The Economic and Financial Risks of a Changing Climate

Insights from Leading Experts

Workshop Report
November 12, 2014
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AAAS
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RESOURCES FOR THE FUTURE

The changing climate is among the most serious challenges now confronting humankind. The American Association for the Advancement of Science's (AAAS's) 2014 report, *What We Know*, as well as recent reports from the US Global Change Research Program, the National Academy of Sciences, the Intergovernmental Panel on Climate Change, and the Risky Business Project all offer ample evidence of the global effects of climate change and the need to act now to mitigate greenhouse gas emissions and facilitate adaptation to changes already taking place.

There also remains an imperative to continue research on some of the most extreme possibilities—known as "abrupt change" or "tipping points," about which less is known—that could be particularly severe in terms of physical and economic consequences. These extremes are the focus of a workshop discussion held on November 12, 2014, and reported here, representing the perspectives of leading physical and social scientists and risk experts. We are pleased to have convened top researchers in these disciplines for a day of in-depth discussion.

On behalf of AAAS and RFF, we thank Lawrence Linden, a visionary and passionate philanthropist whose insights inspired and helped shape the workshop.

Alan I. Leshner
CEO Emeritus
American Association for the Advancement of Science

Phil Sharp
President
Resources for the Future

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The Economic and Financial Risks of a Changing Climate: Insights from Leading Experts

Workshop Report

Molly Macauley

Introduction and Overview

"Addressing climate risk requires an unusual degree of collaboration between scientists and economists. While scientists have developed a solid understanding of how the climate is responding to the buildup of greenhouse gases, they recognize that there is considerable uncertainty about the long-run impacts and the potential damages. Economists understand that creating incentives to conserve on the production of those pollutants is the most efficient way to address the problem, but the determination of the appropriate magnitude of those incentives is a complex valuation problem that requires quantifying the present value of those very uncertain long-run impacts. It's not just the expected damages that matter, but also how bad the worst-case scenarios might be. This is basic risk management, but operating in difficult terrain. Any attempt to quantify the appropriate policy response will require scientists and economists working together, asking tough questions, and breaking the boundaries of their professional silos."

— Bob Litterman, chairman, Risk Committee, Kepos Capital; advisor, "What We Know: The Reality, Risk, and Response to Climate Change," AAAS; and RFF board member

We know that climate change poses risks. Our understanding of what is at stake has largely been expressed as physical phenomena: a rising sea level, more frequent and severe extreme weather, and other potentially significant environmental damages. These changes are informed by decades of scientific research that shows that physical and ecological losses are already occurring—and at accelerating rates. As such, the global financial burden of a changing climate could be truly enormous but, to date, we are still unsure how much climate change will cost society as a whole.

Missing, however, is not only the expression—and understanding—of these losses in economic and financial terms but also their characterization, including an understanding of the risk and uncertainty surrounding these damages. Effectively addressing climate change would be difficult even if we knew exactly what would happen. Compounding the difficulty is that uncertainty. There is some chance the problem will be mild, some that it will be severe, and some that it will be catastrophic. The effects could happen soon, in a few decades, or into the next century. Some could be abrupt, while others could be more gradual. Geographic distribution is also unknown. All of these uncertainties present enormous challenges to policymakers. Can we distinguish changes that may be abrupt? Can we identify the feedbacks or other effects that might create a "tipping point"? How do we extrapolate benefits and costs to possibly irreversible conditions?

Work is already under way to answer these questions. Examples include recent reports by the American Association for the Advancement of Science, the US Global Change Research Program, the Intergovernmental Panel on Climate Change, the National Research Council, and the Bloomberg Philanthropies' Risky Business Project. To continue and extend this dialogue in key directions, the American Association for the Advancement of Science (AAAS) and Resources for the Future (RFF) held a workshop, "The Economic and Financial Risks of a Changing Climate," on November 12, 2014. This summary report features highlights from that day.

Molly Macauley is RFF's vice president for research and a senior fellow.

As a group, we gave thought to the need to work toward adequate specification of loss distributions and investigate their properties, such as tail dependence and risk, spatial and temporal microcorrelations, and variability and co-variability. We discussed the limits of risk transfer through insurance and securitization, and the opportunity to identify and design other types of financial incentives.

Just as important, we discussed how we might better couple expertise in the physical sciences, finance, and economics into the principles of risk science and management to inform our integrated assessment models and other modeling approaches. New science may be necessary and, coupled with greater use of the tools of risk assessment, it has the potential to galvanize the appropriate actions to respond to climate change. Filling these gaps will substantially increase our capacity to describe what is at stake in financial and economic terms, and to improve public policy. The workshop gave specific attention to these needs:

- A better understanding of the state of climate science knowledge and potential gaps. Although the fundamental science of climate change is well understood and subject to great agreement, questions remain. What physical impacts are likely, and where and when? What impacts are less certain but potentially large, and thus merit deeper understanding? What effects might be abrupt or cause a tipping point? Where do the most worrisome sources of uncertainty arise in the modeling of climate science? Identifying these gaps will help distinguish the highest priorities for further physical climate science research.

- A common ground for understanding uncertainty and risk across the physical, financial, and economic sciences. Clarifying and sharpening understanding of the concepts of uncertainty and risk and how they differ in the physical, financial, and economic sciences could help develop common ground to bridge analysis across these disciplines.

- New tools to improve the quantification of uncertainty and the expression of physical effects as economic damages. Workshop participants discussed the properties of loss for which the physical science must inform the financial and economic sciences and vice versa. For instance, we gave consideration to the potential use of tools, including structured expert judgment, to quantify uncertainty and the need to identify what new physical science and economic research could be undertaken to improve these efforts.

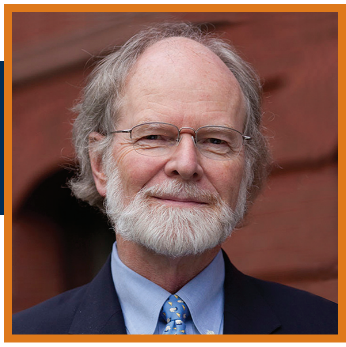
Each of these themes was addressed by a panel of renowned experts—including leading climate and physical scientists, and social scientists with expertise in economics, finance, and risk—and discussed among workshop participants, including leaders, policymakers, and analysts with expertise in climate science, economics, statistics, risk analysis, and finance. At the conclusion of the workshop, Nobel Laureate Dr. Mario Molina gave a public lecture on climate risk. He emphasized points made during the workshop and argued for the urgency of managing risk. You can view the video of the event as well as Dr. Molina's presentation at www.rff.org/mariomolina.

