Some Thoughts on the Value Added from a New Round of Climate Change Damage Estimates

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EPA/DOE Workshop on Improving the Assessment and Valuation of Climate Change Impacts for Policy and Regulatory Analysis: Research on Climate Change Impacts and Associated Economic Damages

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The organizers of the workshop on "Research on Climate Change Impacts and Associated Economic Damages" asked us (among others) to reflect briefly on three summary questions. The first focused on improving reduced-form integrated assessment models. The second asked for an assessment of recent progress with particular attention paid to interactions across sectors. The third invited us to identify important gaps and uncertainties. We will not attempt to answer any of these questions comprehensively. We will, though, offer some hopefully provocative thoughts that address the content of each of them, taken in turn, from a value-added perspective. In doing so, we hope to speak to the issues raised by the broader title of the two-day meeting: "Improving the Assessment and Valuation of Climate Change Impacts for Policy and Regulatory Analysis".

Our first set of comments expresses some concern about the value of specific contributions to integrated assessments and their products. To that end, Section 1 offers a warning to beware of analyses that are so narrow that they miss good deal of the important economic ramifications of the full suite of manifestations of climate change; i.e., they miss interactions in the climate system that allow climate change, itself, to be a source of multiple stress even within one particular sector. Section 1 also makes the point that the largest value added by updated economic analyses of impacts may be found in using their results to identify where more careful consideration of site-specific and path dependent adaptation might be most productive.

Our second set of comments focuses attention on one of the most visible products of integrated assessment modeling – estimates of the social cost of carbon which we take as one example of aggregate economic indicators that have been designed to summarize climate risk in policy deliberations. Our point, argued in Section 2, will be that these estimates are so sensitive to a wide range of parameters that improved understanding of economic damages across many (if not all) climate sensitive sectors may offer only limited value added. Some of these parameters reflect interactions across sectors. Others fall within the prerogative of decision-makers who use the results of integrated assessment to judge the value of mitigation policy. Still others fall within the prerogative of "Mother Nature"; and we must humbly admit that she is not being particularly forthcoming in providing information from which we can glean reliable and timely estimates. We fear, in other words, that the very focus of this workshop may have been guilty of a "type-three error" – that is, in the words of Richard Tol, "barking up the wrong tree".

Having cast some doubt on the ability of improved estimates of economic damages to increase the value of economic damage estimates in integrated assessment modeling designed to inform climate policy deliberations, we offer an alternative approach in Section 3. We begin with the idea that climate policy can perhaps best be understood as a question of setting a carbon-emissions budget for a period of decades rather than centuries – say limiting cumulative emission from the United States to between 170 to 200 gigatons through 2050 as suggested in the report of the "Limiting Panel" to America's Climate Choices [NAS (2010)]. Working from there to suggest how to set a price on carbon, we end this brief note by describing implicitly a research agenda that could (a) effectively inform mitigation decisions while, at the same time, (b) providing economic estimates for aggregate indicators like the social cost of carbon. It is these estimates that can be applied to considerations of the value (or harm) caused by the carbon-emission consequences of non-climate regulations and other market interventions. We believe that working out the technical and practical details of such an approach could pay the greatest dividends – an approach that would use the results of integrated assessment models to characterize policy context and judge economic tradeoffs.

Section 1: Beware of Spurious Precision and Incomplete Models.

The workshop offered glimpses into current work across a wide range of sectors and contexts, but we are worried that any single paper could be taken as comprehensive coverage of what is known and/or what needs to be known. Take, for example, the contribution by Mendelsohn, Emanuel, and Chonabayashi on tropical cyclone damage. We do not mean to pick on this paper, but it does speak to climate impacts in a sector with which we have some familiarity. The authors used historical records to calibrate simulations of future cyclones with and without climate change using a collection of 4 global circulation models along the A1b SRES storyline. Based on statistical associations of storm intensity and observed damages, they conclude that "Increasing future income and population is predicted to increase annual tropical cyclone damages from $26 billion to $55 billion even with the current climate. However, damages as a fraction of GWP are expected to fall from their current rate of 0.04 percent in 2010 to 0.01 percent in 2100."

While the analysis is solid as far as it goes, we are afraid that it makes only a small contribution to our understanding of vulnerability to coastal storms that could easily be misinterpreted for two reasons. First of all, while the analysis did use four alternative climate models to simulate the future implications of 70,000 simulated cyclones, it did not provide any insight into the true range of possible damage futures. It did not, for example, explore alternative socio-economic futures (either within A1b with respect to geographical distribution of populations and development or across alternative story-lines). Nor did it explore uncertainty boundaries defined by its estimates of damage elasticities (with respect to income and population). It did not even explore uncertainty boundaries defined by any portion of the reported range of equilibrium climate sensitivity – an increasingly common feature of contemporary impacts analyses. It follows that the $26 to $55 billion *range* must be understated; it is easy to envision not-implausible economic futures for which $26 billion is too high, but it is equally easy to envision futures for which $55 billion is way too low.

The analysis also falls well short of providing comprehensive estimates of the economic damage of either tropical cyclones or coastal storms more generally. This is, in part, because it completely ignores major components of potential damage. Loss of life comes to mind in this regard; and while ignoring this risk avoids the controversy about international distributions of the value of a statistical life, it does so at the expense of severely limiting the coverage of the reported estimates.

In addition, because the analysis relies heavily on central tendencies in its statistical representation of future damages, it misses entirely the enormous inter-annual variability in cyclone damage about which insurance and re-insurance companies would be far more interested. Katrina dominates any damage time series over the past few decades in a way that is not reasonably reflected in the annual means (or medians, for that matter). Indeed, only researchers who recognize that the sheer magnitude of a Katrina-like outlier cannot be excluded from any year's potential exposure will be able to appreciate the enormous adaptation challenge that it poses. Spreading annual risk geographically may not be enough for tropical cyclones. It may be necessary to spread risk over time, as well; but to do so would require regulator reform of the sort now being suggested by Kunreuther and Useem (2010).

