ENERGY & ENVIRONMENT

Cleaning Up Our Mess

On climate change, what is our obligation to future generations?

BY DAVID K. LEVINE

Young environmental activists often say that older generations are creating a future climate disaster. They argue that current generations are obligated to take decisive action against global warming now to lessen its effects on generations to come. In the words of prominent Swedish activist Greta Thunberg: "Young people must hold older generations accountable for the mess they have created. We need to get angry and transform that anger into action."

The foisting of some cost onto an unwilling third party — what is known as a "negative externality" — has long been a concern of policymakers and economists, and climate change will certainly have future costs. At the same time, carbon-fueled wealth creation, both in the past and ongoing into the future, has benefits — including positive externalities — for future generations, especially in poorer countries that are only now beginning to develop quickly or will do so in the future. A proper appraisal of current generations' environmental obligation to the future must be mindful of both the costs and benefits, to determine how large that obligation is and what policies would best meet it.

This article offers such an appraisal. No doubt, it will face two groups of critics: those who deny the current, best-available science indicating that the climate is changing, and those who deny the economic analysis of the effects of that change. This article is intended for people who aren't among either group of "deniers."

HOW MUCH WARMING?

The basics of climate change are well known. Carbon dioxide and other greenhouse gases in the atmosphere act as a sort of blanket, trapping some of the heat from the sun instead of allowing it to escape into space. Human emissions of greenhouse gases like carbon dioxide enhance this blanket effect, resulting in rising planetary temperatures.

There are considerable uncertainties about how warming will unfold and how the planet will respond. Climate scientists have

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produced numerous models, built on different assumptions, to estimate how much and how quickly warming will occur. Among the most respected of these models are those produced by the Intergovernmental Panel on Climate Change (IPCC). Figure 1 reproduces estimates from the most prominent models used in the most recent assessment.

The figure is not entirely self-explanatory. The horizontal axis is the year. The IPCC does not consider its estimates past 2100 to be very reliable, but it does offer projections through 2300. The vertical axis is the amount of warming that is estimated to occur, measured in degrees Celsius above the pre-industrial period, which ended in the mid-18th century. The curves displayed, with labels such as SSP1–1.9 and SSP5–8.5, are composite best estimates of the outputs of different models under different assumptions. Scenario SSP5–8.5 is the IPCC's "worst-case scenario," assuming that there will be no change in humanity's current course of growth, energy production, and carbon emissions. This is almost certainly unrealistically pessimistic, but that is the nature of worst-case scenarios.

CREATIVENATURE / GETTY IMAGES

COSTS OF CLIMATE CHANGE

How large are the future costs of climate change? Using its composite models, the IPCC offers descriptions of the socio-economic future under the different warming estimates. The first chapter of the IPCC's most recent assessment report describes these scenarios as follows:

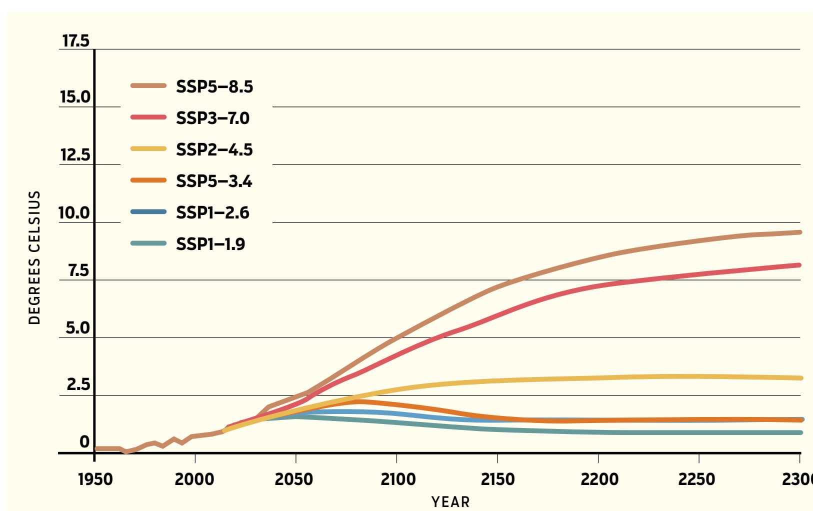
> The Shared Socioeconomic Pathways SSP1 to SSP5 describe a range of plausible trends in the evolution of society over the 21st century. They were developed in order to connect a wide range of research communities and consist of two main elements: a set of qualitative, narrative storylines describing societal futures and a set of quantified measures of development at aggregated and/or spatially resolved scales. Each pathway is an internally consistent, plausible and integrated description of a socio-economic future, but these socio-economic futures do not account for the effects of climate change, and no new climate policies are assumed. The SSPs' quantitative projections of socio-economic drivers include population, gross domestic product and urbanization.

Notice that, by the IPCC's own description, these socio-economic scenarios are not scientific estimates. Rather, they are "qualitative, narrative storylines" and "quantified measures … at aggregated and/or spatially resolved scales." This is disappoint-

FIGURE 1

Global Temperature Change

IPCC estimates of the increase in global temperature over time above pre-industrial level.



SOURCE: *Climate Change 2021: The Physical Science Basis. Contributions of Working Group 1 to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge University Press, 2021.

ENERGY & ENVIRONMENT

ing because the IPCC could have used more rigorous analyses produced by economists; such analyses are particularly important because economists incorporate human responses to climate change in their models. Instead of that work, the IPCC turned to projects using methodologies assembled by non-experts.

Let's look at some examples of economists' work on global warming. Figure 2 presents four prominent estimates, three contained in the 2006 report prepared for the Government of the United Kingdom by Nicholas Stern, chair of the Grantham Research Institute on Climate Change and the Environment, and the fourth based on a model formulated by Yale economist William Nordhaus.

Figure 2 also is not entirely self-explanatory. The horizontal axis indicates warming above pre-industrial temperatures measured in degrees Celsius, while the vertical axis indicates the resulting percentage loss in per-capita gross domestic product from warming as compared to what would have occurred without warming. Notice that this figure does not factor in the passage of time; rather, it simply indicates that, for a given amount of warming, the models estimate an amount of per-capita GDP loss. So, for instance, the Nordhaus model predicts that a 4°C increase in global mean temperature would result in a decrease in per-capita GDP of about 5% from the output that would have occurred without warming. Interestingly, though environmentalists often praise the *Stern Review* and criticize Nordhaus's work, Nordhaus offers the gloomier predictions.

