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A Research Agenda to Improve Economic Estimates of the Benefits of Climate Change Policies

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1 Introduction

Currently available estimates of the economic damage associated with climate change over time vary widely. To determine how such estimates, usually calibrated in terms of the social cost of carbon, could be improved, the Organization for Economic Cooperation and Development (OECD) hosted an expert meeting on the Economic Benefits of Climate Change Policies in early July of 2006. More than twenty experts met to survey the current state of knowledge on the economic benefits of climate policies and to think provocatively about what should be done to advance understanding of those benefits in the face of uncertainty and acceleration in the pace of observed effects.[1] They focused their attention on methods, metrics, national/sector studies, risk management, and the needs of several "consumers" of information.

This volume offers updates of many of the key papers presented at the meeting. It begins with a brief overview of the current state of knowledge, follows with an identification of research needs and concludes with a suggestion for how the research community might proceed. Given the broad ranging discussions it is not possible to attribute all of the insights to their specific sources. Links to papers presented during the Forum are provided in the references.

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[1] A complete list of all experts, registered observers and OECD staff present may be found on the dedicated web site: http://www.oecd.org/env/cc/benefitsforum2006

2 A Brief Review of the Current State of Knowledge

The matrix in Figure 1 is perhaps the most effective way to summarize the state of the art in analyzing the economic impact of climate change and therefore the economic benefit of climate policy. It is a version of a similar figure found in Downing & Watkiss (2003), and it was a focal point of the prepared and spontaneous remarks offered by many of the participants on current knowledge (see Downing, 2006; Watkiss, 2006; Hope & Alberth, 2006; Hope, 2008; Watkiss & Downing, 2008). The columns are calibrated by the degree to which the complication of climate change science is captured by benefits analysis. Columns begin with coverage of projections of relatively certain climate change trends (e.g. average temperature, sea level rise), move on to consideration of the bounded risks of extreme events (including precipitation) and climate variability along those trends, and end with representations of possible abrupt change and/or abrupt impacts. The rows are calibrated by the degree to which coverage of impacts are captured from an economic perspective. Rows begin on the left with coverage of market impacts, move on to consideration of non-market impacts, and end with socially contingent impacts (e.g. multiple stresses leading to famine and migration) across multiple metrics that cannot always be quantified in economic terms.

The shadings depicted in Figure 1 offer a view of the degree to which the literature has thus far handled the 9 different combinations of science and impacts. The dark gray shading in area I suggests a relatively heavy population of coverage by researchers. The lighter-grey shading in areas II, III, IV and V suggests limited coverage in a small group of studies that attempted to provide insight into market-based impacts of bounded risks and abrupt change and or non-market impacts of climate trends with or without taking bounded risks into account. Finally, the remaining areas are barely shaded at all because it is nearly impossible to find any credible analyses of these combinations of science and impacts. We now take each combination in turn.

2.1 Area I

The diagram illustrates the judgment that most of the existing research has focused on market impacts along relatively smooth scenarios of climate change. In this context, researchers have noted the importance of site-specificity, the path dependence of climate impacts and the adaptive capacity of various systems. Chapter 18 of Intergovernmental Panel on Climate Change (2001) made this point explicitly, and it is one of the most robust conclusions of the Third Assessment Report. It is echoed by Kuik et al. (2008) and Hunt (2008) and it was confirmed in Chapters 17 and 18 of Intergovernmental Panel on Climate Change (2007*a*).