Mendelsohn, *et al.* also ignore the contribution of even modest sea level rise to damages associated with storms of all shapes and sizes. The authors are, in fact, completely wrong when they assert on the basis of simple statistical analysis of damages (in the text that describes the content of Figure 5) that "common small storms are not different before and after climate change." Kirshen, *et al.* (2008), Rosenzweig, *et al*. (2010), and others have argued convincingly that sea level rise elevates storm surges associated with any coastal storm and therefore amplifies any storm's potential for causing economic damage. The mechanism is really quite simple. Elevated storm surges driven by routine sea level rise can make what is now, for example, a 20-year storm look like the current 50-year storm in terms of economic exposure. In other words, what is now the 50-year storm in terms of economic consequence can turn into an every other decade (on average) event at some point – and for some locations, some time in the relatively near-term future. Table 1 offers some evidence of what this association could mean for what is currently the 100-year storm in Boston and New York along two SRES emissions trajectories and central tendency sea level rise.

Figure 1 brings this simple process (for storms of all dimensions) into geographic focus by plotting the frequency of threshold anomalies per year for 5 different locations along the north-eastern coastline of the United States from 1920 through 2005; these are locations that have experienced, on average between 2.6 cm and 2.8 cm of sea level rise per decade since 1920. The various panels of Figure 2 show what this process understanding means for an urban coastal community in Boston. Offered simply as an illustrative example, it shows damage profiles (without adaptation) at 20-year increments that were drawn randomly from probabilistic representations of historical weather patterns (without altering intensity or frequency in anticipation of climate change). This historical pattern was then superimposed upon sea level trajectories that reach 100 cm and 60 cm by 2100.

Notice that damages from the worst 5% of the storms (including, perhaps, an occasional representation of a hurricane or a severe winter nor-easter with hurricane force winds) are expected to climb over the century by as much as 250% (along the 100 cm trajectory); this is flooding analog to what Mendelsohn, *et al*. estimate as a function of storm intensity that is implied by the first rows of Table 1. More importantly, notice that damages from the other 95% of the storms are expected to increase similarly and persistently over time at rates that are determined by the underlying sea level rise scenario.

Clearly, these risk profiles show that common storms *can be quite different under climate change when the local characteristics of climate change are more comprehensively represented*; and clearly, those differences can produce some relatively large economic consequences. These sorts of risk profiles can also help decision-makers decide how and when to respond to a growing climate-related risk. Table 2, for example, charts the increase in the estimated expected internal rate of return for an investment in protective infrastructure that would (a) cost $390 million (in real dollars) to implement, (b) commit the city to 10% maintenance expenses thereafter, and (c) not guarantee complete protection from the upper end of the damage distribution. These *economic* estimates show that the need for adaptation could be urgent (or not), depending on the degree to which this public investment would complement private investment [see, e.g., Ogura and Yohe (1977)] and the speed with which sea level are seen to be rising rise.

Section 2: Value Added for Aggregate Economic Indicators like the Social Cost of Carbon.

Downing and Watkiss (2003) warned that economic analyses of climate change damages failed to cover much of what might be in store for the planet (especially in terms of socially contingent consequences and abrupt events). While little has changed to allay their concerns, this section will not rehash their arguments. It will, instead, ask (and, to some degree, answer) a simple question: "What difference would marginal contributions to economic damage estimates (for the impacts and sectors that we can model) make on the major economic aggregates that some believe most significantly inform climate policy deliberations?" We know that uncertainty compounds through the climate system as we move from (a) economic activity to (b) greenhouse gas emissions to (c) changes in their atmospheric concentrations to (d) changes in global mean temperature and other climate variables to (e) impacts in physical and biological systems to *(f) economic estimates of associated damages with and without adaptation.* Since new estimates of economic damages speak only to the last (italicized) association, it would seem fool-hearty not to hypothesize that the answer to this question is "Not much!"

To begin to explore the potential validity of this hypothesis, we used the latest version of the PAGE integrated assessment model (PAGE 09) to track the implications of three possible implications of a new round economic damage estimates (of the sort presented at the workshop) on the distribution of estimates of the social cost of carbon.[1] The baseline scenarios worked from a representation of the SRES A1B storyline whose default settings produced the range of temperature trajectories depicted in Figure 3. The three experimental changes from the default settings were designed to reflect improved (or at least altered) understanding of economic damages across the board. Results (calibrated in terms of the social cost of carbon) from the default-setting baseline and three experiments are recorded in Table 3 and depicted graphically in Figure 4. In every case, the summary statistics of Table 3 and the histograms of Figure 4 were produced from monte carlo simulations that involved 100,000 distinct manifestations of the complete set of underlying random

[1] See Hope (2006) for details of the structure of the PAGE models. For updates included in PAGE09, see http://climatecost.cc/images/Policy_brief_4_PAGE09_Model_vs_2_watermark.pdf.

variables that PAGE 09 can accommodate.

In the first experiment (Case A in Table 3), new economic research was assumed to reduce the range of the parameters that calibrates estimates for economic sectors and coastal zones by 50% without changing their means or the modes. In the second experiment (Case B), new research was assumed to reduce the modes by 50%. Since the distributions of all parameters are triangular in PAGE 09, reducing the mode by 50% reduces the mean by almost 9% and puts an additional 17% of the probabilistic density below the old mean. This might not seem like much from a modeling perspective, but we submit that it reflects what would be a gigantic change against conventional wisdom that is anchored by the inertia of decades of earlier research. The third experiment (Case C in Table 3) repeats Case B in the opposite direction; i.e., the mode is increased by 50%.