For this analysis, I will mainly use the Nordhaus numbers because he presents the most worrisome future. At the far end of the curve, his model estimates that an 8.6°C warming will result in a 16.5% decrease in what income otherwise would be. To put that in perspective, world income in the Great Depression fell about 15%. That was a tremendous, history-shaping loss, though it was not an existential catastrophe. Likewise, an 8.6°C warming would not result in a "planet on fire," but it is something that humanity should consider taking reasonable steps to mitigate.

We can use the Figure 1 warming projections and the Figure 2 economic effect estimates to get a better sense of the time frame and effects of warming under various assumptions. For instance, if the SSP5–8.5 scenario is realized and the planet warms by 6°C a century from now and then by 8.6°C by 2200, Nordhaus estimates that would result in a GDP-per-capita loss in 2200 (compared to what otherwise would have resulted) equivalent to the Great Depression. That would be a large loss and, unlike the Great Depression, GDP per capita would not recover a decade or two later.

On the other hand, there is quite a difference between a Great Depression now and one in 200 years: the latter includes 200 years of economic growth, fueled in part by carbon-based energy. There is considerable difference in the resulting living standards between a 16.5% loss in income in the 1930s or today as compared to that loss in 2200.

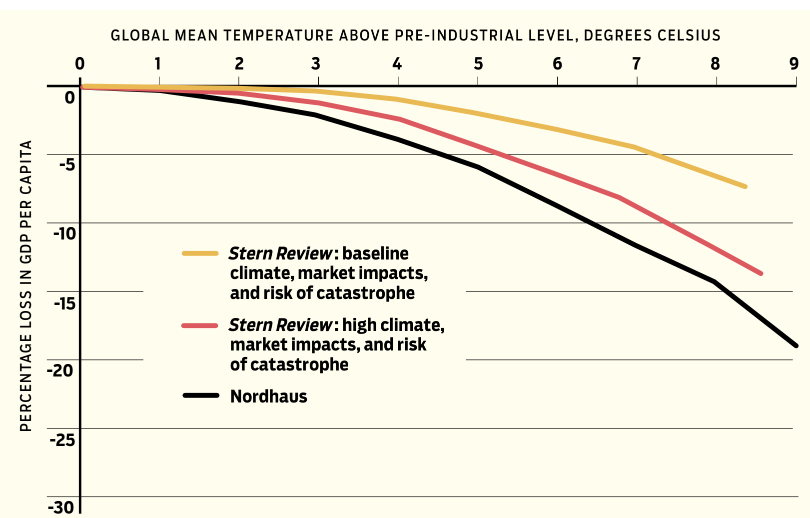
Or is there? What if a warming climate severely hampers economic growth between now and 2200? In essence, there are two extreme possibilities, with a range of possibilities in between, for how economic growth will play out as the planet warms. One is that economic growth will halt as a result, and future generations will be no richer or poorer than we are. But if that happens, then carbon emissions will fall because there will be less economic demand for energy given the lower production. We will be in a scenario more like SSP2–4.5 then SSP5–8.5. That, in turn, would mean the planet would warm about 3°C compared to today, yielding a 2% GDP-per-capita loss. That's still a painful drop, akin to the loss experienced in the Great Recession of the first decade of this century, and the economy would not likewise bounce back in a decade or so. On the other hand, this loss is not the global catastrophe that often is envisioned by climate activists. Again, the potential for this loss recommends taking reasonable steps to mitigate climate change but does not demand the drastic steps that some climate activists call for.

Notice that the discussion above keeps referring to climate-change-driven losses in GDP per capita "compared to what otherwise would have resulted." It's important to recognize that we do not know how much growth will occur over the next 200 years, either with or without warming. Economic growth is driven by technological progress and by poor countries adopting advances that have propelled rich countries. Yet, the rate of the former is uncertain because we cannot know what technological breakthroughs will or will not hap-

FIGURE 2

The Cost of Warming

Loss in per-capita income from an increase in global mean temperature as compared to baseline growth without climate change.



SOURCES: *The Stern Review on the Economics of Climate Change*, by Nicholas Stern, Cambridge University Press, 2007; "Climate Policy," by John Hassler, Per Krusell, and Jonas Nycander, *Economic Policy* 31(87): 503–558 (2016).

pen in the future. The rate of the latter likewise is uncertain because many institutional barriers must be overcome for poor countries to grow, and we cannot know how much success or failure there will be in overcoming those barriers. It is possible there could be no economic growth in the future at all, and it is also possible there could be growth at rates higher than at any other time in human history.

We may get a sense of the future by looking at the recent past. From 1960 to 2020, world per-capita income grew from about $3,584 to $10,520 (in constant 2015 U.S. dollars). That is, it nearly tripled in less than 60 years. If that growth would continue between now and 2200, per-capita GDP would multiply nearly 27 times. But let's be conservative and assume growth would only multiply by 16 over the next 180 years in the absence of climate change. If we then subtract 16.5% in accordance with Nordhaus's estimated cost of climate change, world GDP per capita would still multiply by more than 13 between now and 2200 — an enormous gain for humanity.

But perhaps that growth rate is also wildly optimistic. For an even more conservative estimate, consider that U.S. per-capita GDP in 2020 was about $63,414 (in current dollars) as compared to the world figure of $10,910. If the world economy were only to double in the next 200 years, meaning that the rest of the world only partially catches up to where the United States is today, then the lower growth rate would mean energy use and carbon emissions would follow a warming scenario between the IPCC's SSP2–4.5 and SSP3–7.0. That would yield around 4°C of warming and, according to Nordhaus, about a 4% loss in per-capita GDP. That would mean that, in 200 years' time, our descendants would be 92% better off than we are.

This does not mean that the effects of climate change should be dismissed, but it puts those effects in perspective. The best science indicates that if we do nothing to halt climate change, the effect of global warming on our children will be modest and descendants will be considerably better off than we are. Moreover, the positive effects of economic growth are so much stronger than the expected damage from climate change as to make these rough calculations robust to substantial errors in either the rate of warming or its resulting economic damages. Still, there is reason to try to mitigate climate change, but it is important that those efforts not blunt the economic growth that will benefit future generations, especially those living in poorer countries.

WHAT IF CLIMATE CHANGE IS WORSE THAN WE EXPECT?

Although our best available science indicates that the positive effects of economic growth will substantially eclipse the negative effects of climate warming, this should not be understood as a call to inaction. The expected effects of warming are serious and represent costs imposed on people who are not responsible for them. Further adding to the concerns about climate change, the expected effects could prove inaccurate and the actual effects be far more severe.

Forever is a long time / Emitted carbon remains in the atmosphere for a long time, only slowly being removed by plant and other processes. As a result, even if all carbon emissions were to cease today, the carbon already produced from human activity will continue to affect the climate long into the future.

