Challenge

ISSN: 0577-5132 (Print) 1558-1489 (Online) Journal homepage: https://www.tandfonline.com/loi/mcha20

The Economics of Mitigating Climate Change?

What Can We Know?

Richard A. Rosen & Edeltraud Guenther

To cite this article: Richard A. Rosen & Edeltraud Guenther (2014) The Economics of Mitigating Climate Change?, Challenge, 57:4, 57-81, DOI: 10.2753/0577-5132570405

To link to this article: https://doi.org/10.2753/0577-5132570405

The Economics of Mitigating Climate Change

What Can We Know?

Richard A. Rosen and Edeltraud Guenther

Economic analyses of the long-term costs of mitigating climate change are unknowable, argue these authors. To base climate policy on them is irresponsible. However, the authors support the moral argument that it is necessary to control climate because its likely devastating effect on human civilization is reason enough to pursue climate mitigation policies. This technical paper is a valuable retort to economic oversimplifications prevalent in the climate change literature.

RICHARD A. ROSEN *is a senior fellow and founder of the Tellus Institute in Boston. He has researched energy system, climate, and electric utility policy issues since 1976 and on behalf of the U.S. Department of Justice and state attorneys general. He has written reports on his specialty, energy system planning and forecasting methodologies, for the U.S. Department of Energy and the Environmental Protection Agency.* ***EDELTRAUD GUENTHER*** *holds the chair in environmental management and accounting at the Technische Universitaet Dresden. Since 2005, she has held a joint appointment as visiting professor at the University of Virginia's Mcintire School of Commerce, teaching and researching in the field of sustainability management. This article is a re-edited and shortened version of an article published under the same title in the online journal* Technological Forecasting and Social Change *(February 22, 2014).*

Challenge, vol. 57, no. 4, July/August 2014, pp. 57–81.

ISSN 0577-5132 (print)/ISSN 1558-1489 (online)
DOI: 10.2753/0577-5132570405

Over the past decade, dozens of articles, reports, and papers have addressed the economics of mitigating climate change (Edenhofer et al. 2010; van Vuuren et al. 2011). The negative impacts of climate change on the physical world have become more frequent, and most proposed climate mitigation targets have become more stringent. Today, the generally accepted temperature target, on which most governments agree, would limit the increase caused by greenhouse gas emissions emanating from human-related activities to 2°C (3.6°F), relative to preindustrial times, by 2100. As years pass, the time remaining to meet that target decreases quickly, given recent rates of increase in greenhouse gas concentrations in the atmosphere. Furthermore, the costs of mitigating climate change will tend to increase if mitigation is delayed and if future energy technology costs and performance characteristics follow current forecasts.

The best and most recent comprehensive reviews of the economics of mitigating climate change appeared in the Working Group III report of the Fourth Climate Assessment of the Intergovernmental Panel on Climate Change (IPCC) and the Stern Review, sponsored by the British government in 2006 (IPCC 2007; Stern 2007). We focus on them here. The economic modeling efforts for analyzing climate change mitigation for the new Fifth IPCC Climate Assessment, released in April 2014, are also the basis for our analysis. It is, therefore, particularly timely to reassess the state of the art in estimating the net benefits or costs of mitigating climate change over the next hundred years and, moreover, to discuss the scientific rigor and the political relevance of these studies.

At this point in the evolution of trying to estimate the net benefits or costs of mitigating human-induced climate change through 2100, we should ask how our understanding of these estimates has evolved since 2006, if it has, and what we now really know. This question is particularly important in considering the even stricter mitigation scenarios that are consistent with limiting the temperature increase to less than 2°C over this century. This article, therefore, primarily addresses three questions:

1. Has there been much, or any, progress made in producing rea-

sonably accurate net benefit or cost estimates for mitigating climate change over the next century since 2006?

2. Is progress even theoretically possible, especially in light of the likely very wide range of changes in the future cost and operating parameters of both supply- and demand-side technologies?

3. What should we substitute for economic forecasts of mitigation costs to lay a more profound basis for decision-making to mitigate climate change?

The analytical context for addressing these vexing questions is the large number of fundamental uncertainties inherent in attempting to make such projections. Many of these uncertainties reflect what are often called deep or radical uncertainties, which further research today cannot resolve for the long-term future (Walker et al. 2003; Zurek and Henrichs 2007). As is the case in most complex systems, economic forecasts are highly uncertain in a scientific sense after a fairly short initial period, just as daily weather forecasts are unknowable for a month, or even less. However, most integrated assessment models used to analyze the economics of climate change have hundreds of input parameters, each of which is highly uncertain in the long run. Thus, this review of past attempts to determine the economics of climate change mitigation over the long run leads directly to the hypothesis that the net benefits or costs are unknowable because of the many deep uncertainties involved (INET Blogs 2013; Pearce and Weyant 2008). In addition, mitigation scenarios represent major transformations of the economy relative to baseline scenarios and, thus, represent large and highly nonlinear changes that will strongly impact the development of new energy technologies on both the supply and demand sides, as well as other relevant technologies that offset greenhouse gas emissions worldwide.

Thus, falsely claiming to know that a hundred-year analysis of the economics of mitigating climate change shows "net costs" of X percent of the gross domestic product (GDP) serves only to scare off politicians and other policymakers from doing much to mitigate climate change. Yet "net costs" are almost always reported to the public, not net economic benefits of mitigation, for reasons that are fundamentally unjustifiable. Consequently, decisions to mitigate climate change are not popular, and politicians try to avoid this topic in election campaigns.