In the pages that follow, each panelist has provided a summary of his or her remarks, including key issues and areas for further research and discussion. Combined, these pages highlight some of the most critical aspects of the economic and financial risks from climate change faced by society today. We hope these perspectives continue to improve understanding as we work to better manage the risks of a changing climate.

The State of Climate Science: Characterizing What We Know, What Is at Risk, and What Is Uncertain (Panel 1)

What is the state of climate science now, and how will it change over the next several years? What physical impacts are likely—and where and when will they occur? What impacts are less certain but potentially large, and thus merit deeper understanding? What effects may be abrupt or create feedbacks leading to tipping points? Where do the most worrisome sources of disagreement arise in the modeling of climate science? How can societal needs be given weight in setting the physical science agenda?

- James McCarthy: Climate Change as a Risk Assessment Problem
- Rong Fu: The Importance of Uncertainty Feedback in Climate Prediction
- Debra Peters: The Ecological Challenges Posed by Climate Uncertainty
- Charles Kolstad: Identifying Opportunities to Reduce Uncertainty
- Robert Mendelsohn: Assessing and Managing Climate Change Outcomes
- Robert Kopp: Sources of Uncertainty within the Field of Climate Science



James McCarthy

Climate Change as a Risk Assessment Problem

Over the last two centuries, we've seen profound changes in atmospheric composition as greenhouse gases have increased—notably carbon dioxide, by about a third. We know that an increase in greenhouse gas concentrations has caused a warming of the surface of the planet and of the oceans, down to depths of thousands of meters. This warming is also melting polar ice. Looking back over the last two centuries, there's very little uncertainty about any of this.

However, if we look forward a century—the period that the Intergovernmental Panel on Climate Change (IPCC) reports have focused on—what is to be made of uncertainties in IPCC projections? How much of the current coastline will continue to be habitable a century from now? How much of the lands that currently produce the food supply to sustain Earth's more than seven billion people will continue to be as productive? How will the oceans continue to function, both physically and biologically? They, too, provide essential protein for the developing world.

"We are constantly questioning whether what we know is as 'known' as we think it is, and where with further understanding we could be more confident of the future than we are today."

Many people who wish to use scientific information to prepare for the future could gather from a discussion among scientists and economists, such as ourselves at this conference, that there are uncertainties—huge uncertainties in some cases—that might seem to make it difficult to know how to respond to the threat of climate change. We are constantly questioning whether what we know is as "known" as we think it is, and where with further understanding we could be more confident of the future than we are today. A good example of this is what has happened with projections regarding sea level rise in the IPCC reports. At the time the Third Assessment Report closed its books in 2000, published research did not indicate that there would be a large contribution of Greenland ice melt to sea level rise in the current century. Within only a few years, however, it became clear that this was wrong—Greenland was changing in ways that had not been anticipated.

In 2007, the IPCC's Fourth Assessment Report treated sea level rise very cautiously. The inability to estimate the contribution of Greenland and Antarctic ice melt to sea level rise resulted in an underestimated projection. By the time the Fifth Assessment Report was published in 2014, projections for ice melt contribution to sea level rise could be included, and IPCC projections over the current century were revised upward. This example shows how uncertainty grew as we learned more, and then diminished as understanding of the rechanges in Greenland ice became more complete.

There's a great deal we don't know about the climate system, and we can't presume that all aspects of it will continue working in the future as they do today. We have to contend with this uncertainty as we do with other uncertainties in our everyday lives. Fundamentally, climate change is a risk assessment problem, and there is extraordinary expertise in other parts of society in dealing with risk assessment. Uncertainty cannot be an excuse for inaction in addressing climate change.

James McCarthy is a professor of biological oceanography and the Alexander Agassiz Professor of Biological Oceanography at Harvard University's Department of Organismic and Evolutionary Biology. McCarthy is also the acting curator of the Malacology Department at Harvard's Museum of Comparative Zoology.

Rong Fu

The Importance of Uncertainty Feedback in Climate Prediction

Drought is among the most damaging and least understood natural hazards. Rich countries such as the United States are more vulnerable to extreme droughts than we realize. In 16 out of the last 21 years in the United States, we've suffered from droughts that have caused more than $1 billion in damages; on average, each drought costs around $9 billion adjusted to 2011 US dollars.

"It's very hard to justify to the public that we need to pay for a certain level of adaptation when we are unable to predict droughts—but having even imperfect information with an acceptable confidence level can help inform drought emergency management decisions."

But beyond the dollars, my experience during the 2011 Texas drought is a good example of how droughts can cause instability in a society. The drought prompted Homeland Security to move into Texas, and the state drought emergency manager discussed evacuating more than 100,000 residents in San Angelo, in western Texas, because of dwindling water reserves. Some towns actually organized themselves together to guard their reservoirs for fear that someone else would steal from them. This really illustrates what kind of a panic droughts cause, even in a place that is actually very well prepared for such an event. Imagine similar droughts happening where people are less capable of coping.

I like to bring up the point that tolerance for uncertainty depends on its risks and impacts because it's very helpful for climate scientists to know someone's tolerance for uncertainty. We may not be able to be 100 percent sure about something, but if we are told what level of uncertainty is "acceptable" for someone's needs, we can work toward that goal. For example, after the 2011 drought, state emergency management told us, "If you can say with 60 percent certainty that there will be another drought this summer, I can walk into the governor's office and activate an emergency." They don't need 100 percent certainty—they don't even need 80 percent certainty. In this case, 60 percent was good enough. Now, three years later, we are able to offer drought predictions that are better than 60 percent of the scale.

In places such as Texas that tend to suffer from long-term droughts, people are actually very willing to adopt and invest in preventative measures. However, in order to get funds approved by voters, we need to provide credible climate information.

It's very hard to justify to the public that we need to pay for a certain level of adaptation when we are unable to predict droughts—such as the one in 2011–2012—but having even imperfect information with an acceptable confidence level can help inform drought emergency management decisions. It's situations like this that make uncertainty feedback so helpful for climate scientists in terms of setting appropriate prediction goals.

Rong Fu is a professor at the Jackson School of Geosciences at the University of Texas, Austin.

Debra Peters

Ecological Challenges Posed by Climate Uncertainty

As a principal investigator for a long-term research program and a scientist in the USDA, I can tell you that uncertainties in climatic drivers make ecologists very nervous. We've been collecting long-term data at many ecological and agricultural research sites across the United States and globally, in some cases for over 100 years. This means we have a lot of data, and we feel like we understand our ecosystems very well—up until the climate drivers start changing beyond the range of historic variability. These changes make us nervous because they cause the rules between the physical drivers and the biota to change—and, in particular, during extreme events, including heat waves, freezes, floods, and droughts.