That is why Nordhaus, Stern, and others recommend reducing carbon emissions. Figure 3, taken from Nordhaus, presents a baseline (that is, no change in the current pattern) annual carbon emission level and suggested alternative emission levels. The horizontal axis is time, while the vertical axis is annual global carbon emissions. Nordhaus recommends limiting global carbon emissions to around 40 gigatons per year around the middle of this century, and lower emissions in subsequent years. Stern recommends even more dramatic limits that would yield net-zero carbon emissions around the year 2040.

Why the different recommendations? A good explanation is offered by Martin Weitzman in a 2007 *Journal of Economic Literature* article that I summarize:

Stern argues that, as an ethical matter, the well-being of future generations should be valued as much as that of current generations. That sounds reasonable enough, but non-economists are not generally aware of all the implications of this idea. Weitzman offers some calculations to make it more understandable.

In our discussion above, we only looked at costs 200 years into the future. But the consequences of global warming will last a very long time after that, so Nordhaus's worst-case estimate of a 16.5% GDP per-capita loss from climate change will persist long after that year. To give a conservative sense of how large the total loss would be, assume that there are no damages from global warming for the first 200 years, but then a 16.5% loss each year afterward. That would sum to an enormous loss in income. Stern calculates that, to avoid this loss, we should be willing to give up an amount equal to 80% of that loss — that is, 13.2% of our current GDP, starting now and continuing forever. In other words, Stern's ethics demand that we suffer an economic loss nearly as large as the Great Depression starting immediately and continuing on permanently in order to prevent an even worse economic loss starting 200 years from now. Moreover, only 18% of the cost of that future will occur within the next 400 years, and 55% of it lies more than 800 years in the future. Forever is a long time.

Climate scientists' pessimism / Some climate scientists worry that a warming of 4°C would have a more severe effect than what our above estimates suggest. For example, respected chemist and climate scientist Will Steffen said in a 2016 lecture:

> The problem there is that, in my view, it is impossible to survive that sort of change. That's beyond human physiology

ENERGY & ENVIRONMENT

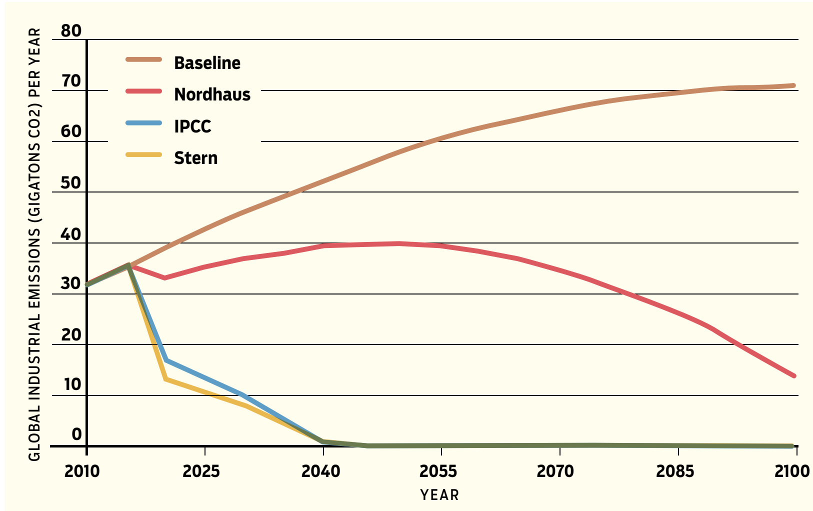
> to deal with that sort of change.... Our cities are designed for [a pre-industrial temperature level]. And remember, a lot of our infrastructure is designed for a hundred years ... [but we will have much higher temperatures in] 85 years. ... [T]hat's a collapse scenario. Physiologically, we can't survive that. So, the real challenge is we've got to make sure we [limit warming to] 2°C.

In essence, Steffen argues for following the emissions limits currently proposed by the IPCC, which aspires to limit warming to 2.5°C as shown in Figure 3.

FIGURE 3

Emissions Alternatives

Baseline carbon emissions and recommended emission limits.



SOURCE: "A Review of the Stern Review on the Economics of Climate Change," by William D. Nordhaus. *Journal of Economic Literature* 45(3): 703–724 (2007).

Why does the IPCC and Steffen worry about outcomes that are more dire than those projected in the damage assessments? Climate scientists are good at analyzing climate models and forecasting the likely effects on temperature given a specific path of carbon emissions, such as the resulting sea level rise, incidence of storms, and so forth. But they are not experts at considering the adaptation ability of human beings; economists are. And when climate scientists try to do economics — just like when economists try to do climate science — we should be concerned.

The late economist Julian Simon offers a cautionary tale for both climate scientists and economists. Just a few decades ago, there was broad concern that, given population growth, humanity would soon run out of vital natural resources. Simon was an expert in the adaptability of human systems to change and the consequences for natural resources, and he argued that the concern was overblown; economic incentives would lead humans to adapt well to changes in resource availability. His views have stood the test of time relatively well. But he also had strong views on topics that he was not an expert — climate change being a particular example — and on that topic his views have not fared well.

Just as Simon was wrong about global warming but right about the economic consequences of population growth, so I believe that climate scientists are right about climate change but wrong about its economic consequences. They fail to appreciate the power of human adaptability.

Frog theory / A great deal of climate change work by non-economists is grounded in what I call the "frog theory" of human behavior. We know the cliché: if you put a frog in a pot of water and gradually raise the temperature, the frog will not notice and will eventually boil to death instead of jumping out of the pot. Likewise, some environmental commentators assume humanity will fail to adapt successfully to the effects of a warming planet.

Here is an example from a 2010 *Proceedings of the National Academy of Sciences* (*PNAS*) article by climate scientists Steven Sherwood and Matthew Huber that exemplifies frog theory:

> In principle, humans can devise protections against the unprecedented heat such as much wider adoption of air conditioning, so one cannot be certain that [the earth] would be uninhabitable. But the power requirements of air conditioning would soar; it would surely remain unaffordable for billions in the third world and for protection of most livestock; it would not help the biosphere or protect outside workers; it would regularly imprison people in their homes; and power failures would become life-threatening. Thus, it seems improbable that such protections would be satisfying, affordable, and effective for most of humanity.
>
> We conclude that a global-mean warming of roughly 7°C would create small zones where metabolic heat dissipation would for the first time become impossible, calling into question their suitability for human habitation. A warming of 11–12°C would expand these zones to encompass most of today's human population.