Given that these results are based on 100,000 runs, there is a 95% chance that another set of 100,000 runs would produce means in every case that are within $2 of these reported values. The summary statistics therefore strongly suggest that it would be unlikely that reducing the range of economic damage estimates would change the mean estimate for the social cost of carbon even though the 99th percentile estimate might fall by more than 10%. Cases B and C, where the mode changed, did show significant changes in the mean and slight changes in the 5th to 95th percentile ranges; but these changes are nothing to write home about in terms of making policy. Indeed, the histograms portrayed in Figure 4 depict vivid portraits of robust i*nsensitivity* to new information about economics. Estimates range from $0 through nearly $10,000 or more per ton in every case, but the modal estimates all lie between $25 and $50 per, the median estimates all fall in the neighborhood of $50 per ton, and the means (excluding the top 1% of the estimates) all hover between $80 and $90 per ton (adding the top 1% of the estimates would add roughly $20 to these values).

The relative insensitivity of these statistical values is supported by analysis of the marginal contributions of uncertainty in the underlying random variables to the overall variability in estimates of the social cost of carbon. Transient climate response dominated for every case, followed (among sources reflecting human attitudes or activities) by the pure rate of time preference (about 60% as influential and transient sensitivity), relative risk or inequity aversion (about 50% as influential), indirect effects of sulfates (about 25% as influential), and non-economic effects (also about 25% as influential). The influence of the exponent coefficient for economic damages lies below all of these and some others – roughly one-eighth as influential in determining the range of estimates in the social cost of carbon as transient climate sensitivity.

The various panels of Figure 5 display the actual correlation estimates. They show, for example, that increasing transient climate response parameter (TCR) by 1 standard deviation above its mean in the default case would increase the social cost of carbon by $67 while doing the same for the economic damages parameter (POW-1) would increase the social cost of carbon by only $9. Similar disparity is clearly apparent for the other three cases. Put another way, any change in economic estimates of damages that new literature might produce is easily undone by small adjustments in other parameters and/or purposeful adjustments in judgmental parameters (e.g., time preference or risk and inequity aversion).

The numerical results reported here are, to be sure, highly model-specific both with respect to the sources of uncertainty that are represented explicitly in its structure and the way those sources are depicted. Other models may suggest that dramatic change in the overall distributions of economic damages might be more (or less) influential in determining the social cost of carbon, but we do not think that the qualitative conclusion that they illustrate. We do not think, in other words, that our hypothesis of minimal value added is right would be weakened substantially if other models were similarly exercised.

Section 3: Barking up a Different Tree for Value Added.

To us, at least, it follows from the hypothesis that we raises and supported in Section 2 that economic aggregates should not be the (sole) foundation upon which to build climate policy. They can, at best, contribute to an understanding of context within which policy alternatives derived from other sources should be evaluated. That is to say, they can contribute to analyses of whether or not those alternatives can achieve their stated climate objectives at least cost and, in some cases, whether or not they might be doing more harm than good. There is, after all, such a thing as dangerous climate policy; see, for example Tol and Yohe (2007). In addition, the more detailed modules from which these aggregates are constructed can help decision-makers and researchers alike identify where careful consideration of an expanded set of adaptation options might be most productive. Nonetheless, we fear that trying to devise a way to set the price of carbon (or the economic value of emissions reductions or increases from a non-climate policy, for that matter) equal to something like the social cost of carbon is probably a fruitless enterprise. Moreover, justifying impacts analyses completely on the basis of improving the quality of their contributions to estimates of the social cost of carbon is likely to be a misguided enterprise.

So what should we be doing, instead? The authors of the report of the Limiting Panel to America's Climate Choices [NAS (2010)] offered what we view to be a solid suggestion. They recommended a multi-step process that would begin with assessing a wide range of climate risks that will materialize over the medium to long-term. They recognized that these risks will be calibrated in many monetary and non-monetary metrics and that it will be up to the political process to determine a socially acceptable level of risk. Given that determination, it should be possible to identify long-term mitigation targets in terms of temperature increases and associated ranges of atmospheric concentrations; and from there, it should be possible (a) to deduce a medium-term global carbon emissions budget that would put the planet on a path from which iterative decisions based on new climate science and technological development could be designed and implemented effectively and (b) infer the United States (and other country, for that matter) contributions to that budget.

Each of the steps noted above can, of course, be identified as a research topic, particularly the iterative component of evolving long-term policy objectives and medium-term carbon budget targets. Several researchable topics come to mind almost immediately. What should be monitored to inform iterative decisions, for example? How should "mid-course" corrections be implemented, and what types of institutions need to be created to make them maximally efficient? And how frequently should they be undertaken?

More to the point of this workshop, though, how could a medium-term carbon budget target be achieved? NAS (2010) concluded that it is necessary (but not sufficient by any means) to set a price on carbon that increases predictably and persistently over the applicable time period. Since even a medium-term emissions budget can be viewed as an inter-temporal exhaustible resource problem, the first-order answer to how to price carbon comes straight from Hotelling (1931): compute the scarcity rent for year one and let it increase over time at the rate of interest. The actual best trajectory will depend, of course, on the rate of growth in economic activity, the rate of technological innovation in non-carbon intensive energy sources and carbon sequestration, and other factors that cannot be predicted accurately for 40 year time periods; but these insight highlights yet another set of researchable questions about quantification and short-term term iteration processes. Perhaps the most practical approach would involve identifying technologies that could contribute most to emissions reductions and evaluating the cost of carbon that would be required to make them economically competitive with fossil-base alternatives at the time they would become viable. As described in Yohe, *et al* (2007), the appropriate initial scarcity rent could, quite simply, be the level that would, if it were to climb at the rate of interest, reach the pricing threshold at just the right time; but this, too, is a researchable issue.

And what role can damage estimates play in all of this? It seems to us, as noted above, that they provide context in a very important sense. Ranges of aggregates like the social cost of carbon offer fundamental access to the answers of questions like "What combinations of normative and scientifically-based parameters produce discounted marginal damage estimates that are consistent with carbon pricing proposals born of technological modeling and national carbon emissions budgets? And are those combinations consistent with the normative view of how the world should behave from which the long-term objectives and medium-term targets were derived?" Their content, in other words, is not numerical; it is, instead interrogatory.

Section 4: A Concluding Thought.

