The economics of global climate variability

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When economists and governments estimate the future economic costs of climate change, they tend to focus on modeling the long-term upward trend in global mean temperatures. Yet by neglecting to model the variation around this trend, it is likely that they have underestimated the economic costs by trillions of dollars (Calel et al. 2020). These previously unaccounted-for costs suggest that the benefits of resilience to climate extremes may be significantly undervalued. Improving the understanding of climate variability and its relationship to global warming in cost estimating approaches could greatly facilitate building that resilience.

The climate policy debate has long been heavily influenced by one type of economic forecasting model that was pioneered by Nobel Prize winning economist William Nordhaus, and which are commonly referred to as "integrated assessment models", or IAMs for short. It was this type of model that economist Lord Nicolas Stern relied on in 2006 when he made his case that the British government needed to pursue a more ambitious climate policy. The US government today relies on these models to forecast climate change damage and estimate the "social cost of carbon" – a number that informs everything from new vehicle mileage standards to the US position in international climate negotiations. Indeed, whenever a US government agency performs a Regulatory Impact Assessment to estimate the costs and benefits of any substantial policy change, they are required to count the economic harm of releasing each additional tonne of greenhouse gas emissions into the atmosphere. The "social cost of carbon" is an estimate of this harm, and understandably, the exact number used has been hotly contested in the courts and from one presidential administration to the next.

Through these legal and political battles, there is one important limitation of these models that has not received much attention: the models do not take into account the inevitable and largely unpredictable fluctuations in global temperatures around the relatively smooth long-term warming trajectory. This may seem like a small oversight, but a new study by Calel et al. (2020) demonstrates the importance of such fluctuations, which lead to a probability distribution rather than a single value for the economic damages

