clarify that this issue does not concern climate science. I believe that mainstream climate science, particularly as summarized by the UN's Intergovernmental Panel on Climate Change, provides the best available assessment of the changes to our physical environment that a given level of greenhouse-gas emissions will cause and that policymakers should use it as the starting point for their own work. But we depart the world of climate science for that of climate economics when we turn to the question of how those changes will affect human society via their influence on public health or infrastructure or the economy.

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[1] See Oren Cass, "Overheated: How Flawed Analyses Overestimate the Costs of Climate Change," Manhattan Institute for Policy Research, March 2018, https://www.manhattan-institute.org/html/overheated-how-flawed-analyses-overestimate-costs-climate-change-10986.html; see also Oren Cass, "The Problem with Climate Catastrophizing," *Foreign Affairs*, March 21, 2017, https://www.foreignaffairs.com/articles/2017-03-21/problem-climate-catastrophizing.

The common failure to consider adaptation has profound consequences for how people conceptualize climate change, leading to what I call *climate catastrophism*. If the entire brunt of a century of climate change were to land on civilization tomorrow—if a substantial share of agricultural output suddenly vanished, if sea levels were suddenly several feet higher, if regions accustomed to temperate summers suddenly experienced outdoor temperatures to which they were unaccustomed, if hundreds of millions of people were suddenly displaced—the result might well be catastrophic. But if those changes occur gradually (as they are expected to), if they emerge in a world far wealthier and more technologically advanced than today's (as we expect it to be), and if policymakers ensure that people have the information and incentives to plan well (something over which we have control), then climate change will impose real costs but ones that we should have confidence in our ability to manage.

* * *

The no-adaptation fallacy reaches its most concrete and absurd results in formal economic analyses of climate costs, and it is here that I want to focus your attention today. In recent years, prominent studies that purport to forecast the cost of climate change have begun to rely on statistical analyses of the effects of temperature variation. These correlation-based, temperature-impact studies—hereinafter referred to as temperature studies—start with present-day relationships between temperatures and outcomes such as mortality or economic growth. They extrapolate from those relationships a proportionally larger response to long-term projected climate warming and assign dollar values to the very large impacts that appear to emerge.[2]

A critical assumption underlying such an extrapolation is *ceteris paribus*, or "other things constant." The effect of small, random fluctuations in today's temperatures will only hold for large, gradual, permanent changes in future temperatures if no confounding factors exist and nothing in the world changes. For most economic studies, that construct is a valuable one. The whole point, typically, is to isolate the specific effect of one variable on another in the present. In estimating how additional years of education boost income, for instance, one need not worry that the labor market might look different eighty years hence.

In the climate context, however, this framework is wholly inappropriate. Given decades to respond to a gradual shift in temperatures, "other things" most certainly will not be "constant." Studies typically acknowledge that they assume no adaptation, but announcing a bad assumption does not make it a good one. They will sometimes argue that adaptation is unlikely to occur, by showing that it has not occurred in the past. But

[2] Most temperature studies, including those discussed here, acknowledge their failure to account for adaptation or caveat that their conclusions will not hold if adaptation occurs. Nevertheless, their no-adaptation findings are reported as credible estimates of future climate costs.

a failure to adapt to small, temporary changes says nothing about whether a society would adapt to large, permanent ones.

An adaptation may represent a cost-effective response to a large change in underlying climate but offer very little return on investment if implemented in response to a small change, or in response to unpredictable fluctuations. The failure to install an air conditioner for a year with one extra 90°F day, for instance, does not mean that air conditioners will not be installed in the face of 40 extra 90°F days annually. Adhering to a standard workday when the average temperature shifts from 82°F to 83°F does not rule out adjusting the workday, should the average reach 95°F.

Even where adaptations are immediately cost-effective, they may nevertheless be gradual. Social norms, economic configurations, and technologies emerge over time. Even if temperature fluctuations are enormous in magnitude, adaptations will be impossible where their implementation period is longer than that for which the condition lasts. People living in a location where the temperature swings annually by 10°F around an 80°F average may wish that it could sometimes have the permanent characteristics of a 70°F location and sometimes have those of a 90°F location, but that's not plausible; it will instead adapt to the behaviors optimal for an 80°F average with high variability. But if the underlying average shifts from 80°F to 90°F, a very different range of adaptations becomes likely.

The conceptual flaws of temperature studies are laid bare in the implausible outputs that they yield. Yet those outputs are accepted uncritically by the newsmedia and even the federal government, as reflected in last year's GAO report on climate costs—an assessment that relied overwhelmingly on such studies.

At the request of Senators Maria Cantwell (D., Washington) and Susan Collins (R., Maine), the GAO worked from December 2015 to September 2017 to review "the potential economic effects of climate change impacts and resulting risks to the federal government." Its report, "**Climate Change: Information on Potential Economic Effects Could Help Guide Federal Efforts to Reduce Fiscal Exposure**" (hereinafter: *GAO*),[3] summarized two other studies that drew on and synthesized a further range of studies to provide national-scale estimates of the economic costs of projected climate change for the United States (see Figure 1).