Answers to the research questions identified in Section 3 that were informed directly by our brief comments in Sections 1 and 2 would not be unique, of course, and that complication must be acknowledged from the start. So, too, should the pervasive uncertainties that will not, in many cases, be resolved in a timely fashion. We close, therefore, with a reference to a lesson articulated almost two decades ago by Lester Lave – an economist of considerable note and wide experience in climate-related issues who worked for decades at Carnegie Mellon University in Pittsburgh. He once told the then fledgling Center for the Study of the Human Dimensions of Global Environmental Change that "If it does not make a difference of a factor of two, then it is inside the noise. With that fact of life we will simply have to learn to cope." Correcting for misrepresenting trends inside that noise is, quite fundamentally, why iteration is so essential in all of this – it is the first order question that must be confronted directly if we are to have any success in *Improving the Assessment and Valuation of Climate Change Impacts for Policy and Regulatory Analysis*.

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Table 1. Estimated Storm Surge Elevations and Return Times of the Current 100-year Storm Anomalies for Boston and New York. Estimates based on median sea level rise scenarios for the B1 and A1FI SRES scenarios with historical pace of local sea level rise indicated in parentheses. Source: Kirshen, *et al.* (2008).

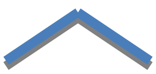
	Storm Surge Elevation			Recurrence of 2005 100 yr Storm	
Location	**2005**	**2050**	**2100**	**2050**	**2100**
Boston (2.65 mm/yr; 1921-2005)					
B1	2.9 m	3.0 m	3.1 m	15 yr	5 yr
A1FI	2.9 m	3.2 m	3.8 m	3 yr	<< 2 yr
New York (2.77 mm/yr; 1920-2005)					
B1	2.8 m	2.9 m	3.0 m	50 yr	30 yr
A1FI	2.8 m	3.1 m	3.7 m	30 yr	3 yr

Table 2. Estimated Internal Rates of Return for Investment in Protective Infrastructure over Time: Estimates of the expected internal rates of return for investing in a $390 million (real terms) protective infrastructure against the increasing economic risk driven by climate change and portrayed in Figure 1 for an urban area in Boston. Source: Yohe, *et al.* (2010)

Year	**1 meter SLR(2100)**	**0.6 meter SLR(2100)**
2010	2.1%	-0.5%
2015	3.8%	0.2%
2020	4.3%	0.4%
2025	5.2%	0.8%
2030	6.4%	1.3%
2035	8.4%	1.8%
2040	12.4%	2.5%
2045		3.4%
2050		5.0%

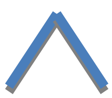
Table 3: Summary Results for the Social Cost of Carbon (per ton of CO_2): Summary results from 100,000 runs for the default settings are compared with cases in which (Case A) the range of economic damages in general and attributed to sea level rise shrinks by 50%, (Case B) the ranges of both stay the same but the modes shrink by 50%, and (Case C) the ranges of both stay the same but the modes increase by 50%. Schematics of the critical distributions are provided for each.

Case	Min	5th	Mean	95th	99th	Max	Mean of Lower 99%	Contribution of Top 1% to Mean
Default	-$4	$12	$106	$259	$1191	$12215	$85	20%



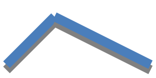
Symmetric default settings for the economic damage and sea level rise calibrations

Case A	-$1	$12	$106	$258	$1168	$10084	$85	20%



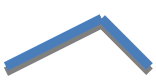
Ranges for the two economic damage parameters diminished by 50%

Case B	-$2	$10	$102	$248	$1108	$9131	$80	22%



Ranges preserved but distribution skewed with the mode 50% lower

Case C	-$3	$13	$111	$272	$1218	$13166	$89	20%



Ranges preserved but distributions skewed with the mode 50% higher

Figure 1: Observed Frequencies of "Over-threshold" Events in Select Locations along the Northeastern Coastline of the United States since 1920: The number of "points-over-threshold (POT) anomalies per year for each site; a strongly increasing trend in the number of POT anomalies was detected at all sites. Source: Kirshen, *et al.* (2008).