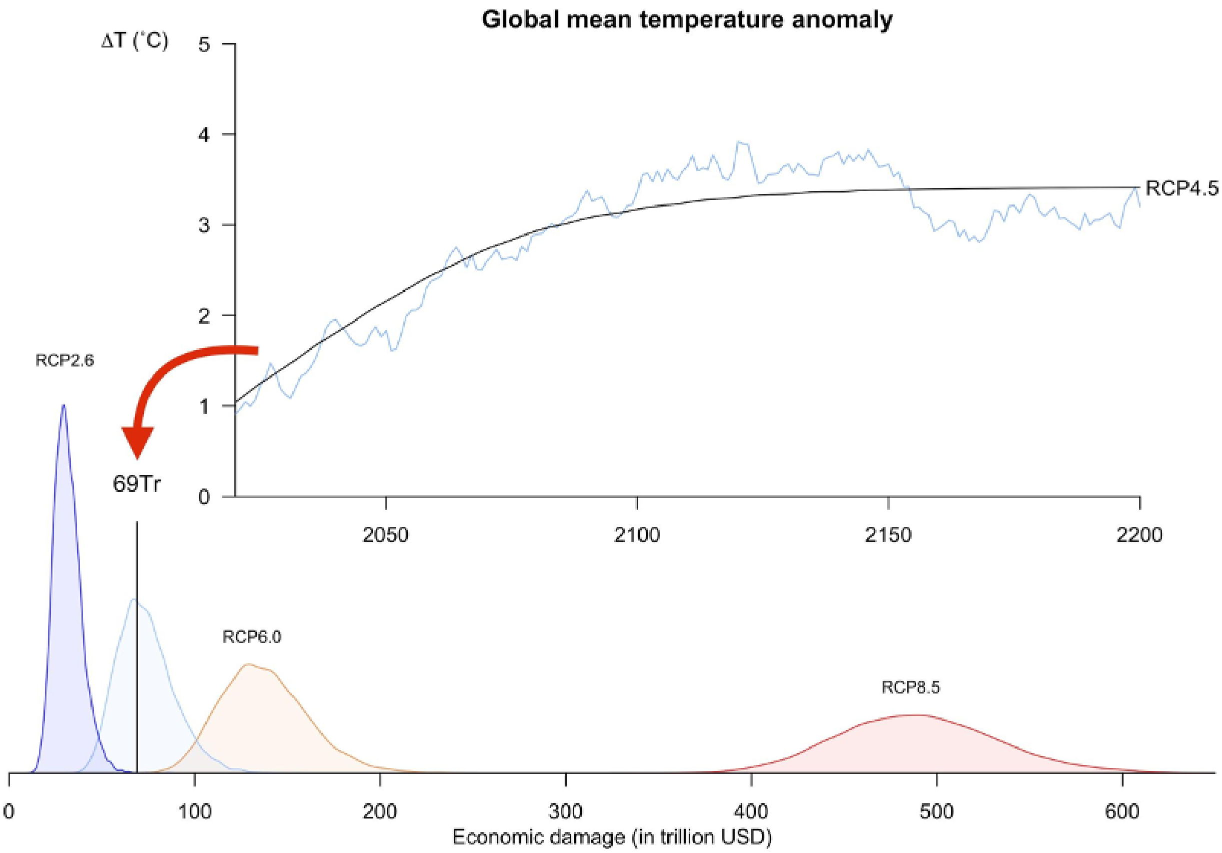


Figure 1. The top panel shows the trajectory of the global annual mean temperature when a deterministic climate model is forced according to RCP4.5 (in black), along with an illustrative trajectory from a stochastic climate model (in blue). The bottom panel shows the corresponding probability distributions of economic damage, based on samples of 10,000 trajectories for each RCP. The black vertical line shows the damages associated with the deterministic trajectory in the top panel.

under each scenario of future atmospheric greenhouse gas concentrations. For instance, under RCP4.5 (an intermediate Representative Concentration Pathway), with fairly conservative economic assumptions about the way the future impacts of warming are valued, the damages associated with climate change are not $69 trillion, as in the deterministic case, but range from $51 trillion to $101 trillion (5-95% range; see Figure 1). For comparison, the world economy today is worth about $80 trillion, so this is quite a wide distribution. Figure 1 also shows that the probability distribution skews toward higher values, and that the distributions for different RCPs are fairly well separated. The first message is therefore that while there is high confidence that RCP4.5 will have smaller economic damages than RCP6.0, which will in turn have smaller damages than RCP8.5, the magnitude of those damages has a large element of intrinsic, unavoidable uncertainty, with a disproportionate risk of tail events. We need to plan for the future with this in mind.

The second, more subtle, message is that a cost can be associated with the existence of a distribution. Damages can be separated into two components: the deterministic or expected damages, and the cost of uncertainty in those damages. The cost of the uncertainty can be thought of