"These land–atmosphere interactions that start small and propagate to have large impacts are the really big uncertainties that may become more frequent in the future as both the climate and land-use drivers change."

It's very difficult for ecologists to deal with extreme events because we need long-term data to observe and understand events that rarely occur. Take something that occurs very infrequently, such as the Florida citrus freeze: How do we study that? How do we prepare for that? Droughts are a little easier to prepare for because drought occurred more frequently in our history; but as they become more frequent, we have to figure out how to actually define a drought. We often use the Palmer Drought Severity Index, but that's more of a climatic definition when what we really need is an ecosystem-based definition that reflects the impacts to the biota. We're still struggling with how to get that translation right in order for us to understand and manage for these extreme events.

The other aspect of these events deals with space. A lot of ecological studies are small-plot studies, at a scale as small as a meter square in grasslands and up to a hectare in forests. You can imagine those plots don't represent very much area, and we have to do replications in order to understand these problems really well. What we really need to know is how to extrapolate these small-plot dynamics spatially so we can predict how large landscapes will respond to climate change. These large landscapes are difficult, if not impossible, to replicate. Propagating events—such as wildfires or species invasions—come into play when we put space and time together in what we call cross-scale interactions.

The Dust Bowl is a classic historic example of an event that propagated in time and space that we still don't understand very well at all. Present-day haboobs continue to occur with major impacts on air quality in the Southwest. These land–atmosphere interactions that start small and propagate to have large impacts are the really big uncertainties that may become more frequent in the future as both the climate and land-use drivers change. Although our long-term data are invaluable at providing context for the present and future, the changing rules will make predictions of the future challenging without a strong understanding of the underlying mechanisms and their interactions that are driving those changes.

Debra Peters is an ecologist and adjunct associate professor at New Mexico State University. Peters is also a research scientist at the USDA-ARS Jornada Experimental Range, as well as the lead principal investigator on the Jornada Basin Long-Term Ecological Research Project.

Charles Kolstad

Identifying Opportunities to Reduce Uncertainty

Looking at the benefits of mitigation—which are often either quantitatively or qualitatively an issue—inevitably involves looking at impacts as well. I'm not talking about simply totaling up the costs and benefits and deciding what to do. I'm saying that if you want to look at the benefits of mitigation, you need to have an estimate of the impacts, and a lot of the focus regarding impacts is on what happens in the most likely case.

What we know from many sources is that lower-probability, high-consequence outcomes can actually dominate the calculation of expected benefits. It would be really helpful if we had a broader perspective on the range of possible outcomes for different forcing levels so that we could have a better estimate of the benefits of mitigation. This involves a lot of subtleties, including whether we have an actual estimate of probabilities (risk versus uncertainty). In some cases, uncertainties are accompanied by irreversibilities, which are much more significant than uncertainties absent irreversibilities. Ultimately, the value of information of this sort can be vital to people with large budgets for reseach and development in Washington. It's a large task to ask people to come up with probabilities, and it's an even larger task to ask them to calculate how much $1 million will allow you to change a certain probability. Focusing research in areas that actually have the most payoff in terms of reducing uncertainty will be important going forward.

In terms of adaptation, one area that presents a problem is adaptation that's not autonomous, or otherwise not done by private agents such as farmers, business owners, or homeowners. This includes measures that require government action, coordination, or planning, and involve public goods such as electric grids or road systems that need moving. We all know that our political systems are variable in their responsiveness to crises, and some of that adaptation may not occur, may be slow to occur, or may end up occurring imperfectly. We shouldn't just be looking at uncertainty as a way to better evaluate the world we see. Uncertainty affects many different kinds of agents in the world—including governments—and there are a whole host of instruments that have already been set up to deal with these uncertainties. We don't need to eliminate uncertainty—uncertainty is fine as long as it's quantified.

> **"Focusing research in areas that actually have the most payoff in terms of reducing uncertainty will be important going foward."**

We may identify scenarios for which reducing uncertainty is economically beneficial. If the payoff for reducing that uncertainty is significant, then we may want to focus on that. In other cases, reducing uncertainty may be unwarranted. The paradigm of economics applied to this issue is incredibly rich and subtle theoretically. It's true that the applied analyses that we've seen so far, which are mostly in integrated assessment models, are primitive for good reasons. It's a big world and resources are extremely limited, but the opportunities are great for making progress in these areas.

Charles Kolstad is a senior fellow at the Stanford Institute for Economic Policy Research and the Precourt Institute for Energy, as well as a professor, by courtesy, of economics. Kolstad is also a university fellow at Resources for the Future and a faculty research associate at the National Bureau of Economic Research.

Robert Mendelsohn

Assessing and Managing Climate Change Outcomes

If we look at the best guess that most scientists and economists have about what's actually going to happen with climate change, it looks like it's a serious—but not catastrophic—problem. What we're trying to talk about today is not our best guess as to how this system works but, rather, what is our worst guess? In other words, what's the worst that might happen?

Well, the worst possible thing that could happen is that we spend a lot of money on mitigation very poorly, and we get destroyed by climate change anyway. But let's look more closely at how climate change might destroy us. What kinds of climate problems could cause that, and can we as scientists eliminate some of those possibilities? What is on my list of severe concerns? One is that the planet gets enveloped with frequent monster storms. A second concern is runaway warming—that somehow we've underestimated positive feedbacks, and climate sensitivity is actually much higher than we think. Third, I am worried about the big glaciers in Greenland and Antarctica suddenly melting very quickly. Any of these possibilities could be catastrophic. Can we rule out some of these concerns as not being possible?

If we can't rule them out completely from a scientific point of view, then the next question is, can we manage them? Are there ways that we can change our behavior that actually reduce their likelihood? Clearly, aggressive mitigation can lower the possibility of such catastrophes. But can we take action to specifically target and manage each of these problems?

Climate change is particularly difficult because there's a large lag between cause and effect. The full consequences of the emissions we generate today will take many decades to unfold. That makes the benefits of mitigation much lower from an economic perspective. The long delay also makes the problem more politically challenging, because voters and therefore politicians have very short time horizons. If the consequences of emissions were more immediate, it would be easier to convince voters of the prudence of mitigation. The long delays also add to the uncertainty surrounding benefit estimation. These problems reduce the perceived urgency of greenhouse gas mitigation. If we start global mitigation now, we can begin to have an effect on global concentrations. There are many modest mitigation efforts that would begin to reduce our global emissions.

Further, I believe a modest across-the-board approach to reductions in carbon emissions would have a very good chance of being adopted by nations around the world. One of the reasons that we are doing almost nothing about emissions is that we currently give the world only two choices: either adopt stringent mitigation or don't do anything at all.