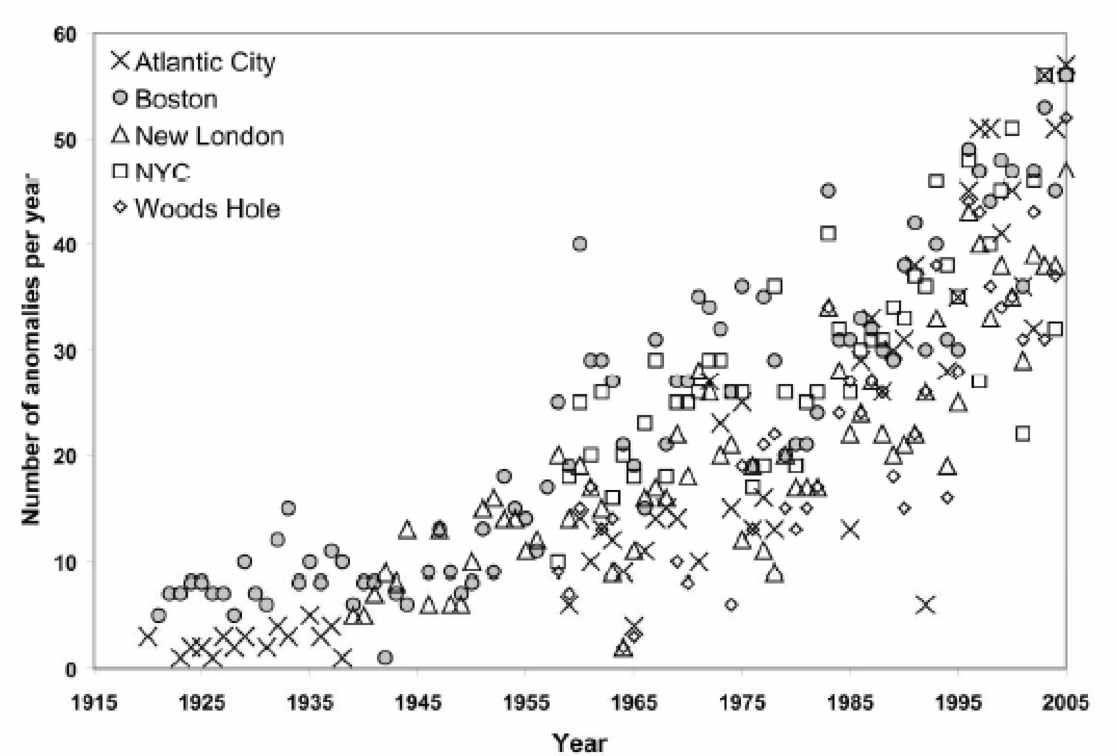
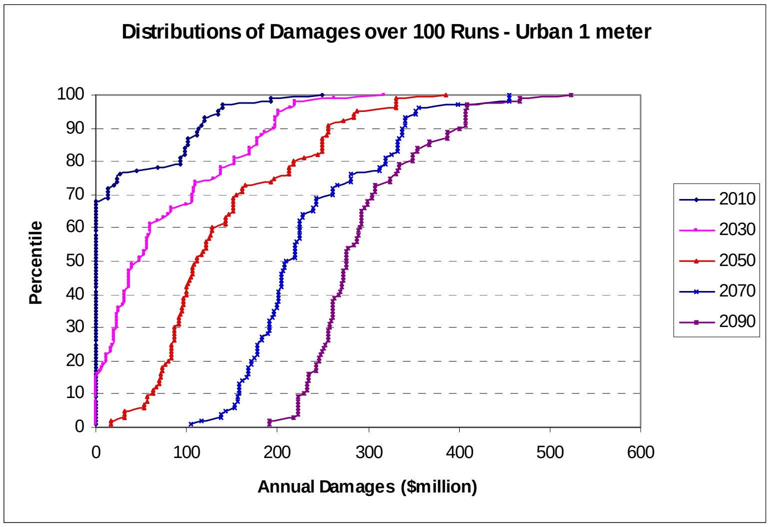
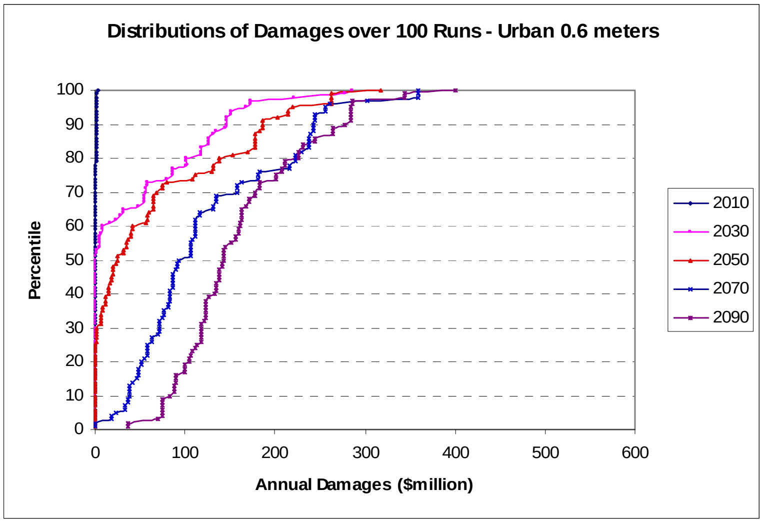


Figure 2: Damage Profiles from Coastal Storms over Time for Two Sea Level Rise Trajectories: Distributions of economic damage across 100 runs for two sea level rise scenarios. Panels A and B indicate economic damages from coastal flooding in selected years in the future for an urban area in Boston along 1.0 and 0.6 m sea level rise scenarios, respectively. These estimates do not include adaptation. Source: Yohe, *et al.* (2010)



Panel A



Panel B

Figure 3: Global Mean Temperature (relative to pre-industrial levels): The thick middle line represents the mean for an A1b-style story-line with default settings. 75th and 95th percentiles runs for the 100,000 permutations run above the mean; 25th and 5th percentile trajectories run below.