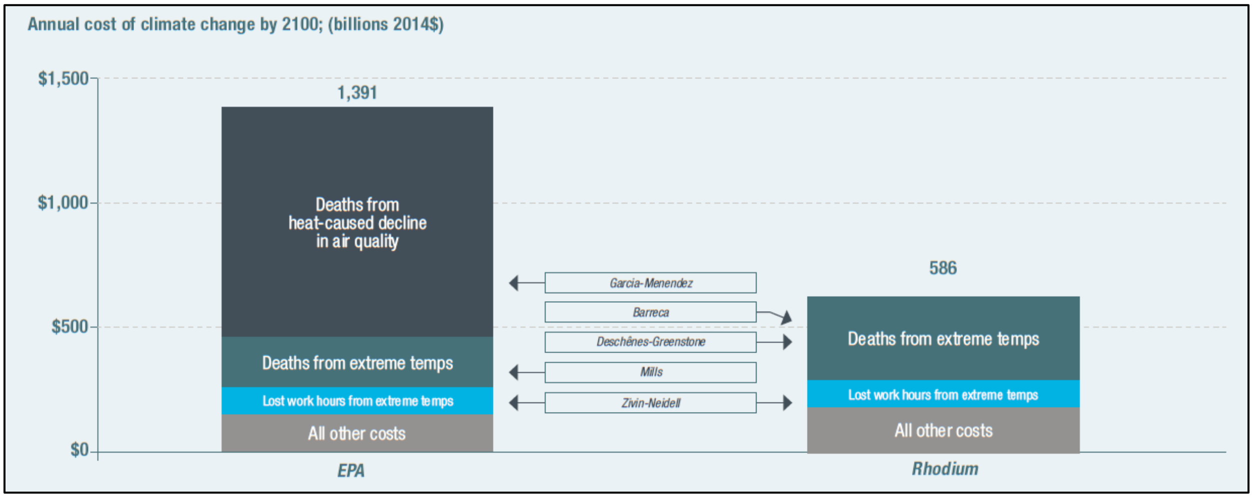
In both of these synthesis studies, the largest costs and vast majority of total costs derive from temperature studies that assert correlations between higher temperatures and more extreme-heat deaths, more air-pollution deaths, and fewer hours worked. The two synthesis studies *GAO* relied on are:

[3] U.S. Government Accountability Office, "Climate Change: Information on Potential Economic Effects Could Help Guide Federal Efforts to Reduce Fiscal Exposure," Sept. 2017, https://www.gao.gov/assets/690/687466.pdf.

- "**Climate Change in the United States: Benefits of Global Action**," published in June 2015 by the U.S. Environmental Protection Agency (*EPA*).[4] This study estimates that by 2100, climate change annually will cost the U.S. $1.3 trillion–$1.5 trillion more than if aggressive action were taken to mitigate warming. At least 89% of this sum comes from temperature studies.

- "**American Climate Prospectus: Economic Risks in the United States**," published in October 2014 by the Rhodium Group (*Rhodium*),[5] a research consultancy. This study estimates that by 2100, climate change will cost the U.S. $228 billion–$945 billion per year. At least 71% of this sum is based on the estimates from temperature studies.

FIGURE 1: Sources of Climate-Change Cost Estimates in the *GAO* Report



Note: Midpoints shown where analyses provide both high and low estimates. Rhodium reports estimates in 2011$, updated here to 2014$, using the U.S. Bureau of Economic Analysis GDP deflator. The *GAO* overview of *Rhodium* reports duplicative totals for "lost lifetime labor supply" and "storm losses," excluded here. *EPA* provides no 2100 estimate for power-systems savings; the 2050 value is used here. The *EPA* estimate understates sea-level impact by comparing it with a mitigation case in which sea levels still rise.

A review of the studies that account for the majority of costs provides a helpful view into how such studies are conducted and why they should be ignored. The following pages discuss, in turn, two studies used by *EPA* to produce its estimates of air-pollution and extreme-temperature mortality, and then two studies used by *Rhodium* to produce its estimate of extreme-temperature mortality.

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[4] U.S. Environmental Protection Agency, "Climate Change in the United States: Benefits of Global Action," June 2015, https://www.epa.gov/sites/production/files/2015-06/documents/cirareport.pdf. *EPA* includes $10 billion–$34 billion in energy-system costs reported for 2050; it provided no estimate for 2100.

[5] Robert Kopp et al., "American Climate Prospectus: Economic Risks in the United States," Rhodium Group, Oct. 2014, https://gspp.berkeley.edu/assets/uploads/research/pdf/American_Climate_Prospectus.pdf. *Rhodium* provides alternative measures for heat-related mortality and coastal impacts. The totals here use the methodologies that produced the highest cost estimates. Rhodium figures, as reported by *GAO*, use constant 2011 dollars. Figures here are updated to 2014 dollars.

The very fact that researchers are identifying small changes in air-quality and direct *deaths from heat* as the primary costs of climate change should indicate that something has gone wrong in how we are evaluating the issue.

The* EPA *Assessment of Climate Costs

The majority of all climate-related costs identified by *EPA* for the United States by the year 2100 derive from small changes in air quality; that study is discussed first. The second largest cost, from extreme-temperature deaths, is discussed second.

Pollution-Related Mortality: Fernando Garcia-Menendez et al., "U.S. Air Quality and Health Benefits from Avoided Climate Change Under Greenhouse Gas Mitigation," ***Environmental Science & Technology*** **49 (June 2015): 7580–88. (*Garcia-Menendez*)**

Higher temperatures can interact with other environmental processes to change the atmospheric concentration of pollutants, even if pollutant emission rates do not change. For instance, ground-level ozone ("smog") gets worse on hot days. *EPA* tried to quantify these air-quality effects based on *Garcia-Menendez*. That study combined existing air-quality and climate-change models to forecast changes in atmospheric concentrations of ground-level ozone and particulate matter by 2100 if emissions remained constant but temperatures increased. It found that while concentrations would increase in some places and decrease in others, the average U.S. resident would be exposed to slightly increased levels of pollution: an increase of 3.2 parts per billion for ozone and 1.5 $\mu g\ m^{-3}$ (micrograms per cubic meter) for particulate matter (or, respectively, 2.6 parts per billion and 1.2 $\mu g\ m^{-3}$ greater than an alternative scenario in which climate change is aggressively fought).