Such a claim that the world will need to incur net costs to mitigate climate change would then serve no scientific purpose, since we cannot know if it is true. Committing to embarking on a vigorous campaign to mitigate climate change is fundamentally a moral issue, not a long-run economic issue. Claiming that this imperative can be based on projections founded in incremental economic changes to our current trajectory also undervalues the importance of more radical, but desirable, changes to our consumption patterns that could be implemented to mitigate climate change, while improving our way of living. Our analysis concludes that we should stop trying to assess the long-run economics of mitigating climate change, since that is unknowable. Instead, modeling work on the economics of mitigating climate change should focus on the details of how to actually make it happen, beginning now, in a way that minimizes costs and maximizes the well-being of all people on our fragile planet over the short to medium term.

Three Key Aspects of Integrated Assessment Models

Since almost all the recent assessments of the economics of climate change have relied on "integrated assessment models" (IAMs), this article focuses on enhancing our understanding of how those models typically calculate the net benefits and costs of mitigation over the next century. At the most general level, IAMs attempt to couple a representation of the world's economic systems to its energy- and land-use systems for about a dozen regions of the world in order to calculate how greenhouse gas emissions are likely to change as the magnitude and structure of the economy changes. The models then couple these projections of greenhouse gas emissions into the atmosphere, biomass, and oceans to simple climate change assessment models that yield likely temperature increases for any given future year.

This article does not delve into the issue of the incremental ecological and other damages that are avoided by mitigating climate change to a specified level relative to a base or reference case set of damages. The topic of damages is very important, as we discuss below, but none of the previous damage functions incorporated into IAMs seem to have much basis in fact, nor could they since economic damages from climate change are just beginning to be felt worldwide (Hunter and Schmidt 2004; Ortiz and Markandya 2009; Pindyck 2009).

This article considers two main aspects of existing climate IAMs: (1) their overall structure and level of technological disaggregation and (2) the reasonableness of the input assumptions, both historic and future, for key parameters within these equations, including those that apply to new energy supply and end-use technologies. These topics are treated solely from the perspective of how they affect the calculation of the net benefits and costs of mitigating climate change and the usefulness of these results to policymakers who are trying to significantly mitigate climate change.

To What Should the Costs of a Mitigation Scenario Be Compared?

To calculate the net benefits or costs of mitigating climate change, we must compare two scenarios. Most studies compare the net costs of a "reference" or "baseline" case to the net costs of a mitigation case, such as a scenario in which the global temperature increase is limited to 2°C by 2100. The construction of the reference case usually only assumes that no new climate-mitigation policies are implemented beyond those in place today. Conceptually, then, the reference case represents the costs to society that would actually result if the current level of climate change–mitigation policies were maintained.

But there is a major problem with this approach. Integrated assessment modelers (and models) cannot forecast with reasonable accuracy what would actually happen to the trajectory of greenhouse gas emissions if no new mitigation policies were adopted worldwide over the next fifty to a hundred years. In particular, failing implementation of new climate change–mitigation policies, there might be a major economic crisis resulting from climate change that causes the trajectory of GDP, or other economic indicators, to deviate substantially from the assumed projections. But integrated assessment modelers never model feedback between the amount of climate change and economic growth and would have an extremely difficult time doing so if they tried. The economy in a reference case could also begin to collapse because of the depletion of fossil fuel reserves, or because of a financial crisis. But even without considering climate change or resource depletion, no economist could possibly forecast the global economy for the next fifty to a hundred years with any reasonable accuracy for the purpose of policy-making. And because forecasting the future of the energy economy for the next fifty to a hundred years is impossible (not just difficult), there is no valid baseline emissions scenario to which the costs of a mitigation scenario can be compared.

It is not surprising, then, that when different IAMs calculate the net costs or benefits of mitigating climate change, the models and modeling teams end up using a very wide range of greenhouse gas–emissions trajectories as their reference case (IPCC 2007, figure 3.8, 187). This reflects, in part, the tremendous uncertainty in making fifty- to a-hundred-year economic and greenhouse gas emissions forecasts. The uncertainties reflect both the uncertainty in the underlying economic (GDP) forecasts as well as the uncertainties associated with how the assumed internal operating parameters and costs of dozens of energy supply and demand technologies will change over the long run in this scenario. Thus one cannot simply compare the net costs of mitigating climate change across different model results without explicitly accounting for the differing emissions trajectories of the reference cases. For example, if two models develop a mitigation scenario for the same level of temperature increase in 2100, but one model needs to reduce average emissions by 50 percent more than the other relative to their reference cases during the 2005–2100 period, then one would expect the net costs of mitigating this higher level of reference case emissions to be more than 50 percent higher in order to achieve the same final mitigation scenario. (The net costs would probably be more than 50 percent higher because the net marginal costs of mitigation tend to increase the greater the mitigation requirement.) In conclusion, right from the beginning, if the research community cannot even develop a reasonably accurate reference case with very limited uncertainty over the next hundred years, then the net long-run costs of mitigating climate change cannot be calculated either, since they are derived by identifying the usually small differences in costs between the reference case and mitigation case scenarios.[1] Yet doing so is impossible for all the reasons stated above.

The Stern Review and Its Meta-Analysis of IAM Net Cost Results

The famous 2007 Stern Review relied solely on the results from other research team IAMs regarding the net cost of mitigating climate change. The review lists many requirements of an adequate IAM methodology for computing the net costs and benefits of mitigation (Stern 2007). It says that a broad assessment of net costs "requires a thorough modeling of consumer and producer behavior, as well as the cost and choice of low-GHG [greenhouse gas] technologies" (p. 268). It goes on to say,

> Models should cover a broad range of sectors and gases, as mitigation can take many forms, including [reducing] land-use and industrial-process emissions. Most models, however, are restricted to estimating the cost of altered fossil-fuel combustion applied mostly to carbon, as this reduces model complexity. Although fossil-fuel combustion accounts for three-quarters of developed economies' carbon emissions, this simplifying assumption will tend to over-estimate costs, as many low-cost mitigation opportunities in other sectors are left out. (Stern 2007, 269)

The Stern Review then lists the key model comparison studies carried out in, or recently before, 2006 and comments that "the wide range of model results reflects the design of the models and their choice of assumptions, which itself reflects the uncertainties and differing approaches inherent in projecting the future" (p. 269). The Stern critique of typical inadequacies in IAMs, with which we agree, describes, therefore, a major methodological problem with its own reported results, as seen below.