"Climate change is particularly difficult because there's a large lag between cause and effect. The full consequences of the emissions we generate today will take many decades to unfold."

Of course, a modest proposal to reduce emissions is not by itself going to eliminate the possibility of catastrophic problems. In fact, we do not know whether even a stringent mitigation program will stop every possible catastrophe. We may well want other tools that lead to more rapid responses from the Earth's systems. If there was ever a motivation for studying geoengineering, having a tool that could stop catastrophes once they appear is highest on my list.

Robert Mendelsohn is the Edwin Weyerhaeuser Davis Professor of Forest Policy at Yale University's School of Forestry & Environmental Studies. He is also a professor of economics in Yale's Department of Economics, as well as a professor in Yale's School of Management.

Robert Kopp

Sources of Uncertainty within the Field of Climate Science

In the American Climate Prospectus, we divided the major sources of uncertainty in climate projections into five parts. The first is emissions uncertainty, itself derivative of socioeconomic, technological, and policy uncertainty, which plays an increasingly dominant role in climate projection uncertainty starting in the second half of this century.

The second is uncertainty in the global mean temperature response to a given emissions pathway. While the simple radiative response of the planet's energy balance to greenhouse gases is quite well understood, the feedbacks that amplify that response have significant uncertainties. Cloud feedbacks are an important source of uncertainty in the conventional measure of climate sensitivity. On longer timescales, vegetation and aerosol albedo feedbacks may play an important role. The current difficulty of climate models to reproduce past warm climates points to some of the challenges here.

The third source of uncertainty is the relationship between global mean change and regional climate change—and, as Tip O'Neill would have recognized, all climate change is ultimately local. But at a local level, you don't just have to worry about planetary energy balance; you have to worry about how the Hadley circulation will change, how the Gulf Stream will change, and so forth. Moreover, regional heterogeneity has distributional consequences—in the American Climate Prospectus, we found that business as usual is likely to decrease mortality in the Pacific Northwest while driving a significant mortality increase in the US Southeast.

Uncertainties multiply again because natural variability—our fourth source of uncertainty—in complex dynamic systems is large, and it is larger at the regional scale than in the global mean. In much of the world, the emergence of local climate change from local variability will not occur until the second half of the century. That the Earth will store heat in response to a radiative forcing is inescapable, but where it will store heat—both geographically, and as divided between the ocean and the surface atmosphere—can fluctuate over time.The fifth source of uncertainty is what are colloquially called "tipping points"—abrupt changes in the behavior of components of the Earth's system.

"While the simple radiative response of the planet's energy balance to greenhouse gases is quite well understood, the feedbacks that amplify that response have significant uncertainties."

The transition between a glacial and an interglacial world is an example of such a tipping point, and one that we do not yet understand in full. For some tipping points, such as the collapse of the marine-based portion of the Antarctic ice sheet and its consequent sea level effects, it may be possible to come up with reasonable (but non-unique) probability estimates; others—such as the collapse of terrestrial or marine ecosystems—we currently have no way to quantify.

I spend a lot of time on sea level rise, but it's the uncertainty in ecosystem responses—and the warning provided by ancient events such as the Permo-Triassic extinction, the Paleocene-Eocene Thermal Maximum, and ocean anoxic events—that keeps me up at night.

Robert Kopp is an associate professor in the Department of Earth and Planetary Sciences and the associate director of the Rutgers Energy Institute at Rutgers University. Kopp also served as the lead scientist for the American Climate Prospectus, the technical analysis underlying the Risky Business Project.

The Economics of Climate Change: Uncertainty, Likelihood, Risk, and Judgment (Panel 2)

Can we clarify and sharpen understanding of the concepts of uncertainty and risk, and how these concepts differ in definition and application across the physical, financial, and economic sciences? Can we find common ground to make practical use of these terms? Keywords such as risk, likelihood, and uncertainty are widely used—but how are they used in climate science, finance, economics, and risk management? Can we agree on common, intellectually grounded, policy-relevant definitions of uncertainty and risk? As important, can we connect these concepts more precisely to be meaningful for finance and economics, on the one hand, and climate science, on the other?

- Raymond Kopp: Climate Assessment Tools Available to Policymakers
- Bob Litterman: The Importance of Quantifying Climate Risks
- Robert Engle: The Role of Volatility in Climate Change Models
- Michael Greenstone: The Challenges of Estimating a Social Cost of Carbon
- Terry Dinan: Information Needed to Make Mitigation and Adaptation Decisions
- Noah Diffenbaugh: Valuing Certainty when Assessing Climate Outcomes

Raymond Kopp

Climate Assessment Tools Available to Policymakers

For the most part, the way we have constructed our discussions is to focus on how we make policy decisions under a great deal of uncertainty. It's something that many of us who interact with policymakers on a daily basis struggle with—either at the federal level, the international level, or the very local level—as we try to help them think through these difficult decisions.

> **"There is a social cost of carbon number out there that tries to capture damages and, perhaps, use those numbers to make decisions. Unfortunately, much of this process is now compounded by this deep uncertainty we have with respect to not only the science but also, perhaps, with some of the economics as well."**

I think we should focus on the tools that policymakers use to help themselves think about the design of a policy as they go forward. One of those tools turns out to be something economists use all the time, though it may not be familiar to the general public: assigning a dollar value to damages. This is particularly relevant for environmental issues, where the environmental consequences of certain actions can be calculated based on the problems created by air pollutants, water pollutants, and more.

We do this for a couple of different reasons. The first is that it allows you to look across a broad array of threats and rank them in terms of some concept of impact by using dollar values. This tool has also taken on a life of its own in regulatory processes, where agencies look at the actions that could be undertaken to reduce a particular environmental damage. By looking at the costs of doing so, they can roughly try to equilibrate actions with avoided costs.

For example, if controlling sulfur dioxide emissions from power plants has a damage number of somewhere around $150 or $200 per ton, then you would look at marginal control costs that were essentially below or equal to those damage numbers. It's a rough-and-ready way of thinking about policy. In this particular case, there is a social cost of carbon number out there that tries to capture damages and, perhaps, use those numbers to make decisions.

Unfortunately, as we all know, much of this process is now compounded by this deep uncertainty we have with respect to not only the science but also, perhaps, with some of the economics as well. All of these factors make climate policy a very difficult issue.

Raymond Kopp is an RFF senior fellow and the co-director of RFF's Center for Energy and Climate Economics.

Bob Litterman

The Importance of Quantifying Climate Risks

I want to focus on how risk managers think about the problem of climate change. The answer to this problem is based on a concept called the social cost of carbon. What economics tells us is that incentives matter—and what the social cost of carbon essentially answers is the following question: What is the appropriate incentive, today, to reduce emissions? And, in particular, how does that incentive depend on uncertainty?

