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OVERHEATED: HOW FLAWED ANALYSES OVERESTIMATE THE COSTS OF CLIMATE CHANGE

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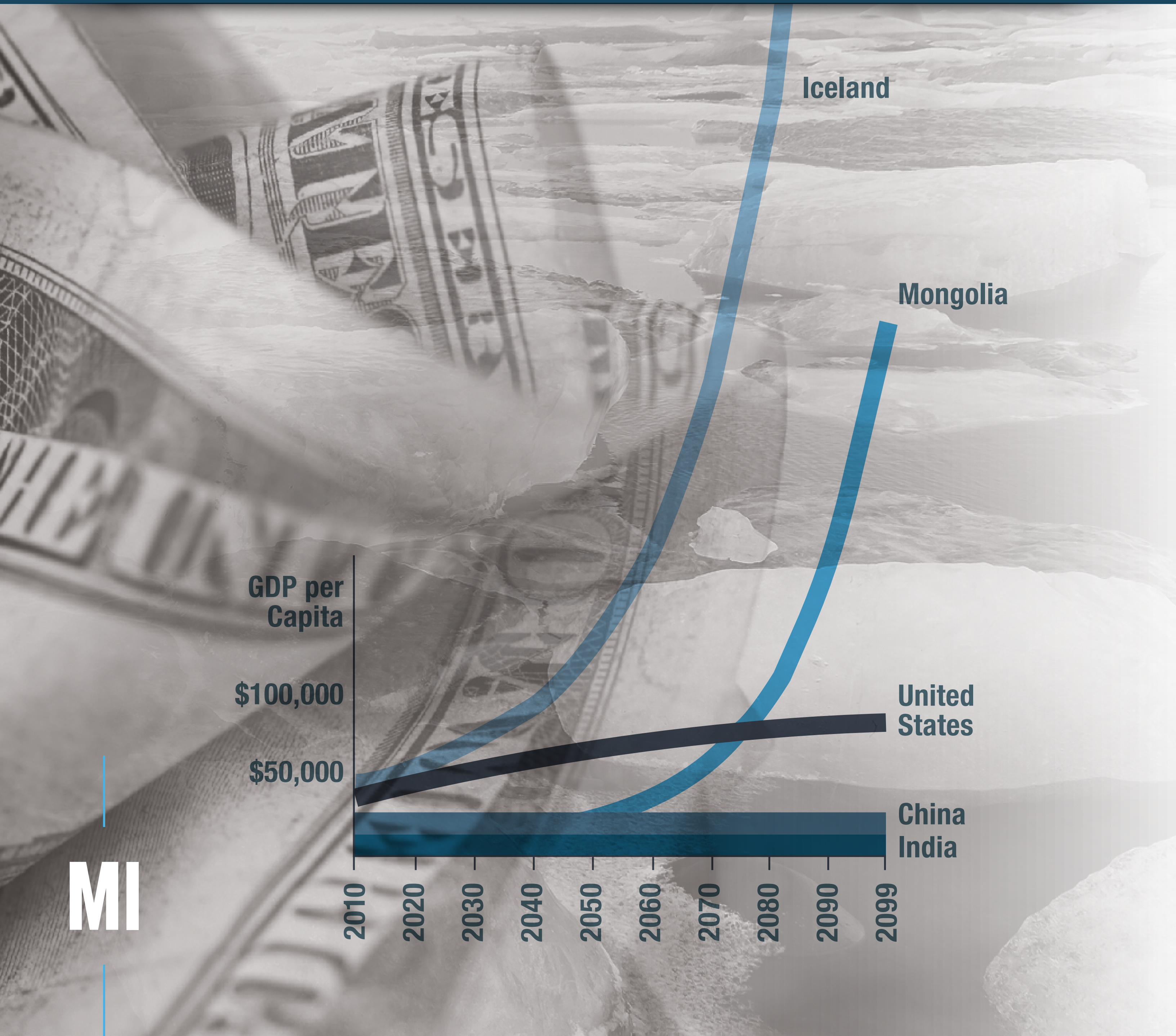

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About the Author

Oren Cass is a senior fellow at the Manhattan Institute, where he focuses on energy, the environment, and antipoverty policy. In 2015, Politico recognized him as one of 50 "thinkers, doers and visionaries transforming American politics." He has written about climate policy for publications including the *Wall Street Journal* and *Foreign Affairs*, testified before House and Senate committees, briefed EPA and White House officials, spoken at MIT and the University of Texas, and appeared on NPR and the BBC. The *Washington Examiner*'s Byron York called Cass's analysis "the best commentary on Trump and Paris."

In 2011–12, Cass was the domestic policy director for Mitt Romney's presidential campaign, where he shaped campaign policy and communication on issues from health care to energy to trade. Prior to joining the Manhattan Institute, he was a management consultant for Bain & Company in the firm's Boston and New Delhi offices, where he advised global companies across a range of industries on implementing growth strategies and performance-improvement programs. Cass holds a B.A. in political economy from Williams College and a J.D. from Harvard University, where he was an editor and the vice president of volume 125 of the *Harvard Law Review*.

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Executive Summary

Prominent recent studies that forecast the cost of human-caused climate change 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.

This paper examines a set of such studies that the U.S. Environmental Protection Agency and the U.S. Government Accountability Office have used to estimate the costs of human-caused climate change for the U.S. by the end of the 21st century. The costs include deaths from extreme heat, lost hours of work from extreme heat, and deaths from heat-caused air pollution. The paper also examines another study, published in *Nature*, that projects the effect of human-caused climate change on global economic production.

Key findings

- Temperature studies do not offer useful projections of deaths and lost hours of work for extreme heat, or deaths due to heat-caused air pollution, in the U.S. The projection of lower global economic output due to projected human-caused climate change is also flawed.