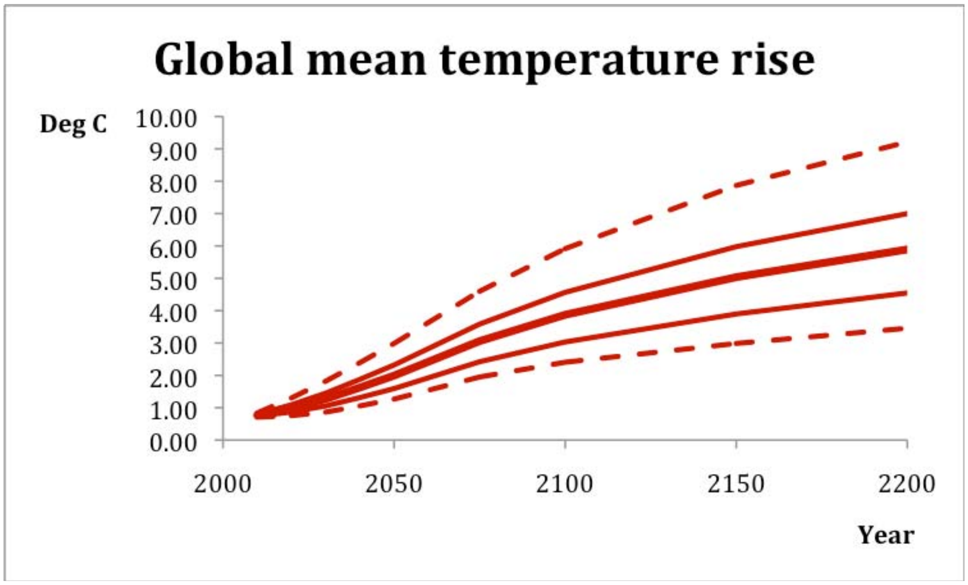
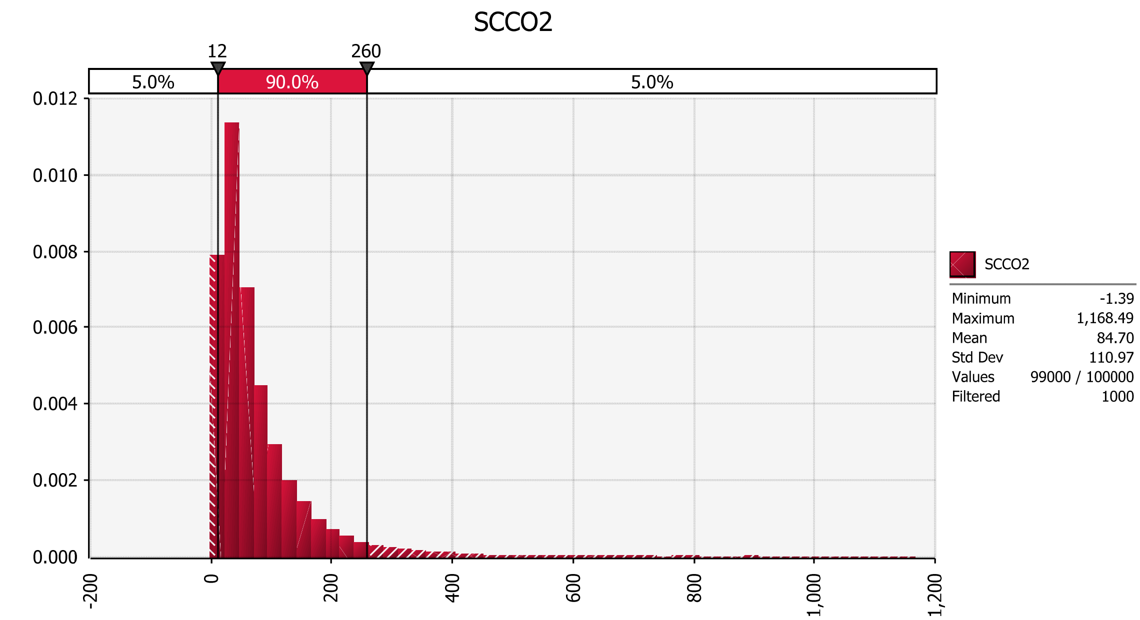
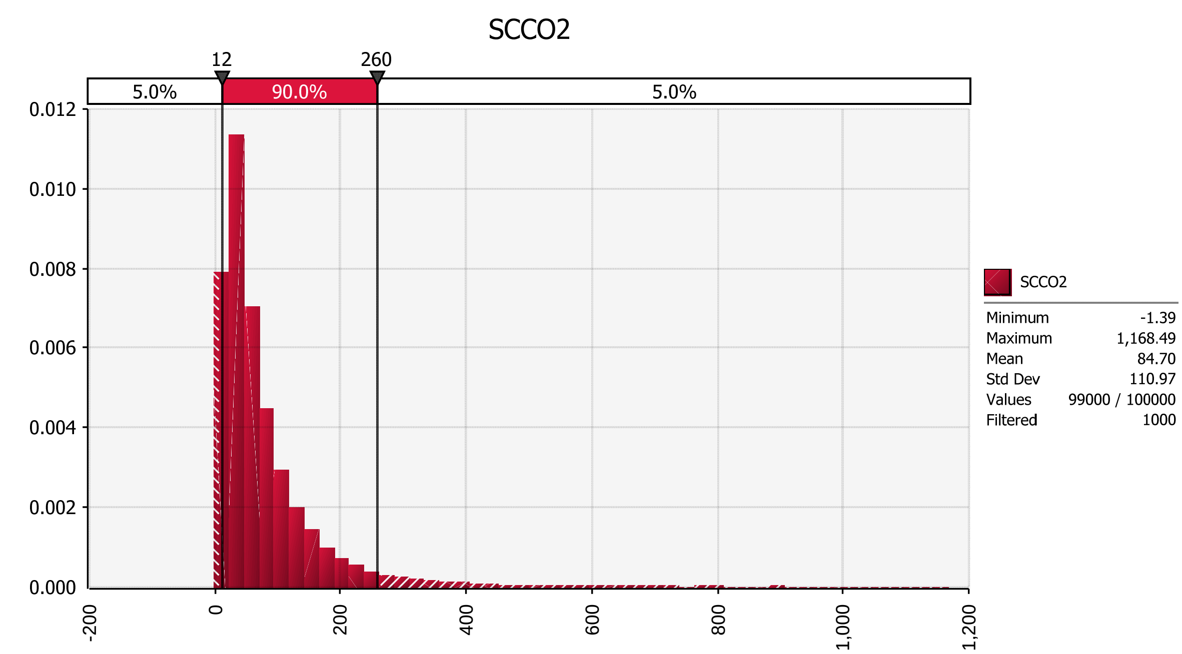