Nordhaus (2006, 2008) describe GEcon, a method of matching economic data more effectively to the geographic scale of climate impacts analysis (i.e., 1

	Uncertainty in Valuation →			
Uncertainty in Predicting Climate Change ↓		**Market**	**Non Market**	**(Social Contingent)**
	Projection (e.g., sea level Rise)	**I** Coastal protection Loss of dryland Energy (heating/cooling)	**IV** Heat stress Loss of wetland	**VII** Regional costs Investment
	Bounded Risks (e.g. droughts, floods, storms)	**II** Agriculture Water Variability (drought, flood, storms)	**V** Ecosystem change Biodiversity Loss of life Secondary social effects	**VIII** Comparative advantage & market structures
	System change & surprises (e.g. major events)	**III** Above, plus Significant loss of land and resources Non-marginal effects	**VI** Higher order Social effects Regional collapse	**IX** Regional collapse

Figure 1: Coverage of Existing Economic Analysis of the Impacts of Climate Change Related Risks. Most existing studies have been limited to market-based sectors, though a few have moved beyond region I to include non-market impacts along projected trends (region IV), bounded risks in market and non-market sectors (regions II and V) and abrupt change to selected market sectors (region III). Source: Derived from Downing & Watkiss (2003).

degree by 1 degree cells with global coverage). It offers the promise of supporting better analysis of market impacts along climate scenarios, but only if the significant challenge of incorporating geographic diversity in adaptive capacity along specified development pathways can be overcome. In any case, aggregation across even market-based impacts can hide a multitude of differences across populations and regions. It follows that opportunities still exist for potentially profound improvement even in the relatively densely populated upper-left corner of the matrix.

2.2 Areas II, III, IV and V

A few studies authored by Nordhaus & Boyer (2000), Tol (2002*a*,*b*) and Stern et al. (2006) among others have tried to include non-market impacts driven by trends in climate change (area IV), but seldom in a comprehensive way, since data are limited and methods are controversial at best. Others, notably West & Dowlatabadi (1999), Yohe et al. (1999) and Strzepek et al. (2001), have tried to capture the market-based implications of extreme events whose intensities and frequencies have been or will be altered by a changing climate, but their efforts to add content to area II have been most successful when framed in the limiting context of impact thresholds beyond which climate variability produces severe damage. It should be noted, though, that the geographic scaling offered by GEcon could add to our understanding here, as well.

Nordhaus & Boyer (2000) were essentially alone in their initial attempt to incorporate abrupt climate change. They therefore contributed to area III, but their approach was not based on robust analysis of associated damages. Instead, Nordhaus and Boyer hypothesized the risk of large costs (on the order of 10% of global economic activity) with low probabilities halfway through the current century and included some aspects of the willingness to pay measure to avoid such risk in their calibration of global damages. The same authors tried to bring assessments of non-market impacts into their integrated assessments of climate change, but their efforts were severely limited by a paucity of robust economic estimates of impacts. Link & Tol (2004) made some progress incorporating abrupt change, but Stern et al. (2006) was the first attempt at comprehensive inclusion to attract much attention. Some, like Yohe & Tol (2007) have argued, however, that the Stern team double-counted these damages since they built their compounding damages estimates for abrupt and/or catastrophic change around the earlier Nordhaus and Boyer baseline.

The Millennium Ecosystem Assessment (Millenium Ecosystem Assessment, 2005) is a new contribution to areas IV and V. That work stopped short of assigning economic values to ecosystem services, but various working groups in the MEA process developed scenarios within which those services produced utility, and some attention was paid to climate change.

2.3 Areas VI through IX

Downing & Watkiss (2003) and Watkiss & Downing (2008) note that the current state of knowledge has almost nothing to say about impacts and vulnerability calibrated in the non-market impacts of abrupt change in and the multiple metrics of socially contingent impacts. It follows that integrated assessments of optimal climate policies are missing much of the action, especially when global connections are recognized. It is, more specifically, through these socially contingent vulnerabilities that climate impacts in one place (e.g., the developing countries) can be felt elsewhere (e.g., in Europe or the rest of the developed world). It does not necessarily follow, however, that work needs to be done to try to calibrate these vulnerabilities, once they are described rigorously, in terms of economic damages. Yohe (2004) offered a perspective on the benefits of climate policyby noting that fitting multiple vulnerabilities calibrated in multiple numeraries into a cost-benefit framework would be a productive tact. He argued, instead, that developing and applying new decision-frameworks, like risk management and risk-weighted outcomes, would advance knowledge more effectively.

