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GLOBAL IQ

Global integrative quantitative assessment

Climate change mitigation as catastrophic risk management

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SUMMARY FOR POLICY-MAKERS

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

In particular, there has been a focus on 'fat tails' in the economics of climate change, i.e. the unusually high, but still very low, probability that the impacts of climate change could be huge, and what this implies for the emissions targets that economists recommend. This focus on fat tails in climate change policy has mirrored a broader intellectual trend towards arguing for the importance of fat tails, exemplified in the popular books of Nassim Nicholas Taleb[2] and Ian Bremmer and Preston Keat[3], for instance.

But by looking at fat tails, which are of course a probabilistic concept, economists have also awakened to the fact that it may be unrealistic to pretend we can characterise the impacts of climate change with unique probabilities at all. Climate change may be a deeper problem of uncertainty, rather than a traditional risk situation like betting on roulette or pricing a motor insurance policy, where we can be relatively confident in the probabilities we apply. By embracing uncertainty, recent economic research mainly argues for taking extra precaution in setting global carbon emissions targets. Precaution can even be priced and one recent paper suggests that more than half of society's total willingness to pay to cut carbon emissions may be due to precaution where risks are unknown[4].

KEY OBSERVATIONS

Revisiting the results of the Stern Review

What did the *Stern Review* say about the benefits and costs of emissions abatement and what did its results depend on? The *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, i.e. 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.

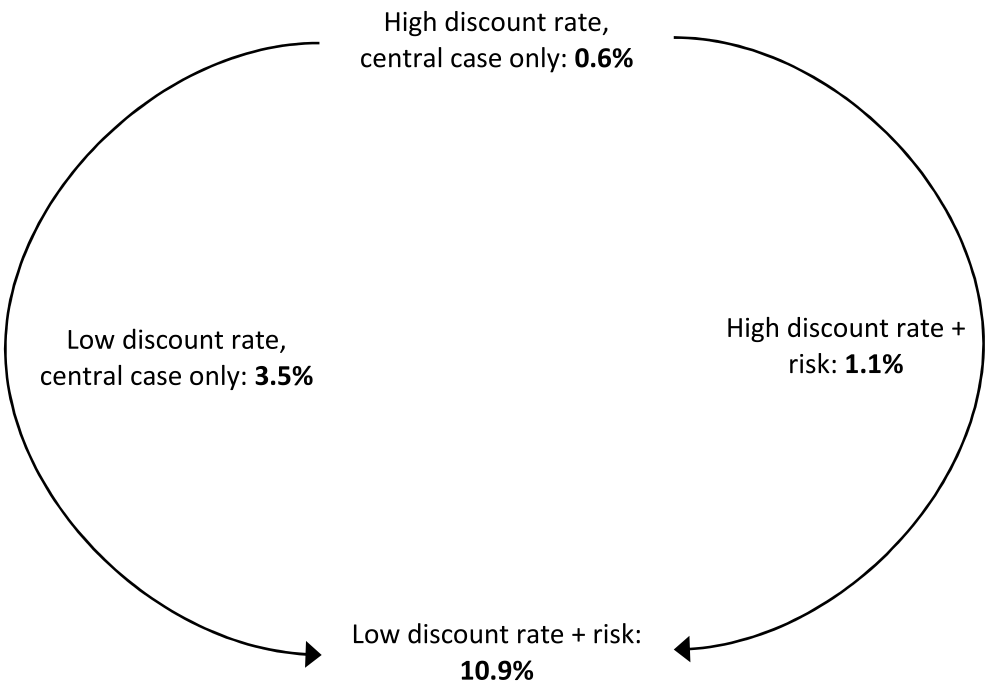
Using such a model[5], the *Review* found that the economic cost of climate change along a business-as-usual emissions path was equivalent to a permanent reduction today of global GDP of 11%, within a range of 5-20%. To put this in context, the global economy is currently growing at around 3% per year[6], so it is equivalent to losing about four years' worth of growth, within a range of about two to seven years. To a committed environmentalist, that may not sound like a lot. On the other hand, by the standards of economic modelling of any issue it is a huge estimate, so the newspapers of the time were not entirely exaggerating when they branded the results "apocalyptic"[7] and a "doomsday vision"[8].