Garcia-Menendez applied existing EPA formulas to these pollution increases to estimate that unchecked global warming would cost 57,000 lives per year in 2100, relative to an alternative scenario with aggressive action against global warming.[6] *EPA* assigned a value of $930 billion per year to those lives. The number of deaths seems alarming but appears much less consequential when placed in the context of present-day experience.

Here's why. The paper estimated that unchecked climate change would increase ozone levels by 2.6 parts per billion and particulate-matter levels by 1.2 $\mu g\ m^{-3}$, over the alternative scenario.[7] But those concentrations have fallen since 2000, from 82 and 13.4, respectively. In 2009 alone, particulate matter fell by an amount almost equal to the increase that climate change would cause over the century. In most of the years from

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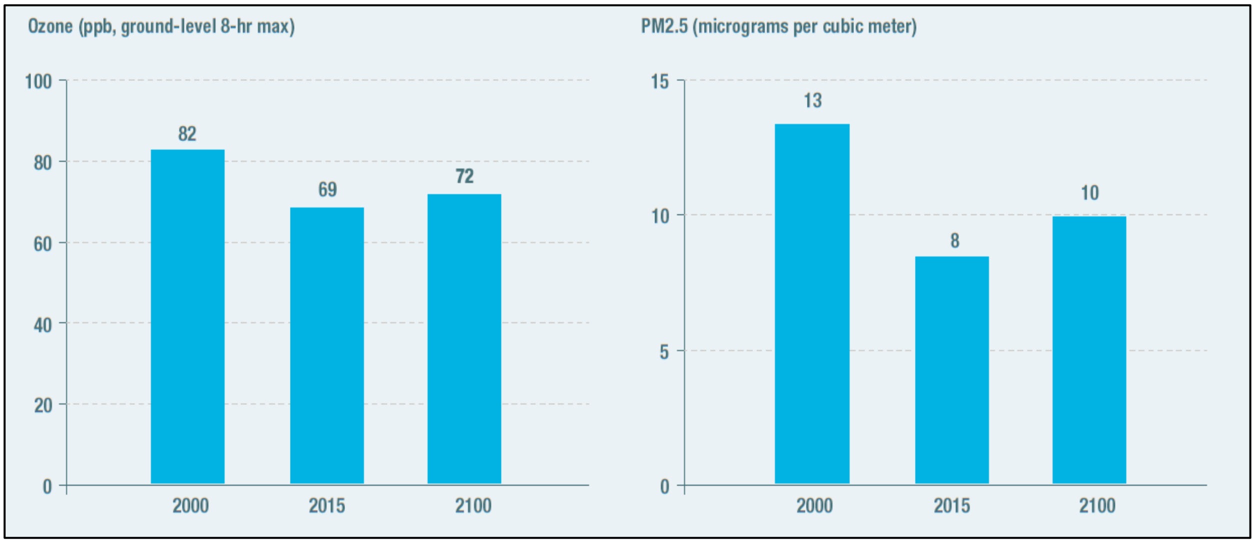
[6] *Garcia-Menendez*, Table 2.

[7] While *Garcia-Menendez* reports the effect of climate change on population-weighted concentrations, the underlying EPA data presented here on nationwide levels between 2000 and 2015 are not population-weighted.

2000 to 2015, ozone levels fluctuated by more than the climate-induced effect over a century.[8] Put another way, the forecasted effect of climate change on air pollution is to return atmospheric quality from 2015 to 2011 levels (see Figure 2).

Garcia-Menendez also implicitly assumes that recent decades' extraordinary pollution reductions will cease for the rest of the century and that no new technologies will reduce human exposure to pollution or its danger to health. In fact, ozone and particulate-matter levels for most of the country are already below thresholds that EPA deems safe, and those levels will almost certainly be far lower by century's end. In the context of a century of economic, social, technological, and environmental change, the identified impact of climate change on air pollution is barely noise. Yet it represents the majority of costs of all climate effects that *EPA* reports—$930 billion of $1,391 billion.[9]

FIGURE 2: Air-Pollution Concentrations in 2000, 2015, and 2100



Source: *Garcia-Menendez*; "Particulate Matter (PM2.5) Trends," U.S. Environmental Protection Agency; "Ozone Trends," U.S. Environmental Protection Agency.

<u>Temperature-Related Mortality:</u> David Mills et al., "Climate Change Impacts on Extreme Temperature Mortality in Select Metropolitan Areas in the United States," *Climatic Change* 131, no. 1 (July 2015): 83–95. (*Mills*)

The *EPA* estimate of costs due to additional heat deaths in 2100 relies on *Mills*. That study examined the effect on mortality rates from days of "extreme" heat (or cold) in 33 cities, defined, respectively, as days with a low temperature in the warmest 1% of the city's lows, or a high temperature in the coldest 1% of the city's highs. In Pittsburgh, for example, 99% of daily low temperatures were less than 21.7°C (71.1°F); a day with a