2.4 Using the results

Despite these shortcomings in coverage, researchers and, in some cases, policy makers have nonetheless used the results of analyses that populate the matrix (particularly those drawn from area I) to conduct assessments of optimal climate policies and to compute estimates of the social cost of carbon and other greenhouse gases. These social costs are estimated by tracking the damage caused over time by releasing an addition unit of ton of a greenhouse gas like carbon into the atmosphere and discounting those estimates back to the year of its emission. That is to say, the social cost of carbon represents the "marginal cost" of carbon emissions; alternatively, it represents the "marginal benefit" of a unit of carbon emissions reduction.

Estimates of the social cost of carbon that currently available in the published literature vary widely. The OECD workshop was informed by an early survey conducted by Tol (2005) which reported that fully 12% of then available published estimates were below $0. Their median was $13 per ton of carbon, and their mean was $85 per ton. Tol (2007) offers an updated survey of more than 200 estimates. His new results show a median for peer-reviewed estimates with a 3% pure rate of time preference and without equity weights of $20 per ton of carbon with a mean of $23 per ton of carbon. Moreover, he reports a 1% probability that the social cost of carbon could be higher than $78 per ton given the same assumptions; and he notes that the estimates increase rapidly with lower discount rates.

Tol (2007) thereby suggests at least one reason why the range of estimates of the social cost of carbon is so large? Hope & Alberth (2006) provides some additional insight derived from exercising his PAGE model; his results are displayed in Table 1. The choice of discount rate and the incorporation of equity weights are extremely important, and both lie within the purview of decision-makers. High discount rates sustain low estimates because future damages become insignificant. Conversely, low discount rates produce high estimates because fu-

Table 1: Major factors causing uncertainty in the social cost of carbon. Relative importance is measured by the magnitude of the partial rank correlation coefficient between the parameter and the SCC, with the most important indexed to 100. Source: Hope (2006, 2008).

Parameter	Definition	Sign	Range	Index
Climate sensitivity	Equilibrium temperature rise for a doubling of CO2 concentration	+	1.5–5 °C	100
PTP rate	Pure time preference for consumption now rather than in 1 years time	-	1–3% per year	66
Non-economic impact	Valuation of non-economic impact for a 2.5°C temperature rise	+	0–1.5% of GDP	57
Equity weight	Negative of the elasticity of marginal utility with respect to income	-	0.5–1.5	50
Climate change half-life	Half life in years of global response to an increase in radiative forcing	-	25–75 years	35
Economic impact	Valuation of economic impact for a 2.5 deg C temperature rise	+	-0.1–1.0% of GDP	32

ture damages are important. Meanwhile, strong equity weighting across the globe support high estimates because poor developing countries are most vulnerable. Conversely, weak or no equity weighting can produce low estimates because poor developing countries do not factor heavily in the overall calculation. Hope (2006, 2008) concludes, however, that the climate sensitivity (i.e., the increase in global mean temperature that would result from a doubling of greenhouse gas concentrations from pre-industrial levels) is the largest source of variation. It is possible to derive high estimates for the social cost of carbon even if you assume low discount rates and almost no equity weighting. All that is required is the assumption that the climate sensitivity lies at the high range of the latest range of estimates.

For present purposes, though, it is important to note that estimates of non-market damages are extremely important, dominating even estimates of market damages in relative importance in explaining the wide variation. Assumptions about what might emerge from more thorough investigations of regions IV through VI are therefore critical if more than a little unfounded. Perhaps even more troubling is the observation that few if any of the estimates recognize abrupt change (regions III, VI, and IX); and none venture into anything contained in the right-hand column (regions VII through IX). Given these omissions, it clear that many of the shortcomings in our current ability to populate the lightly shaded regions of Figure 1 with credible analyses significantly undermines our ability to compute the social cost of carbon, and thus to infer the economic benefit of climate policy, with any degree of confidence.