- The crucial (though not the only) flaw of temperature studies is that they neglect human adaptations to a changing climate. Such adaptations have already been made by industrial societies expanding into warm regions, such as the American South and Southwest. The temporary effects of temperature variations—such as an unusual hot spell—cannot be equated with a long-term change in temperature patterns. For example, the failure of people to install air conditioners in a year with one extra 90°F day does not mean that they won't do so in the face of 40 extra 90°F days.

- Properly understood, temperature studies do not offer useful predictions of the future costs of projected human-caused climate change.

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Introduction

Policymakers use estimates of climate change's expected effects to assess the magnitude of the challenge and formulate cost-effective responses. Such estimates are inherently speculative: they require the translation of forecasted temperature increases into effects such as rising seas or more frequent droughts, the translation of those effects into impacts on human society such as inundated coastal property or declining agricultural yields, and the translation of those effects into dollar terms. Of course, to be relevant, projections of the societal impact of climate change should provide some account for how society might respond—by building seawalls, improving irrigation, relocating resorts and farms, or even developing entirely new technologies.

Thus, a sea-level study might apply a range of estimated temperatures throughout the 21st century to a model that translates temperature into a rate of ice melt for Greenland and Antarctica and then translates runoff from that melt into a rate of sea-level rise. That estimated rise could be applied to a database of coastal populations and property values at various elevations to determine who and what might be placed at risk and estimate the cost of relocation or constructing barriers. Each assumption along the way can be studied and scrutinized. For instance, scientists have estimated that ice melt in Greenland could contribute between two and six inches of sea-level rise by 2100.[1] But scientists are constantly refining these estimates both higher and lower; one recent analysis finds that models may be overestimating runoff into the ocean by 20% to 60%.[2]

Prominent recent studies (see sidebar, ***Research Discussed in This Report***) forecasting the cost of human-caused climate change sidestep this process, instead relying solely on statistical analyses of the effects of temperature variation. These correlation-based, temperature-impact studies—hereinafter referred to as temperature studies—link higher temperatures directly to outcomes such as rising mortality or declining economic growth on the basis of historical correlations and then use those correlations to extrapolate the potential effects of projected temperature increases in the future. For example, if a temperature study were to find that each additional day in a given city or region with an average temperature above 90°F produces an additional 100 fatalities, and climate models forecast an additional 40 such days annually in the area, the study would conclude that the area will experience 4,000 excess fatalities.

If the procedure involved here seems off, that's because it is. This report explains the technical details of why. But plain common sense can help, too. Temperature studies insist that even marginally warmer temperatures make people and the economy worse off; yet for generations, the American population has insisted on migrating southward. Are people doing so against their best interests, or are the statistical analysts missing the bigger picture?

In any event, cost estimates from temperature studies vastly exceed those from more traditional analyses of climate change's expected effects on the physical world. Perhaps consequently, these studies have gained rapidly in prominence: they now account for the overwhelming share of costs in climate assessments.

At the request of Senators Maria Cantwell (D., Washington) and Susan Collins (R., Maine), the U.S. Government Accountability Office worked from December 2015 to September 2017 to review "the potential economic effects of climate change impacts and resulting risks to the federal government."[3] Its report, "Climate Change: Information on Potential Economic Effects Could Help Guide Federal Efforts to Reduce Fiscal Exposure" (*GAO*), 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. 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:

- "American Climate Prospectus: Economic Risks in the United States," published in October 2014 by the Rhodium Group (*Rhodium*), a research consultancy, assesses the economic effects of climate change on coastal property, health, agriculture, energy, labor productivity, and crime. It estimates that by 2100, climate change will cost the U.S. $228 billion–$945 billion per year.[4] At least 71% of this sum is based on the estimates from individual temperature studies.
- "Climate Change in the United States: Benefits of Global Action," published in June 2015 by the U.S. Environmental Protection Agency (EPA), assesses the economic effects of climate change on health, infrastructure, electricity, water resources, agriculture and forestry, and ecosystems. It estimates that by 2100, climate change annually will cost the U.S. $1.3 trillion–$1.5 trillion.[5] At least 89% of this sum comes from temperature studies.

Rhodium and *EPA*, along with other recent syntheses, share many authors and studies (see **Figure 1**). They also share a flawed set of underlying assumptions and analyses that render their estimates of future climate costs of no practical use.

The remainder of this paper reviews the studies that account for most of the costs in the *Rhodium* and *EPA* estimates, as well as in a study published in June 2017 in *Science*, "Estimating Economic Damage from Climate Change in the United States" (*Hsiang*). It also reviews a study published in *Nature* in November 2015, "Global Non-linear Effect of Temperature on Economic Production" (*Burke*), that pushes the envelope further in the direction of abstract analysis, yielding even larger but even less credible cost estimates. Each section of this paper takes up a key cost of climate change as estimated by recent temperature studies: heat deaths, labor productivity, air pollution, and the economy.

Research Discussed in This Report

Individual Temperature Studies

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. (hereinafter: *Deschênes-Greenstone*)

Joshua Graff Zivin and Matthew Neidell, "Temperature and the Allocation of Time: Implications for Climate Change," *Journal of Labor Economics* 32, no. 1 (Jan. 2014): 1–26. (*Zivin-Neidell*)

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*)

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*)

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

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)*

Solomon Hsiang et al., "Estimating Economic Damage from Climate Change in the United States," *Science* 356, no. 6345 (June 30, 2017): 1362–69. *(Hsiang)*

Syntheses of Individual Studies

Robert Kopp et al., "American Climate Prospectus: Economic Risks in the United States," Rhodium Group, Oct. 2014. (*Rhodium*)