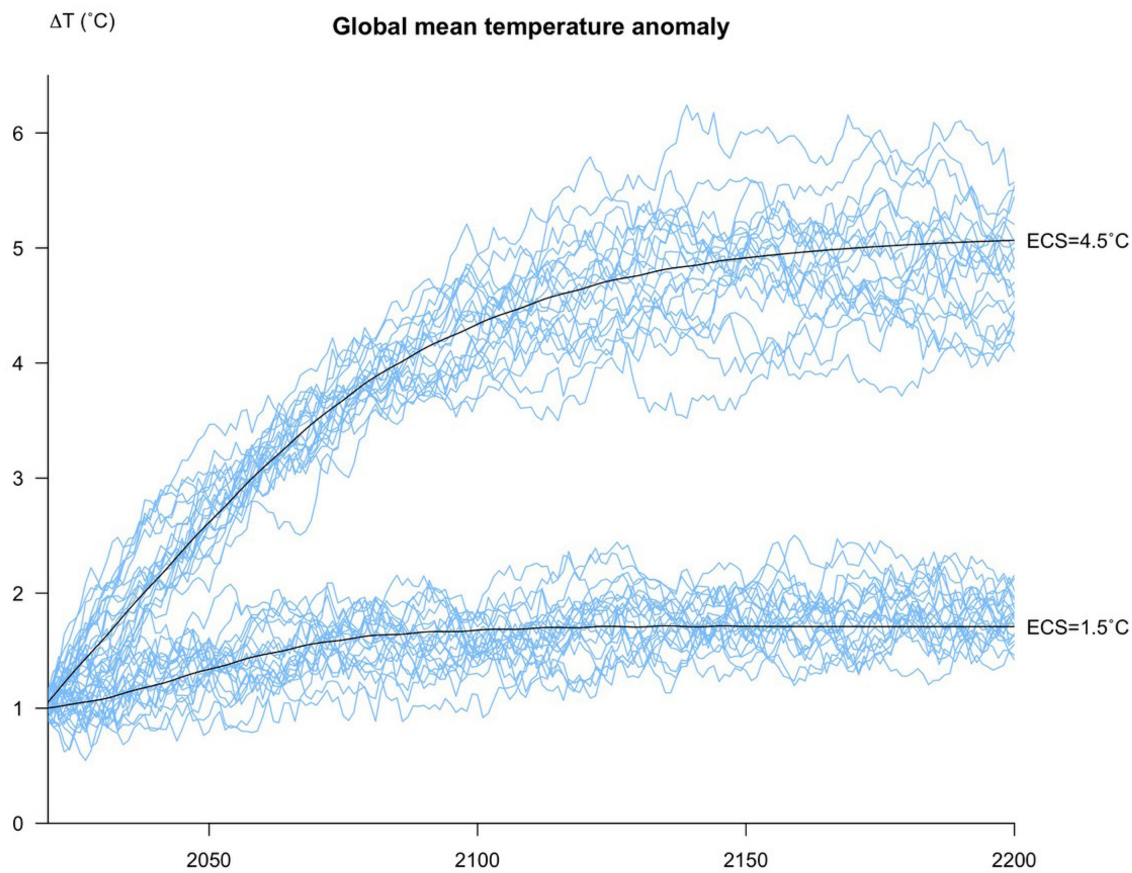


Figure 2. The IPCC assesses that the Equilibrium Climate Sensitivity (ECS) is "likely" between 1.5˚C and 4.5˚C. For each of these boundary cases, we plot the trajectories of the global annual mean temperature when a deterministic climate model is forced according to RCP4.5 (in black). For each case, we also plot 20 temperature trajectories from a stochastic climate model (in blue). These small ensembles illustrate a general feature of the stochastic climate model: that the ensemble-wide temperature variance is higher for higher values of the ECS.

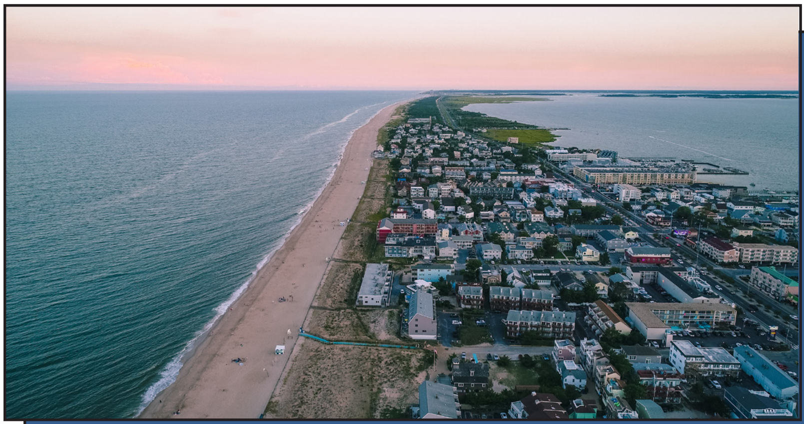
as the financial value of insurance against the variability, were such an insurance product available. The value of such insurance turns out to be anywhere from $10 trillion (RCP2.6) to $50 trillion (RCP8.5) when measured in today's money. If we decide we care more about damages that occur in the distant future than is reflected in standard economic assumptions, or that we are more risk-averse, then the value of insurance is even greater.

How do these costs arise? One reason is that, with some years that are cooler than the expected trajectory and others that are hotter, the hotter years will have disproportionately harmful consequences. In addition, variability in global mean temperatures show significant auto-correlations, sometimes leading to several hotter-than-average years in a row, or even decades. The cooler-than-average years are not enough to compensate for this risk, and this accentuates the skew in the damage distribution.

This is only part of the story though. Evaluating the costs associated with global variability requires consideration of how different sources of climate risk interact. One important risk factor in current forecasts is uncertainty about how responsive global temperatures will be to large increases in atmospheric carbon dioxide concentrations. It is far too responsive for comfort, but would doubling atmospheric carbon dioxide lead to a 3˚C, or 5˚C, or even greater increases in mean global surface temperature? Estimating climate sensitivity remains an ongoing research challenge. The twist here is that in a simple stochastic climate model, a stronger global temperature response also tends to be associated with greater year-to-year fluctuations (see Figure 2). Being dealt a bad hand in the climate casino (Nordhaus 2015), then, does not just mean higher global temperatures, but also more unpredictable temperatures. When projecting costs into the future, including variability increases the costs associated with low-sensitivity projections somewhat, but the costs associated with the high end of the climate sensitivity distribution become disproportionately greater. In the presence of underlying uncertainty about climate sensitivity, therefore, global climate variability pushes out the tail of the damage distribution even further, and significantly increases the expected economic costs of climate change.

