R E S P O N S E

Comment on *Climate Change and U.S. Interests* by Freeman and Guzman

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I. Introduction

In this sobering article, Freeman and Guzman (FG) challenge the argument that the United States could be a "climate change winner," which asserts that, due to its temperate climate and advanced economy, climate change will benefit the United States relative to other countries or even in absolute terms. They argue that, setting aside any moral argument that the United States has an obligation to act aggressively to reduce emissions, it is independently in its self-interest to do so.

The article for the most part focuses on systematic downward biases in economic damage estimates, including: (1) undue past and present optimism about future warming; (2) symmetric treatment of uncertainties that have asymmetric impacts on damages; (3) failure to account for catastrophic events, non-market costs, cross-sectoral impacts, and impacts on productivity; and (4) failure to account for the ways in which climate change impacts abroad, including increased food and water scarcity, extreme weather events, and disease outbreaks, could affect U.S. economic and military security.

The authors conclude with a rough benefit-cost assessment. They add up a collection of estimates for several damages missing from the models, and compare these against the cost of mitigation for a 500-550 parts per million stabilization scenario in 2050. They find that the benefits to the United States of mitigation exceed the costs: for a global expenditure equal to 4% of U.S. gross domestic product (GDP), the United States could avoid damages equal to 15% of GDP—an estimate that still excludes many potentially severe damages they identify.

FG concede that any individual damage estimate in this exercise might not stand up on its own. Nevertheless, they argue, the sum of them provides a more accurate and reliable figure than one that ignores them altogether.

We think this conclusion is sound and can think of several other factors that would increase the benefit-cost ratio in further support of FG, including current impacts of climate change that are outpacing expectations, appropriate discount rates, equity weighting, and risk aversion. We discuss these in Sections II and III below. We then shift focus in Section IV, and ask a bigger question: is benefit-cost analysis the best way to answer the "climate change winner" question? While we commend the authors' valiant attempt—papers like this are unavoidable in climate policy debates and need to be written—huge risks and path dependency make cost-benefit analysis a poor instrument for assessing appropriate climate policies. We suspect the authors agree, but that they realistically recognize that winning the debate in a benefit-cost framework is important, given its predominant influence in economics.

II. Current Impacts

Although damage estimates represent impacts from *additional* emissions above baseline levels, the paper would benefit from a discussion of U.S. impacts already underway, because they suggest the severity of future damages caused by inaction. We make three observations: (1) the inventory of current impacts is largely negative, and shows that even small changes in global temperature can lead to high damages; (2) average global temperature changes mask variation—some regions have experienced increases far above the average; and (3) adapting to these impacts has proved difficult.

The list of current negative impacts associated with climate change in the United States is staggering; it would be impossible to do it justice in a short comment. To note just a few: large-scale forest dieback; record numbers and sizes of forest fires; record floods and other heavy precipitation events; record heat waves; record pest and insect outbreaks; increased pollen production and asthma rates; population relocations from impacted coastal areas; sinking infrastructure above melting permafrost; stresses on energy and water systems, including salinization of fresh water supplies and early winter snowpack melting; ocean acidification; coral reef destruction; loss of sea ice, wildlife, and wildlife habitats; rapidly melting glaciers; and declines in cold-water fish populations.

An increase *of only 1.5 degrees F* in average global temperatures is associated with all of these changes, some still not fully materialized due to lags in the system. Many of these changes have been large in magnitude and have obvious economic impacts. Some statistics from a recent report[1]: the number of days with very heavy precipitation increased from 12% to 58% across different regions of the United States from 1958-2007 (p.44); since the mid 1980s, the average number of acres burned in forest fires increased from 45 to approximately 100 (p. 82, 5 year average); in the Cascade Mountains in the Northwest, snowpack declined by an average of 25% over the past 40 to 70 years, with some areas losing up to 60% (p.135); between 1999 and 2007 reservoirs in the Colorado River system, which supplies over 30 million people, lost approximately half of their water storage after the worst drought in 100 years of record keeping; Alaska average winter temperatures have increased by 6.3 degrees F, and the Midwest and Great Plains more than 7 degrees F (p.139 and 9, respectively); since 1992, the number of extreme weather electricity grid disturbances increased 10 fold (p.58); since 1999, 28,000 cases of West Nile virus have been reported, with over 1,100 deaths (p.95); between 1995 and 2009, the seasonal length of allergenic ragweed pollen production increased by as much as 44%.[2] The list goes on and on.