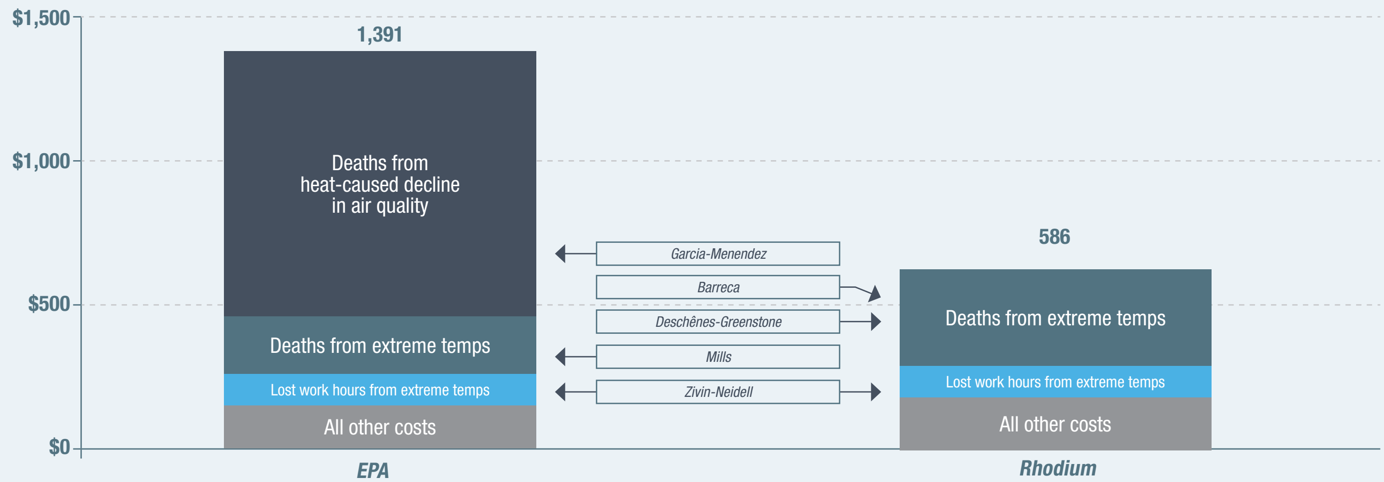
U.S. Environmental Protection Agency, "Climate Change in the United States: Benefits of Global Action," June 2015. (*EPA*)

U.S. Government Accountability Office, "Climate Change: Information on Potential Economic Effects Could Help Guide Federal Efforts to Reduce Fiscal Exposure," Sept. 2017. (*GAO*)

FIGURE 1

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

Annual cost of climate change by 2100; (billions 2014$)



Of the cumulative $2 trillion (midpoint estimates) in climate-change costs highlighted by *GAO*, nearly $1.7 trillion derive from five temperature studies.

*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.

Climate Change and Mortality

Climate change may increase deaths from extreme heat. This may be offset by reduced deaths from cold, but many studies conclude that on balance, higher temperatures will cause more deaths overall. *Rhodium* and *EPA* use different studies to establish estimates of heat-related deaths:

• The EPA estimate of costs due to additional heat deaths in 2100 relies on *Mills*. *Mills* studied 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 warmer minimum temperature would count as "extremely hot."[6] For each city, the researchers measured the change in mortality on days with temperature extremes during 1989–2000.

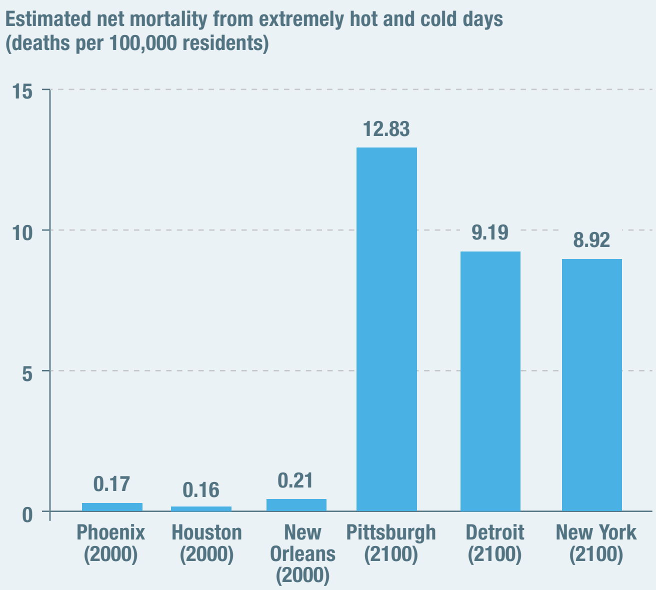
Using climate models, the researchers then estimated for the years 2000 and 2100 a distribution of daily temperatures for each city. In 2000, the climate model's simulation of Pittsburgh had fewer than five extremely hot days;[7] for 2100, it had approximately 70,[8] each of which *Mills* assumed would 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[9] to more than 7,500 in 2100,[10] 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.[11] 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.[12] Across all cities, excess fatalities by 2100 would exceed 12,000.

The *Mills* estimates of heat deaths exemplify the most severe and oft-discussed flaw[13] in temperature studies: the assumption of no adaptation. These studies of temperature effects rely on historical data but attempt to predict the response to temperature variation 100 years later. This is appropriate only on the assumption that society's reaction to a given variation will be the same at both points in time. That assumption is a poor one.

FIGURE 2

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.

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 (see sidebar, ***Adaptation to a Changing Climate***). 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 laid bare by single-city mortality estimates. *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 2**).