To get a better sense of the kinds of additional future uncertainties that even the Stern Review fails to address, we will refer the reader to a lengthy technical critique we have published elsewhere of the meta-analysis of IAM-generated cost projections carried out by Barker, Qureshi, and Koehler, which the Stern Review itself commissioned and on which it relied (Barker et al. 2006; Rosen and Guenther 2014). This meta-analysis seems to have provided the primary basis for the Stern Review's conclusion that the net costs/benefits of mitigating climate change (on a present-value basis) by 2050 probably lie in the range of a cumulative (not annual) loss of GDP of 1 percent, plus or minus 3 percent, by 2050. At first, this appears to be quite a wide range compared to the central value, and it allows for the possibility that GDP growth could be at least as high as 2 percent more in the mitigation scenario than in the reference case, or 4 percent lower. But, on the other hand, since even +2 percent in cumulative GDP growth over forty to forty-five years is only about +0.05 percent per year, on average, we see that the entire range of results cited by both Barker et al. (2006) and Stern (2007) is, in fact, extremely small relative to average historical global GDP growth rates, which were in the range of 2–3 percent per year. Anyone who is aware of typical inaccuracies in making economic forecasts, even over the short run, would assume that the cumulative uncertainty in such estimates in the long run would be vastly greater than the average annual value of 0.05 percent in the results cited in the Stern Report (Stern 2007).[2] (Paul Krugman [2014]recently characterized such a small annualized figure as a "rounding error.") Consequently, then, the Barker meta-analysis was not a valid basis on which the conclusions of the Stern Review could appropriately rest.

The IPCC's Fourth Climate Change Assessment, 2007

For our purposes, the most relevant chapter in the IPCC's Fourth Assessment is chapter 3 of the Working Group III report, "Issues Related to Mitigation in the Long Term Context" (IPCC 2007). There, the authors point out that "the costs of stabilization crucially depend on the choice of the baseline, related technological change and resulting baseline emissions; stabilization target and level; and the portfolio of [mitigation] technologies considered. . . . Additional factors include assumptions with regard to the use of flexible [policy] instruments and with respect to revenue recycling [of carbon taxes]" (IPCC 2007, 172). As a basis for analysis, the chapter uses the results of the Energy Modeling Forum (EMF 21) scenarios and the Innovation Modeling Comparison Project (IMCP) network scenarios (Energy Modeling Forum 2011a, 2011b). However, the authors note that "these new modeling comparison activities are not based on fully harmonized baseline scenario assumptions, but rather on 'modeler's choice scenarios'" and that "further uncertainties have been introduced due to different assumptions and modeling approaches" (p. 174). It is important to note that Barker et al.'s meta-analysis of economic results for the Stern Review, discussed above, included most, if not all, of these scenarios run by the same IAMs as well (Barker et al. 2006, 18–20). Chapter 3 also states that another difficulty in making analytically sound comparisons between the economic results of different IAMs is that the "information and documentation of the scenarios in the literature varies considerably" (p. 174), which is a nice way of saying that important parameter values and model methodologies for running many scenarios were never well documented in the literature.[3]

Since our focus here is on the economic costs and benefits of mitigating climate change, it is important to point out first that, as the IPCC states, "there are different metrics for reporting costs of emissions reductions, although most models report them in macroeconomic indicators, particularly GDP losses" (2007, 172). That the results of different model runs are reported in terms of different metrics adds to the lack of clarity about how to interpret the net costs or benefits of mitigating climate change in the literature, if not to the uncertainty in the reported numbers themselves. Changes in GDP in going from a baseline to a mitigation scenario, in particular, reflect not only the costs and benefits of mitigating climate change, but also many complex related changes within the economy, e.g., rebound effects for energy demand. Yet the IPCC cites the net costs of mitigation over the long run as one of the most important results of chapter 3. The reported results range from very small net benefits to the statement that "GDP losses in the lowest stabilization scenarios in the literature (445–535 parts per million carbon dioxide [CO_2] –equivalent) are generally below 5.5 percent by 2050" (2007, 172; see note 1). Furthermore, there is a much more fundamental question as to whether decreases to the GDP really represent a net cost to society or a net benefit. Clearly, the answer depends on what components of the GDP are decreasing or increasing. For example, if the share of GDP due to the highly polluting fossil fuel industry decreases, then, other things being equal, society will be better off. But the IPCC fails to discuss this key issue at all in its Fourth Assessment.