That sounds alarming, but do climate scientists know much about the future power requirements and cost of air conditioning, let alone human ability to adapt to their growing need? Such rhetoric is not a substitute for a careful economic assessment, and cost assessments are what economists do. They investigate how much air conditioning is needed, how much power is required, whether people might be better off moving to another location, and if so, how much it will cost.

Three other points are worth noting. First, Sherwood and Huber define "uninhabitable" as meaning that a person cannot survive outdoors in ordinary clothes for more than a few hours.

But if that's the case, then much of today's population already live in such zones. I doubt that anyone in, say, Minneapolis is foolish enough to go outside for several hours in mid-winter in street clothes. Just as in cold climates there is heating for indoors and coats for outdoors, so in hot, humid climates there is air conditioning for indoors and there are, for example, cooling vests that provide thermal protection when one is outdoors. An economist will further point out that as temperature rises, demand for these vests will rise and vest manufacturers will grow more competitive, facing strong incentive to lower their cost and improve their design.

Second, integrated assessment is important. In the more popular literature, we read how global warming will increase the use of air conditioning, requiring more power. What is often not mentioned is that warming will also reduce the use of heating. An integrated assessment indicates how the costs and benefits of one change will combine with the other, and what the overall cost or damage will be.

The final point has to do with frog theory itself. If large areas become uninhabitable, people won't stay there; they'll move. Economists know this and have estimates of the involved costs. And, worth noting, frog theory doesn't even correctly describe frogs: contrary to the cliché, once the temperature becomes hot enough, they will in fact jump out of the pot.

The issue of heat versus cold is an important one. Increased temperature when it is hot is bad, but increased temperature when it is cold is good. This means that there are beneficial effects of warming as well as detrimental effects, and an integrated assessment accounts for both. Consider, for instance, the effect on human deaths of extreme temperatures: according to a 2019 paper by François Cohen and Antoine Dechezleprêtre, in Mexico, "89 percent of weather-related deaths are induced by cold (<10°C) or mildly cold (10–20°C) days and only 1 percent by outstandingly hot days (>32°C)."

HOW ARE ECONOMIC DAMAGES ESTIMATED?

Integrated assessments underlie the *Stern Review* and Nordhaus estimates depicted in Figure 2. Figure 4, taken from work by economist Richard Tol, updates the *Stern* estimates, with the solid line indicating the central estimate and dotted lines representing a range of effects because of uncertainty. The axes are the same as in Figure 2: global temperature increases along the horizontal axis and damage as a percentage of per-capita GDP along the vertical axis. The circles correspond to published integrated assessments — all the ones that Tol was able to locate. Quite a few of them are in the 2.5°C–3°C range, and cluster around a 2% per-capita GDP loss, consistent generally with the Stern estimates in Figure 2. There are some much more recent studies that assess damages from warming as high as 5.5°C–6°C, with the resulting economic cost as high as about 5%. Those are also consistent with the *Stern* estimates in Figure 2, although those estimates were not available at the time Figure 4 was compiled.

Notice that Figure 4 shows a lot of uncertainty. The economic loss from a warming of 2.5°C–3°C could plausibly range as high as 10% of per-capita GDP. That would be a large loss, but it would not be fully realized until 50 years from now. Given that global GDP per capita is currently more than doubling every 50 years, the growth effect would still dominate this global warming effect. If the warming were to be 6°C, the cost could plausibly range as high as 20%, but that is still dwarfed by the growth effect.

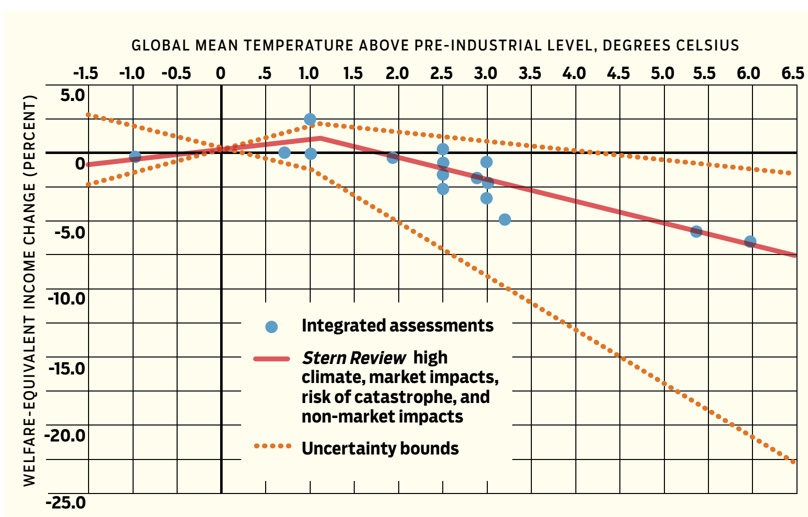
This raises a question: Given that careful cost estimates that incorporate all the data about humidity, temperature, human physiology, cost of air conditioning, and so on generally top out at a maximum increase of 6°C, where do the estimates from an ultimate warming of 11.5°C come from? The answer is extrapolation: a curve is fitted to the estimates for 0°C–6°C and is then extended out to 11.5°C. It is not extrapolated linearly but assumes that the amount of curvature in the 0°C–6°C range will continue into the higher temperatures.

Large warming and migration / How seriously should we take the damage estimates for relatively large warming of 8°C–12°C? Weitzman, who is generally well-received by climate activists, has argued that the consequences could be far worse than the extrapolations, although he does not provide evidence of why this might be the case. In assessing the consequences of climate change, it is important to realize that no matter how badly cli-

FIGURE 4

A Range of Estimates

Integrated assessments and high-impact *Stern* estimates, with uncertainty bounds.



SOURCE: "The Economic Impacts of Climate Change," by Richard Tol. *Journal of Economic Perspectives* 23(2): 29–51 (2009).

mate change affects one location — e.g., flooding, heat, extreme climate events — there are other locations not subject to those problems. As climate change worsens circumstances in some locations, it will improve them in others; stretches of the American South may become less hospitable, but stretches of Canada will become more so. And people can move from the less hospitable to the more hospitable.

However, some people warn, at some scale, social and economic systems will no longer be able to cope with masses of migrants and we will face a human catastrophe — think of how relatively minor migration riles much of the developed world today. In part because of this concern, Weitzman believes the economic loss at 12°C might be 99% — that is, virtually all of GDP. In contrast, Nordhaus estimates that a 12°C warming would yield a loss of around 30% — a giant loss to be sure, but not the catastrophe that Weitzman suggests.