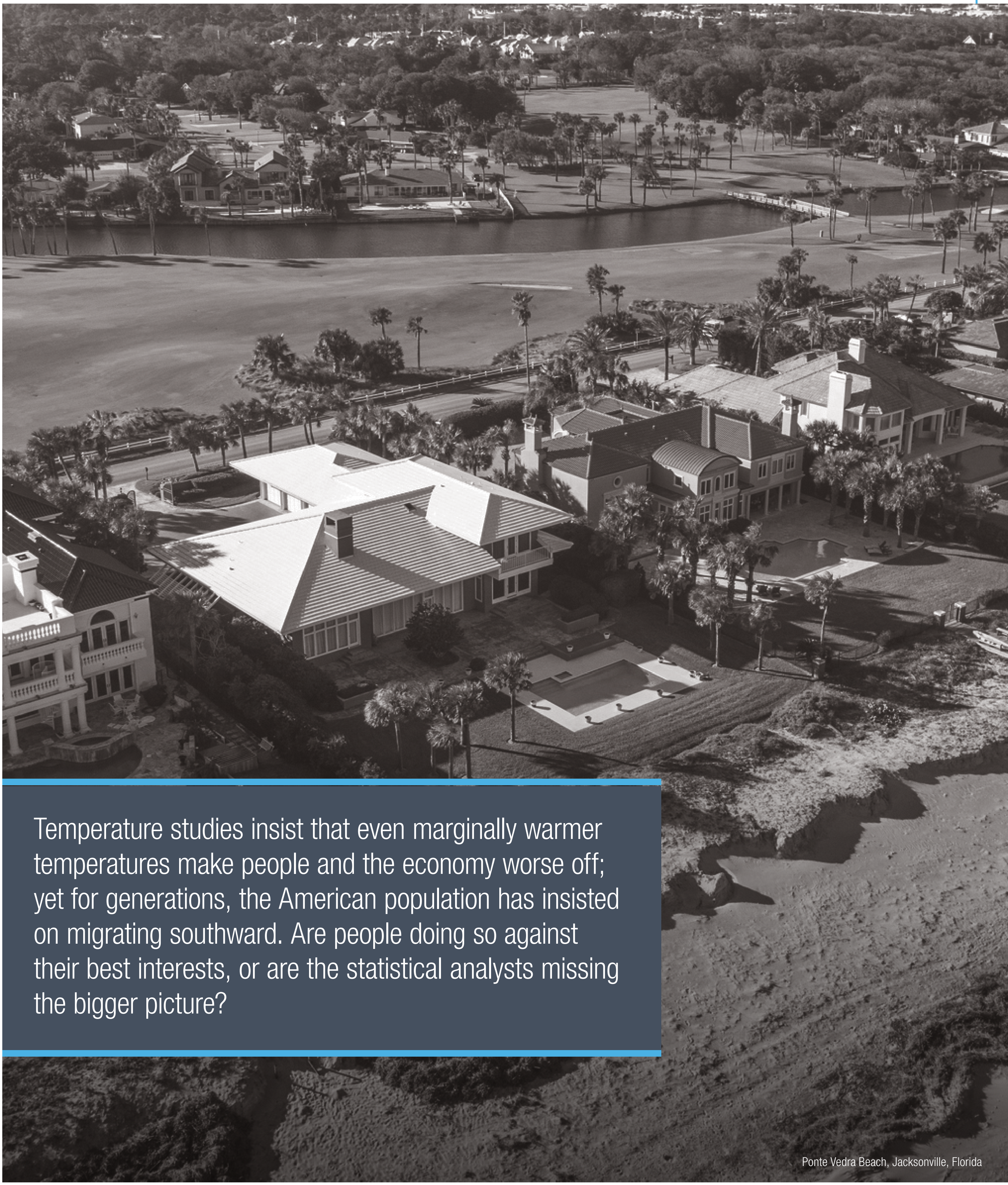
Mills explained that its main findings "explicitly exclude consideration of the possibility of there being an adaptive response over time to extreme temperatures." Still, *Mills* did provide an alternative analysis in which every city increases its extreme-heat threshold to that of present-day Dallas. With this alternative assumption, extreme-heat deaths fell by almost two-thirds.[14] *EPA* did not use this result.

- *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 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.[15]

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.[16] 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).[17]

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, *Barreca*—which is also cited by *Rhodium*, of which Deschênes and Greenstone themselves are coauthors, and which is discussed next.



Temperature studies insist that even marginally warmer temperatures make people and the economy worse off; yet for generations, the American population has insisted on migrating southward. Are people doing so against their best interests, or are the statistical analysts missing the bigger picture?

Ponte Vedra Beach, Jacksonville, Florida

Adaptation to a Changing Climate

Why might a society's response to a given temperature in 2100 differ significantly from its response if that temperature were to occur suddenly in the colder climate of 2018? The answer starts by understanding that potential adaptation has five distinct dimensions:

- **Biophysical.** Humans acclimate to different temperatures, and their responses to those temperatures differ after prolonged exposure. This is conventional wisdom for anyone who has ever found the weather in some unaccustomed place unpleasant.
- **Behavioral.** Humans will react differently to temperatures outside the ordinary. Some of this is purely psychological, while some is quite practical: for example, light snow creates a unique traffic hazard in areas where drivers are not accustomed to driving in the snow.
- **Technological.** Societies develop and adopt technologies appropriate to their climate. Air-conditioning is an obvious example, but many elements of urban infrastructure, home design, and personal wardrobe, for instance, are tailored to local climate.
- **Social.** A society's norms and practices conform to its expected climate. In colder climates, certain sports are not played during the winter. In warmer ones, more work may be done early and late in the day, with a siesta occupying part of the afternoon.
- **Economic.** The skills people acquire and the professions they pursue will depend in part on their local climate. So, too, will their local economy's sources of comparative advantage and the types of industries that develop. Agriculture and tourism are obvious examples of this effect, but transportation and construction are influenced as well.

Society will not make any of these adaptations in response to mere day-to-day or even year-to-year variations in temperature in the way that it would adapt to decades-long climate shifts, because adaptations cost money and take time. An adaptation may represent a cost-effective response to a large shift in underlying climate but offer very little return on investment if implemented in response to a small shift, or in response to impermanent fluctuations.