Besides the uncertainty and confusion created by relying on different models using different metrics to report their net cost results, another significant source of uncertainty is whether or not the models include estimates of the economic damage avoided by mitigating climate change. In fact, as noted above, most climate IAMs do *not* include estimates of net damages, a major omission if one wants to give policymakers a clear and comprehensive view of the economic trade-offs of mitigating climate change. In addition, chapter 3 states, "Due to considerable uncertainties and difficulties in quantifying nonmarket damages, it is difficult to estimate SCC [social cost of carbon] with confidence. Results depend on a large number of normative and empirical assumptions that are not known with any certainty" (IPCC 2007, 173). This is also very likely the main reason why most IAMs do not include estimates of avoided damages when quantifying the net costs of mitigating climate change, but one might make the same equally valid statement about almost all the long-term input assumptions these models make. Finally, chapter 3 of the IPCC report points out that another source of uncertainty and inaccuracy in all the economic results is that for the IAMs on which it relies, "the risk of climate feedbacks is generally not included in the . . . analysis" (p. 173). Despite the fact that climate change will impact the reference or baseline case more strongly than any mitigation case, the IPCC does not take into account at all this differential impact on the world economy in the future. However, these differential impacts on metrics such as the GDP could be very substantial, even far larger than the impacts on GDP of attempting to simply mitigate climate change.

How, then, in light of all these acknowledged profound uncertainties and omissions, did the IPCC derive the net costs of mitigation that they report for comparison purposes, for different levels of mitigation? And why does the IPCC believe it is reasonable to even report such uncertain results given the serious misinterpretations of these results that could occur?

Section 3.2 in the IPCC report describes how the baseline scenarios were developed. Given that different modeling teams with different baseline scenarios assumed very wide ranges of the key drivers of CO_2 emissions, such as population and GDP growth, the results for baseline CO_2 emissions had an enormous spread by 2100, from nearly 0 tons per year to more than 200 gigatons per year. (For comparison purposes, the current levels of CO_2 emissions are "only" about 30 gigatons per year.) Interestingly, the average results for improvements in energy efficiency alone in the baseline scenarios were about 1 percent per year, ranging from about 0.5 percent to 1.9 percent per year depending on the model. As the report itself notes, "This range implies a difference in total energy consumption in 2100 of more than 300 percent—indicating the importance of the uncertainty associated with this ratio" (2007, 183).

Section 3.3 of the ICCP (2007) report's chapter 3 then describes how the mitigation scenarios were produced. Mitigation or abatement measures for reducing greenhouse gas emissions include structural changes in the energy system, fuel switching, greater use of low- or no-carbon energy supplies such as nuclear generation of electricity and carbon sequestration technologies, enhanced energy efficiency, and changes in land use (pp. 200–201). Figure 3.20 in the report provides an interesting perspective on the relationship between the cumulative CO_2 emissions of the baseline cases compared to the same quantity for the mitigation scenarios for the pairs of IAM runs analyzed in the

IPCC report (2007, 201). (A "pair" of scenarios is a mitigation scenario and the baseline scenario from which it is derived.) The high degree of scatter observed for the data points in this plot means that for any given total amount of CO_2 emissions in a baseline scenario, there is a very wide range of emissions reductions and, therefore, of absolute levels of emissions of the corresponding mitigation scenarios analyzed by the IAM teams. This demonstrates that for the same baseline level of emissions over the 100 years from 2000 to 2100, different IAMs or different sets of input assumptions lead to very different results for CO_2 emissions from the corresponding mitigation scenario in the different pairs of scenarios. This high degree of scatter would also lead to a high degree of scatter and uncertainty in the incremental costs of mitigation, if these costs were plotted in a similar fashion.

Section 3.3.5.3 of the Fourth IPCC Assessment report (2007) specifically addresses the issue of the "stabilization" or mitigation cost results that derive from the many pairs of baseline/mitigation scenarios analyzed. Again, the report stresses that the economic results are given in three different metrics depending on the IAM used: GDP losses, the net present value of abatement costs, and carbon prices. These cost results are presented separately for each output metric, as they should be, in figure 3.25 (2007, 205). This figure shows the relationship between the net costs, as measured by each of the three different metrics, and the stabilization targets or "categories." (A stabilization "category" represents a fairly narrow range of expected temperature increases due to climate change over the long run.) Again, as expected, we find a wide range of economic results for any given stabilization category. For example, for the strictest mitigation categories I and II, the net long-run economic results for each of the three metrics can vary by factors of five to ten, or more. Thus, the IPCC analysis indicates that depending on the IAM used and the set of cost and price assumptions input to each IAM for any single scenario, the net costs or benefits of mitigating climate change are projected to vary widely, even when the results are segregated by both the type of economic metric reported and the likely impact on the climate of the mitigation scenario.

Finally, the IPCC report provides a summary of the quantitative economic results for mitigation categories I and II. It finds that "[the cumulative global] GDP losses of the lowest stabilization categories (I&II) are generally below 5.5 percent by 2050. . . . The absolute GDP loss numbers for 2050 reported above correspond on average to a reduction of the annual GDP growth rate of less than . . . 0.12 percentage points for the categories . . . I & II" (2007, 206). (Note again that the cumulative 5.5 percent reduction in GDP by 2050 is claimed by the IPCC to translate into an annual average reduction of only about 0.12 percent in each year from 2000 to 2050.) This statement implies that out of an annual average GDP growth rate of, perhaps, 2.0 or 2.5 percent projected throughout the twenty-first century in the baseline case, the change in GDP due to climate change mitigation is assumed to be able to be measured, on average, as precisely as 0.12 percentage points per year for fifty years.

On the contrary, given all the uncertainties and variability in the economic results of the IAMs, especially for category I and II results, the claimed high degree of accuracy in GDP loss projections is highly implausible. After all, economists cannot usually forecast the GDP of a single country for one year into the future with such a high accuracy, never mind for the entire world for fifty years or more. We must conclude from the results cited by the IPCC itself that projecting GDP losses due to mitigating climate change to be below 5.5 percent cumulatively by 2050 is quite unknowable to any reasonable degree of accuracy, especially in light of the huge uncertainties that exist for each of hundreds of input parameters to each IAM that this argument does not even take into account.