The report finds very few adaptation measures being taken in response to these strains. And, against all of the negative impacts, only a handful of positives, e.g., slightly longer growing seasons, reduced heating demand (but increased cooling demand), and increases in warm water fish species.

In addition to the impacts FG detail, these observations further suggest that damage estimates are too low, in particular estimates currently being used to inform U.S. climate policy. In February 2010, the U.S. government published its first official damage estimate for use in regulatory impact analysis. One of the models it used predicted net benefits from warming up to almost 5.4 degrees F (3 degrees C; FUND model)[3]; the impacts already underway suggest this is unrealistic. The models have also been criticized for making overly optimistic adaptation assumptions. For example, the default version of PAGE2002 assumed that in developing countries, eventually 50% of economic damages (e.g., property damage from rising sea levels) would be eliminated by low cost adaptation. In the wealthier OECD countries, it assumed that 100% of the economic damages resulting from the first 3.6 degrees F (2 degrees C) of warming, and 90% of economic damages above 3.6 degrees F, would eventually be eliminated. For non-economic (e.g., impacts on wilderness areas and animals) and non-catastrophic damages, adaptation is assumed to eventually remove 25% of impacts everywhere.[4, 5, 6] Current trends make adaptation assumptions like these implausible.

III. Discount Rates, Equity Weighting, and Risk Aversion

The inability to monetize impacts clearly keeps damage estimates low. Of equal importance are three parameters imposed upon the damages that actually are monetized, but were not addressed in detail by FG. The first is the social discount rate, used to compare costs and benefits now to those in the future,[7] the second is equity weighting, used to compare the impact of costs imposed on poor countries compared to rich ones, and the third is risk aversion, used to capture the fact that people are willing to pay premiums to reduce risks.

A. Discount Rates

FG note in their conclusion that sufficiently high discount rates could make the costs of mitigation appear higher than the benefits. The flip side of that is that a low discount rate could do the reverse, independently of the additional damages they discuss.

1. Global Climate Change Impacts in the United States, (Thomas R. Karl et al., eds., Cambridge Univ. Press 2009), *available at* http://downloads.globalchange.gov/usimpacts/pdfs/climate-impacts-report.pdf.
2. Lewis Ziska et al., *Recent Warming by Latitude Associated With Increased Length of Ragweed Pollen Season in North America,* Proc. Nat. Acad. Sci., Feb. 2011, *available at* http://www.pnas.org/content/early/2011/02/11/1014107108. Calculation from North Dakota observation in Table 1.
3. Interagency Working Group on Social Cost of Carbon, Appendix 15A. Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866, *in* U.S. Department of Energy, Final Rule Technical Support Document (TSD): Energy Efficiency Program for Commercial and Industrial Equipment: Small Electric Motors (2010), *available at* http://www1.eere.energy.gov/buildings/appliance_standards/commercial/pdfs/smallmotors_tsd/sem_finalrule_appendix15a.pdf.
4. No adaptation is assumed for catastrophic damages. All assumptions in PAGE2002 and PAGE09 discussed here were confirmed through personal communication with the model's author, Chris Hope. More detail for PAGE 2002 can also be found in Chris Hope, *The Marginal Impact of CO_2 From PAGE2002: An Integrated Assessment Model Incorporating the IPCC's Five Reasons for Concern,* 6 Integrated Assessment 19, *available at* http://journals.sfu.ca/int_assess/index.php/iaj/article/download/227/190.
5. The updated version of PAGE, PAGE09, has significantly revised adaptation assumptions that better reflect observed trends. After the first 1 degree C of warming, only 15% of economic damages from the next 2 degrees C can be eliminated in developing countries, and 30% in developed. Economic damages *beyond 3 degrees C total* of warming can no longer be eliminated anywhere by low cost adaptation. 15% of non-economic damages up to 2 degrees C can eventually be removed by adaptation, and (as in PAGE2002) no adaptation is assumed to be possible for catastrophic damages in PAGE09. *Id.*
6. Frank Ackerman et al., *Did the Stern Review Underestimate U.S. and Global Climate Damages?* 37 Energy Pol'y 2717–21(2009).
7. The social discount rate is used for assessing social costs and benefits, including externalities, in contrast to the private discount rate, which is used to assess private investments.