By contrast, on an emissions path to stabilise the atmospheric concentration of greenhouse gases at 550 parts per million (compared with about 445 ppm today), the *Review* estimated that the economic cost of climate change was 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 path – a saving or benefit of 10% of global GDP to be precise -- and the *Review* separately judged that the cost of doing so through for example rolling out renewable energy technologies would be much lower, of the order of 1% of global GDP. The *Fifth Assessment Report* (AR5) of the Intergovernmental Panel on Climate Change (IPCC) has collected more recent estimates of mitigation costs and put the median estimate of the cost of stabilising atmospheric greenhouse gases at 550 ppm at closer to 2% of global GDP[9], thus painting a more pessimistic picture. Nonetheless this is clearly still very much lower than the benefits estimated by the *Review*.

After the *Review*, economists debated the assumptions underpinning these results. The debate became largely fixated with the so-called discount rate, i.e. 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 wellbeing[10]. 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 *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, they depended on the *combination* of a low discount rate on the one hand, and the application of a probabilistic approach to modelling on the other hand, which incorporated a risk of high-impact scenarios[11] (see Figure 1). To be more precise, in the world of Integrated Assessment Modelling these are scenarios in which the global climate responds very sensitively to carbon emissions, and in which in turn climate change triggers a severely adverse reaction in the economy and society. Prior to the *Review*, there had been little formal probabilistic modelling and little attention paid to these high-impact scenarios in the modelling, which instead had focused on the outcomes in a central, best-guess scenario.

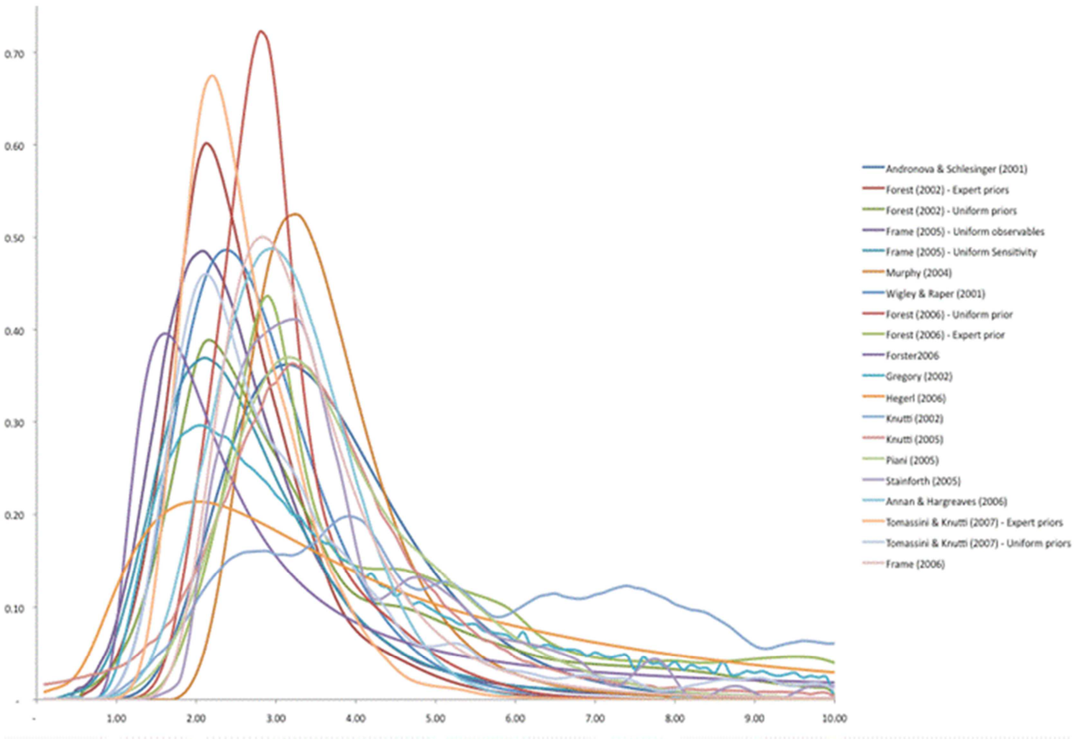
Figure 1. The total economic cost of climate change, as a percentage of global GDP, under different discount rates and with/without explicit modelling of multiple scenarios[11].



