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Climate Change Mitigation as Catastrophic Risk Management

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Since Nicholas Stern published his influential *Review on the Economics of Climate Change* for the British government in 2006, economists have become increasingly interested in how the value of climate policy, especially the reduction of greenhouse gas emissions at the global level, depends on risk and uncertainty.[1] New lines of research make the case that mitigating climate change is above all an exercise in catastrophic risk management.

In particular, economists have focused attention on the "fat tails" of climate change, that is, the unusually high, but still very low, probability that the impacts of climate change could be catastrophic, and what this implies for the emissions targets that economists recommend. This focus on low-probability but severe-consequence events has mirrored a broader intellectual trend focused on the importance of "fat tails," exemplified by the popular books of Nassim Nicholas Taleb[1] and Ian Bremmer and Preston Keat.[2]

But by looking at the probabilities of fat tail consequences, economists have also realized that it may be unrealistic to assign discrete probability estimates (e.g., there is a 65% chance of X occurring) to the impacts of climate change. If so, then climate change is affected by what economists sometimes formally describe as "uncertainty"[3,4] or "ambiguity,"[5] where the probabilities of the consequences of actions are not precisely known.

Recent economic research mainly argues that in this context of uncertainty, it is prudent to take extra precaution when setting global carbon emissions targets, making them more ambitious.

Precaution can even be priced, insofar as one recent paper suggests that more than half of society's total willingness to pay to cut carbon emissions stems from aversion to ambiguity about the impacts of climate change.[6]

Examining the Results of the *Stern Review*

What did the *Stern Review* say about the benefits and costs of emissions reduction and what did its results depend on? The *Stern Review* famously advocated deep cuts in emissions, based in part on a comparison of the economic benefits and costs of emissions reductions using an integrated assessment model, that is, a computer simulation model integrating a simple representation of the global climate system with a more-or-less equally simple representation of the global economy.

Using this model[7], the *Stern Review* found that the economic cost of climate change along a business-as-usual emissions path was equivalent to a permanent reduction today of global gross domestic product (GDP) of 11%, within a range of 5–20%. To put this in context, the global economy is currently growing at around 3% per year,[8] so it would be equivalent to losing about 4 years worth of economic growth, within a range of about 2 to 7 years. To an environmentalist, that may not sound like a lot. On the other hand, by the standards of economic modeling it is a huge estimate, so the newspapers of the time were not entirely exaggerating when they branded the results "apocalyptic"[9] and a "doomsday vision."[10]

By contrast, on an emissions path to stabilize the atmospheric concentration of greenhouse gases at 550 parts per million, the *Stern Review* estimated that the economic cost of climate change would be only about 1% of global GDP. Thus, most of climate change's negative impacts could be avoided by cutting emissions to get on to this stabilisation path—a saving or benefit of 10% of global GDP to be precise—and the *Stern Review* separately judged that the cost of doing so (e.g., of rolling out renewable energy technologies) would be much lower, about 1% of global GDP. The *Fifth Assessment Report* (AR5) of the Intergovernmental Panel on Climate Change (IPCC) assessed more recent estimates of mitigation costs and put the median cost of stabilizing atmospheric greenhouse gases at 550 ppm at closer to 2% of global GDP,[11] thus painting a more pessimistic picture. Nonetheless, this estimated cost is clearly still very much lower than the benefits suggested by the *Stern Review*.

After the *Stern Review*, economists debated the assumptions underpinning these results. The debate became largely fixated with the so-called discount rate, that is, a vital parameter in economic analysis that dictates the weight placed on costs and benefits in the future: the lower the discount rate, the higher the weight on the future. The *Stern Review* set an unusually low discount rate, which Stern has subsequently defended resolutely on ethical grounds; he sees no justification in treating successive generations unequally in terms of their well-being.[12] Since most of the impacts of business-as-usual climate change remain in the very far-off future, the low discount rate did indeed play a role in generating the *Stern Review*'s large cost estimates.

However, what was mostly overlooked in this debate was that the discount rate was not the only important assumption driving the results; rather, the results depended on the combination of a low discount rate and the application of a probabilistic approach to modeling, which incorporated the risk of high-impact scenarios[13] (see Figure 1). To be more precise, in the world of integrated assessment modeling these are scenarios in which the global climate responds very sensitively to carbon emissions, and in which climate change triggers a severely adverse reaction in the economy and society. Prior to the *Stern Review*, there had been little formal probabilistic modelling of these high-impact scenarios, which instead had focused on the outcomes in a central-tendency, best-guess scenario.