Guidelines by the U.S. Environmental Protection Agency (EPA) stipulate a social discount rate of 1% to 3% for impacts spanning multiple generations, while the U.S. Office of Management and Budget prescribes a social discount rate of 3% to 5%, allowing for sensitivity analysis from 1% to 3% for intergenerational impacts. Yet, in calculating its damage estimate (called the "social cost of carbon," or SCC), the U.S. government chose 2.5%, 3% and 5%. It used the SCC with the 3% rate as its main (or "central") estimate, arriving at a value of $21 per ton of CO_2. At 2.5% and 5%, respectively, the SCC was $35 and $4.7. Using the same models but proscribed intergenerational discount rates produces much higher SCCs. Johnson and Hope[8] re-ran the models used by the government, obtaining SCCs of $266, $122, and $62, for discount rates of 1%, 1.5% and 2%.

FG discuss the need to use a full probability distribution for climate sensitivity estimates rather than point estimates, due to the convexity of impacts for any given temperature increase (as temperature increases, damages become increasingly worse). An interesting parallel can be made with respect to the discount rate: it is also convex, with damage estimates increasingly higher the lower the discount rate. For example, an estimate of the SCC using a probabilistic 1% versus 3% discount rate, each with an equal chance of 50%, would yield an SCC of approximately $144,[9] compared to the deterministic value of $62 at the 2% midpoint. A similar calculation with 1% versus 5% yields approximately $135,[10] compared to a value of $21 at 3%. Both of these increase the $21 estimate by more than 6 fold.[11]

For comparison purposes, the Administration's central estimate SCC of $21/ton of CO_2 would imply total damages from today's emissions of roughly 1% of current US GDP ($21 x 7 billion tons annual emissions/$14 trillion). Assuming a central discount rate of 2% in the 1% to 3% intergenerational range translates to 3% of GDP ($62/ton of CO_2), a probabilistic discount rate between 1% and 3% yields 7.2% of GDP ($144/ton of CO_2), and a probabilistic discount rate between 1% and 5% translates to 6.8% of GDP ($135/ton of CO_2). Taking FG's estimate of 4% U.S. GDP mitigation cost, the discount rate alone flips the benefit-cost ratio from less than 1 to greater than 1.

One question that emerges from this discussion is whether a high discount rate could outweigh the effect of a more complete representation of damages as advocated for by FG. In this instance, the authors would need different criteria from benefit-cost analysis to make their case.

Yohe and Hope[12] conducted such an exercise, by comparing the effect of changing climate sensitivity assumptions and the shape of the damage function in PAGE09 with changing the discount rate. They found an increase in the SCC resulting from increasing expected damages of about $80, versus a $70 decrease from increasing the discount rate.[13]

B. *Equity Weighting*

FG's argument does not rely upon any moral obligation the United States might have to bear a larger mitigation burden than poor countries—in fact, it is explicitly distinct from it. But it is interesting to see what happens to the SCC if one tries to account for inequitable climate impacts. One common way to do this in benefit-cost analysis is through equity weighting, which assigns more weight to each additional dollar of damage incurred as income levels decline. An equivalent amount of damages will thus be valued more for a low income than high income region. The method reflects the economic concept of diminishing marginal utility of income, which stipulates that as income increases, the utility obtained from each additional dollar is less. With losses in income resulting from climate damages, the concept works in reverse.