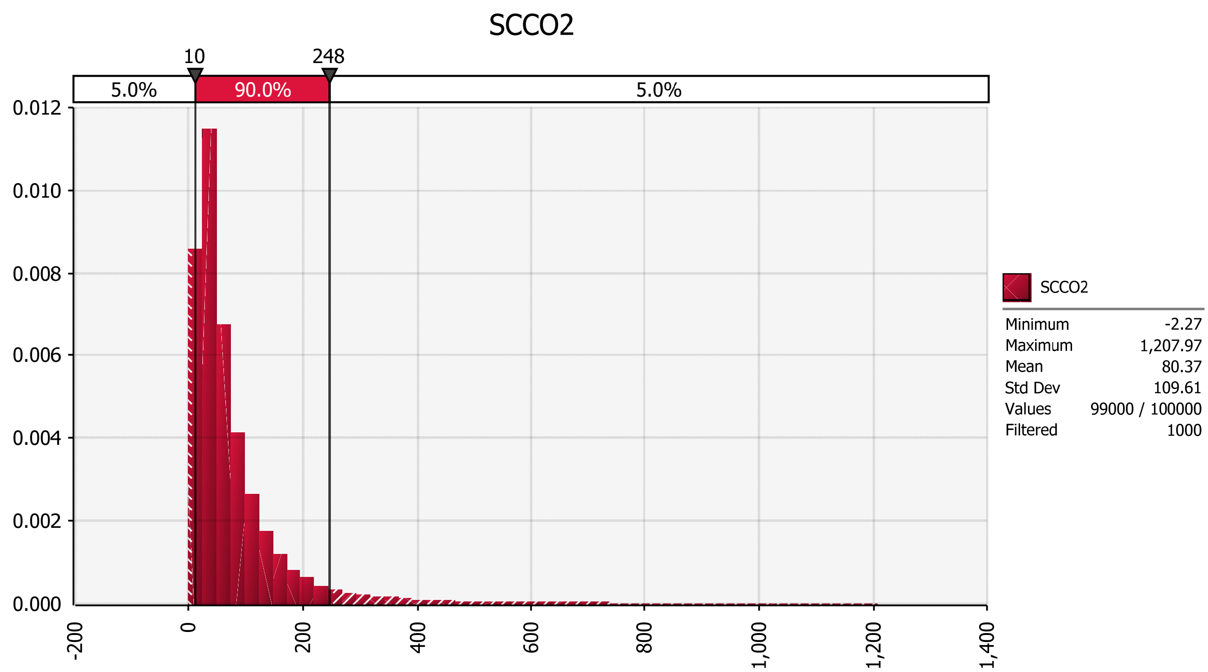
Figure 4: Histograms of the Social Cost of Carbon. Distributions of estimates of the social cost of carbon from 100,000 randomly selected futures (excluding the upper 1% of the estimates so that the shapes become clear). Panel A depicts the default baseline. Panel B depicts Case A – reduction in the range of the parameters that calibrates estimates for economic sectors and coastal zones by 50% without changing their means or the modes. Panel C depicts Case B – 50% reductions in the modes of those parameters without changing their ranges. Panel D depicts Case C – 50% exaggeration of the modes of those parameters without changing their ranges.