This crucial point can be understood by a couple of simple examples. The failure to install an air conditioner for a year with one extra 90°F day does not mean that air conditioners will not be installed in the face of 40 extra 90°F days. Adhering to a standard workday for outdoor jobs when the average temperature shifts from 82.1°F to 82.3°F does not rule out adjusting the workday, should the average reach 92.3°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. The people who live in a location where the temperature swings annually by 10°F around an 80°F average may wish that it could behave like a 70°F location one year and a 90°F location the next, but this is 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.

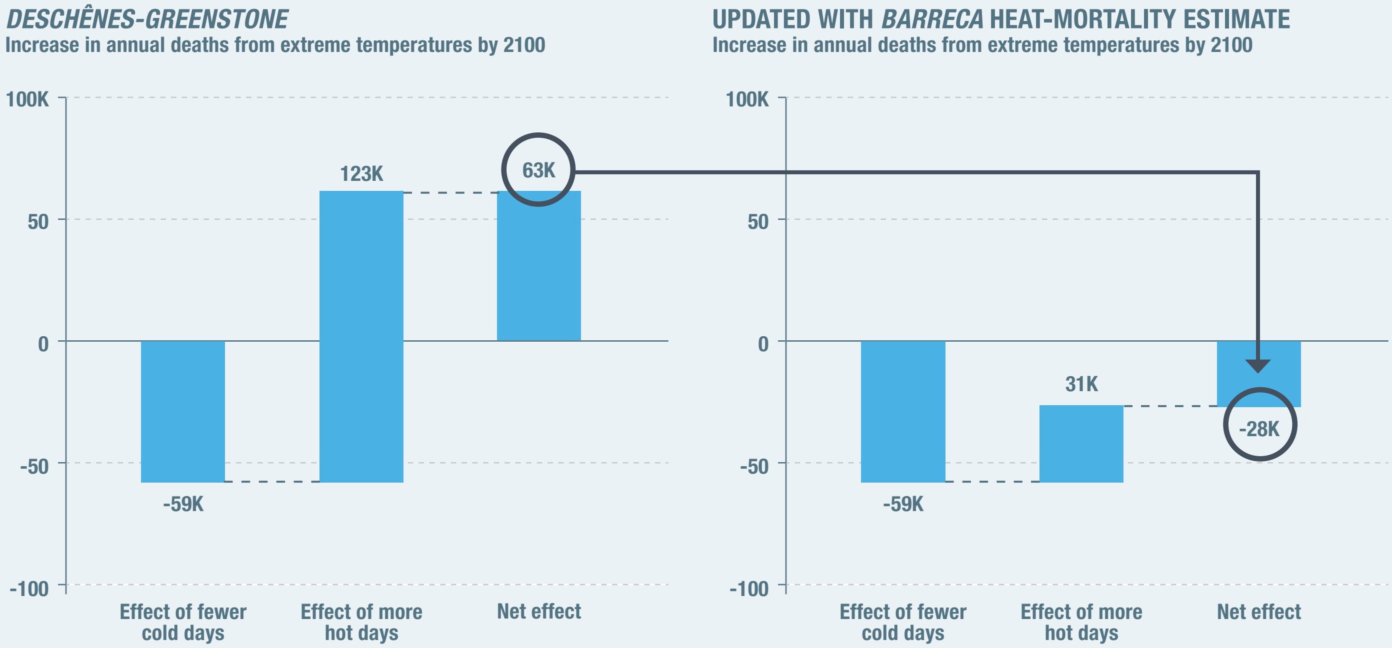
As a result, responses detected to small-scale, short-term temperature changes cannot be automatically extrapolated to the large-scale, long-term ones.

• *Rhodium* also cites *Barreca*[18] 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.[19]

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.

FIGURE 3

With Adaptation, Does Climate Change Still Increase Mortality?



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).[20] Yet with *Barreca*'s lower estimate of heat-related costs (only a 1.5% increase in the mortality rate by the 1990–2004 period),[21] the cold-related benefits would dominate. Climate change would reduce mortality by roughly 28,000 lives annually (see **Figure 3**).

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.[22] 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%.[23]

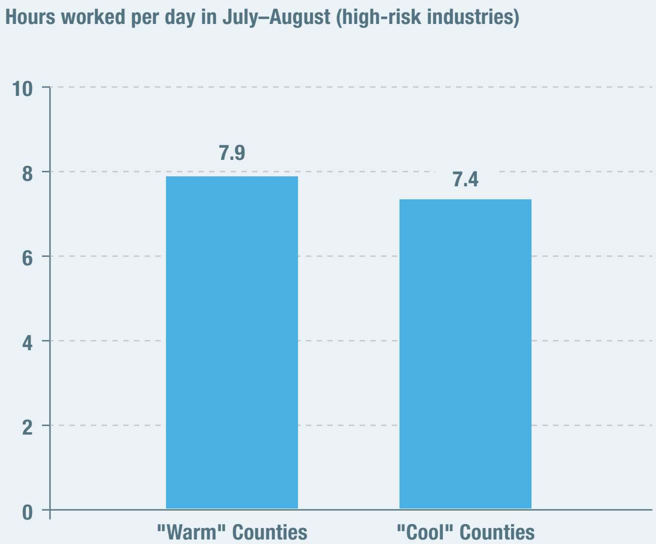
Climate Change and Labor Productivity

Some studies have claimed that a warmer climate will lead to declines in labor productivity and hours worked. *Rhodium* and *EPA* both rely on one of these studies, *Zivin-Neidell*, to estimate the effects of climate change on labor. *Zivin-Neidell* used an approach similar to that of *Deschênes-Greenstone*: it recorded the maximum daily temperature in every U.S. county on every day from 2004 to 2006, grouped the temperatures into five-degree increments, and compared them with data on time spent working from the Bureau of Labor Statistics 2003–06 American Time Use Survey, in which individuals record their activities over a 24-hour period.