Fat tails

While also concerned about discount rates, Harvard economist Martin Weitzman reacted to the *Stern Review* somewhat differently[12,13]. He actually wondered whether Stern had pursued the risk story far enough and his contributions on this topic have had a powerful effect on shaping the subsequent research agenda. Looking at the science of climate change[14], Weitzman was confronted by evidence of the sort presented in Figure 2, in which 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) are collected. 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[15].



Almost whichever distribution we would choose, Weitzman correctly noticed that it would have a fat tail of very high temperature responses running up to 10C and even beyond. By contrast, the model that Stern used was based on the climate sensitivity being not more than 4.5C. So while the *Stern Review* explicitly modelled disaster scenarios, it did not go very far into the tail, at least as far as warming of the planet is concerned.

As an aside, the more recent IPCC AR5 has affirmed this broad picture of the scientific evidence. In the analysis of Working Group I on the Physical Science Basis[16], the consensus view of the scientists taking part is that climate sensitivity is 'likely' to be 1.5-4.5C, where likely corresponds to at least a 66% probability, it is 'extremely unlikely' to be less than 1C, i.e. no more than a 5% probability, and it is 'very unlikely' to be greater than 6C, 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 the shape of the probability distribution over the temperature response to emissions has inspired several recent research projects, which have sought to re-run Integrated

Assessment Models of climate change, replacing old distributions of climate sensitivity that were either inappropriately truncated or had too little probability in the tail – or worse still the climate sensitivity was simply a point estimate – with new, fat-tailed distributions.

Among those, one is a direct re-analysis of the *Stern Review* results[17]. It shows that the economic cost of climate change increases by a factor of more than three when fat-tailed distributions are substituted for their thin-tailed counterparts. Indeed, the cost of climate change is now high enough that the discount rate matters much less.

With these results, the narrative on what constitutes economically efficient climate change policy is beginning to change. For years it has been thought of in economics primarily as a long-term investment with a relatively sure pay-off, therefore the question has been what is our commitment to intergenerational equity as embodied in the discount rate? Increasingly, however, it 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 modelling – that it was out of step with the science in a way that was relatively easy to correct – it has cast the spotlight on other analytical and empirical challenges, and raised new questions. One challenge is that, even in a world of fat tails, the economic value of emissions abatement still depends sensitively on the specification of the damage function[18] in Integrated Assessment Models, a single equation or sometimes a set of equations, which link changes in global temperature as an index of climate change with economic costs. This function has always been crucial to the models, because it is only with a damage function that the loop is closed between emissions, climate change and economic prosperity. Without it, climate change is an inconsequential by-product of growth.

The problem is that very little is known about the nature of the damage function. The basic approach to specifying it, in particular single-equation, aggregate damage functions, is to fit a curve through the data. The data are underlying studies in the literature on climate change impacts, which, using a variety of approaches, are able to give an estimate of how much of a loss in global GDP is incurred when the global mean temperature hits a particular point. You might imagine there are legions of such estimates, but you would be wrong. According to a recent paper[19], there are in fact just sixteen independent estimates at the global level.