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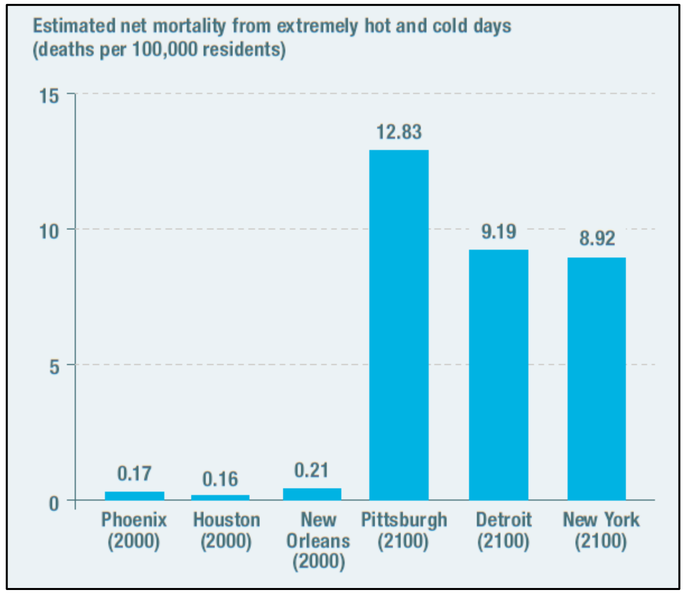
[8] "Particulate Matter (PM2.5) Trends," U.S. Environmental Protection Agency; "Ozone Trends," U.S. Environmental Protection Agency.

[9] *EPA*, pp. 78–79; see also *GAO*, p. 22.

warmer minimum temperature would count as "extremely hot."[10] For each city, the researchers measured the change in mortality on days with temperature extremes during 1989–2000.

FIGURE 3: Heat-Related Mortality in Select Southern Cities (2000) and Northern Cities (2100)



Source: The 2000 and 2100 city estimates come from the same *EPA* extrapolation of *Mills*. See *EPA*, Extreme Temperature, Figure 1.

Using climate models, the researchers then estimated for the years 2000 and 2100 a distribution of daily temperatures for each city. In 2000, the climate model's simulation of Pittsburgh had fewer than five extremely hot days;[11] for 2100, it had approximately 70,[12] each of which *Mills* assumed would have the elevated mortality level associated with extremely hot days in the past. Overall, *Mills* estimated that extreme-heat deaths in the 33 cities studied would rise from fewer than 600 in 2000[13] to more than 7,500 in 2100,[14] even if their populations remained constant.

EPA employed the *Mills* methodology but used a different climate model to forecast the increase in extremely hot days, applied the work to additional cities, and accounted for population growth over the century.[15] In the *EPA* model, Pittsburgh's annual death rate from extreme temperatures increases 30-fold, from 0.4 per 100,000 people in 2000 to 12.8 in 2100.[16] Across all cities, excess fatalities by 2100 would exceed 12,000.

The *Mills* estimates of heat deaths provide a quintessential illustration of the flaw in an assumption of no adaptation. The study uses historical data to predict the response to temperature variation 100 years later, which presumes that society's reaction to a given variation will be the same at both points in time. That assumption is a poor one.

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[10] *Mills*, Online Resource 1.

[11] *Mills*, Online Resource 2.

[12] *Mills*, Online Resource 5.

[13] *Mills*, Online Resource 3.

[14] *Mills*, Table 2.

[15] E-mail correspondence with David Mills, Jan. 17, 2018. See *EPA*, "Extreme Temperature," n. 29, for discussion of *EPA*'s extension of the *Mills* model to additional cities.

[16] *EPA*, "Extreme Temperature," Figure 1.

If global warming makes heat currently regarded as extreme more frequent and less surprising, then temperate cities will almost certainly make adaptations to function better in heat, much as people moving to cities in warmer climates have already done. But *Mills* assumes, implausibly, that an anomalous temperature in 2000 does the same harm as an equal, but by then less anomalous, temperature in 2100.

The implausibility of the no-adaptation assumption is most obvious in the single-city mortality estimates it produces. *EPA* uses the model in *Mills* to estimate 12,000 annual heat deaths nationally in 2100. Much of the estimate stems from temperature increases in northern cities such as Pittsburgh, Detroit, and New York, with forecasted heat-related mortality rates of 12.8, 9.2, and 8.9 per 100,000. Yet southern cities such as Phoenix, Houston, and New Orleans, which were already hotter in 2000 than northern cities are predicted to be in 2100, had mortality rates in 2000 of only 0.2 per 100,000 (see Figure 3).

Mills explained that its main findings "explicitly exclude consideration of the possibility of there being an adaptive response over time to extreme temperatures." Still, *Mills* did provide an alternative analysis in which every city increases its extreme-heat threshold to that of present-day Dallas. With this alternative assumption, extreme-heat deaths fell by almost two-thirds.[17] *EPA* did not use this result.

The Rhodium *Assessment of Climate Costs*

In sharp contrast to *EPA*, *Rhodium* did not incorporate any cost estimate for air pollution into its analysis; temperature-related mortality thus plays a much larger role. *Rhodium* used two different studies to develop its cost estimate for temperature-related mortality. The first, which applied a historical mortality rate to future warming, pointed toward a very high cost estimate. The second focused specifically on adaptation and found that Americans have become well-adapted to extreme heat thanks to air-conditioning. But *Rhodium* concluded anyway that climate change will cause tens of thousands of American deaths each year by century's end, leaving its discussion of future adaptation to a separate chapter that did not inform its top-line cost estimate.