2.5 The Seeds of Progress

Given the likelihood that improvements will be slow in coming, an alternative approach to traditional benefit analysis is to view climate policy in terms of reducing risks. Risk-weighted measures derived directly from first principles (i.e., a simple definition of risk as the probability of something happening multiplied by some measure of the associated consequences) already exist; see Jones & Yohe (2006, 2008). They can be used to produce cumulative probability distributions of climate-related impacts denominated, for example, in currency (mostly from market sectors), in terms of the likelihood of crossing critical thresholds of tolerable experience (mostly from non-market areas though applicable to the multiple metrics of the third column), or in terms of the likelihood that an abrupt change might occur. As a result, they can produce comparable depictions not only of risk itself, but also its sensitivity climate policy at various points in time. Even a preliminary pass across three illustrative contexts show a diversity of response to policy intervention—some responses are likely to be relatively large and/or immediate while others are small and/or delayed. Decision-frameworks designed to process this sort of information exist in other context, of course, but they have yet to be applied widely to the climate arena.

The critical role played by the insurance industry, which can increase the ability to adapt to climate change, but is also a vulnerable economic sector, is highlighted by Dowlatabadi & Cook (2006, 2008). However, the insurance sector is not monolithic. Its operation and its relative efficacy are both determined in large measure by (1) regulations and approaches that vary from region to region, from country to country and, in some cases, from state to state and (2) the overall health of economies within which insurance companies invest their holdings while they wait for claims. It cannot be assumed that the industry, even with the development of extensive re-insurance mechanisms, will be able to provide the level of risk spreading often portrayed in textbook treatments of how insurance should work to improve welfare; and so it cannot be assumed that the promise of increased social welfare can be attained with or without factoring climate risk into the equation.

The refinement and, in some cases, the development of suitable metrics also holds promise in promoting progress across the matrix. While area I is certainly based on keeping track of important state variables, the development of comparable metrics across multiple evaluative criteria is particularly critical in the other areas. For relatively self-contained and easily described physical impacts like sea level rise, the implications of gradual trends (erosion and salt water intrusion, for example), bounded risks (coastal storms producing catastrophic damage and prolonged periods of recovery or abandonment), and abrupt change (the potential of dramatic long-term or perhaps even sudden inundation from an accelerated melting of the Greenland Ice Sheet or a collapse of the West Antarctic Ice Sheet, respectively), the metrics are relatively clear. They include, for example, the economic value of private property and public infrastructure, the number of people at risk, and ecosystem services of the type identified in Millenium Ecosystem Assessment (2005)); see Nicholls et al. (2006), Tubiello & Rosenzweig (2008) and Rosenzweig & Tubiello (2006).

For other impacts like agriculture, however, the identification of important metrics for tracking effects down any column, but particularly the third, is more elusive; see Tubiello & Rosenzweig (2008). It is clear that metrics need to be germane to local stakeholders. It may even be true that they need to be identified by local stakeholders. It is not enough, for example, that forests will continue to flourish in the northeast region of the United States; residents there want sugar maple trees to dominate their forests. It follows from this simple example that important metrics will vary from site to site and from time to time with the same overwhelming diversity that confounds the calibration of local levels of potential adaptive capacity. Nonetheless, metrics must be clearly understood, both in terms of what they measure and how they are connected causally to climate change.

3 A Research Agenda to Improve Estimates of Economic Benefits of Climate Change Policies

Where should we go from here? We list below several research topics that seem to be particularly important and a set of questions that need attention. Some aspects of the topics, e.g., improvements in geo-economic datasets or development of adaptation cost estimates, can be tackled immediately; others, by their nature, will require fundamental research over a longer term. Some of the information generated could help fill the short-term needs for policy making; other results will provide the building blocks for securing better information in the long-term. In most cases, short and long-term tasks will need to planned and execute in a relatively seamless fashion to be ensure the best results. Also, because this community functions differently than some other research communities (i.e., research is usually conducted by independent scientists instead of by large integrated teams), we identify some structural adjustments to the way research is approached that could lead to more coherence while still encouraging creativity and innovation.