My colleague on this panel, Michael Greenstone, has led the US government effort to answer the question of how stringent mitigation should be, and the answer his team came up with reflects a cost of about $40 per ton of carbon dioxide emissions. But science, as expressed in the Intergovernmental Panel on Climate Change synthesis report, has also addressed this question—and what the scientists say is that they don't trust these economic models. In particular, scientists point out that the economic models don't address the issue of irreversibility, or the potential for very high-impact/low-probability outcomes. This causes scientists to be skeptical of economic models that, in any case, can produce a wide range of potential values—and the scientists recognize that the implication of this distrust is to be cautious. Uncertainty about the validity of the economic models raises the appropriate price of emissions.

My answer to the scientists is that they are correct, but this criticism alone is not adequate. Scientists must quantify what they mean when they talk about worst-case outcomes associated with climate risk, because quantification is what the economists need in order to incorporate better estimates of key concepts, such as marginal utility. We're going to fail to act soon enough and end up spending too much on emissions mitigation—and, in the end, we may not be successful if we don't have better quantification about appropriate incentives. We need more input from science, better estimates of probabilities of bad outcomes, and better quantification of potential damages—there are no other inputs that can tell us the social cost of carbon. No policymaker can tell us what the real risks of climate change are, and no public vote is going to tell us what appropriate incentives will spur emissions reductions. Responsible governments should come to scientists and economists and require us to be specific about risks and appropriate pricing. I hope that happens soon, and I hope we'll have better answers for them.

Science may not be able to identify a single best climate target, as the IPCC report admits, but we can determine what an appropriate emissions price should be today. This is an investment and asset-pricing problem. When we talk about worst-case scenarios, it is not because there are arbitrary costs associated with reducing huge risks—it's just that for worst-case scenarios, marginal utility is the highest. We have to decide how much weight to give to these worst cases. We can't ignore them and we can't continue to make policy based only on expected outcomes. We have to take into account the full range of the distribution of outcomes and weigh them based on probability and marginal utility—this is why scientists and economists must start collaborating more to determine appropriate climate policy.

"Responsible governments should come to scientists and economists and require us to be specific about risks and appropriate pricing."

Bob Litterman is the chairman of the Risk Committee at Kepos Capital, as well as a founding partner. He is also a member of RFF's board of directors.

Michael Greenstone

The Challenges of Estimating a Social Cost of Carbon

The social cost of carbon estimates the dollar value of climate change impacts caused by a one metric ton increase in carbon dioxide (CO_2) emissions. These damages include effects related to agriculture, energy use, freshwater resources, sea level rise, storm damage, and human health. Think of it like this: there's an extra ton of CO_2 that goes into the atmosphere. That will change concentrations of greenhouse gases, which will affect temperature, which will affect economic activity. And because science tells us that those emissions stay in the atmosphere for a very long time, they'll affect economic activity for decades to come. We then take that stream of damages and trace it back to today using some discount rate—this is what the social cost of carbon tries to accomplish.

"Action will be determined by values and politics and other of factors that are outside of our social cost of carbon models. What we can do is take what the scientists tell us about how the climate will change and come up with an estimate of the damages that, in my opinion, is a critical input in the political process."

There are a number of reasons that I think the government's $35 to $40 number might be too small. The first is that the models used to estimate the social cost of carbon don't really admit uncertainty about what the damages will be. They don't capture how much people dislike uncertainty, especially when large losses are possible, or how much they will pay to get rid of it. People's willingness to pay to avoid large risks is seen in the variety of robust markets for insurance around the world.

In addition, the calculations fail to reflect that there will likely be very different impacts across regions and, even within regions, among individuals. Yet an emerging literature indicates that climate change will disproportionately harm some countries (for example, Bangladesh) and particular subpopulations within countries (residents of Miami, for example). Society tends to assign more urgency to issues when a subgroup of individuals bears a disproportionate share of loss. Think about the response to Hurricane Sandy, compared to responses to other issues that affect everyone but by only small amounts.

Another issue to consider is what the "right" discount rate is—a confusing question on many levels. Yet it plays a critical role in determining the social cost of carbon. Recent research suggests that climate mitigation investments—unlike investments in the overall stock market—may pay off when the economy is doing poorly and additional income is especially valuable. If this assumption is correct, it argues for using a lower discount rate than has previously been the case. Consider gold, an asset class that has an annual rate of return of just two percent. In comparison, the stock market's average annual rate of return is around seven percent. Yet people are willing to hold gold and other assets with low mean annual rates of return because they pay off when other investments and income opportunities are poor. The choice of a discount rate in this range may well be appropriate and would tend to increase the social cost of carbon.

At the end of the day, the social cost of carbon determines the right response to climate change from an economic perspective. But action will be determined by values and politics and other factors that are outside of our social cost of carbon models. What we can do is take what the scientists tell us about how the climate will change and come up with an estimate of the damages that, in my opinion, is a critical input in the political process.

Michael Greenstone is the Milton Friedman Professor in Economics at the University of Chicago, as well as the director of the interdisciplinary Energy Policy Institute at Chicago.

Photo credit: Robert Kozloff

Terry Dinan

Information Needed to Make Mitigation and Adaptation Decisions

We've talked a lot about better communication between economists, scientists, and modelers, but the ultimate recipients of information about the risk and uncertainties associated with climate change are policymakers. They are the ones who will be making decisions about the extent to which we will enact policies to mitigate—to reduce—emissions. In addition, along with private entities, policymakers will make decisions about the extent to which we adapt to climate change. Choices about mitigation and adaptation require different types of information.

Given the fact that today's emissions will affect the climate over many decades, decisions about mitigation hinge on the long-term effects of climate change. Those long-term effects are very uncertain. We simply don't know enough about the presence of thresholds and of climate interactions to attach probabilities to the potential for catastrophic damage at various changes in the average global temperature. At present, regulatory decisions about mitigation are based on the social cost of carbon (SCC)—and a large fraction of that measure is based on very uncertain information about the risk of catastrophic outcomes. However, the SCC is presented as a very precise value. I worry a bit that the precision with which the SCC is reported can provide an illusion of certainty that does not accurately reflect the fact that a key reason for mitigation is the concern about small-probability, high-cost outcomes. As a result, I suggest that the SCC might benefit from being accompanied by additional qualitative information on the potential for thresholds and climate interactions to result in rapid changes in climate, as well as the types of damage that might result from those rapid changes.