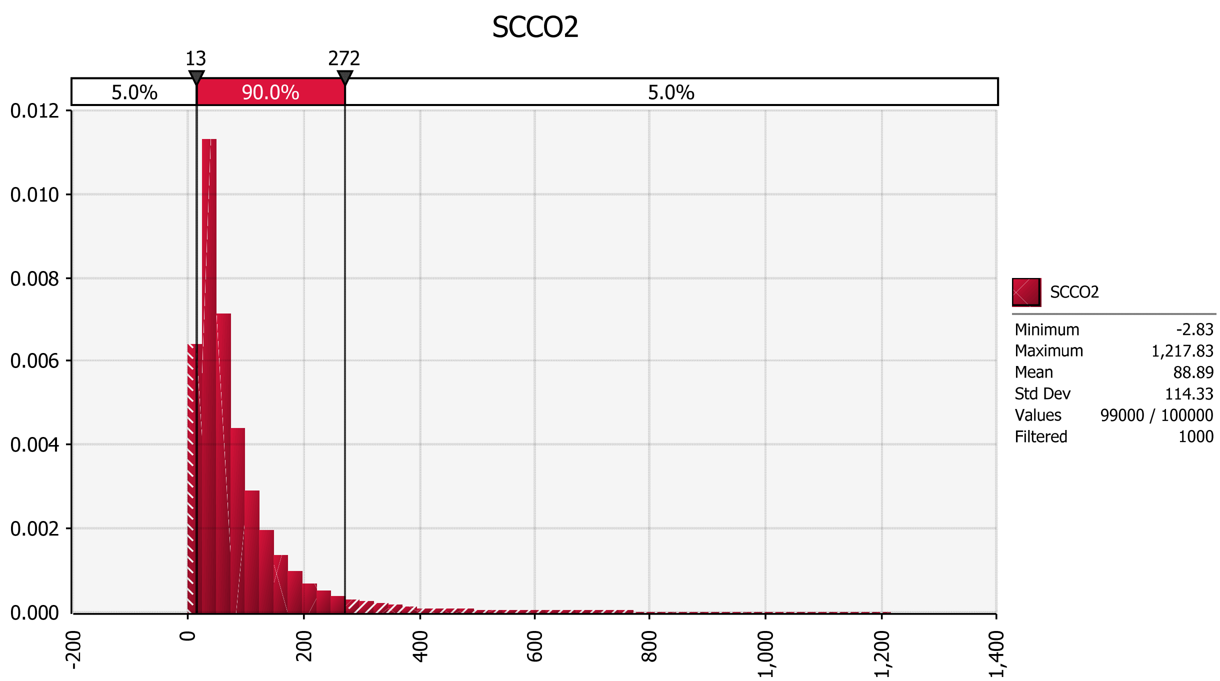
Panel A



Panel B

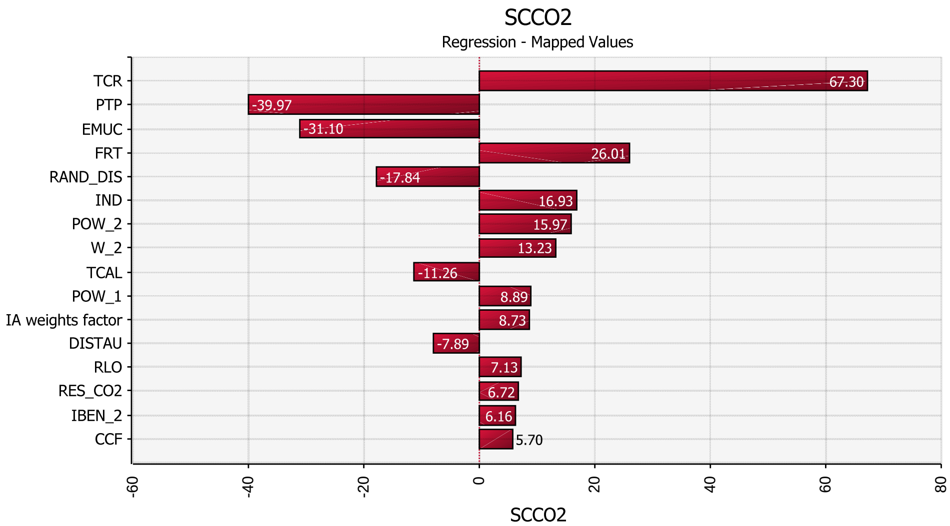


Panel C

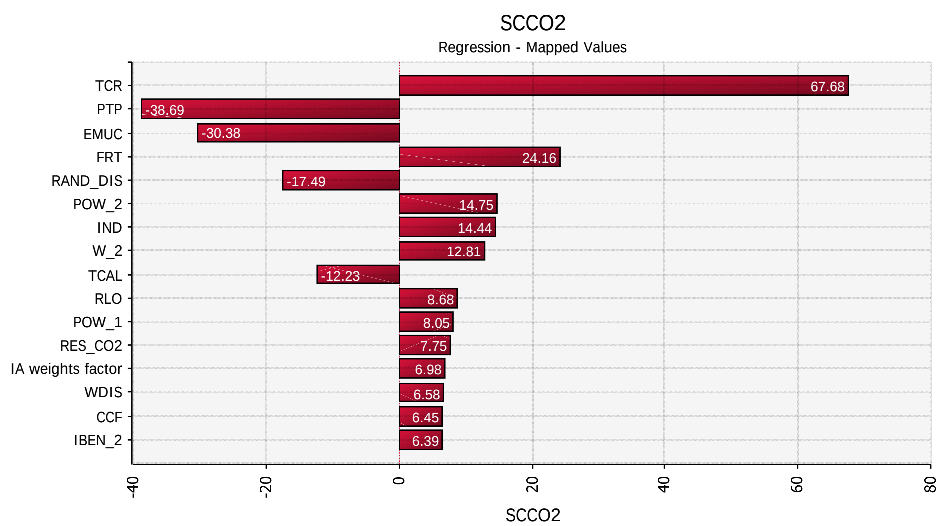


Panel D

Figure 5: Marginal Contributions of Various Parameters to Variability in Estimates of the Social Cost of Carbon. The bars indicate the direction and strength of various parameters in sustaining variability in estimates of the social cost of carbon; cases are as defined in Figure 4.[2] The value of 67 assigned to transient climate response (TCR) indicates, for example, that increasing TCR by 1 standard deviation above its mean would increase the social cost of carbon by $67. Increasing the economic damages parameter (POW-1) by 1 standard deviation would, by way of contrast, increase the social cost of carbon by only $9.

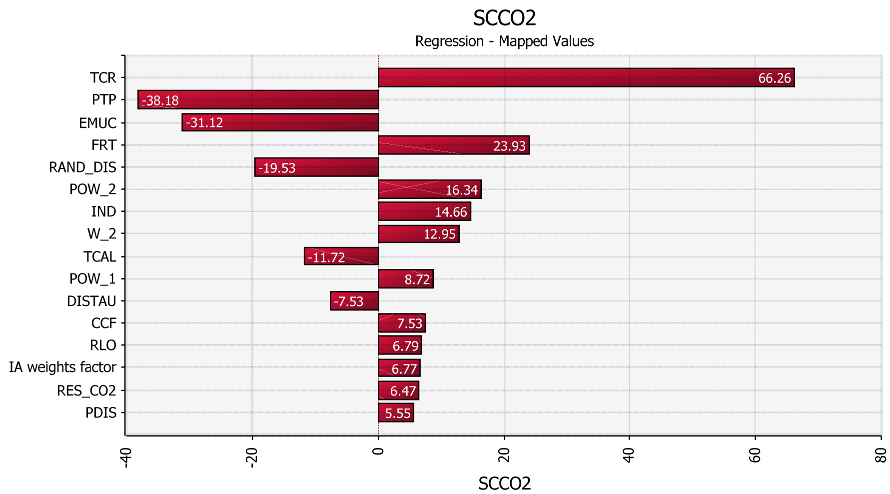


Panel A

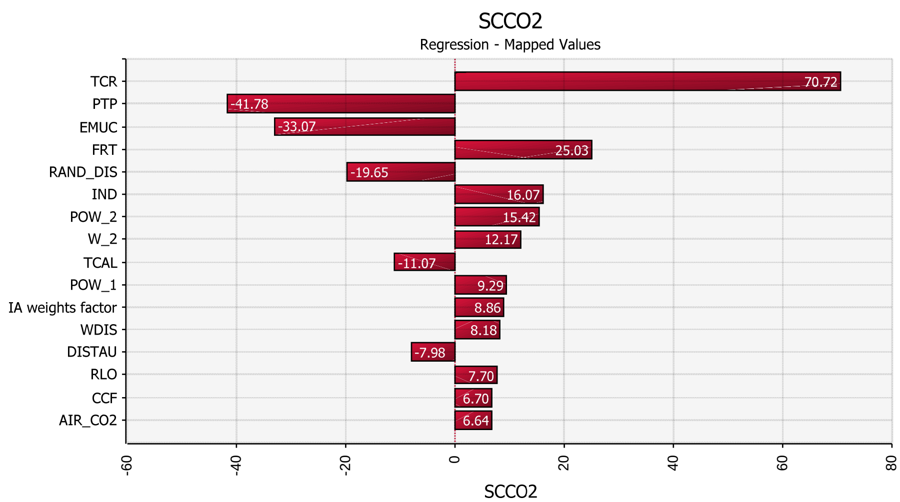


Panel B

[2] Partial Glossary: TCR – transient climate response; PTP – pure time preference rate; EMUC – (negative of the) elasticity of the marginal utility of consumption; FRT – feedback response time; IND – indirect effect of sulfates; POW-2 – exponent of the non-economic impact function; W_2 – non-economic impact at calibration temperature; TCAL – calibration temperature; POW-1 – exponent of the economic impact function.



Panel C



Panel D