Zivin-Neidell found no statistically significant effect of temperatures on overall hours worked, even for days with temperatures above 100°F, which, they wrote, "suggests that, consistent with recent findings, time allocated to labor on net is not responsive to changes in temperature." But the researchers looked separately at industries that the National Institute for Occupational Safety and Health considers "heat-exposed": agriculture, forestry, fishing, hunting, construction, mining, transportation, utilities, and manufacturing. Within this "high-risk" subset, very high temperatures did

FIGURE 4

Current Daily Hours Worked in Hot Versus Cold Climates*



*"Warm" counties are the 1/3 of U.S. counties in the top third of the 1980–89 July–August temperature distribution; "cool" counties represent the bottom 1/3 of the distribution.

Source: *Zivin-Neidell*, Table 2. *Zivin-Neidell* only reports hours worked in warm versus cool counties on an aggregate basis, including for individuals who were not working at all. Figures here are scaled up to work-hours per person working using the ratio reported for the overall high-risk population.

appear to reduce hours worked—by up to almost one hour per day for temperature >100°F. Both *Rhodium* and *EPA* apply this finding to the expected increase in very hot days to estimate the total loss in economic activity by 2100.

Zivin-Neidell provided a plausible test to rule out potential adaptation: it found a similar response to >90°F days in both warm and cold counties. This would suggest that the response to a hot day may not change as the climate warms. This does not rule out possible technological innovation in the future (such as cooling vests) or sectoral economic change (the share of workers conducting manual labor in 2100 may be much lower or such economic sectors may relocate in time or place). But its finding of decreased work in high temperatures is the most plausible of the results reviewed here and also makes intuitive sense: reduced work on hot days is itself an adaptive strategy—the sort of behavior that keeps workers safe.

Nevertheless, *Zivin-Neidell* illustrates a second shortcoming of temperature studies: a lack of context. A model can forecast only what it is designed to forecast; here, the marginal effect of extreme heat on hours worked—but not the absolute number of hours worked or labor productivity itself. *Zivin-Neidell* does find that workers in high-risk industries work less on days of extreme heat—but it also reports that those in the hottest third of American counties work more on a typical summer day than those in the coolest third of counties (see **Figure 4**).[24] Hot weather reduces hours worked on the days when it occurs, but hotter climates within the U.S. do not necessarily experience fewer hours worked overall.

Why might this be? Perhaps heat-sensitive workers in hotter climates compensate for the need to work less on very hot days by working a slightly longer day on other days.[25] Regardless, the study's findings do not support a conclusion that a shift toward a warmer climate with more hot days will mean lower economic output.

Climate Change and Air Quality

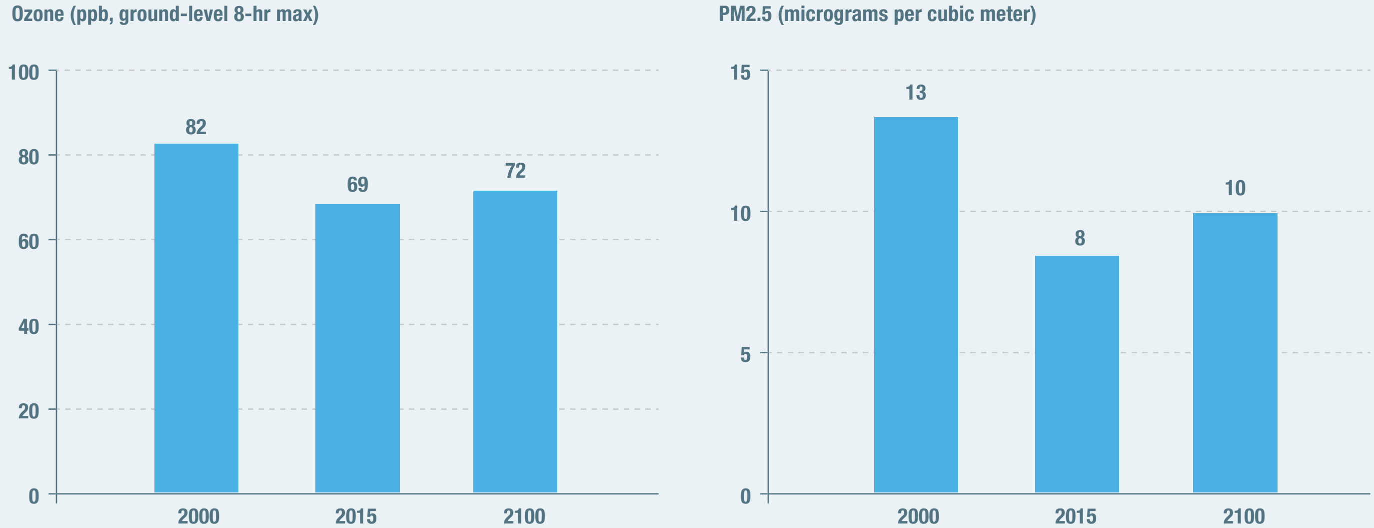
Higher temperatures can also interact with other environmental processes to change the atmospheric concentration of pollutants, even if pollutant emission rates do not change. For instance, ground-level ozone ("smog") gets worse on hot days. *EPA* tried to quantify these air-quality effects based on another study, *Garcia-Menendez*.[26] *Garcia-Menendez* 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 µg m^{-3} (micrograms per cubic meter) for particulate matter (or, respectively, 2.6 parts per billion and 1.2 µg 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.[27] *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 µg m^{-3}, over the alternative scenario.[28] But those concentrations

FIGURE 5

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

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 2000 to 2015, ozone levels fluctuated by more than the climate-induced effect over a century. Put another way, *the forecasted effect of climate change on air pollution is to return atmospheric quality from 2015 to 2011 levels* (see **Figure 5**).[29]

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.[30]

Purely statistical arguments cannot be evaluated without a real-world context. If climate change were projected to create unprecedented conditions, there might be no alternative to reliance on abstract statistical models. But where forecasted conditions for 2100 resemble past or present experiences, those experiences and likely technological advances should be the starting point (not the end point) for discussion.