In contrast with mitigation, decisions about adaptation hinge on the relatively near-term effects of climate change. Those effects, in general, depend on factors that are somewhat easier to define in terms of probability distributions. Governments and private entities are already making decisions about adaptation. For example, coastal communities are making choices about infrastructure, building codes, and zoning based on their expectations of the potential for increased damages from rising sea levels and hurricanes. There is a great opportunity for economists and scientists to provide information that can inform those types of decisions. To the extent possible, providing localized information about changing probabilities of damages over the next couple of decades would be very helpful.

> **"The social cost of carbon (SCC) is presented as a very precise value. I worry that the precision with which the SCC is reported can provide an illusion of certainty that does not accurately reflect the fact that a key reason for mitigation is the concern about small-probability, high-cost outcomes."**

Finally, I think it is important to note that the efficient amount of mitigation depends not only on the expectations of climate change damages but also on the cost of mitigation. Those costs are also uncertain. Policies that encourage research and development on emissions-reducing technologies and that provide uniform incentives for emissions reductions throughout the economy, such as putting a price on carbon, help minimize the cost of achieving any particular emissions limit.

Remarks are the author's personal views, and not those of the Congressional Budget Office.

Terry Dinan is a senior advisor at the US Congressional Budget Office.

Noah Diffenbaugh

Valuing Certainty when Assessing Climate Outcomes

I have been thinking about how to incorporate our understanding of physical climate change—and uncertainty in physical climate change—into the price of emissions. A big challenge is that, in order to know the real price of emissions, we ultimately need to know all the impacts of a given level of climate change. But in addition to uncertainty in the climate system, there is a great deal unknown about how natural and human systems will respond to climate change. A lot of my work has been focused on trying to understand what the impacts are of unconstrained climate change. If we could identify all of the impacts in the world and add them up, we could calculate a per-ton cost of carbon. But the reality is that we'll never be able to add up all possible climate impacts in advance. Even if we knew the exact trajectory of the climate system, there exist an infinite number of possible impacts.

In addition, the biggest uncertainty about how much climate change there will be over the next century comes from the human dimension. Future levels of greenhouse gases will be what really determine what global warming will look like going forward, much more so than uncertainty due to things such as climate sensitivity and cloud feedbacks. It's been known for some time that stabilizing the climate at any level requires zero emissions—it's a fact of the energy balance of the planet. But we've learned that even with perfect knowledge of the forcing pathway, and of the physical workings of the climate system, the climate system is so complex that there is an "irreducible" uncertainty that limits the predictability of the regional and local climate phenomena that are so critical for climate impacts. So the reality is that physical climate science cannot provide certainty about the future, but, at the same time, we do know that there's some likelihood of experiencing a catastrophic outcome.

There is some potential for dealing with these irreducible uncertainties. We can use our emerging knowledge of how global warming has already influenced natural and human systems. It is clear that we are already experiencing impacts from global warming.

"The greatest challenge of pricing risk [is] incorporating the possibility of a truly catastrophic outcome."

For example, we have mountains of evidence that indicate that global warming not only is happening, but that it has altered the probability of high-impact extreme events, such as the severe heat that occurred in the United States in 2012, and the probability of extreme flooding, such as what occurred during Superstorm Sandy. And so to what extent can we use these known impacts—and their known damages—to figure out the real cost of carbon emissions? But even that won't get us to the greatest challenge of pricing risk—incorporating the possibility of a truly catastrophic outcome, such as the collapse of the West Antarctic ice sheet (and the associated sea level rise).

We don't know if there will be a seven-meter rise in sea level, or if the Earth will warm by 10 degrees. But there's some real possibility that these things will happen, and the total damage that occurs if they do is much more than the cost of avoiding them. So, my question is: How do we price these kinds of risks and uncertainties, when there are real but ultimately unknowable probabilities of crossing thresholds that would induce catastrophic outcomes? Or, put another way, what is the value of being certain that we will avoid those outcomes?

Noah Diffenbaugh is an associate professor at Stanford University's School of Earth Sciences and a senior fellow at the Stanford Woods Institute for the Environment.

Properties of Loss to Inform Physical and Social Science Research, Modeling, and Policy Analysis (Panel 3)

What are the properties of loss for which the physical science must inform the financial and economic sciences and vice versa? Can the use of tools, including structured expert judgment, help to quantify uncertainty and identify what new physical science research could be undertaken to improve the quantification of uncertainty? What tighter coupling of physical and social science is required to make progress in new modeling and policy design?

- Carolyn Kousky: The Role of Extreme Events in Climate Risk Assessment
- Roger Cooke: Building a Rational Consensus about Climate Uncertainties
- Jonathan Bamber: The Role of Expert Judgment in Climate Change Analysis
- Michael Oppenheimer: Dynamic Vulnerability and Exposure to Climate Risks
- Kerry Emanuel: Extreme Climate Events as Threshold Phenomena
- Martin Weitzman: Choosing Discount Rates for Climate Issues

Carolyn Kousky

The Role of Extreme Events in Climate Risk Assessment

We are discussing damages from climate-related "tail events." We focus here on two distinct classes of events, which vary in the magnitude of their impact. The first is changing extremes, such as more intense hurricanes. The damages from these types of events can be substantial, but tend to be local or regional. The second is global catastrophic impacts. These could be related to tipping points or abrupt climate changes, or they could emerge when climate acts as a threat multiplier, creating a chain of consequences with global implications.

Damages from both involve the interaction among physical and socioeconomic systems. Analysis thus requires an integration of findings and collaboration across disciplines. Modeling damages from both types is challenging and full of uncertainties, as they are characterized by interdependencies and feedbacks—it may require rethinking our traditional analytic tools.

Looking first at extreme events, estimates of annual worldwide damages in the last decade range from $94 billion to $130 billion. Yet these do not account for underreported data or non-market damages and often do not include indirect costs. Damages have been growing over time. Multiple studies have sought to untangle the determinants of this growth, generally finding that it can be attributed to where and how we are building. In some areas and for some hazards, a climate signal is emerging in loss data. Climate scientists tell us this will only intensify. This suggests a need in projections of disaster losses to consider not just changes in the climate system but also how those interact with demographic shifts and other socioeconomic changes.

Even changing extreme events can create challenges for traditional risk management. Insurance, for example, works best for independent and thin-tailed risks. Disasters may increasingly violate these criteria, leading to breakdowns in markets where coverage cannot be offered at a price that is profitable and that insureds are willing or able to pay. We've already seen a range of government interventions in disaster insurance markets in response. Looking across these, it is clear that society is struggling with how to balance helping those in need ex post with minimizing excessive risk taking ex ante. This is will be an increasingly important adaptation question.

When we shift our attention to the possibility of climate catastrophe at a global scale, uncertainty becomes even more challenging. Scientists have identified possible global catastrophes, such as rapid and extreme sea level rise, and modeling their impacts poses fundamental challenges. But the real challenge is the unimaginable impacts. If history is any guide, there will undoubtedly be surprises.