<u>Temperature-Related Mortality:</u> Olivier Deschênes and Michael Greenstone, "Climate Change, Mortality, and Adaptation: Evidence from Annual Fluctuations in Weather in the US," *Applied Economics* 3, no. 4 (Oct. 2011): 152–85. (*Deschênes-Greenstone*)

Deschênes-Greenstone underlies the *Rhodium* estimate of heat deaths due to warming. This study used an approach different from that of *Mills*; it grouped temperatures into 10-degree-Fahrenheit buckets (70°–80°F, 80°–90°F, >90°F, etc.), counted the days with

[17] *Mills*, Table 2.

average temperatures at each level in each U.S. county in each year during 1968–2002, and compared these counts with total mortality rates in each county and year. The researchers found that an additional very cold (<30°F) or very hot (>90°F) day was associated with 0.5–1.0 additional deaths per 100,000 people.[18]

Like *Mills*, *Deschênes-Greenstone* used climate models to estimate the temperature distribution at the end of the century. Their analysis found that climate change would reduce cold-related deaths somewhat but increase heat-related deaths much more. The average county saw one >90°F day each year during 1968–2002 but would see 44 such days each year during 2070–99.[19] If the danger of experiencing a daily temperature within a given bucket did not change, the result of climate change would be 123,000 more heat-related deaths and 59,000 fewer cold-related deaths each year, for a net impact of 63,000 additional deaths by 2100 (totals do not sum due to rounding).[20]

Unlike *Mills*, *Deschênes-Greenstone* focuses on an absolute threshold of >90°F for an extremely hot day, valid for all locations and times. Whereas *Mills* assumes that the ability to cope with high temperatures is location-specific and does not change with climate, *Deschênes-Greenstone* assumes that certain temperatures are more costly everywhere and always.

This approach has the virtue of allowing the researchers to consider more carefully the effects of climate adaptation because it can compare the future effects of global warming—for example, higher temperatures in northern cities—with conditions that exist today, such as temperatures in southern cities, and thereby assess whether cities in already-hot climates have already made adaptations. Technological advances may further improve adaptation to hot weather, but if a study can at least show that present-day adaptations do not improve hot cities' resilience, it can better justify high estimates of global warming's harms.

Deschênes-Greenstone conducted several useful analyses to test for adaptation and found that absolute extreme heat worsened mortality in both hotter and colder climates. Yet their conclusion was undermined by a subsequent paper—which is also cited by *Rhodium*, and of which Deschênes and Greenstone themselves are coauthors.

<u>Temperature-Related Mortality:</u> Alan Barreca et al., "Adapting to Climate Change: The Remarkable Decline in the US Temperature-Mortality Relationship over the Twentieth Century," *Journal of Political Economy* 124, no. 1 (Feb. 2016): 105-59. (*Barreca*)

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[18] *Deschênes-Greenstone*, Figure 2.

[19] *Deschênes-Greenstone*, Table 1.

[20] *Deschênes-Greenstone*, Table 5.

Rhodium also cites *Barreca*[21] for its calculation of extreme-temperature deaths. But rather than focus on projecting deaths from extreme temperature in the future, *Barreca* demonstrates the extraordinary reduction in such deaths in the past. *Barreca* found that the lethality of temperatures above 90°F fell by 80% from the first to the second half of the 20th century, thanks primarily to the adoption of residential air-conditioning. This trend continued even within the second half of the 20th century, with the mortality effect falling by half from the 1960–79 period to the 1980–2004 period.[22]

The researchers concluded that air-conditioning "has positioned the United States to be well adapted to the high-temperature-related mortality impacts of climate change." Applying the *Deschênes-Greenstone* estimate of 42.3 additional >90°F days by 2100, they estimated that climate change could cause roughly 60,000 additional deaths in 2100 at the 1960 level of air-conditioner adoption. But at the 2004 level of air-conditioner adoption, "the null hypothesis that additional 80°F–89°F and >90°F days would have no impact on mortality cannot be rejected." Or, to put this in plain English: additional extremely hot days could mean zero additional heat deaths.

Eliminating the extreme-heat estimate from *Deschênes-Greenstone*, or even reducing it to the statistically insignificant estimate provided in *Barreca*, raises another possibility: climate change could reduce extreme-temperature mortality. *Deschênes-Greenstone* estimated nearly 60,000 cold-related deaths avoided (specifically, a 2.8% reduction in the mortality rate), offset by twice as large an increase in heat-related deaths (a 5.8% increase in the mortality rate).[23] Yet with *Barreca*'s lower estimate of heat-related costs (only a 1.5% increase in the mortality rate by the 1990–2004 period),[24] the cold-related benefits would dominate. Climate change would reduce mortality by roughly 28,000 lives annually (see Figure 4).