If one compares the basic results for the net long-run costs of mitigation between the 2007 IPCC report and the Stern Report, the similarity in these results is not surprising, since the set of IAM runs analyzed in the Stern and IPCC reports substantially overlap. However, it is not at all clear why the IPCC chapter 3 coauthors appear to believe that the results as presented in their figure 3.25 represented a reasonably complete range of results, given the many uncertainties and cost components involved in making such estimates that they do not even model. The range over which most economic results happen to cluster based on the input assumptions chosen by various IAM research teams does not even necessarily reflect the most likely range of values for the results. Problematically, the IPCC never attempted to present or analyze the actual ranges for different input assumptions the IAMs actually utilized to determine if a reasonably robust range for each parameter (of hundreds) had been relied on. Without analyzing the uncertainty in each type of individual input assumption, one cannot reasonably conclude that the results of the model runs do or do not represent a full range of uncertainty with respect to the possible economic costs and benefits of mitigating climate change. Thus, simply relying on the range of economic results the modeling teams just happened to choose to produce is not a scientific and systematic methodology for developing evidence relevant to the economics of mitigating climate change.

Energy Efficiency and the EMF 25 Study

The uncertainty in the extent to which investments are made in new energy-consuming technologies (the demand side) applies equally to major investments in entire new office buildings, new factories, new homes, or new cars. The carbon emissions for any single new investment in the same type of such items could easily vary by 20 percent, 40 percent, or even more, with respect to older alternatives, especially in the transportation sector. Consequently, the greenhouse gas emissions consequences of investments in new energy-consuming technologies in even a base or reference case would be highly uncertain, unless each new technology investment, in each year, could be precisely modeled. The emissions consequences of investments in new energy-consuming equipment and facilities, given changing consumption patterns, would be even more uncertain in a mitigation scenario.

Most climate IAMs are very simplistic in their treatments of end-use technological change, assuming nearly exact continuity of past energy-efficiency trends and a decrease in energy use of about 1.2

percent per dollar of GDP per year, when averaged over all sectors of the economy.[4] Building off that underlying historical trend, one critical question is how prominent IAMs account for energy efficiency improvements (and the investment decisions leading to such improvements) in climate change mitigation scenarios relative to the relevant reference case. This is a very important issue because enhanced energy efficiency is usually the first policy priority in real-world planning to mitigate climate change. Therefore, the net costs or benefits of investments in enhanced energy-efficient equipment for building shells, factories, transportation vehicles, and so on may prove to be either the largest or second-largest contributor to the total net costs and benefits of overall climate change mitigation as measured by the GDP, or other metrics. (The costs or benefits of changing the fossil fuel–based sources of energy to renewable energy sources are the other major contributor to changes in GDP.)

Amazingly, the recent literature on the economics of climate change contains almost no papers or reports that review the details of how IAMs treat investments in enhanced energy-efficiency technologies for each sector of the economy, and, separately, the impact on energy consumption of changing lifestyles. This is also true for the IPCC's Fourth Climate Assessment, as well as for the Stern Review. And, surprisingly, even though the Barker and Jenkins (2007) analysis relied on in the Stern Review claimed to focus on induced technological change as a new contribution to the literature, it barely mentioned enhanced energy efficiency as a type of such induced technological change and did not analyze it in appropriate detail.

However, one major exception to this void in the literature stands out: "Energy Efficiency and Climate Change Mitigation," a major study done by the Energy Modeling Forum (EMF) project 25 (Energy Modeling Forum 2011a). In fact, this project likely began in 2009 because of such widespread neglect of the topic of enhanced energy efficiency up to that point. (Note that this was fully two years after the publication of the IPCC's Fourth Assessment.) The EMF project 25 led to both a March 2011 report and a much longer set of articles published as volume 32 of the *Energy Journal* in October 2011 (Energy

Modeling Forum 2011a, 2011b). More than fifty energy and climate modelers and analysts, covering members of almost all the climate change–related IAM modeling teams throughout the world, participated in this project.

Although this project focused solely on the United States, it relied on the same basic methodologies used to model the economics of mitigating climate change worldwide. Specifically, EMF 25 analyzed the results from ten different IAMs run for the United States. Here we will focus on the analysis presented in the March 2011 report (Energy Modeling Forum 2011a). The "highlights" section of that report noted that some IAMs used for the study had an explicit treatment of some options (new technologies) for energy efficiency, while others relied more on "market responses and economic equilibrium," which probably means that only a very aggregate analysis of energy efficiency was performed (2011a, ix). In addition, the highlights note, "Other structural model features, parameter values and assumptions about key conditioning factors appear to be primary contributors to differences in model outcomes" (p. ix). Finally, one of the study's main conclusions was that "improvements are required to make the models more useful for policymaking" on energy efficiency (p. ix).

As noted, enhanced energy efficiency is a very important form of induced technological change for climate change mitigation because it is often very cost-effective for investors, that is, it has positive net economic benefits prior to consideration of any economy-wide rebound effects. (It saves people money.) This reflects the fact that national energy systems are not currently close to a state of economic equilibrium, in part because the world has substantially underinvested in enhanced energy efficiency in the past. Thus, the more new energy-efficient technologies are available, and the cheaper they become, the more likely the net costs of mitigating climate change as a whole will be negative, that is, there will be net benefits. New lifestyle patterns can accentuate these effects.

However, most of the IAMs that have been run for past IPCC climate assessments and many included in the Barker et al. (2006) database do not model energy efficiency well, or at all, either in terms of its direct impact on the energy system or in terms of the way new investments in energy efficiency impact the GDP. In the extreme case, some climate-related IAMs do not even allow for an increased level of energy efficiency in the mitigation scenarios relative to the baseline or reference scenarios, except, perhaps, implicit changes due to energy price elasticity impacts. In these mitigation model runs, it is not clear if there are any increased investments in energy efficiency modeled that impact GDP calculations, and some models' overly rigid structures may preclude mitigating climate change by enhancing energy efficiency at all.