> **"There is a need in projections of disaster losses to consider not just changes in the climate system but how those interact with demographic shifts and other socioeconomic changes."**

These global catastrophes are systemic threats. Here, risk transfer mechanisms fully fail. Some limited adaptation may be possible, but we are largely in the realm of deciding how much to reduce the probability of these events. Usually when faced with that question, an economist would want to know the answer to two questions: How bad could it be? With what probability? We often don't know either.

Carolyn Kousky is a fellow at RFF.

Roger Cooke

Building a Rational Consensus about Climate Uncertainties

I'd like to throw out some "headlines" on fat tails and uncertainty quantification. The first is that fat tails can ruin your whole day. Think of a stationary situation where we're sampling repeatedly from the same distribution. What does it mean if it happens to have a fat tail? It means that historical averages can have little or no predictive value. It means that things like regression coefficient correlation are very unstable. It means that if you are an insurance company and you are aggregating insurance policies from a whole bunch of independent agents, the average of all of those policies does not converge to your friendly normal distribution with a shrinking standard deviation—it stays just as fat as the original distributions.

Let me give you a simple numerical example. Hurricane Katrina cost, say, $120 billion to $150 billion—but of that, the National Flood Insurance Program (NFIP) paid $18 billion in claims. This constituted the largest payout of claims that it has ever had. Now I say to the NFIP, "I want you guys to sock away enough capital to be 95 percent certain of covering the next worst case." There will be another hurricane that is worse than Katrina, but how bad will it be? They may calculate how much to save up using what I would call a New Mexico tail, which tells them they should sock away about $60 billion.

However, if they were to use a Louisiana tail, they should sock away more than $7 trillion to be 95 percent sure of covering the next worst case. We have a lot of data that can be used to continue studying the dynamics of tails, many of which are getting fatter.

The next headline I'd like to throw out is that we are not getting the narrative of uncertainty correct. Reasoning under uncertainty is hard, and you cannot do it by the seat of your pants. The general public repeatedly makes mistakes about reasoning under uncertainty, and these mistakes are often the same ones made by our scientific community and the Intergovernmental Panel on Climate Change. We are not getting this right, and we need to do better.

"We are not getting the narrative of uncertainty correct. Reasoning under uncertainty is hard, and you cannot do it by the seat of your pants."

My final point is that we need to construct scientific data from expert uncertainty, and see if we can't use that to build a rational consensus about these uncertainties. Why should we do that? Because if we don't, other players will misuse uncertainty. Deniers will use uncertainty to transfer the burden of proof, and alarmists will use uncertainty to focus attention only on the worst cases. The only way to deal with that is to achieve a rational consensus on the quantification of uncertainty—something that I think is possible for us to achieve.

Roger Cooke is the Chauncey Starr Senior Fellow at RFF.

Jonathan Bamber

The Role of Expert Judgment in Climate Change Analysis

For about the last 30 years, I've been using observational data combined with prognostic numerical models to study the ice sheets covering Antarctica and Greenland. My focus has been on trying to understand the processes that control their behaviors, and projecting these behaviors over a period of time to assess their impact on sea level rise.

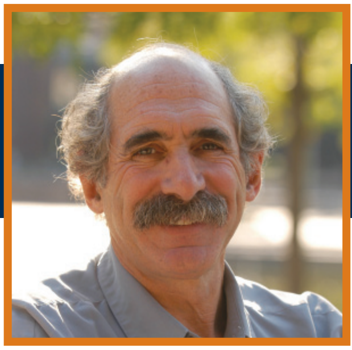
For quite a while now, I've realized, however, that these models aren't appropriate tools for the job. Our observational data set isn't satisfactory: it is far too short. The prognostic models aren't good enough, for a range of reasons, partly to do with boundary conditions that are almost impossible to constrain. For instance, you have an ice sheet that's five kilometers thick, with little idea of what the conditions are at the bed, which play a critical role in ice motion. There are also many other factors, such as unknown physics or processes, that we cannot adequately parameterize in the models. As a consequence, they are not really suited to making projections. However, we still need to address policy-critical and policy-urgent issues related to sea level rise over the next century, as well as how we plan to deal with them.

"As with any kind of statistical analysis, garbage in gives you garbage out, and it is very important that you identify the appropriate experts and get the right information out of them."

I've recently been involved in a number of expert judgment workshops that have used a formal structured expert judgment approach. One of the things I realized, in doing these workshops, is that the virtual expert—a weighted combination of the people that you've pulled together—has far greater skill than any one individual or an unweighted combination of experts, and can provide unique information about uncertainties in the system that is not achievable any other way. I'm convinced that this is a powerful tool for taking experts, which you can think of as qualitative models of the system, and combining them in a structured way to learn more about the system's uncertainties. A secondary benefit from this expert judgment, something I've seen in the workshops I've organized, is that experts who are doing the science—people that really understand the problem better than anyone else—are also introduced to some issues that they hadn't thought about before.

As with any kind of statistical analysis, garbage in gives you garbage out, and it is very important that you identify the appropriate experts and get the right information out of them. But if you do this in a structured and objective way, your results will be reproducible and you will end up with an objective combination of experts—you can identify who is providing useful information about uncertainty and unknowns. A lot of modelers went into these expert judgment workshops with their arms twisted and became converts because, once they had done it, they understood what the approach is trying to achieve and how it does that. It's not a substitute for research, but it can provide valuable insight into the community's understanding at that moment in time.

Jonathan Bamber is a professor of physical geography in the School of Geographical Sciences at the University of Bristol.



Michael Oppenheimer

Dynamic Vulnerability and Exposure to Climate Risks

When we look at the question of disasters, we automatically approach the issue of climate extremes. We know that we're getting better at projecting some extremes—extreme heat, extreme precipitation, extreme drought, extreme sea level rise—and these projections have allowed us to increasingly attribute some fraction of extreme events to human activity. But risk has three components. It's not just a matter of the physical hazard—it's a matter of who's exposed, how they're exposed, and how vulnerable they are.

In the context of climate change, we know much more about hazards than we understand about exposure and vulnerability, for which adaptation is a response and risk-reduction measure. Our projections of risk have to involve the concept of dynamic vulnerability and exposure, factors that are going to change over time. We don't have much of a handle on the question of dynamic risk from the point of view of the social side, but we are working to close the difference between the physical- and social-side projections. Our current effort is called "developing shared socioeconomic pathways," in which we look forward and imagine, on a scenario basis, future conditions under which human beings would have to respond to physical changes in climate. This will hopefully give us a more coherent and comprehensive picture of how dynamic vulnerability and exposure are, and how to influence them through policy.