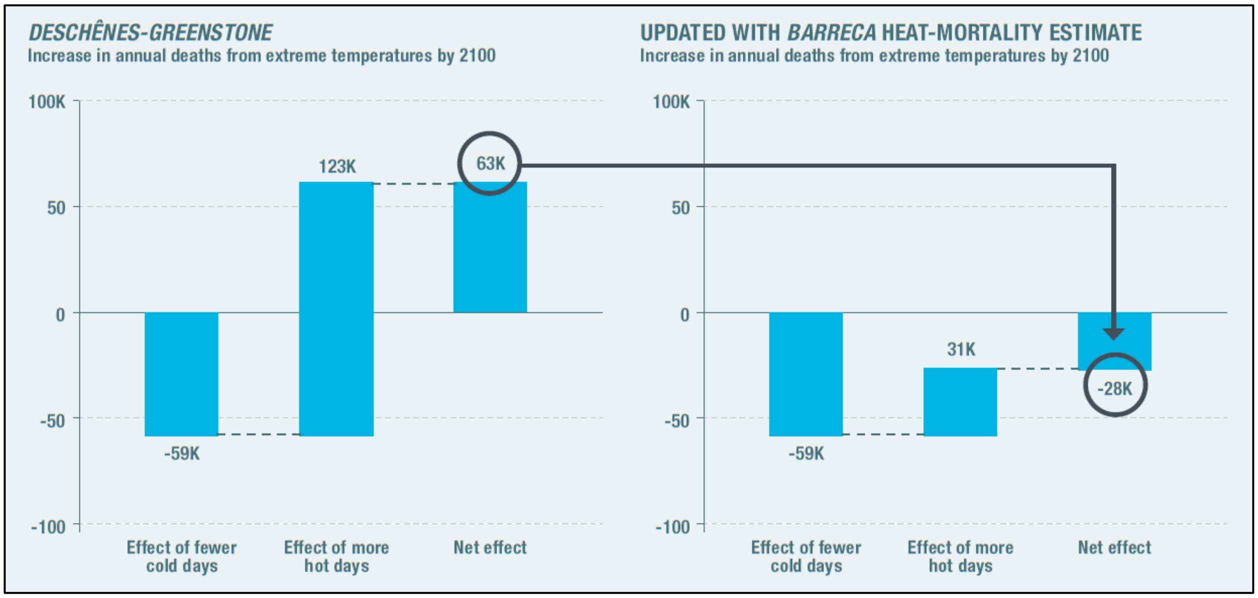
[21] The version of *Barreca* cited here is the paper published in its final form after the release of *Rhodium*. *Rhodium* cites a substantively comparable version of the paper released in Jan. 2013 as an NBER working paper.

[22] *Barreca*, Figure 3.

[23] *Deschênes-Greenstone* presents its final mortality estimates for both increased heat-related deaths and decreased cold-related deaths in Table 5 (cols. 1a–1c). The net effect, an increase of 63,000 deaths, translates to a 3.0% increase in the mortality rate (col. 4).

[24] The suggestion to translate the *Barreca* estimate into terms comparable with the *Deschênes-Greenstone* estimate, as well as the technique for doing so, comes from one of the study's authors (e-mail correspondence with Olivier Deschênes, Dec. 20–22, 2017). The *Barreca* point estimate of 0.0021 for 1990–2004 is divided by six (to account for its two-month exposure window) and multiplied by 100 to give the percentage change in mortality per >90°F day, and then multiplied by 42.3 additional days to give a mortality increase equivalent to those discussed in *Deschênes-Greenstone*. The *Rhodium* authors use a similar process to convert the *Barreca* analysis into terms comparable with *Deschênes-Greenstone*; see Solomon Hsiang et al., "Estimating Economic Damage from Climate Change in the United States," *Science* 356, no. 6345 (June 30, 2017): 1362–69, Supplemental Material, B.3. Given the differences in the *Deschênes-Greenstone* and *Barreca* methodologies and data sets, combining their outputs provides only a rough estimate. The approach is used here to illustrate the large effect of accounting just for already-exhibited adaptation; a full reanalysis would be required to produce a new point estimate.

FIGURE 4: With Adaptation, Does Climate Change Still Increase Mortality?



Rhodium acknowledges *Barreca*'s finding but declines to employ it, instead combining the *Deschênes-Greenstone* and *Barreca* analyses in a way that projects a substantial increase in mortality, while deferring discussion of adaptation to a separate chapter and excluding it from the main cost estimates.[25] If *Rhodium* had used the extreme-temperature mortality decrease that *Barreca*'s adaptation finding implies, rather than forecasting a mortality increase, its total climate-cost estimate would fall by more than 90%.[26]

The Mongolian Century

Temperature studies have progressed even beyond the framework described above, in which temperature is linked to public health; the next frontier establishes an abstract link from temperature directly to economic growth, finding that warmer temperatures slow growth and so climate change could cause the global economy to stall.

[25] *Rhodium*, p. 63; the discussion of adaptation on p. 166 estimates that the effect would remain negative but reduces the magnitude by approximately half.