In model runs where the amount of energy efficiency is allowed to increase in the mitigation scenarios relative to the reference scenarios, the maximum level of increased energy efficiency in EMF 25 often seems to be capped at about 0.5 percent per year, or less, in energy units per dollar of real GDP. This means that the entire economy cannot improve its energy efficiency by more than about 0.5 percent per year, usually starting from an approximate baseline of 1.2 percent per year increase in efficiency per dollar of GDP, the trend over the last several decades. The maximum rate of energy efficiency improvement averaged throughout the economy is, then, only about 1.7 percent per year, or less, in many climate mitigation scenarios. In contrast, even the fairly cautious International Energy Agency has supported policies to increase the level of energy efficiency improvements to about 2.5 percent per year from 2009 to 2035 in the "450 Scenario" in its 2011 annual report, and many environmental organizations argue that similar rates of improvement are possible and necessary (International Energy Agency 2011; World Wildlife Fund International 2011). Even higher rates of improvement are possible from an engineering perspective.

Evidentiary support for our earlier observation that most IAMs overly constrain the amount of enhanced energy efficiency allowed to occur in mitigation scenarios comes directly from the EMF 25 study (2011a). Again, some of the ten models on which it relied were general equilibrium models with very limited technology detail for end-use sectors. Some other models had more end-use technological detail, but instead of assuming that consumers always purchased the lowest-cost and most energy-efficient options, those models often constrained adoption rates for new, more efficient technologies to be consistent with "people's actual behavior," however so determined (p. 1). For the EMF 25 study, although some model input assumptions were made consistent between models for any given scenario, other input assumptions, such as "non-petroleum fuel prices and the costs and availability of electricity generation sources," varied "sharply," causing the results to vary significantly from one model to another (p. 3). The study does not explain why it chose not to harmonize these input assumptions as well. Having many key cost assumptions vary between models for the "same" scenario makes comparing the results of the model runs, as the study tried to do, potentially meaningless, since it is not clear what can be learned about the models themselves unless the results are somehow "corrected," or adjusted, for the differences in input assumptions, of which there are hundreds.

What is the implication, then, of the results of the most intensive model comparison exercise ever to focus on energy efficiency for mitigating climate change? The same modest carbon tax trajectory used in all the model runs was only sufficient to induce incremental efficiency improvements of about 0.5 percent per year through 2030, compared to the International Energy Agency–recommended incremental target of about 1.2 percent per year.[5] This is a very big difference relative to the IEA-recommended level, especially if it is projected far into the future. This difference of 0.7 percentage points per year amounts to about a cumulative 50 percent reduction in energy use by 2100 relative to 2005. Such a 50 percent reduction would clearly make the total costs of mitigating climate change far lower.

The Other Major Determinant of Net Mitigation Costs or Benefits

As noted above, the other major component of the cost of mitigating climate change, besides the cost of enhanced efficiency, stems from decarbonizing the energy supply sector. This includes the electricity, liquid fuels, solid fuels, and gaseous fuel sectors. Examples on the cost side of the equation are the cost of new wind turbines or solar cells to generate electricity and the cost of advanced biofuels for jet aircraft. The savings of converting to renewable energy in these supply sectors come from the displacement of fossil fuel–based electricity and traditional kerosene for aircraft engines, respectively. Again, the net benefit of mitigation derives from the difference between these two sets of costs, though we must also consider the "rebound" effect when calculating the magnitude of the overall macroeconomic benefits. (If the net benefits are negative [net costs], the rebound effect will tend to show lower energy demand in the remainder of the economy, and vice versa.) In theory, one of the virtues of having macroeconomic modules as part of IAMs would be their ability to compute the impacts of trade-offs, such as the rebound effect, within the economy. But a major unresolved issue is whether these existing macroeconomic modules in IAMs are at all accurate when attempting to compute the size of rebound effects or similar economic trade-offs. The lack of knowledge of the accuracy achieved in computing macroeconomic trade-offs between reference-case and mitigation-case scenarios is another major source of uncertainty in attempts to determine net mitigation costs.

The IPCC's Fifth Climate Change Assessment, 2014

The IPCC Working Group III has recently issued its new report on mitigating climate change (IPCC 2014). Most of the material would be quite familiar to readers of the 2007 assessment, and our initial review of the new report indicates that our basic critique of the 2007 report above is, unfortunately, still valid when applied to the new assessment. Thus, a detailed comparison of the two reports would not be appropriate or necessary here, since the underlying analytical methodologies have not changed at all. While the authors of the new Working Group III contribution to the Fifth Assessment report have included even more caveats in the text regarding the role of uncertainty and the limited capabilities of the integrated assessment models on which they relied, because the modeling literature available from 2008 to 2013 was very similar to the modeling literature published before 2007, the authors tell the same basic story as to their conclusions. In particular, they still maintain their basic theme regarding the overall economics of mitigating climate change, namely that there will be net costs to society in the long run in the range of 5–10 percent cumulatively by 2100, if the 2 °C limit for an average global temperature is to be achieved by then. Again, it is a mystery to us how the authors of volume 3 of the Fifth Assessment can both correctly enumerate such a long list of inadequacies in the models and input assumptions relied on to reach their basic conclusion, especially the complete omission of the huge economic damages that would be avoided by mitigating climate change, and at the same time include their numerical net cost results in both the detailed research chapter (chapter 6) and the 2014 Summary for Policy Makers.