So, will climate-change-driven migration unleash societal collapse 150 years from now? That seems unlikely because the annual rate of migration from warming should be slow. Temperature change is gradual. Look back at Figure 1: even at the extreme end of SSP5–8.5, it will take two centuries to move into the 8°C–12°C range. Climate-driven migration would thus be just a small fraction of the across-borders flow of people seeking better living circumstances. If moving into the 8°C–12°C range means that half of the world population will ultimately relocate, that corresponds to a migration rate of just 0.33% per year. That is similar in magnitude to the migration from rural to urban areas that took place in the 20th century. That migration took place unevenly, in ebbs and surges, with both steady flows of people seeking better economic circumstances and surges of people escaping crop and price failures. It is true that a climate migration is likely to be from one urban area to another, but the social and economic costs of relocation — the disruption of life, the cost of transportation, the cost of building infrastructure (houses, workplaces, factories, offices, roads, sanitation, schools, hospitals, and on and on) — are the same regardless of where the immigrants come from. And while most of the 20th century rural-to-urban migration took place over modest distances, some took place between continents — from Europe and Asia to the Americas — at great hardship. Today, modern transportation is not a significant bottleneck: prior to COVID-19, every year commercial airlines carried about four billion people, about half the earth's population.

Let's briefly consider the history of rural-to-urban migration in the second half of the 20th century. In 1950, world rural population was almost 1.8 billion and urban population about 751 million. In 2000, the rural population grew to almost 3.3 billion and the urban population to almost 2.9 billion. This means that while world population grew about 1.8% per year, rural population grew only 1.2% per year. It has long been known that birth rates in rural areas are higher than in urban areas, so at least 0.36% of the world's population migrated from rural to urban areas each year. This migration is similar to projected levels for extreme climate scenarios. Yet, the 20th century rural-to-urban migration did not create society-disrupting hardship: during the same period, per-capita income doubled.

To understand the issues that arise with migration more concretely, consider the situation in Manila, Philippines, a place where climate change is likely to have a major effect because of the city's low elevation next to the Bay of Manila. Philippines has many smaller cities and towns in the highlands that will likely be the target destination for future Manila emigrees. There is nothing amazing about a small town growing to the size of Manila over a period of many decades. For example, Sao Paulo, Brazil grew from a population of about 65,000 in 1890 to 6 million in 1970 and has nearly doubled in size since then. Moreover, many of the immigrants who drove this growth were not Brazilian, but from Italy and Japan. While the rapid growth of Sao Paulo has created some social problems, the city is thriving.

In Bangladesh, another place where low elevation and adjacency to the Bay of Bengal makes it especially vulnerable to climate change, the situation is more complicated. There are cooler highlands nearby: the Eastern Himalayas (not the jagged peaks, but the area south of the tall ranges, an area of rolling hills — the "hill stations" where the British Raj fled the hot Indian summers). But there is a complication here: this appealing cool region is in India and Myanmar. Cross-border immigrants are often unwelcome, and escaping refugees even less so. It is not likely that India and Myanmar will embrace Bangladeshis seeking a cooler environment.

As part of the costs of climate change, economists must consider the costs of future political conflict — and even warfare — from migration. Existing research has reached mixed conclusions about whether climate change increases or decreases conflict in the broad sense, and these costs are not currently included in damage estimates. However, more detailed assessments — for example, combining information about probable paths of migration and data about the effects of migration on conflict — should be possible, and their results will affect our policy decisions about climate change.

This political dimension of migration is an important one. Some institutions cope better than others and some countries and regions are more welcoming to immigrants than others. We see today throughout the world a rising tide of nationalism and xenophobia. Mixed with immigration driven by climate change, this combination has the potential to be explosive. Still, we should not be misled by the current attitude of many rich countries toward immigrants: while there was enormous political turmoil in the European Union over the immigration of a million or so Syrian refugees last decade, Jordan — with a population of less than 10 million — absorbed at least that many refugees over a few short years. Over 10% of the population of Jordan are recent arrivals, yet no social catastrophe has resulted.

It is also important to ask questions about tradeoffs and factor them into our economic analysis. Will richer immigrants be more welcome than poorer ones? Will countries with growing incomes be more hospitable to immigrants than stagnant ones? Is effort better invested in mitigating climate change or in fighting xenophobia and promoting economic growth?

Fortunately, the possibility of 12°C warming and resulting huge damages is small. In particular, the estimates of economists have meaning because the scale of events expected from future global warming are not beyond the bounds of our experience. Even the most catastrophic climate events have human consequences well within the realm of what we know.

Tipping / A criticism of economic damage assessments is that they do not take account of the possibility of "tipping": that warming will trigger a series of irreversible negative events. Three types of tipping events are often cited: runaway glacier melt, runaway greenhouse effect, and what is known as the "hothouse earth" hypothesis.

Reducing an unknown but small chance of disaster by an unknown amount is a difficult guide to policy. Yet, concerns about tipping strengthen the case for action.

Economic models factor in these cataclysmic events only insofar as the IPCC climate models do so, and these IPCC models do not show much effect of tipping points. So, what is the science of tipping and how worried should we be about it?

Let's first consider runaway glacier melt in Antarctica and Greenland, resulting in a much faster rise in sea level than is anticipated in IPCC estimates. The most recent IPCC assessment discusses this type of tipping and considers it more likely than earlier assessments, though the probability is still small. As a result, future economic assessments will factor in this possibility. However, it is likely the new estimates will show only a moderate increase in damages, and that increase will still be dwarfed by the beneficial effects of economic growth.

A runaway greenhouse effect would result from a vicious cycle. Warming releases greenhouse gases that have been trapped in the earth, which in turn produce more warming that results in more gas release. The earth's atmosphere could reach a carbon dioxide concentration similar to Venus, at 95%, and the temperature would rise into the hundreds of degrees. This would certainly put an end to human life and probably all life on earth.

The runaway greenhouse idea has been studied by astrobiologists who have posed roughly the following question: If we were to burn all the coal on earth, would that be enough to trigger a runaway greenhouse? As the earth is quite different from Venus — not least in that we receive a lot less solar radiation — these experts believe this probably can't happen here, but they aren't sure. Fortunately, there is agreement that no level of carbon that we are likely to emit is nearly enough to trigger a runaway greenhouse.