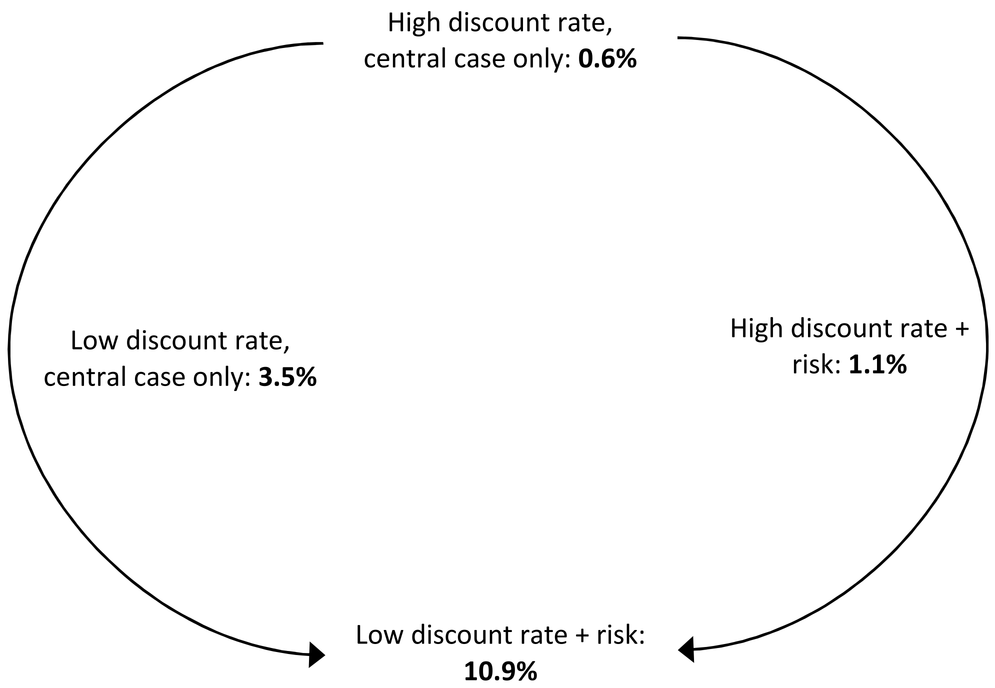

Figure 1. The total economic cost of climate change, as a percentage of global GDP, under different discount rates and with/without explicit modelling of multiple scenarios (adapted from [13]).

Fat Tails

While also concerned about discount rates, Harvard economist Martin Weitzman reacted to the *Stern Review* somewhat differently.[14,15] He wondered whether Stern had pursued the risk story far enough, and his contributions on this topic have had a powerful impact on the subsequent research agenda. Looking at the science of climate change,[16] Weitzman was confronted by evidence of the sort presented in Figure 2, which depicts various estimates of the long-run global temperature response to a doubling of the atmospheric concentration of greenhouse gases (i.e., the key “climate sensitivity” parameter in integrated assessment models). Each estimate is expressed as a probability distribution.