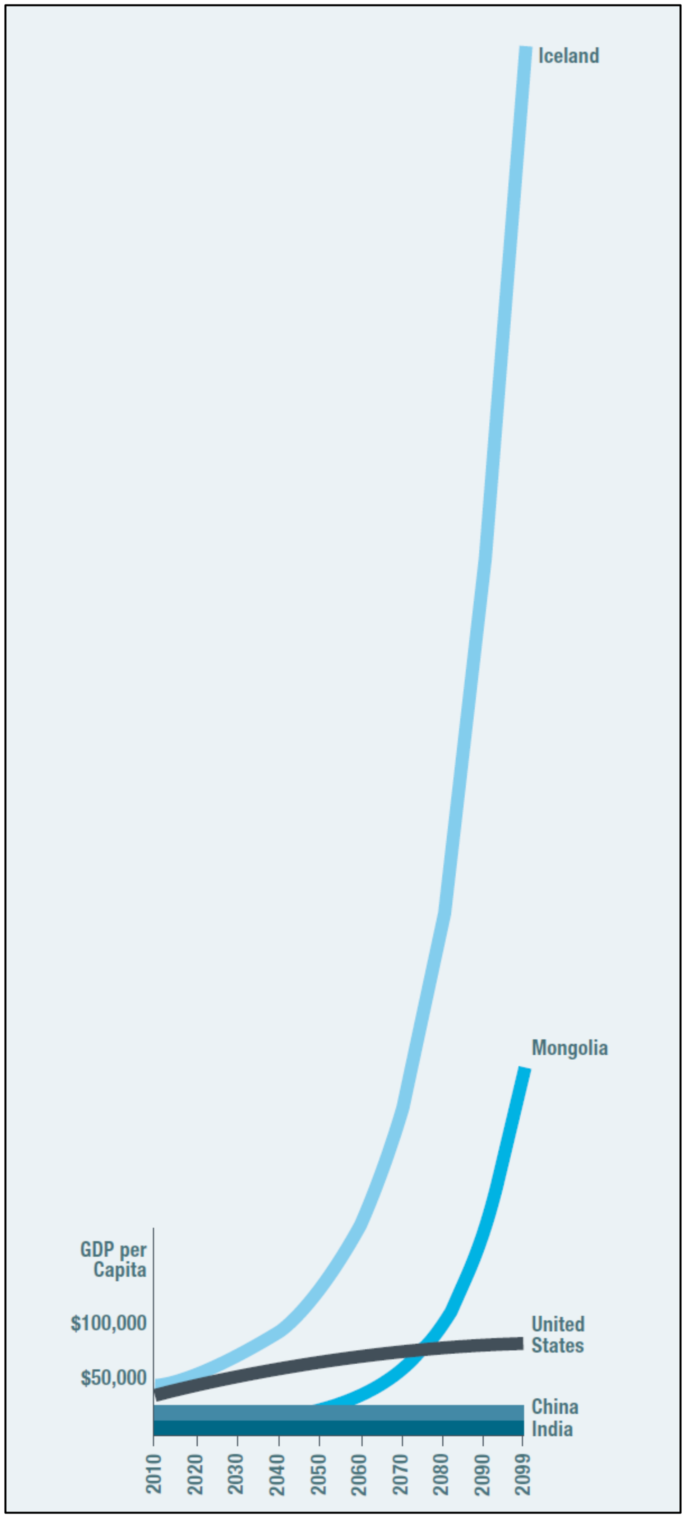
[26] *Rhodium* uses a value-per-life of $7.9 million to yield a midpoint cost estimate of $298 billion (see p. 108), implying roughly 37,000 total excess fatalities. If that were instead 28,000 fewer fatalities, the benefit would be $222 billion. This would change the total estimated cost in *Rhodium* from $557 billion to $36 billion ($586 billion to $38 billion in 2014$).

Marshall Burke, Solomon Hsiang, and Edward Miguel, "Global Non-Linear Effect of Temperature on Economic Production," *Nature* 527 (Nov. 2015): 235-39. (*Burke*)

Burke compares year-to-year variations in a country's average temperature with variations in those same years in economic growth, controlling for associated changes in precipitation. It found that in countries with average temperatures below 13°C (55°F, about the average temperature of Baltimore, Milan, Beijing, or Wellington), growth was better in warm years; countries with higher average temperatures saw better growth in cool years.

Burke theorizes that these short-term fluctuations evinced a universal effect of temperature on growth: every country would see its maximum growth (determined by non-meteorological factors) at a 13°C average temperature—a dynamic that will not change as the climate warms. To extrapolate from this relationship to a possible effect of climate change, *Burke* constructs a model in which every country's baseline temperature is its average during 1980–2010 and its baseline rate of economic growth is that forecasted by the Shared Socioeconomic Pathway (SSP, a widely used set of national GDP predictions that assumes a stable climate). The difference between the baseline temperature and temperature forecasted in some

FIGURE 5: Projected GDP per Capita Following Climate Change



Source: *Burke*; replication data available at https://web.stanford.edu/~mburke/climate/data.html, "Projected per capita GDP with climate change (based on SSP5 and RCP8.5), 2010–2099."

future year by a climate model provides the variation used to predict how growth in that year will vary from the SSP forecast.

Let's say that a country's gradual warming raises its temperature from, for example, 15°C during 1980–2010, to 19°C in 2100. The model attempts to predict the effect on economic growth of a 15°C country experiencing a sudden 19°C year. But the economic performance of other countries with a present-day 19°C average is ignored. The shift in the country's own long-run average is ignored.

Burke builds a modified set of SSP growth forecasts that accounts for the effect of warmer temperatures on every country in every year, and concludes that global warming will reduce per-capita gross world product (GWP) by 23% by 2100.[27]

Projecting each location's response to a century-long temperature change on the basis of how locations reacted to small variations from their own averages in the past produces extremely dubious, if not preposterous, results. *Burke*'s model takes normal economic growth in cold or hot countries as a sign not of economic specialization to a local climate but of often stupendous underlying growth potential that the local climate suppresses.

Burke forecasts that Mongolia, whose per-capita income of $861 made it the 118th wealthiest country in 2010, will leap to seventh in 2100, with a per-capita income of $390,000—more than four times America's projected per-capita income of $90,000. Iceland achieves a per-capita income of $1.5 million, more than twice that of any other country besides Finland ($860,000), with annual economic growth above 5% and accelerating (see Figure 5). Canada's economy becomes the world's second-largest (behind only the U.S.), nearly seven times larger than China's.

Conversely, *Burke* expects India to be the world's poorest country in 2100, with per-capita income no higher than in 2030 and declining at almost 4% per year. It expects Israel, the country that made the desert bloom (and found itself with a water surplus during the intense drought that some consider a catalyst for Syria's civil war), to have a per-capita income in 2100 similar to its 2010 level and declining at more than 2% per year.[28]

Perhaps we should accept that a 23% loss in global per-capita income is plausible, however dramatic. But the model's country-specific outputs are irreconcilable with any plausible understanding of the determinants of economic growth and the potential

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[27] For comparison, this estimate is an order of magnitude larger than the cost of 1%–4% of GDP estimated by the Obama administration in its "Social Cost of Carbon" analysis; see Figure 1B in "Technical Support Document: Social Cost of Carbon for Regulatory Impact Analysis—Under Executive Order 12866," Interagency Working Group on Social Cost of Carbon, Feb. 2010.