But what is most problematic is that there are no data points whatsoever for global warming in excess of 3C above the pre-industrial level, even though according to IPCC AR5 we might encounter 5C warming or even more by the end of this century[16]. Besides the shortcomings of the data points themselves, as an exercise in curve-fitting it means that you cannot constrain the shape of the damage function; it could give modestly increasing costs as warming progresses, or steeply increasing costs. The re-analysis of the *Stern Review* model mentioned just above needed steeply increasing costs, at least with some probability, in order to generate its big numbers. This was (necessarily) loosely based on the assumption that costs in a range of sectors such as agriculture increase more than proportionately with warming, and that damaging tipping points in the climate system[20] like collapse of the West Antarctic Ice Sheet might be crossed.

The possibility, however small, that climate change and its associated damages could in a general sense 'run away' at some point, driving the standard of living, which is the focus of economic models, down to a subsistence level or below, raises a new question. Presumably we 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 establishing some conditions under which the amount we would be willing to pay is without limit.

This is an objectionable finding in many ways, not least because we clearly aren't willing to pay limitless amounts to avoid catastrophes that have miniscule probabilities; otherwise we would be channelling 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[21], 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[22,23]: concern is widespread, yet "it is of secondary importance in comparison to other issues in people's daily lives"[23]. 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 his/her belief in the likelihood of such a scenario, in a similar fashion to contingent valuation studies of the value of a statistical life[24], 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.[21]

Uncertainty and precaution

Besides the implications of fat tails, we can now see, with greater clarity than before, the limits of trying to apply to climate change the standard economics of risk. This is actually crystal clear in Figure 2 and was another main point in Weitzman's papers: while the standard economics of risk, indispensible and conceptually solid in thousands of other applications, works with unique estimates of the probability of whatever outcomes matter, i.e. with a single probability distribution, the current state of scientific knowledge cannot give us that, rather it gives us many alternative probability distributions.

We could try to just choose the 'best' of these distributions, with best being perhaps measured in terms of statistical fit with the data. The problem is the distributions are not independent of each other (different research teams share elements of their method), and the historical temperature record has already been used to generate the estimates, thus precluding us from using it again to determine which of the models best fits the data.

Alternatively we could try to combine the distributions in order to give a composite, like the IPCC's consensus probability distribution for the climate sensitivity mentioned above. Given the state of scientific knowledge, this is going to require some explicit, subjective judgements to be mixed with the objective knowledge that forms part of each of the estimates. But if decision-makers are sensitive to the difference between objective probabilities and subjective weights, and would prefer, all else being equal, to make choices that depend on objective probabilities (known in economics as 'ambiguity aversion'), then it is inappropriate to simply create a composite distribution. An alternative decision model should be used.

The famous experiments of Daniel Ellsberg[25] showed that most decision-makers are indeed ambiguity averse in this way. Given various choices between betting on the outcomes of drawing coloured balls from urns, participants in Ellsberg's experiments demonstrated a systematic tendency to place bets where the numbers of balls of different colours were known, i.e. where the chance of drawing a ball of a particular colour is objectively known (see Box 1). This is a paradox, because it contradicts how these participants should have behaved according to the standard economics of risk, which has no place for ambiguity aversion.

Since the Ellsberg paradox was discovered, models of decision-makers' ambiguity aversion have been applied in various areas of economics, including finance, where it might be 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 towards purchasing stocks and shares in one's own country compared with other countries.

The natural question is; what do we learn if we apply them to climate change? Some very recent papers have done just that[4,26,27], using quite different models of how we are motivated to 'play safe' in the manner isolated by Ellsberg. Different models can co-exist here, because there is no agreement between economists over 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; in demonstrating that our willingness to pay for carbon emissions reductions is higher because of the deep uncertainty about the outcomes of climate change. One paper is in fact able to quantify the extra willingness to pay that is based on this essentially precautionary story; while the numbers should be taken with many pinches of salt, it argues that, for plausible parameter choices, more than half of our total willingness to pay to cut carbon could stem from ambiguity in our knowledge of the climate system and what effect that has on the economic impacts of climate change[4].

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

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 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 similar choice between betting on black in the first urn or black in the second urn. 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 that 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 blue 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".[25] 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 imprecision about the probabilities of outcomes.

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PROJECT IDENTITY

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