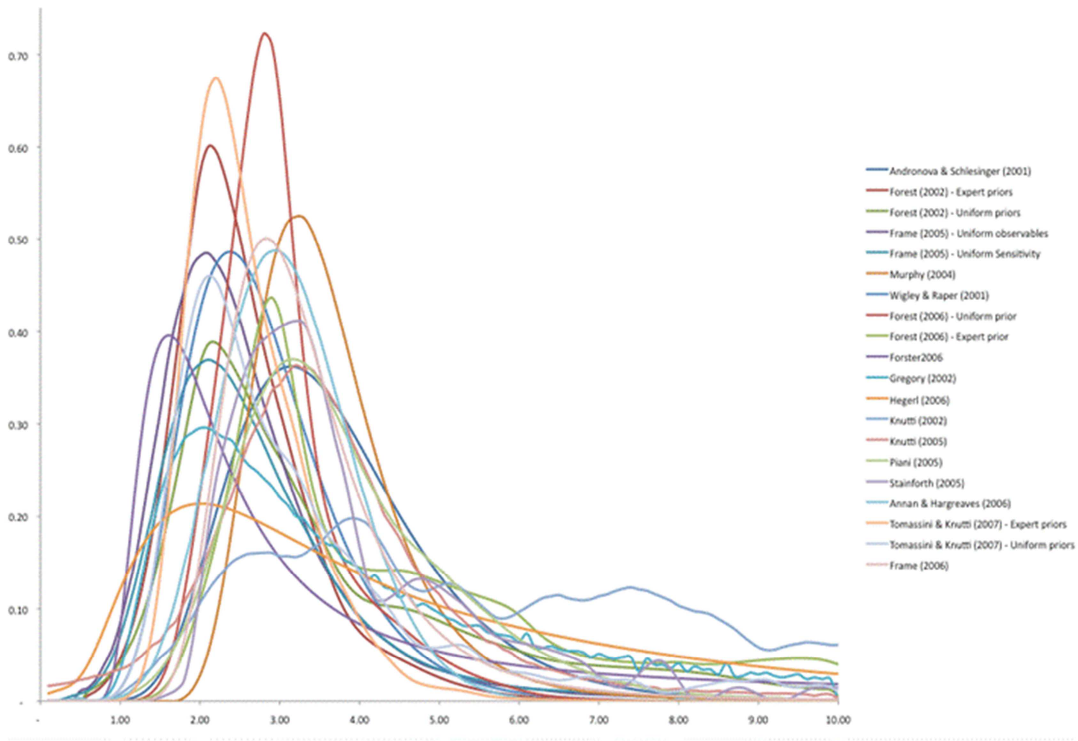

Figure 2. A collection of estimates of the probability distribution of climate sensitivity, i.e. the equilibrium increase in the global mean temperature in response to a doubling of the atmospheric concentration of greenhouse gases from the pre-industrial level[17].

Weitzman observed that most of these distributions had a fat tail of potentially very high temperature responses to a doubling of carbon dioxide, running up to 10°C and even beyond. By contrast, the model that Stern used was based on a climate sensitivity of at most 4.5°C. So while the *Stern Review* explicitly modeled some disaster scenarios, it did not go into the fat tail of potentially much higher global warming.

As an aside, the recent IPCC AR5 Report affirmed this broad picture of climate sensitivity. In the analysis of Working Group I on the Physical Science Basis,[18] the consensus view of the scientists taking part is that climate sensitivity is "likely" to be 1.5–4.5°C, where likely corresponds to at least a 66% probability, it is "extremely unlikely" to be less than 1°C, that is, no more than a 5% probability, and it is "very unlikely" to be greater than 6°C, but since "very unlikely" is defined as up to a 10% probability, this still gives a significant chance of extreme warming.

This basic observation about fat-tailed climate sensitivity has inspired several recent research projects, which have sought to rerun integrated assessment models of climate change, replacing old assumptions about the probability distribution of climate sensitivity that were either inappropriately limited or had too little probability in the tail—or worse still the climate sensitivity was represented merely as a point estimate—with new, fat-tailed distributions.

Among those, one is a direct reanalysis of the *Stern Review* results.[19] It found that the economic cost of climate change potentially increases by a factor of more than three when fat-tailed distributions are included. Indeed, the potential cost of climate change is now so high that the selected discount rate matters much less in determining the final estimates.

With these results, the narrative on what constitutes economically efficient climate change policy is beginning to change. For years, economists have considered climate change mitigation primarily as a long-term investment with a relatively sure payoff, and therefore the key question has been, "What is our commitment to intergenerational equity as embodied in the discount rate?" Increasingly, however, due to our awareness of the potential fat-tail risks of extreme global warming, climate change is being recast as an exercise in managing catastrophic risk, akin to purchasing planetary insurance.

Damage Functions and Attitudes to Risk

Yet while this work has fixed an obvious shortcoming with previous economic modeling—that it was out of step with climate science in a way that was relatively easy to correct—it has also cast the spotlight on other analytical and empirical challenges, and raised new questions. One challenge is that, even in a world of fat-tail risks, the economic value of emissions reduction still depends sensitively on the specification of the damage function[20] in integrated assessment models, a single equation or sometimes a set of equations that estimate economic costs as a function of changes in global temperature. This function has always been crucial to the models, because it is only with a damage function that the loop is closed between greenhouse gas emissions, climate change, and economic prosperity. Without this damage function, climate change would be considered an inconsequential by-product of economic growth.