3.1 Fill in the Rest of the Matrix

One fundamental need is to fill in the rest of the matrix displayed in Figure 1 with particular emphasis on the bottom two rows (bounded risk and abrupt change or impacts) and the right-most column (multicriteria evaluations that can support internally consistent comparisons across different metrics applied to spatially and temporally diverse contexts) . Consideration of the entire matrix makes it clear, though, that filling it in with quality and comparable research will be a major long-term challenge. Indeed, while directing fundamental research efforts to providing insight along the bottom two rows and the right-most column would be most productive, doing so will require extensive expansion of research efforts supported by (1) informed and internally consistent scenarios of socio-economic development, (2) relatively detailed scenarios of how the incidence of extreme events and the impact of abrupt change might be distributed over space and time, (3) carefully constructed time-series of observed and anticipated impacts, and (4) associated evaluations of the costs of adaptation. This research needs to be closely coupled with studies of the physical, ecological and social impacts of climate change. Efforts such as the PESETA project which is supported by the European Commission , could provide improved information on impacts of climate change in various sectors and on estimates of economic impacts, however these remain limited in scope and number. Identify "hot-spots" across a Broad Range of Criteria and Optimize Monitoring

Working to identify "hot-spots" relative to extreme events and abrupt change and calibrated across multiple metrics is another critical next step. Attention can be focused most productively on places or sectors where important climate impacts have or will likely be observed using metrics that have or will be identified. As noted in Intergovernmental Panel on Climate Change (2007*a*,*b*), the ecological literature has already begun to use "hot-spots" to track risks and thresholds of tolerable climate variability in ecosystems and the threat of sizeable species extinctions. The hazards literature tracks risks from extreme events to human and natural communities. The social and economic vulnerability literature tracks risks to human well-being or progress toward Millennium Development Goals across specific regions and specific communities. Recognizing these and other areas where climate impacts are now and/or will become significant and important may allow the broader research community to optimize its monitoring and assessment initiatives—looking at places or sectors where data exist and making sure that the requisite time series are created and sustained and discovering places or sectors (like many of the world's developing countries and most of the non-market arenas) that are likely to be most vulnerable even though the requisite research infrastructure of methods, models and data do not yet exist. In the later cases, "start-from-scratch" efforts face the challenges and opportunities of deciding what to monitor even if it takes fundamental research to determine exactly how to proceed.

3.2 Craft Scenarios of Abrupt Change and the Incidence of Extreme Events taking explicit account of Socio-economic Context

Determining the significant economic impacts of climate change requires a complementary focus on abrupt climate change, extreme events, and abrupt impacts. The community will require "not-implausible" scenarios of global distribution of impacts of "surprises" from the natural scientists to support geographically disaggregated analyses of possible adaptations informed by socio-economic scenarios from which measures of potential adaptive capacity can be drawn and feasibility can be assessed. While there does not seem to be an imminent threat over this century (Intergovernmental Panel on Climate Change, 2007*c*), the long-term consequences,of the potential collapse of the West Antarctic Ice Sheet (WAIS), the rapid melting of the Greenland Ice Sheet, the weakening of the MOC, and the chance of runaway greenhouse effects all need consideration. So do naturally or socio-economic thresholds for even routine climate change as manifest in climate variability; in this context, the capacity to recover from an extreme event through insurance coverage and economic development can be critical. Improve and Utilize Geographically Explicit Models and Data.