Climate Change and GDP: Is the World Headed Toward the Mongolian Century?

Several other reports have garnered widespread media attention for temperature-study-based estimates of climate change's impact on GDP.

For example, a set of authors nearly identical to those responsible for *Rhodium* published a study in *Science* in June 2017. That study, *Hsiang*, drew on the same studies as *Rhodium* to generate detailed, county-level estimates of climate change's impact on GDP. *GAO* reports that "according to EPA officials, this study [*Hsiang*] represents a major advance in the field."[31] *Hsiang* estimates a nationwide cost by the year 2100 of 1.5%–5.6% of GDP but a cost exceeding 20% in some regions. Roughly 80% of the total cost derives from extreme-heat deaths and lost working time.[32] Oddly, *Hsiang* reports costs as a share of GDP but uses GDP in the year 2011 as the denominator.[33] Thus, on top of the aforementioned failures to account for adaptation, it also imagines an economy of 2100 no larger than today's.

Most significantly, whereas *Rhodium* and *EPA* estimate climate costs by summing the damage caused by various effects, another paper—*Burke*—created enor-

> 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.

mous cost estimates by pushing the temperature-study methodology even further. *Burke* is not reviewed in *GAO* but is coauthored by the lead author of *Rhodium* and *Science*. *Burke* provides the most abstract analysis of any surveyed here. After a few introductory references to studies of agricultural and labor productivity (including *Zivin-Neidell*), it abandons consideration of global warming's effect on anything more concrete than national GDP. *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 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.[34]

As in *Mills*, 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.

For instance, according to the *Burke* model, if Cambodia (average temperature 28°C [82°F]) were blessed with an American climate (14°C [57°F]) for the 21st century, it would achieve GDP per capita approaching *$300 million* by century's end. (By contrast, *Burke* uses baseline GDP per capita in 2010 of $36,000 for the U.S. and $400 for Cambodia). But if the U.S. were forced to cope with Cambodia's climate, its per-capita GDP would fall by more than half every decade. If Cambodia and the U.S. shared a climate of 21°C (69°F), similar to that of Houston, Tel Aviv, or Brisbane, then Cambodia's purportedly superior non-meteorological characteristics would send its per-capita income skyrocketing past the American level by 2040.[35]

The effects of predicted global warming are less dramatic but likewise implausible. For instance, *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 6**). 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.[36]

In a blog post, coauthor Marshall Burke addressed critics of the paper, whom he paraphrases as saying, "These results just don't pass the 'sniff test,' " or, "Your impacts are too big, and they just can't be true":

> *As far as I can tell, "this doesn't pass the sniff test" is just a snarky way of saying, "this disagrees strongly with what I thought I knew about the world, and I am uninterested in updating that view.". . . So, yes, the future world might look different than the current world. But saying that is a cop-out, unless you can tell a convincing story as to exactly why the future is going to look so different than the past. Our guess is that you are going to have a hard time telling that story with an appeal to the historical record.*[37]

FIGURE 6

Projected GDP per Capita Following Climate Change, 2010–2100

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"

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 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, and that the Cambodian economy is far more dynamic than its American counterpart, held back from world domination by its latitude. 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 with tests similar to those performed by *Deschênes-Greenstone* and *Zivin-Neidell*. It finds 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.[38]

Burke highlights a final challenge for temperature studies: extrapolating from findings of questionable statistical significance. While findings of possible causal relationships can be valuable even if they fall short of the standard thresholds of statistical significance, applying a dubious small-scale relationship to very large scales can badly overinflate a finding. Many countries studied in *Burke* did not display the relationship that this study took to be global—*of 47 with an average temperature below 13°C, 45% experienced lower growth in warmer years; of 118 with an above-optimum average temperature, 42% experienced higher growth in warmer years.*[39] So much statistical uncertainty surrounded the overall estimate of a 23% loss in per-capita income that the study reported a 29% chance that temperature increases in 2100 would *raise* global wealth.[40] The 95% confidence interval, traditionally used to determine a finding's statistical significance, spans a range of estimates from a more than 50% loss of per-capita income to a more than 50% gain.[41]

Similarly, *Deschênes-Greenstone* reported a statistically significant relationship between extremely hot days and mortality nationwide, but when it considered nine regions separately, it found a statistically significant relationship in only three.[42] Two other regions, the Middle Atlantic (NJ, NY, PA) and the West South Central (AR, LA, OK, TX), exhibited an insignificant inverse relationship: more hot days appeared correlated with *fewer* deaths. Still, multiplying the best nationwide estimate by an increase from one to 44 annual days of >90°F heat produced, in *Deschênes-Greenstone*, a massive death toll.[43]

Many recent temperature-study-based estimates of climate-change cost overextend models constructed from small short-term effects and make untenable no-adaptation assumptions; the large harms that they forecast often represent aggregations of implausible local predictions. When results do account for adaptation and are presented in context, they point toward low and manageable climate-related costs. The odds are vanishingly small that the world is headed toward the Mongolian Century.

Conclusion

The critique of temperature studies in this paper does 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*, alongside the finding that air-conditioning can mitigate heat-related mortality, 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.

But correlation-based temperature-impact studies that produce very high estimates of the economic and social costs of projected climate change—meanwhile ignoring or downplaying the possibility of adaptation and obscuring the inaccuracy of underlying estimates—are distinctly unhelpful.