An evaluation of RCP4.5, with standard economic assumptions and a middle of the road climate sensitivity (3˚C), leads to damages of $69 trillion plus an additional $9 trillion to account for variability. However, when uncertainty in climate sensitivity is accounted for as well, the cost of variability rises from $9 trillion to $25 trillion. Returning to the social cost of carbon – the typical means of summarizing climate damages – it is perhaps surprising to discover that these temperature fluctuations appear to increase the social cost of carbon by less than one percent, despite adding trillions of dollars to damage estimates. The social cost of carbon measures additional future damage from emitting just one extra tonne of carbon dioxide today, over and above some economically optimal trajectory. But in an already warmer world, emitting one extra tonne of carbon dioxide has little impact on global variability; the average or "expected" warming increases, but the variability does not. The same year-to-year variability will inflict slightly greater damage when the world is hotter, which translates into a higher social cost of carbon, but that change is relatively modest. Ultimately, almost the same variability risk will be faced whether or not one extra tonne of carbon dioxide is emitted, which is why it does not show up in the social cost of carbon. This highlights an important limitation in the use of the social cost of carbon to measure climate damage.

The fact that this variability cannot be avoided makes it almost invisible to anyone focused narrowly on the social cost of carbon, but it also makes it more important to prepare for it. Investments could be made in order to prevent the hotter-than-average years or decades from having large climate and economic consequences. Some investment options include, shifting toward a more



resilient food supply chain, building infrastructure that will better withstand future weather extremes, improving disaster readiness capabilities, implementing social programs to help communities which may be in need of resettlement, and so on. When global climate variability is taken into account, it becomes clear that the benefits of these investments are much greater than previously understood. There is still a pressing need to reduce emissions at a faster rate to avoid predictable climate change, and to invest in adaption to gradually rising global temperatures. The unpredictable variation that is expected on top of climate change, though, provides an additional motivation to make investments specifically aimed at lessening the costs of the unpredictable, but inevitable, fluctuations.

These findings point the way, but taking the next step will require a better understanding of the climate variability we are trying to prepare ourselves for. The first question is how best to model the relationship between the statistical characteristics of the global annual mean temperature trajectory. The simple stochastic climate models provide a parsimonious representation of how the mean, the variance, and the auto-covariance of temperatures are physically linked. To what extent can we improve upon this representation?

The second question is how to best model the time-series of properties of the global annual mean temperature. For instance, do all short-term fluctuations gradually dissipate, or do their consequences persist indefinitely (see Fredriksen and Rypdal 2017)? The fact that we have only one brief realization of the actual instrumented climate makes it difficult to fully interrogate its auto-covariance structure, yet society's ability to cope with climate change is likely to depend on understanding the risk of multi-year and interdecadal departures from the long-term trend and society's ability to recover from them.

A third question is how to best map global temperatures to local conditions. Economic assessments of future climate damages rely on forecasts of the global annual mean temperature. The global annual mean temperature is useful in this context both because it is comparatively simple to project and because it is a summary statistic that captures important information about the overall state of the climate system. However, since climate change impacts and economic damages are not distributed evenly across the globe, it is important to consider how that summary statistic translates into on-the-ground realities. If specific climatic features associated with globally hotter-than-average years can be identified (ones that account for disproportionate economic costs), then it may be possible to prioritize investments that build up resilience against those specific sources of risk.

The lion's share of economic damages are likely to be those associated with the rise in expected temperature. Reductions in greenhouse gas emissions would limit these damages. But if the focus is on the social cost of carbon, then many may mistakenly conclude that global variability hardly matters. Even though the effects of global variability are secondary, they will likely be measured in tens of trillions of dollars. There is a great deal that can be done to prepare for this future, and an important part of this preparation should include making a serious investment in gaining a better understanding of the climate variability we are trying to prepare for.

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