Like discounting, equity weighting turns out to have a huge impact on the SCC. Johnson and Hope also re-ran the government's estimate using the most common equity weight in the economics literature (a value of 1 for the "elasticity of marginal utility"). They found that for the government's central estimate (at the 3 percent discount rate), the SCC could increase by as much as 11 fold.

C. *Risk Aversion*

Taking into account risk aversion in the standard benefit-cost framework can also increase the SCC significantly. In an exercise similar to the Yohe and Hope analysis discussed above, Anthoff, Tol, and Yohe[14] compared the effects of discounting versus risk aversion on the SCC. They found that, using market-based discount rates (which are substantially higher than social discount rates), adjusting for risk aversion increased the SCC from approximately $11/tCO_2$ to $32/tCO_2$.[15]

8. Laurie T. Johnson & Chris Hope, Natural Resources Defense Council, Revisiting the SCC Estimates Developed by the U.S. Government: The Effects of Intergenerational Discounting Methods and Regional Equity Weights (2010).
9. (.5 x $266) + (.5 x $21) ≈ $144.
10. (.5 x $266) + (.5*$4.7) ≈ $135.
11. *See* Hope, *supra* note 4. One of the models used by the government, PAGE2002, treats the discount rate probabilistically using a triangular distribution, but this feature was turned off for the U.S. government's estimated SCC by specifying a constant discount rate, consistent with the other two models used by the government (FUND and DICE).
12. Gary Yohe & Chris Hope, *Some Thoughts on the Value Added From a New Round of Climate Change Damage Estimates*, EPA/DOE Workshop on Improving the Assessment and Valuation of Climate Change Impacts for Policy and Regulatory Analysis: Research on Climate Change Impacts and Associated Economic Damages (2011), *available at* http://yosemite.epa.gov/ee/epa/eerm.nsf/vwAN/EE-0566-128.pdf/$file/EE-0566-128.pdf.
13. For details of the methodology the authors used to determine how much to change the assumptions, the reader is referred to the original paper. The calculations here are based upon adding the changes in the SCC resulting from the two changes made in the damage assumptions, as well as adding the changes resulting from increasing two components of the discount rate—the pure rate of time preference and the marginal elasticity of utility.
14. David Anthoff et al., *Risk Aversion, Time Preference, and the Social Cost of Carbon*. 4 Envtl. Res. Letters. 1–7, *available at* http://ideas.repec.org/p/esr/wpaper/wp252.html.
15. Converted from t/C in the original paper.

IV. Strategic Risk Management

Although the benefit-cost case the authors make is necessary in the policy debate, and the incorporation of low discount rates, equity weighting or risk aversion further increase the benefit-cost ratio of reducing emissions, we contend that the framework is not the most appropriate way to assess climate policy. The benefit-cost decision rule stipulates mitigating emissions up to the point where the marginal cost of reducing a ton of CO_2 is equal to the marginal benefit. This paradigm works well for analyzing policies with known and quantifiable impacts if technology is static (technically, cost-benefit analysis assures economically efficient policies under conditions of perfect information and invariant production possibility frontiers). For example, cost-benefit analysis may be a good way to decide whether a new baseball stadium deserves public subsidies, but we don't use cost-benefit analysis to make strategic foreign policy decisions, such as whether to side with the pro-democracy protesters or the Mubarak regime in Egypt.

With climate change, the conditions required for a sensible cost-benefit analysis don't hold. We don't know what the impacts will be. We don't know if, or how many, catastrophic outcomes will occur. And we don't know how to quantify the vast majority of impacts, especially "non-market" damages, such as the intrinsic value of species or ecosystems. (Perversely, economic models often cap damage estimates at the value of GDP, which excludes the very things missing from the models, non-quantified market and non-market damages—yet these damages could be orders of magnitude higher than GDP.)[16]

On the other side of the ledger, we don't know how much it will cost to reduce emissions, or even if there will be net costs or net benefits from emission reduction strategies, excluding avoided climate change damages. A key reason these costs are unknown is that economic models can't predict innovation, even though this is the primary engine of economic growth in advanced economies. For example, climate policies designed to reduce CO_2 emissions from automobiles stimulates innovation in electric vehicle technology, which also has economic and security benefits by reducing U.S. dependence on petroleum.