Conclusions and Policy Implications

We have suggested that there are numerous reasons why the net cumulative benefits or costs of mitigating climate change are, in fact, unknowable for a period as long as fifty to a hundred years, especially for the purpose of basing any climate change–mitigation policy decisions on such calculations. In summary, those reasons are the following.

It is not possible to foretell the emissions trajectory of a reference or base case that assumes that no additional climate change–mitigation policies are adopted, since forecasting the future of the energy/land-use economy over fifty to a hundred years cannot be done to any relevant degree of accuracy. Thus, it is not at all clear what reference-case costs one could validly compare to any mitigation scenario costs. In addition, the impact of climate change itself on the economy, land, ecosystems, and water supplies is not typically modeled, yet these impacts will be very significant.

The mathematical structure of most integrated assessment models is far too aggregate on the demand or energy-consumption side to forecast even a reference case with any reasonable accuracy. And such an aggregate structure cannot lead to an adequate quantification of changes to the total cost of new and existing technologies in a stringent mitigation scenario. The current structure of most, if not all, IAMs is not even capable of forecasting changes in energy efficiency within the major sectors of the economy to any reasonable level of agreement between models, or agreement with "bottom up" efficiency studies.

The neoclassical economic basis of most of the macroeconomic modules contained within climate IAMs, as well as the microeconomic optimization methodology of many, has been strongly challenged by many economists as being inappropriate for forecasting the future of the world economy over long periods. In addition, these models do not even treat the financial sector of the economy explicitly and, thus, cannot predict financial problems caused by the energy sector and climate change, among other factors, that may affect long-term GDP growth (DeCanio 2003).

It is impossible to forecast what kinds of low-carbon supply technologies may be invented in the future, or how the efficiencies and costs of current low- or no-carbon technologies may change over the next century in either a reference case and, separately, in a mitigation case. All these unknowable technology parameters will significantly affect net mitigation benefits and costs for climate change, especially for newer technologies such as biomass-based carbon sequestration, on which many climate mitigation scenarios strongly rely. The same is true for forecasting fossil fuel prices and quantities likely to be available over the next hundred years.

No adequate intermodel comparison studies of either relevant reference cases or mitigation scenarios have been carried out with the quantitative input assumptions for the same scenario harmonized across all models to the extent allowed by their different structures. Because of differences in IAM model structures and in input assumptions, the IAM research community does not even know to what extent differences in economic results for the "same" mitigation or reference cases exist between models because of their differing structures alone.

Many different model results for the "same" or similar mitigation scenarios appear to differ significantly because of the different climate change–mitigation policies modeled and different structural ways of modeling these policies. The IAM research community has not yet developed and agreed upon a uniform or harmonized way of modeling climate change–mitigation policies. In addition, most IAMs cannot even model many important climate change–mitigation policies, such as mode shifting within the transportation sector or changing consumption patterns in industry, because the IAM structures are too aggregate.

Mitigation scenarios omit many types of costs, such as many transaction costs, and most IAMs do not even include avoided climate-induced damage costs in mitigation scenarios as a benefit. This is inexcusable, as both types of costs could be very substantial over fifty to a hundred years (Ortiz and Markandya 2009; Pindyck 2013; Stern 2013).

It is not appropriate to perform statistical meta-analyses on a database composed of an arbitrary set of IAM model results to compute net mitigation costs as the Stern Review did, especially when these results are based on very restricted ranges of model input assumptions and structural parameters. In addition, it is not clear what one could learn from such a meta-analysis, in part because each data point receives equal weight in the meta-analysis. Thus, whichever IAM produces the most scenario results included in the database will influence the results of the meta-analysis the most, for no good reason.

Because the current Western lifestyle cannot possibly serve as a role model for the lifestyles of the 9 billion people likely to inhabit our planet by 2050, significant but unpredictable changes to consumption and production patterns not incorporated in existing climate IAMs are likely to occur, adding another layer of uncertainty to the economic calculations made by these IAMs for the net costs and benefits of mitigating climate change. For the reasons cited above, and other reasons, not only can we not know the approximate magnitude of the net benefits or costs of mitigating climate change to any specific level of future global temperature increase over the next fifty to a hundred years, we also cannot even claim to know the sign of the mitigation impacts on the gross world product, or national GDPs, or any other economic metric commonly computed. Thus, the IPCC and other scientific bodies should no longer report attempts at calculating the net economic impacts of mitigating climate change over the long run to the public in their reports. Since most other aspects of reference and mitigation case scenario results, such as energy technology mixes, depend entirely on the economic trade-offs modeled, they should not be reported either.

The final question is, then, should these findings and conclusions about the inadequacies of current IAMs really matter to policymakers who are trying to figure out when, and to what extent, to implement effective climate change–mitigation policies? Our answer is "no," because humanity would be wise to mitigate climate change as quickly as possible without being constrained by existing economic systems and institutions, or risk making the world uninhabitable. This conclusion is clear from a strictly physical and ecological perspective, independent of previously projected economic trade-offs over the long run, and it is well documented in the climate change literature. As climate scientists constantly remind us, even if the world successfully implemented a substantial mitigation program today, a much warmer world is already built into the physical climate system. And since we can never know what the cost of a hypothetical reference case would be, and since we must proceed with a robust mitigation scenario, we will never be able to determine the net economic benefits of mitigating climate change, even in hindsight. Going forward, the key economic issue on which policymakers (and IAM research teams) should focus is how to implement as cost-effective and stringent a mitigation scenario as possible in the short to medium term, with periodic adjustments to such a plan. Making realistic plans to mitigate climate change requires much more specialized and detailed sectoral planning models than the current IAMs to carry out least cost/maximum benefit planning in each sector of the economy in order to create hopeful, normative mitigation scenarios that improve the well-being of both humanity and the ecosystems of the planet.