The hothouse earth hypothesis is based on the theory that, in the past, the earth's climate was unstable, switching between hotter and cooler periods. The fear is this could happen again in the future, making carbon increases self-sustaining. But, unlike a runaway greenhouse, there are also countervailing forces, so that while the temperature would increase, it would do so only to a limited extent. The question is, how quickly would the temperature increase and to what extent? A 2018 *PNAS* article by Steffen et al. offers some detailed estimates. The period over which this change might take place is unclear. Historically, these transitions took thousands of years, but the triggering rate of climate change was much less then, so perhaps such a climate-change-driven transition would be much faster and fall within the 100-to-200-year period we are assessing. The Steffen article indicates that tipping into the hothouse earth scenario would lead to a temperature increase over pre-industrial levels of about 4.5°C. This is well within the range for which we have damage estimates, and these estimates on the high end are less than 15%. Again, that would be a Great Depression–level economic loss that we should want to mitigate, but it is one that would be dwarfed by the overall economic growth.

What do these grim scenarios mean for economic damage assessments? Increasingly, the assessments are accounting for some probability of a catastrophe. The problem is that reducing an unknown but small chance of disaster by an unknown amount is a difficult guide to policy. Nevertheless, concerns about tipping strengthen the case for sensible action to mitigate warming.

THE RISK OF CLIMATE CHANGE AND THE REASON TO MITIGATE

It should now be clear that there is a great deal of risk involved with climate change. As Figure 4 indicates, our best estimate of the damages from 3.5°C of warming is a loss of anywhere from 0% to 12% of per-capital GDP. From Figure 1's SSP2–4.5, the temperature increase in 2200 is likely to be 2.5°C–4°C.

There are, of course, considerable uncertainties in these estimates. The uncertainty allows for two kinds of policy mistakes: we could overestimate the loss (say, we could expect 4°C of warming, resulting in a 12% output loss, when there is only 2.5°C warming and 0% loss) or underestimate it (vice-versa). Doing the former would lead us to costly mitigation policies that would ultimately prove unneeded, while the latter could lead us to do nothing when, in fact, we should have taken steps to combat climate change.

Economists John Hassler et al. provide a careful analysis of these mistakes in a 2018 *Annual Review of Economics* article. The authors assume that, to mitigate climate change, humanity adopts a "Pigouvian tax" on the use of carbon — a tax intended to inflict an additional cost on the consumer that equals the estimated cost of the negative externalities from climate change. (See "The Pigou Problem," Summer 2008.) In Figure 5, the curves depict the loss that would occur if one or the other of the two mistakes is made. The horizontal axis is time, running from 2010 to 2200. The vertical axis is consumption loss, which is roughly the same thing as damages, but computed from a dynamic emissions model.

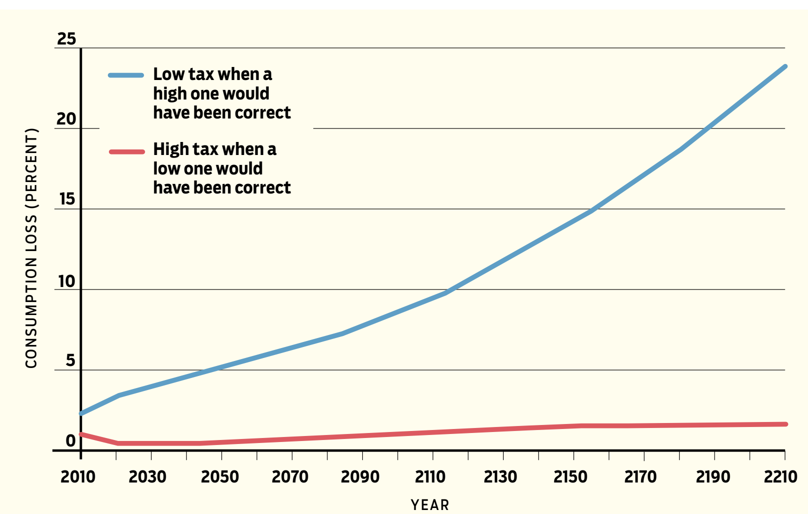
One curve shows what happens if humanity assumes the worst and adopts a high carbon tax, but in fact there was little danger from warming and no loss of per-capita GDP. In that case, we'll have wasted resources combating what ends up not being a problem. Fortunately, the cost of this is low. The other curve shows what happens if humanity assumes it does not need to mitigate climate change and things turn out for the worst. The curve rises quickly and neither our children nor grandchildren will thank us for that. The choice is pretty clear: it isn't costly to prepare for the worst, so we should do that. If we don't, we may get lucky and things turn out for the best, but then again — whatever you think of the IPCC and climate science — unless you are totally gaga, you have to believe there is a chance they are right.

The best estimates of economists, accounting for the risks and uncertainty involved, do not indicate that we should do nothing. Nor should we engage in a crash course of cutting carbon emissions to zero in the next 20 years, because that would be horribly costly for economic growth. Instead, we should follow a middle course, one that allows for much economic growth because it is very important.

FIGURE 5

The Cost of Being Wrong

Projected consumption losses from erroneous carbon taxes.



SOURCE: "The Consequences of Uncertainty: Climate Sensitivity and Economic Sensitivity to the Climate," by John Hassler, Per Krusell, and Conny Olovsson. *Annual Review of Economics* 10: 189–205 (2018).

THE REALITY OF NON-ETERNAL GROWTH

Economics is not about money, nor is economic growth. Economic growth is about people and their having greater access to resources. In rich nations, increased income may mean a second bathroom, a nicer car, a better college for the kids, the opportunity to eat out more often or at a better restaurant, and better security against job loss, poor health, old age, or divorce. Those may seem frivolous to some people, but most residents of developed countries would disagree. In poor countries, increased income means having an indoor toilet, a mosquito net, clean water, access to vaccines and decent medical care, a living place secure against weather, air conditioning, a car, and a chance to make a living by doing something other than back-breaking labor under the hot sun. Those things are not frivolous at all.

Wealth enables one to cope better with changes in the environment, whether from climate change or something else. For example, bad weather causes people to die, but less so for richer people who have heating, cooling, stronger and better protected buildings, and who can remain indoors when the weather is bad. Climate change makes malaria more dangerous, but less so for richer people who have medicines and mosquito nets. Richer countries have the resources to build early-warning systems, shelters, and dykes to protect against cyclones and flooding.

Economic growth leads to global warming. Greater access to economic resources requires energy — lots of it — and the cheaper that energy is, the more a poor country can grow. China exemplifies how this works. In the last 25 years, per-capita income in China increased five-fold. A country that had per-capita income in 1998 similar to Bangladesh now has per-capita income similar to the European Union nation of Bulgaria.

Over that same quarter-century, China's energy consumption has roughly tripled. That energy is very dirty: the country generates about five times as much carbon per unit of income as the United States. The reason for these emissions is that 60% of China's power comes from coal, the worst fuel for carbon emissions. China grew by increasing its energy consumption and it did that by building many cheap but dirty coal-fired power plants.