The problem is that very little is known about the nature of the damage function. The typical approach to specifying the damage function is to fit a curve through the existing data on climate impacts. The data are drawn from published studies on climate change impacts, which, using a variety of approaches, provide estimates of how much global GDP is lost for a given increase in the global mean temperature. One might assume there are many such estimates of the economic impacts of rising global temperatures, but unfortunately that is not the case. In fact, according to a recent paper there are just 17 estimates at the global level.[21]

But much more problematic is that there are no impact estimates whatsoever for global warming in excess of 3°C above the preindustrial level, even though according to IPCC AR5 we might encounter 5°C warming or even more by the end of this century.[18] Consequently, a wide range of curves fit the data equally well, all passing through the data points at up to 3°C warming, but then diverging thereafter, with some giving very modest costs at 5°C warming, and others giving very large costs, eventually large enough to drive average GDP per capita, net the impacts of climate change, down to subsistence levels. Most analyses generating big cost estimates, such as the aforementioned reanalysis of the *Stern Review* model, depend to some extent on the assumption that impacts increase steeply once global warming increases beyond 3°C.

The possibility, however small, that climate change damages could be so large that the standard of living is driven down to subsistence raises a new question. Presumably society would be willing to pay a very large amount, by way of mitigation costs, in order to avoid such a catastrophic scenario, but how much? Weitzman's work caused a lot of trouble for economists by identifying some conditions under which the amount society should be willing to pay is without limit.

This is an objectionable finding in many ways, not least because humanity clearly isn't willing to pay limitless amounts to avoid catastrophes that have miniscule probabilities; otherwise, we would be channeling vast resources on a global scale into preventing large meteorite strikes, for example. So there is presumably an upper bound to our willingness to pay, and this is mechanically easy to introduce in economic models,[22] but at present there is no evidence to inform where that bound lies. Is it 25% of global GDP? Is it 75%? Is it 99%?

One promising line of enquiry might be a dialogue between economists and social psychologists. The latter have surveyed public opinion on climate change in various settings and have painted a mixed picture[23,24]: Concern is widespread, yet "it is of secondary importance in comparison to other issues in people's daily lives."[24] However, there is currently a very large conceptual gap between the type of attitudes and beliefs explored in these studies, asking questions like "How concerned are you about global warming?," and the quantum of interest in integrated assessment models, which is *social* willingness to pay to avoid a global catastrophe. For one thing, it would be necessary to disentangle an individual's valuation of avoiding a catastrophe from that individual's belief in the likelihood of such a scenario, in a fashion similar to contingent valuation studies of the value of a statistical life,[25] for instance. For another, raising the question of social willingness to pay also brings into view the issue of how individual valuations might be aggregated into social valuations.[22]

Uncertainty and Precaution

Besides the implications of fat tails, we can now see, with greater clarity than before, the limits of trying to apply the standard economics of risk to climate change. While indispensible and conceptually solid in thousands of other applications, the standard economics of risk works with discrete estimates of probability, that is, a single probability distribution. Yet the current state of climate science cannot provide a single probability distribution; rather, it can only provide many alternative probability distributions (Figure 2). This was another key point made by Weitzman.[15]

The standard framework could still be applied if one chose the "best" of these distributions, with "best" perhaps defined in terms of statistical fit with the data. The problem is, however, that the different probability distributions produced by different research teams are not independent of each other (different research teams share key elements of their methods), and the historical temperature record has already been used to generate the estimates in the first place, thus complicating its use again to determine which of the models best fits the data.

Alternatively, one could try to combine the distributions in order to give a single composite, like the IPCC's consensus probability distribution for the climate sensitivity mentioned above. The difficulty here is that the reduction of compound probability distributions—that is, in this case weighting each probability distribution in Figure 2 using a subjective assessment of the probability of each study being "right"—is at odds with an important feature of human decision making, called "ambiguity aversion."