Expanding geographically explicit frameworks of economic analysis (like GEcon) to look at sectoral implications and the potential costs of transition from one climate and/or climate policy regime to another is also a critical need. Immediate next steps in developing methodologies to confront these challenges include better data sets and could perhaps concentrate on one country (like the United States) or one region (like Europe) where data are available, but not to exclusion of other locations (where vulnerabilities are likely to be higher) and non-economic metrics (that are likely to record the most significant impacts). The development of these tools, as well as other methodological approaches, should therefore anticipate the simultaneous development of internally consistent socio-economic scenarios born of improved time series data for developing countries. Moreover, their evolution should anticipate the publication of scientifically credible impact scenarios for the incidence of extreme climate-related events and the global distribution of impacts driven by abrupt change.

3.3 Develop Risk-management Applications to Support Climate Policy Decision Making Processes.

Notwithstanding the power of geographically explicit economic analysis, framing the research agenda in terms of filling in the matrix makes it clear that cost-benefit analysis is not necessarily the correct approach for every situation. The next round of research will need to support the development of climate-specific risk management tools for analyzing both adaptation and mitigation. Risk weighted measures can be developed to produce comparable portraits of what might be dangerous impacts over time across multiple metrics of impacts as well as multiple sectors and geographic regions. The resulting site-specific and path-dependent measures hold the promise of plotting the differential impacts of various mitigation strategies on the likelihood of dangerous climate change across a diversity of contexts. Focusing on risk can therefore become a productive way of

- sorting out what is dangerous and what is not,
- determining what dangers can be mitigated by climate policy and what dangers cannot, and

- providing a self-targeting way to identify "hot-spots" where optimized monitoring can be most productive.

Decision frameworks designed to utilize this sort of information have been developed for other contexts, of course; but progress here will be most productive if a complementary effort is undertaken to bring their strength to bear on deliberations of climate policy on the adaptation, mitigation and development. It is particularly important to note that Intergovernmental Panel on Climate Change (2007*b*) underscores the value of risk-based approaches to climate problem when it concludes, in language that was accepted unanimously by governments at the Synthesis Report plenary in November of 2007, that "responding to climate change involves a series of risk management decisions about adaptation and mitigation that account for climate damages, ancillary benefits and costs, sustainability, and equity".

3.4 Adaptation

While there is a slowly emerging knowledge base on the costs of climate change, there is very little information on the economic costs (and benefits) of adaptation. This is a major policy gap, in as much as we now know that we are committed to up to 1 degree of further warming (even if emissions of greenhouse gases were to stop today; see Intergovernmental Panel on Climate Change (2007*a*)). There is a lack of real cost data outside of a few limited sector examples, but there is new evidence that adaptive capacity is dangerously low in developed and developing countries alike; see Intergovernmental Panel on Climate Change (2007*b*). There is therefore a need to build up the information on adaptation options, costs, and the reduction to climate risk that they provide. This could begin with a ex- post evaluation of adaptation responses. There is also a wider need to develop adaptation policy frameworks, i.e. to set out the policy steps in moving from policy visions through objectives and targets, to indicators, and the role for economic information in this policy cycle. Importantly this would allow the first real answers to the policy question of what are the benefits of adaptation, i.e. to put in place in an economic context the net reduction in climate change impacts (in monetary terms) from adaptation. It would also allow an initial prioritization across sectors, identifying where adaptation could provide the greatest reduction in climate change impacts (or the risk of impacts) most cost-effectively. Additional questions and issues that need to be addressed are listed below:

- Broaden and assess the extent of climate impacts from the 0.7 degree warming that has already occurred.
- Identify cases in which adaptation and other responses to climate variability have been successful and build an understanding of the basis of these successes.
- Investigate cases where success has been more difficult (if not impossible) to achieve and build an understanding of the institutional, economic,

political, informational, and other impediments that stood in the way.