Under these conditions, benefit-cost analysis loses its ability to inform rational policy. In a sense, it is a distraction from what might more appropriately be viewed as a strategic decision to invest in carbon-reducing innovation and minimize the risk of catastrophic losses from climate disruption.

People's "revealed preferences" in insurance markets reflect the desire to avoid catastrophic losses even if it costs them more in insurance premiums than the expected value of the payout received. The best analogy is probably life insurance. Parents are willing to pay for policies with negative expected returns in order to protect their children from the low probability, but catastrophic, event of parental death. Risk and losses are reduced in a financial sense, but not all damages can be completely compensated.[17] While incorporating risk aversion within the benefit-cost framework as discussed above is a step in the right direction, it is still in a framework of maximizing expected returns rather than minimizing losses.

Even if economic models were changed to reflect the authors' concerns of missing damages and catastrophic risk, resulting increases in the SCC could be "undone" by making conservative discount rate assumptions, or still result in "too low" an expected damage due to low probabilities being assigned to bad outcomes, or an unwillingness by decisionmakers to equity weight or adjust for risk aversion, as was the case with the U.S. government's SCC.

The benefit-cost framework of expected damages versus benefits can still give the "wrong answer," because it asks the wrong question. Instead, the vast picture of uncertainty the authors paint, including the volume and magnitude of the potential damages they enumerate, suggests a risk management approach. They provide an impressive exposition of how Martin Weitzman so aptly describes the problem:

> There exists here a very long chain of tenuous inferences fraught with huge uncertainties in every link beginning with unknown base-case GHG emissions; then compounded by huge uncertainties about how available policies and policy levers transfer into actual GHG emissions; compounded by huge uncertainties about how GHG-flow emissions accumulate via the carbon cycle into GHG-stock concentrations; compounded by huge uncertainties about how and when GHG-stock concentrations translate into global mean temperature changes; compounded by huge uncertainties about how global mean temperature changes decompose into regional temperature and climate changes; compounded by huge uncertainties about how adaptations to, and mitigations of, climate-change damages are translated into utility changes—especially at a regional level; compounded by huge uncertainties about how future regional utility changes are aggregated—and then how they are discounted—to convert everything into expected-present-value global welfare changes. The result of this immense cascading of huge uncertainties is a reduced form of truly stupendous uncertainty about the aggregate expected-present-discounted utility impacts of catastrophic climate change, which mathematically is represented by a very spread out, very fat-tailed PDF [distribution] of what might be called "welfare sensitivity" . . . [with] the value of "welfare sensitivity" . . . effectively bounded only by some very big number representing

16. Many environmental goods could, in theory, be exchanged in markets but currently are not. They are therefore not reflected in GDP—which measures the monetary value of all goods and services exchanged in the economy. In addition, there are "non-market" environmental goods, which cannot be exchanged in private markets, such as the aesthetic value of clean air or the "existence" value of a species or ecosystem. Economists conduct surveys to estimate what people are willing to pay for market and non-market goods that are not bought and sold in markets. The number of these is very large, making GDP a poor estimate for wealth and welfare.

17. It is important to note that risk management does not address moral arguments with respect to poor countries and future generations unless the level of risk reduction chosen by the United States is the same as what those populations would choose.

something like the value of statistical civilization as we know it or maybe even the value of statistical life on Earth as we know it."[18]

The only sensible policy that emerges from this picture is one that reduces probabilities of catastrophic outcomes by strategically investing in a clean energy future.

18. Martin L. Weitzman, *On Modeling and Interpreting the Economics of Catastrophic Climate Change*, 91 Rev. Econ. & Stat. 5-6 (2009).