This is the dilemma of climate change. China — with its power plants, air-conditioned cities, huge dams, subways, high-speed trains, modern highways, air-conditioned cars, and massive construction capability — is vastly better able to tolerate climate change than Bangladesh. Yet, those capabilities — and the Chinese people's considerable improvement in living standards — result from the energy use that yields global warming. So, is it better for a developing country to tolerate increased warming and become rich through carbon-fueled energy, or remain poor in an effort to fight global warming (perhaps while China and others push ahead with coal-fired power)? Consider this question from the perspective of people living in the developing world: why should the developed world — which got rich from carbon fuel — try to impede the developing world?

Property rights / In the developed world, some environmental activists and political leaders are so concerned about climate change that they are willing to sacrifice considerable future economic growth to combat it. These drastic measures seem unnecessary. In the last decade, several advanced economies have reached "peak carbon" and, in the pursuit of efficiency, found ways to reduce carbon emissions per unit of economic output. This has resulted in these countries continuing to have strong economic growth while reducing total emissions, and this trend should continue and spread to other developed countries. (See "Is a Green New Deal Even Necessary?" Winter 2021–2022.)

Unfortunately, this virtuous trend is unlikely to reach the world's poorer countries anytime soon. These countries have the most to gain from economic growth *and* the most to lose from global warming. Many of them are in particularly vulnerable areas — e.g., they are vulnerable to rising sea levels or are in already hot regions that will grow hotter — and their low incomes provide them few resources to contend with a warming planet. These countries will need large amounts of energy to boost their resources, and that almost certainly means they will need to consume large amounts of fossil fuel. If these poor countries grow as China did, by greatly increasing their carbon emissions, rich countries that want to mitigate climate change will face a dilemma: do they try to induce the developing world to cut emissions by using incentives, or by coercion? A recent controversy between the president of Brazil, Jair Bolsonaro, and the president of France, Emmanuel Macron, exemplifies this issue.

In the summer of 2019, several large fires broke out in the Amazon rainforest. The rainforest's plant life serves as a giant carbon sink, removing carbon from the air and serving as a globally valuable natural resource. But the rainforest is threatened by slash-and-burn deforestation for logging and farming. Not only does slash-and-burn reduce the carbon sink, but the clearing adds to emissions. It also sparks forest fires and is believed to have caused the 2019 blazes.

Since 2008, Norway — following the incentive strategy — had made payments to Brazil's Amazon Fund to protect the rainforests, with total transfers of over $1 billion. But when Bolsonaro entered office in 2019, he de facto shut down the Fund's governance, and slash-and-burn activities increased. Understandably, Norway ended its payments.

Macron has argued for the coercion strategy. He threatened to veto a trade agreement between France and Brazil (and several other nations) if the fires weren't stopped. His position is understandable given the results of Norway's more cooperative strategy. But is it ethical to threaten poor countries (Brazil's per-capita GDP is one-fourth France's) with economic sanctions if they do not stop damaging the environment in their pursuit of better economic conditions? And, keep in mind, the developed countries that make these threats obtained their wealth in part through immense fossil fuel use.

Moreover, would such threats ultimately be effective? France is an important trading partner, but it is hardly the only potential one. China does not seem concerned about Brazil's deforestation and could simply replace France as a trading partner.

A POLICY FOR GROWTH AND WARMING MITIGATION

As disappointing as Norway's experience with Brazil was, offerings incentives to developing nations is likely the best strategy to reduce global emissions, both practically and ethically. Consider, again, Bangladesh. The United States could simply pay Bangladesh to use cleaner energy technologies. For example, we could establish a kind of negative carbon tax: if Bangladesh installs a more environmentally friendly power plant (e.g., highly efficient gas-fired cogeneration, or wind or solar power) that will produce some number of kilowatt-hours over its lifetime, we could compute how much carbon would have been produced by an equivalent coal plant and subsidize the cleaner plant by what would have been carbon tax on the fossil fuel the other plant would have used. Such use of Americans' tax money likely would be much more effective at combating climate change than, say, the purchase of electric buses.

In short, the best policy to tackle climate change is to "pick the low-hanging fruit" — to look for low-cost policies that have a relatively large effect on reducing emissions. And the biggest low-hanging fruit is emissions from the burning of coal. There is a lot of coal around the world, and it is cheap to extract and burn. That is why coal-fired power plants have fueled China's growth. The thing is, coal ultimately is not that much cheaper than greener alternatives like more-efficient gas cogeneration or — in the not-too-distant future — widespread solar and wind generation, both of whose prices continue to fall. A modest carbon tax would make coal uncompetitive with its cleaner competitors. Since the tax is modest, even if we overestimate the effects of global warming, the cost of that error would be low. And if we hold global coal use to its current level, that will do a lot of good if it turns out that we have underestimated the effects of warming.

Consider Figure 6. Here, the horizontal axis, again, is time. The vertical axis is the level of coal use with "3" being the current level. The solid lines show what happens if we do nothing (no carbon tax): coal use will grow to almost 100 times the current level in 200 years. If we have underestimated climate change, this growth in coal consumption will do a great deal of damage.

The dashed lines indicate what happens if we implement a

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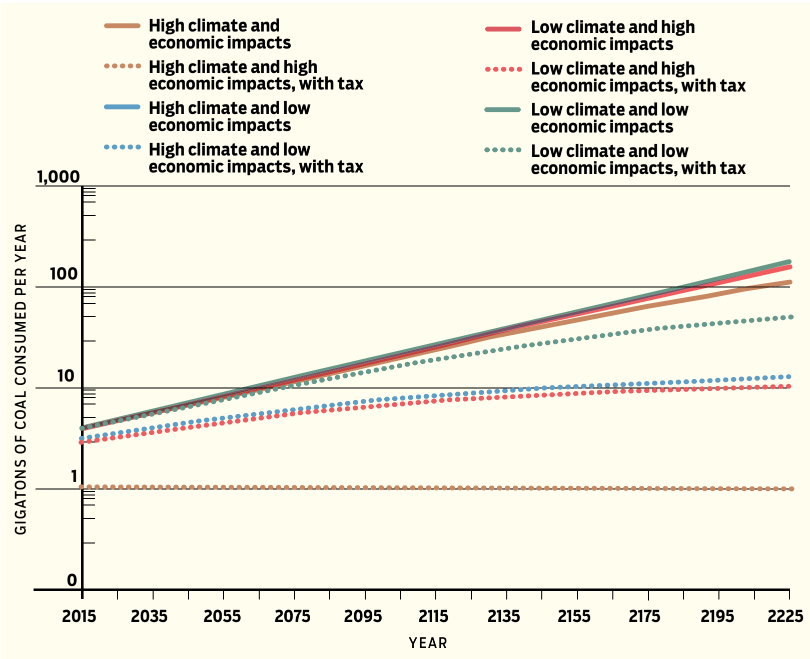
Figure 6

Coal Consumption Scenarios

Projected annual coal use under different economic sensitivity and carbon tax assumptions.