- Assess the appropriate role of equity weighting in the calculation of the social cost of carbon. Is it different for global policy and individual countries?
- Determine what is the appropriate role of estimates of the social cost of carbon in framing climate policy and in bringing the shadow-price of carbon to bear on public and private investment decisions, e.g., infrastructure, buildings, transportation fleets, and alternative energy development.
- Evaluate the costs of adaptation and how they can be computed in different sectors and regions
- Evaluate the threshold of risk that private insurance and re-insurance markets can be expected to cover over time without an extensive public backstop programs. Also, consider how climate risks, particularly those associated with extreme events or abrupt change, can be factored into insurance premiums across the wide range of administrative contexts current displayed within the U.S., Europe, and developing countries.
- Determine how risk averse various levels of government are in different societies and what the implications are for efforts to assess the benefits of climate change policies?
- Consider how iconic sectors or heritage sites should be factored into the framing of climate policy.
- Drawing on experience with other long-term social policy issues, determine how to motivate near-term climate policy actions in the face of persistent uncertainty about the economic benefits of climate policies.
- Assess the importance of transition costs in comparing alternative climate policies (or the timing of implementing a specific climate policy).
- Consider the complementary and/or competitive roles of mitigation and adaptation in a climate portfolio.
- Consideration of cross linkages between sectors (i.e. the wider multiplier effects)—these are widely considered to be important, but there is no evidence.

3.5 A Near-term "Science Plan" and Structure

The "economic benefits" climate change community is vibrant and active, but its collective efforts would be more productive if each researcher could locate his or her work in answering a specific question under the umbrella of a unifying "science plan". The International Geosphere and Biosphere Program (IGBP) and the International Human Dimensions Program (IHDP) have established formal mechanisms by which they create such plans to help researchers leverage their work across informally organized agendas. These plans add context to research proposals, provide contacts for collaboration, and offer mechanisms for integrating results around the globe. In the climate area, even an informal plan would offer ways by which the policy community can voice their needs so that research that is located in a larger initiative and can be more easily identified as maximally productive.

A key step would be to assess how the needs identified above could be sorted, coordinated and further developed into a collection of integrated initiatives for submission to funding agencies and research administrators. Moreover, an appropriate level of support would need to be identified so that policy makers desiring better information would know what new resources would be required.

The wide range of research needs noted in Section 2 cries out for some synthetic structure to promote at least collegial interactions among researchers, especially when they work individually on one specific topic located in diverse list of interrelated issues of the sort offered above. If additional information is to be forthcoming for the next IPCC report and to help guide national policies, an improved means to informally coordinate research and to develop initiatives warrants exploration. A number of international institutions, such as the IHDP or OECD, could serve as conveners of a process to improve coordination among individual researchers and groups.

4 Conclusions

Available estimates of the social cost of carbon vary widely. They are influenced by factors such as climate sensitivity, site-specific and path-dependent climate impacts, assumptions about adaptation that are also site-specific and path-dependent, as well as choices about discount rates and equity weights. The current state of knowledge has almost nothing to say about impacts and vulnerability calibrated in the non-market impacts of abrupt change and the multiple metrics of socially contingent impacts.

There are many issues that need attention, but several broad research initiatives could lead to better information, namely:

- Filling in the matrix with comparable studies, particularly studies of bounded risk and abrupt impacts that are coupled with studies of the physical, ecological and social impacts of climate change.

- Identifying hot-spots across a range of regions/sectors that are susceptible to extreme events and abrupt change (hence significant economic impacts) and working to ensure that proper time series data of all types are collected.

- Crafting scenarios of abrupt change and the incidence of extreme events taking into consideration the possible socio-economic context.

- Improving and utilizing methods such as geographically explicit models and data.

- Developing risk-management applications to support climate policy making processes.

If policy makers want better information for decision making, then significant advance in the state of the art will be required and this will only come about through a significant expansion of resources.

Finally, in light of the current decentralized global economic benefits research effort, serious consideration needs to be given to developing a unifying "Science Plan" under which research efforts could be made more cohesive and productive. At a minimum an effort is needed to explore the merits, dimensions, contents and costs of a "Science Plan", including a means of coordinating research in the future.

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