Notes

1. Small differences between any two types of forecasts, such as forecasts of net costs for two different scenarios, are subject to greater error than either of the separate forecasts from which the differences are derived, especially when the sign of the difference is not even known.

2. The precise Barker results from table 4 for all 1,335 scenarios and model runs included a net cumulative (not annual) GDP loss of 0.9 percent, plus or minus one standard deviation of 2.0 percent (Barker et al. 2006, 19).

3. We have even found it to be difficult or impossible to find many key input assumptions for the IAMs relied on in the research team Web sites. As Barker et al. say, "Many of the one-sector growth models are calibrated on long-term growth paths, but few report any formal fitting to historical data" (2006, 9).

4. This is not surprising in light of the fact that the coefficients in most models are fit by statistical means to historical data.

5. Whether a much higher carbon tax trajectory would have achieved a result in the EMF 25 study much closer to a 1.2 percent per year incremental increase in efficiency cannot be determined from the study's results.

For Further Reading

Barker, T., and K. Jenkins. 2007. "The Costs of Avoiding Dangerous Climate Change: Estimates Derived from a Meta-Analysis of the Literature." UNDP, Human Development Report. Cambridge Centre for Climate Change Research, University of Cambridge, UK. http://hdr.undp.org/sites/default/files/barker_terry_and_jenkins_katie.pdf.

Barker, T.; M. Qureshi; and J. Koehler. 2006. *The Costs of Greenhouse Gas Mitigation with Induced Technological Change: A Meta-Analysis of Estimates in the Literature*. Cambridge: 4CMR.

De Canio, S. 2003. *Economic Models of Climate Change: A Critique*. New York: Palgrave Macmillan.

Edenhofer, O.; B. Knopf; T. Barker; L. Baumstark; E. Bellevrat; B. Chateau; P. Criqui; M. Isaac; A. Kitous; S. Kypreos; M. Leimbach; K. Lessmann; B. Magne; S. Scrieciu; H. Turton; and D. van Vuuren. 2010. "The Economics of Low Stabilization: Model Comparison of Mitigation Strategies and Costs." *Energy Journal* 31, no. 1: 11–48.

Energy Modeling Forum. 2011a. "Energy Efficiency and Climate Change Mitigation." EMF Report 25, no. 1 (March). Stanford.

———. 2011b. *Energy Journal* 32, Special issue.

Hunter, J., and F. Schmidt. *Methods of Meta-Analysis: Correcting Error and Bias in Research Findings*. Thousand Oaks, CA: Sage, 2004.

INET Blogs. 2013. "Non-Routine Change, Imperfect Knowledge, and Economic Science." March 22, http://ineteconomics.org/research-program/imperfect-knowledge-economic-science/.

International Energy Agency. 2011. *World Energy Outlook 2011*. Paris.

Intergovernmental Panel on Climate Change (IPCC). 2007. *Contribution of Working Group III to the Fourth Assessment Report*. Cambridge: Cambridge University Press.

———. 2014. "Contribution of Working Group III to the Fifth Assessment Report." https://www.ipcc.ch/report/ar5/.

Krugman, P. 2014. "Salvation Gets Cheap." *New York Times*, April 17, http://www.nytimes.com/2014/04/18/opinion/krugman-salvation-gets-cheap.html?_r=0/.

Ortiz, R., and A. Markandya. 2009. "Integrated Impact Assessment Models of Climate Change with an Emphasis on Damage Functions: A Literature Review." Working Paper 6, Basque Center for Climate Change, Bilbao, Spain.

Pearce, J., and J. Weyant. 2008. *Inputs Not Numbers: The Appropriate Use of Economic Models*. Washington, DC: Pew Center on Global Climate Change.

Pindyck, R. 2009. "Modeling the Impact of Warming in Climate Change Economics." http://web.mit.edu/rpindyck/www/Papers/The-Economics-of-Climate-Change-Economics/.

———. 2013. "Climate Change Policy: What Do the Models Tell Us?" *Journal of Economic Literature* 51, no. 3: 860–72.

Rosen, R., and E. Guenther. 2014. "The Economics of Mitigating Climate Change: What Can We Know?" *Technological Forecasting and Social Change* (February 22).

Stern, N. 2007. *The Economics of Climate Change—The Stern Review*. Cambridge: Cambridge University Press.

———. 2013. "The Structure of Economic Modeling of the Potential Impacts of Climate Change: Grafting Gross Underestimation of Risk onto Already Narrow Science Models." *Journal of Economic Literature* 51, no. 3: 838–59.

Van Vuuren, D.; J. Edmonds; M. Kainuma; K. Riahi; A. Thomson; K. Hibbard; G. Hurtt; T. Kram; V. Krey; J. Lamargue; T. Masui; M. Meinshausen; N. Nakicenovic; S. Smith; and S. Rose. 2011. "The Representative Concentration Pathways: An Overview." *Climatic Change* 109: 5–31.

Walker, W.; P. Harremoes; J. Rotmans; J. van der Sluijs; M. van Asselt; P. Janssen; and M. von Krauss. 2003. "Defining Uncertainty—A Conceptual Basis for Uncertainty Management in Model-Based Decision Support." *Integrated Assessment* 4, no. 1: 5–17.

World Wildlife Fund International. 2011. *The Energy Report: 100% Renewable Energy by 2050*. Gland, Switzerland.

Zurek, M., and T. Henrichs. 2007. "Linking Scenarios Across Geographical Scales in International Environmental Assessments." *Technological Forecasting and Social Change* 74: 1282–95.