[28] The authors provide country-specific model results at https://web.stanford.edu/~mburke/climate/data.html; see "Projected per capita GDP with climate change."

course of economic development in the coming century. It might seem unfair to hold the study accountable for its least reasonable-seeming implications. Sure, the results for Iceland and Mongolia are wrong, but how much can that matter if they contribute little to the ultimate result? That is the wrong way to analyze the issue. Either one believes the premise that gradual shifts in temperature will drive economic growth on the basis of the curve that *Burke* derives, or one does not. If a statistical model makes easily falsifiable predictions, it is a bad model.

To believe *Burke*, one must believe that a gradual rise in average temperature from 0° (32°F) to 5°C (41°F) will turn Iceland and Mongolia into the leading economies of the 21st century. The more plausible conclusion is that responses to large, gradual temperature changes are qualitatively unlike responses to small temperature fluctuations and that the entire enterprise in *Burke*, as in other adaptation-ignoring temperature studies, is flawed.

Burke attempts to defend its assumption of no adaptation by showing that countries responded similarly to short-term temperature fluctuations before and after 1990, suggesting that no adaptation has occurred to date. It also finds that rich and poor countries responded similarly, suggesting that future wealth will not insulate countries from the effects of warming. But such findings say nothing about whether relationships identified for fractional-degree variations can be extrapolated to multiple degrees of warming, or how countries will respond to not just yearly fluctuations but changes in their own underlying baselines.

Analyses like *Burke* will likely proliferate as researchers employ the same statistical techniques to generate large estimates of climate costs in a variety of contexts. For instance, earlier this year the Federal Reserve Bank of Richmond published a working paper that applied a similar methodology across U.S. states and found that climate change "could reduce U.S. economic growth by up to one-third over the next century."[29]

Such a finding is particularly bemusing because, as the authors acknowledge, the effect is largest in southern states—ones that have shown strong economic growth in recent years. Reporting on the findings, the *Wall Street Journal* observed, "their projections partly reflect the emergence of the southern U.S. as a major contributor to national economic growth. As overall temperatures rise, they'll hit that already warm zone hard."[30] Americans are moving in large numbers to the nation's warmest states, and

[29] Riccardo Colacito et al., "Temperature and Growth: A Panel Analysis of the United States," *Federal Reserve Bank of Richmond*, Working Paper 18-09 (Mar. 2018), https://www.richmondfed.org/-/media/richmondfedorg/publications/research/working_papers/2018/pdf/wp18-09.pdf.

[30] Michael S. Derby, "Climate Change May Deeply Wound Long-Term U.S. Growth, Richmond Fed Paper Finds," Wall Street Journal, May 2, 2018, https://blogs.wsj.com/economics/2018/05/02/climate-change-may-deeply-wound-long-term-u-s-growth-richmond-fed-paper-finds/.

such states have exhibited especially robust economic performance, and somehow this *compounds* rather than refutes the concern that warm temperatures will lead unavoidably to economic stagnation.

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The flaws in these temperature studies do not mean that researchers should abandon estimates of the future costs of human-caused climate change. There is every reason for policymakers to continue to carefully consider legitimate cost estimates. So, too, researchers should continue to study the concrete effects of absolute changes in temperature and the nature of associated adaptation, as these findings help to identify which climate-related threats are the most severe and which adaptations may require changes in public policy.

For example, continued research on sea-level changes and their implications for coastal development will be invaluable to responsible public policy in the decades to come. In *Deschênes-Greenstone*, the authors also study the effects of extreme temperatures on energy consumption and show that it (and the associated cost) rises significantly. Just because adaptation is desirable and likely to occur does not make it free.

Policymakers should work to ensure that society has the best possible <u>information</u> about likely effects of climate change and the right <u>incentives</u> to take that information into account. Specifically:

- Continue to invest in climate science. If decision-makers from urban planners to farmers to coastal property owners are to make intelligent investments that build resilience and adapt to changes in climate, they will need the best possible forecasts of what those changes are likely to be.

- Focus research directly on adaptation. Rather than accept the convenience of modeling a future without adaptation, emphasize the need for better understanding of adaptation pathways: Where will it occur naturally? Where will it occur but at a cost or only with better policy? In what situations might adaptation be insufficient and what contingency planning is required? Understanding the answers to those questions will highlight the costs that are most concerning and point toward the policy responses that might be most effective.

- Ensure that decision-makers have the right incentives to account for climate change and its costs. If government insulates people from the costs of climate change, they will not have sufficient incentive to prepare for the costs or avoid them. Insurance products must accurately reflect risk; the price of water must reflect its supply and demand; urban planners must understand their own cities will be responsible for upgrading infrastructure that they build unwisely.

Finally, the prospect of adaptation to climate change does not mean that mitigation is unimportant. Ultimately, greenhouse-gas emissions must decline if atmospheric concentrations are to stabilize. Low-cost, low-carbon energy technologies therefore remain vital and Congress should continue to fund research and development in this area. Congress should also review its use of subsidies, which today serves primarily to prop up wind and solar industries that have had decades to become competitive. Subsidies should be time-limited for a given technology, to keep innovation focused on solutions with the potential to out-compete fossil fuels in the market—especially in the developing world.

Thank you again for the opportunity to appear before the Committee. I hope my testimony will be helpful to you as you assess economic analyses of, and consider appropriate federal responses to, climate change.