If someone is ambiguity averse, it means that that person prefers situations in which his or her actions have consequences whose probabilities are precisely known, to situations in which the consequences of actions have imprecise probabilities, even if in the latter case the reduction of compound probability distributions would give composite probabilities that are the same as in the former case. Put differently, ambiguity should not be reduced to risk, because decision makers do not respond to the two situations in the same way. The famous experiments of Daniel Ellsberg[5] demonstrated this. Given various choices between betting on the outcomes of drawing colored balls from urns, participants in Ellsberg's experiments demonstrated a systematic tendency to place bets where the numbers of balls of different colors were known (see Box 1).

Since Ellsberg's experiments, models of decision makers' ambiguity aversion have been applied in various areas of economics, including finance, where it has been used to explain many seemingly odd patterns of investment that cannot be explained by the standard economics of risk, like the large risk premium on stocks and shares relative to safe bonds, and even the bias toward purchasing stocks and shares in one's own country compared with other countries.

The natural question is, what do we learn if we apply ambiguity aversion to climate change? Some very recent papers have done just that, using quite different models of how we are motivated to "play safe" in the manner isolated by Ellsberg.[6,26,27] Different models can coexist here, because there is no agreement between economists on exactly what model should replace the standard economics of risk in situations where we are more uncertain. Indeed, some economists think the standard model should still apply.[28]

Despite the differences in the models of decision-making, however, these papers are unified in offering a precautionary motive for mitigating climate change. They do this by demonstrating that our willingness to pay for carbon emissions reductions is higher because of the ambiguity about the outcomes of climate change. Willingness to pay is measured in terms of the value that a social planner puts on emissions reductions in theoretical or empirical (i.e., integrated assessment) models. While the numbers should be taken with many pinches of salt, one paper argues that, for plausible parameter choices, more than half of our total willingness to pay to cut carbon could stem from the ambiguity in our knowledge of the climate system and what effect that has on the economic impacts of climate change.[6] This "ambiguity premium" is isolated by analyzing the willingness to pay to cut carbon of a society that is assumed to be ambiguity neutral, and comparing it with a society that is assumed to be ambiguity averse.

First imagine an urn containing 100 balls, 50 of which are red and 50 are black. One ball will be drawn at random. Would you prefer to bet on red or on black? If you win the bet you receive $100. Most experimental subjects are indifferent.

	Red is drawn	**Black** is drawn
Bet on **red**	You win $100	0
Bet on **black**	0	You win $100

Now imagine a second urn with 100 red and black balls, but this time they are in unknown proportion. Would you prefer to bet on red or on black? Most are again indifferent.

Now you are given a third choice, between betting on red in the first urn, the one where you know that ½ of the balls are red/black, and betting on red in the second urn, the one where you don't know how many balls are red/black. This choice is not as obvious, but many choose to bet on red in the first urn.

Finally you are given a choice between betting on black in the first urn or black in the second urn, which is exactly the same as choice three, except the balls are black rather than red. This choice is not obvious either, but many also choose to bet on black in the first urn over black in the second urn.

The problem is, this pattern of choice cannot be reconciled with a reasonable use of probabilities as defined by the standard economics of risk: If you prefer in the third choice to bet on red in the first urn, you apparently believe there are fewer red balls in urn two than urn one (fewer than 50 to be precise), but this is inconsistent with being indifferent between betting on red and black in both of the first two choices, and with preferring to bet on black in urn one in the fourth choice.

Nonetheless, this pattern of choice is intuitive to many, and indeed a key feature[29] of Ellsberg's experiments was that participants tended to stick to their choices even when confronted with the problem as just defined: "Some violate the axioms cheerfully, even with gusto … others sadly but persistently, having looked into their hearts, found conflicts with the axioms and decided … to satisfy their preferences and let the axioms satisfy themselves."[5] The paradox can be resolved by introducing a richer model of choice in which, one way or the other, the decision maker is assumed to be averse to ambiguity.

Box 1. The Ellsberg ambiguity experiment; the two-urn version.

Conclusions

The *Stern Review* stimulated a burst of economic research into its assumptions that supported the conclusion that strong action should be taken globally to reduce emissions of greenhouse gases. While much attention was devoted to the discount rate, it can be argued that subsequent work on risk and uncertainty, notably on the possibility of fat tails in the climate system and on ambiguity about the consequences of climate action, has also been highly productive. In particular, this work has steadily shifted the way climate change mitigation is conceptualized by economists, away from being an investment with long-term, sure payoffs, toward a form of planetary-scale insurance against catastrophic environmental risks.

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NOTES

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