If a statistical model makes easily falsifiable predictions, it is a bad model.

Endnotes

Connor Harris, a policy analyst at the Manhattan Institute, provided research assistance for this report.

1. John A. Church and Peter U. Clark, "Chapter 13: Sea Level Change," in Thomas F. Stocker et al., eds., *Climate Change 2013: The Physical Science Basis, Contribution of Working Group I to the Fifth Assessment Report of the IPCC* (Cambridge: Cambridge University Press, 2013). See Table 13.5 regarding "median values and *likely* ranges for projections of global mean sea levels (GMSL) and its contributions in metres in 2081–2100 relative to 1986–2005" (emphasis in original).
2. Laurence C. Smith et al., "Direct Measurements of Meltwater Runoff on the Greenland Ice Sheet Surface," *Proceedings of the National Academy of Sciences* 114, no. 50 (Dec. 2017): E10622–E10631.
3. *GAO*, p. 3.
4. *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.
5. *EPA* includes $10 billion–$34 billion in energy-system costs reported for 2050; it provided no estimate for 2100.
6. *Mills*, Online Resource 1.
7. *Mills*, Online Resource 2.
8. *Mills*, Online Resource 5.
9. *Mills*, Online Resource 3.
10. *Mills*, Table 2.
11. 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.
12. *EPA*, "Extreme Temperature," Figure 2.
13. 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.
14. *Mills*, Table 2.
15. *Deschênes-Greenstone*, Figure 2.
16. *Deschênes-Greenstone*, Table 1.
17. *Deschênes-Greenstone*, Table 5.
18. The coauthors of *Barreca* were Karen Clay, Olivier Deschênes, Michael Greenstone, and Joseph S. Shapiro. The version of *Barreca* cited in this MI report 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.
19. *Barreca*, Figure 3.
20. *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).
21. 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 *Hsiang*, 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.
22. *Rhodium*, p. 63; the discussion of adaptation on p. 166 estimates that the effect would remain negative but reduces the magnitude by approximately half.
23. *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 $38 billion in 2014$).
24. *Zivin-Neidell*, Table 2.
25. The study looks for another form of adaptation called "catch up," in which workers adjust to working fewer hours on a hot day by working more hours on the immediately surrounding days, and finds no such effect.
26. *Rhodium* discusses air quality but does not provide damage estimates.
27. *Garcia-Menendez*, Table 2.
28. 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.
29. "Particulate Matter (PM2.5) Trends," U.S. Environmental Protection Agency; "Ozone Trends," U.S. Environmental Protection Agency.
30. *EPA*, pp. 78–79; see also *GAO*, p. 22.
31. *GAO*, n. 38.
32. *Hsiang*, Figure 5.
33. *Hsiang*, Supplemental Material, J.2.

34 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.

35 My calculations are based on coefficients reported in *Burke*, Extended Data Table 1, and baseline country values are provided by the authors at https://web.stanford.edu/~mburke/climate/data.html; see "Projected per capita GDP without climate change." Calculations exclude negligible precipitation effects included in *Burke*.

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

37 Marshall Burke, "Climate Change and the Global Economy," *G-FEED*, Oct. 26, 2015. The paper was published in the November 2015 issue of *Nature* but first appeared online on Oct. 21, 2015.

38 In his Oct. 26 blog post, Burke acknowledges: "Whether people respond differently to short- versus longer-run changes in temperature is an empirical question, and one that is often tricky to get a handle on in the data." He directs readers to a working paper (dated Jan. 14, 2015) that he coauthored, which finds that U.S. corn and soybean farmers have made only minimally successful adaptations to global warming to date. The paper was eventually published; see Marshall Burke and Kyle Emerick, "Adaptation to Climate Change: Evidence from US Agriculture," *American Economic Journal: Economic Policy* 8, no. 3 (Aug. 2016): 106–40. But Burke acknowledges that such findings may not apply generally. He does not address the quality or plausibility of the *Burke* country-level outputs, instead concluding: "But again, just claiming that responses derived from studying 'weather' are a bad guide to understanding 'climate' is not that satisfactory. Show us how long-run responses are going to be different."

39 *Burke*, Fig 1h.

40 For the 23% figure, see *Burke*, p. 235; for the 29% figure, see p. 238 and Extended Data Table 3.

41 *Burke*, Fig 5a.

42 *Deschênes-Greenstone*, Table 3.

43 The study reports a lower net effect of climate change because the increase in deaths from extreme heat is partially offset by a reduction in deaths from extreme cold.

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Abstract

Prominent recent studies that forecast the cost of human-caused climate change rely on statistical analyses of the effects of temperature variation. These correlation-based, temperature-impact 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.

This paper examines a set of such studies that the U.S. Environmental Protection Agency and the U.S. Government Accountability Office have used to estimate the costs of human-caused climate change for the U.S. by the end of the 21st century. The costs include deaths from extreme heat, lost hours of work from extreme heat, and deaths from heat-caused air pollution. The paper also examines another study, published in *Nature*, that projects the effect of human-caused climate change on global economic production.

Key Findings

1. Temperature studies do not offer useful projections of deaths and lost hours of work for extreme heat, or deaths due to heat-caused air pollution, in the U.S. The projection of lower global economic output due to projected human-caused climate change is also flawed.

2. The crucial (though not the only) flaw of temperature studies is that they neglect human adaptations to a changing climate. Such adaptations have already been made by industrial societies expanding into warm regions, such as the American South and Southwest. The temporary effects of temperature variations—such as an unusual hot spell—cannot be equated with a long-term change in temperature patterns. For example, the failure of people to install air conditioners in a year with one extra 90°F day does not mean that they won't do so in the face of 40 extra 90°F days.

3. Properly understood, temperature studies do not offer useful predictions of the future costs of projected human-caused climate change.

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