SOURCE: "The Consequences of Uncertainty: Climate Sensitivity and Economic Sensitivity to the Climate," by John Hassler, Per Krusell, and Conny Olovsson. *Annual Review of Economics* 10: 189–205 (2018).

Pigouvian carbon tax under different scenarios. One dashed line represents the case where we have overestimated the effects of warming and the resulting damage is small. In this case, the line is quite close to what we envisioned if the tax had worked perfectly. The other dashed line represents our underestimating the effects of climate change, and the Pigouvian tax helps to mitigate those costly effects.

In short, humanity simply needs to get rid of aging and inefficient coal-fired plants and stop building new ones. We can accomplish this with a moderate carbon tax that will not do great harm to growth or prosperity. And if we fail to take this relatively low-cost step and climate change proves worse than we expect, we will indeed have made a mess for our children, grandchildren, and generations to come.

CONCLUSION

From my reading of the expert literature, accepting the best estimates of scientists and analyzing critically — and accepting — the best estimates of economists, it would be foolish to engage in extreme measures to combat climate change. It would also be foolish not to pick the low-hanging fruit and adopt reasonable policies that would protect us from the risk that our estimates turn out to be optimistic. The best of those policies would be a carbon tax to discourage the building and continued operation of coal-fired power plants, and instead promote the use of cleaner forms of generation.

It is also important in mitigating climate change not to squander resources. There is a great deal of insularity in current climate policy: most countries focus on their own carbon emissions rather than world emissions. It may seem a problem only for the Swedes that they chose to set an excessively high carbon tax and phased out much of their carbon-based generation, which contributed little to global warming, or that countries like the United States use their climate-change spending to replace diesel buses with electric ones. But the problem is much bigger because the climate is a global commons: those resources could have been used to much greater effect by subsidizing greener energy in developing countries.

Another point worth noting: Though our analysis indicates that global warming does not pose an *existential* threat to civilization, that does not mean we should do nothing about it. We march and vote and adopt public policies to combat many problems that aren't existential threats. Climate change is a greater problem than most. There is every reason not to subsidize meat and fossil fuel production, every reason not to burn down forests and not to burn coal, every reason to investigate technologies that will mitigate climate change, and every reason to introduce a moderate global carbon tax in rich countries and an anti-carbon subsidy for poor ones. We should not lose sight of other problems in our effort to mitigate climate change, but we should also not lose sight of climate change in the press of solving other problems. R

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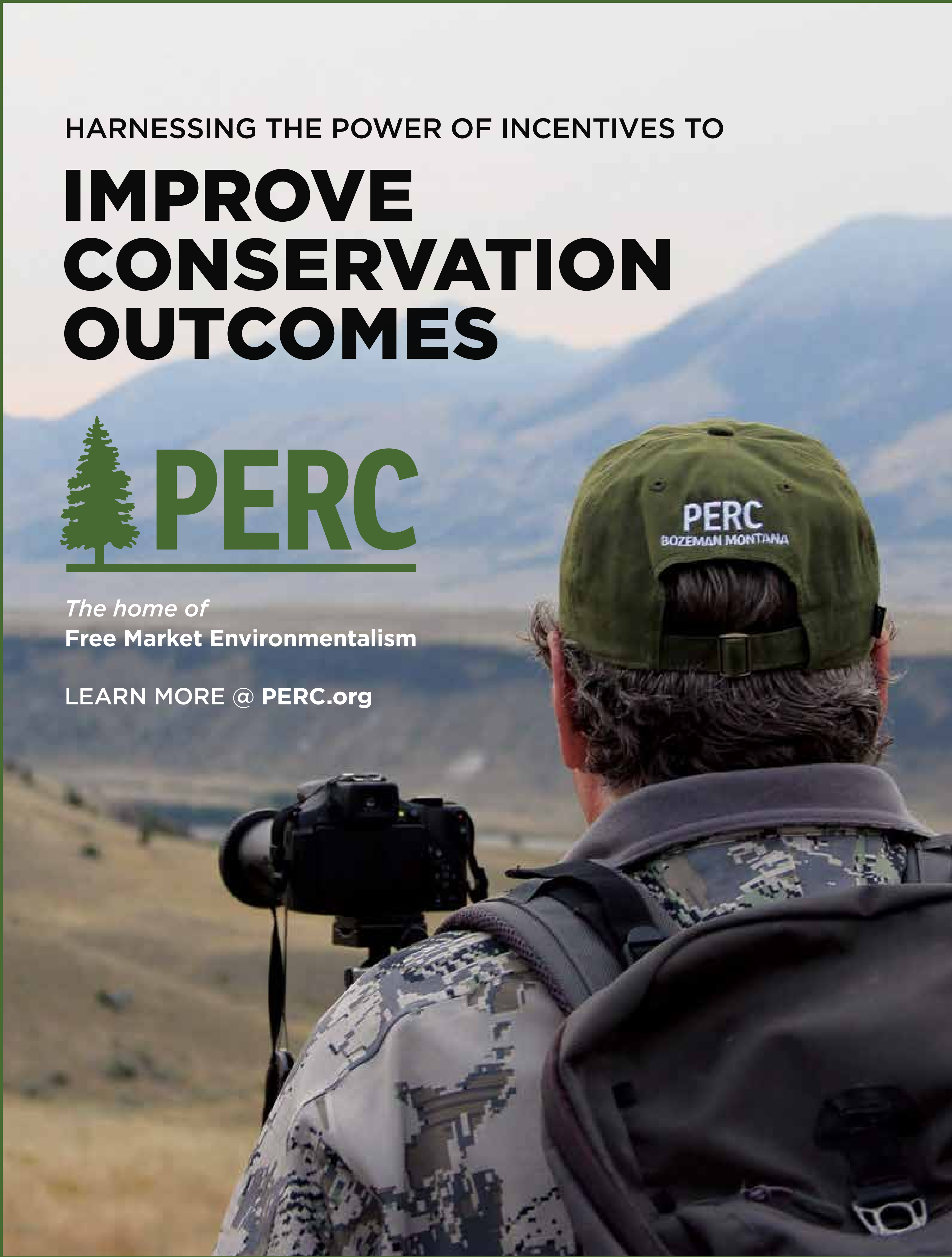

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