Another insight I gathered, particularly from watching how Hurricane Sandy played out, is that there is a shortfall regarding what is sometimes referred to as adaptation capacity, or the theoretical ability to adjust to climate extremes even in the current climate. There's a shortfall between what's hypothetically possible and what actually happens under extreme conditions in the real world. For instance, we had a mayor in New York City who talked about climate change incessantly, and had a planning office that was doing a very good job anticipating climate-related disasters compared to other metropolitan areas. Still, we fell short during Sandy's aftermath, where a lot of things that should have been done weren't, some people died who could have been saved, and recovery and restitution after the event are still incomplete.

"There's a shortfall between what's hypothetically possible and what actually happens under extreme conditions in the real world."

The hardest problem of all is to understand the gap between what we think people ought to be able to do and how real political systems react under extreme circumstances. Ultimately, what we need to drive at is a comprehensive probabilistic view of disasters that doesn't just assign probabilities to the hazard side of the equation, but also tackles the tough problem of trying to assess the probabilities of exposure and vulnerability, as well as how people might react under future disaster circumstances.

Michael Oppenheimer is the Albert G. Milbank Professor of Geosciences and International Affairs in the Woodrow Wilson School and the Department of Geosciences at Princeton University, as well as the director of the Woodrow Wilson School's Program in Science, Technology, and Environmental Policy. He is also a faculty associate of the Atmospheric and Ocean Sciences Program at the Princeton Environmental Institute and the Princeton Institute for International and Regional Studies.

Kerry Emanuel

Extreme Climate Events as Threshold Phenomena

One of the things that has impressed me the most about studying damages done by storms around the world—not just to buildings and infrastructure, but to society as a whole—is how much they are becoming threshold phenomena. Let me illustrate this in a few ways, because it bears on the problem of climate change.

Typhoon Haiyan devastated the Philippines in 2013. If you were watching as it happened, and if you are like me, you probably got the impression that this is what happens when a Category 5 typhoon hits a developing country, while a country like the United States would have been able to handle an event of that size perfectly well. Nothing could be further from the truth. The Philippines gets hit by Category 5 typhoons regularly, yet you don't often read about events like these in the *New York Times* because that particular society is very well adapted to those kinds of storms.

What happened was that Typhoon Haiyan was a little bit beyond the experience of the Philippines. Many people who died in that storm were in evacuation shelters that were built to withstand an ordinary Category 5 typhoon. In the United States, we have better data going back earlier on events like this. Roger Pielke, Jr. has attempted to normalize hurricane damages to a common standard of population and wealth. If you look at the statistics from our 150-year history of hurricanes, 80 percent of the normalized damage was done by 8 storms. This teaches us that it's the few events that go outside of a society's experience base that really do the most damage.

So how does this bear on the problem of climate change? I would argue that this becomes a question of how rapidly the tail of a distribution evolves compared to the timescales over which we are able to adapt to storms. I really don't have much appreciation for that second timescale; climate change probably wouldn't be such an issue if we could adapt very quickly, but I perceive that climate change is happening faster than we can accommodate its effects.

"It's the few events that go outside of a society's experience base that really do the most damage."

This is part of the reason why we see insured damages around the world from weather-related catastrophes soaring upward. As we continue to study tail problems, one of the biggest things we have to keep in mind in relation to climate change is that relatively small changes in the tail of distributions can have disproportionately large effects when they're outside the realm of our experience.

Kerry Emanuel is the Cecil and Ida Green Professor of Atmospheric Science in the Massachusetts Institute of Technology's Program in Atmospheres, Oceans, and Climate.

Martin Weitzman

Choosing Discount Rates for Climate Issues

Most people agree we should be putting some—with an emphasis on "some"—effort into controlling greenhouse gas emissions. But because economics wants to be quantitative, the question then arises: How much effort should we expend on reducing emissions relative to other things?

I view modeling the economics of climate change as a problem from hell, especially at high greenhouse gas and high temperature-change levels. We're pushing the concepts and tools of economic analysis up to, and arguably beyond, the limits of applicability. As you've now heard, a useful summary statistic is the social cost of carbon. We can try to shoehorn this problem into a kind of emissions cost-benefit analysis or an integrated assessment model, but I am left feeling uneasy when it's used in this scenario. Even for the low-temperature and low-greenhouse gas scenarios, a cost-benefit analysis of climate change is much fuzzier than an ordinary cost-benefit analysis, right off the bat. Should we expand the highway or not? Should we build a bridge here? These questions are not easy and involve some level of uncertainty, but climate change introduces far more uncertainty. So how should we specify, evaluate, and discount future damages? How do we incorporate the tail risks of extreme events with low probabilities?

When trying to answer these questions, we have to discount what happens in the future. Unfortunately, even for small temperature changes, the discount rate we choose makes a huge impact on what our answer is—that's why we sometimes say that the biggest uncertainty in the economics of climate change appears to be the uncertainty about what discount rate to use. Of course, this also impacts our computation of the social cost of carbon, because we're trying to estimate impacts and changes that are far into the future. In all scenarios, the discount rate we choose is going to define what the legitimate social cost of carbon is to a distressingly large extent. Ultimately, we want insurance against the negative future effects of emissions. This insurance aspect—insuring against some really bad event—becomes more and more prominent at higher greenhouse gas concentrations.

"We sometimes say that the biggest uncertainty in the economics of climate change appears to be the uncertainty about what discount rate to use."

The reason we want to keep these greenhouse gas concentrations down is that we're on a ship with a tremendous amount of inertia, and it's going to be very hard to turn it around once these scenarios start playing out. So what would we like to know from scientists? There's a dismal dilemma at play here. It's important to have greater knowledge of these tail risks but, by their very nature, tail risks are very far out of the ordinary, so applying ordinary methods or looking at the past doesn't really suffice. Nevertheless, I'd like to see us focus on this.

Martin Weitzman is a professor of economics at Harvard University.

In Recognition of Lawrence Linden

RFF Board Member and Chair Emeritus, Lawrence Linden, holds a strong personal commitment to creating a more sustainable world shaped by smarter policy. Linden is founder and trustee of the Linden Trust for Conservation, and his insights inspired and helped shape the workshop covered in this report.

Linden addressed the workshop participants during lunch and offered perspectives on economic risk and climate change.

> "The obvious lesson is that science can inform policy and society—and society has to act through the government. The government, in the terms that we are looking at here today, has a political process. It integrates social cost, technical analysis, values, and others measures to create a political decision."
>
> —Lawrence Linden, November 12, 2014

For more information about the workshop or this publication, contact Molly Macauley, RFF vice president for research and senior fellow, macauley@rff.org.

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