RISK AND UNCERTAINTIES, ANALYSIS AND EVALUATION: LESSONS FOR ADAPTATION AND INTEGRATION

G. YOHE[1,2] and H. DOWLATABADI[2]

[1]*Department of Economics, Wesleyan University, Middletown, CT USA*
[2]*Center for Integrated Study of the Human Dimensions of Global Change, Carnegie Mellon University, Pittsburgh, PA USA*

Abstract. This paper draws ten lessons from analyses of adaptation to climate change under conditions of risk and uncertainty: (1) Socio-economic systems will likely respond most to extreme realizations of climate change. (2) Systems have been responding to variations in climate for centuries. (3) Future change will effect future citizens and their institutions. (4) Human systems can be the sources of surprise. (5) Perceptions of risk depend upon welfare valuations that depend upon expectations. (6) Adaptive decisions will be made in response to climate change *and* climate change policy. (7) Analysis of adaptive decisions should recognize the second-best context of those decisions. (8) Climate change offers opportunity as well as risk. (9) All plausible futures should be explored. (10) Multiple methodological approaches should be accommodated. These lessons support two pieces of advice for the Third Assessment Report: (1) Work toward consensus, but not at the expense of thorough examination and reporting of the "tails" of the distributions of the future. (2) Integrated assessment is only *one* unifying methodology; others that can better accommodate those tails should be encouraged and embraced.

Key words: uncertainty, risk, adaptation, extreme events, (credible) information, integrated assessment

1. Introduction

The research community is beginning to come to grips with the implications of a long recognized truth: uncertainty and risk are ubiquitous in the global climate change arena. Careful and systematic recognition of uncertainty along multiple dimensions will, from now on, play an increasing role in both evaluating the relative merits of alternative mitigation strategies *and* assessing the relative strengths of the methods by which we conduct those evaluations. This paper offers a personal list of specific insights that can be drawn from a growing collection of analyses designed to investigate how societies and/or systems might respond to climate impacts about which our understanding is now and will continue to be uncertain and evolving. Its fundamental purpose, though, will not be to survey that literature. It will, instead, be lessons supported by a representative subset of those analyses and which Working Groups II and III can use to display more accurately the state of our understanding in Third Scientific Assessment Report (TAR) of the Intergovernmental Panel on Climate Change (the IPCC).

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Section 2 lists ten lessons drawn from the current state of the art, such as it is, and from some casual contemplation of history; they are drawn most directly from analyses of adaptation to global change under conditions of enormous uncertainty. Section 3 then draws two larger conclusions from the preliminary list. In the first, it will be argued that the IPCC's desire for consensus on issues of natural and social science could leave us singularly ill-prepared to cope with climate change because they could easily leave the most accurate descriptions of what might happen in the future on the "cutting room floor". The second builds on the first to suggest that sole reliance on integrated assessment as a unifying methodology for global change analysis is inappropriate. Integrated assessment has a role to play, but proceeding as if it were the only way of conceptualizing the global change issue could easily lock decision-makers into a mode of analysis that cannot now and will not in the near to medium term (and perhaps never) be able to accommodate adequately the complexity of what is to come.

2. Lessons from the State of the Art

The list of robust lessons that can be drawn from analyses of how human systems might adapt to global change is small, but it is growing. This section offers a representative sampling that is designed to pose more questions than it answers. The mismatch is appropriate, though; despite its obvious importance, the field is still very young.

2.1. IMPACTS MUST BE DETECTED AND THEIR SOURCES ATTRIBUTED

Moser and Cash (forthcoming) exemplify the work of William Clark and his colleagues at the Kennedy School at Harvard University. They have taught us that it is no longer enough for analyses of adaptation to include only descriptions of "who knows what?" and "when?" in their conceptualizations of the problem. Perception is as much of an issue as reality, and so additional care must be taken to address issues like:

- When do people or institutions know whatever is required for them to act?
- Where do they get their information (from the IPCC, from government agencies, from in-country scholars and scientists, from commercial venders, and so on...)?
- How do decision-makers decide which information is credible and which is not?
- What metrics (scientific, social, cultural, economic, and so on...) are employed to judge the severity of an impact (or set of impacts) and thus the necessity of either an adaptive or mitigating response?

It is, however, difficult to observe the *impacts* of secular changes in climate parameters. The detectable impact signal is most often that due to extreme events. Technical change, and other inputs to most relevant activities (agriculture, tastes for outdoor activity, and so on) tend to evolve more rapidly than climate. It may be, therefore, that only systems teetering on the brink of failure are likely to be at significant and detectable risk from climate change. In these cases, of course, the final nail in their coffin is likely to be attributed to climate change.

Lesson 1: Events and impacts which are likely to be detected and responded to by socio-economic systems are likely to be extreme realizations of climate in each location, and tracking how systems collect, evaluate and process information is critical.

2.2. INDIVIDUALS AND SYSTEMS ALREADY RESPOND TO CLIMATE

Few of the potential impacts associated with future climate change are totally new. The hazards to be confronted have spatial and temporal influences that extend beyond the experiences of current or similar socio-economic regimes. Societies have, nonetheless, developed a large number of coping strategies; and, as a result, the list of relevant questions for climate change impact assessment and adaptation are:

- Will existing hazard response systems be of sufficient scale to cope with expected changes in the magnitude of future hazards?
- Will the new magnitudes of hazards persuade society of the need to provide new and more efficient coping strategies?
- Will larger variation require strategies for coping with risks that have, to date, been left uncovered?
- Will preferences change in the light of new experiences and thereby redefine what is considered a “hazard” and what is accepted as an appropriate “coping strategy?”

Lesson 2: History may not be *the* guide in viewing how adaptation unfold with future changes in the definition of “hazardous change”; but it certainly is *one* appropriate guide that should not be ignored.

2.3. THE ENVIRONMENT FOR ADAPTATION EVOLVES

The impacts of climate change have, all too often, been estimated for futures that embody new and exaggerated hazards without reflecting upon how the pattern of exposure to those hazards might evolve. In the context of coastal development, for example, Yohe, *et al*., (1996) and West and Dowlatabadi (in press) have demonstrated that it is not enough to portray rising seas and changes in storm patterns through, say, the year 2050. The socio-economic effects of these and other physical impacts need to be examined within a portrait of the future for which answers questions like these have been posited:

- Have coastal communities changed in their character?
- What is the nature of economic activity in these regions?
- What is the nature of capital at risk?
- What is the micro-demographics of coastal development?
- Have local regulations for coastal development evolved?
- How is insurance regulated in the area?

In general, these sorts of “conditioning” factors evolve more rapidly than climate change, and so they may have a far greater effect on both the significance of anticipated impacts and the nature and efficacy of adaptation measures to climate change.

Lesson 3: It is essential that future adaptation to climate change be analyzed within consistent portraits of what the future might bring and how citizens and institutions of that future might assess value.

2.4. MARKET RESPONSES MAY NOT BE IMMUNE TO SURPRISES

It has been argued that the economy in much of the developed world is largely divorced from environmental factors so that climate impacts will be imperceptible [see, *e.g.,* Mendelsohn and Neumann (in press)]. At the same time, however, economic sectors which take climatic variable as an inputs (*e.g.,* agriculture) are frequently thought to be most vulnerable. Analyses of adaptation under risk and uncertainty should examine if these two positions are mutually exclusive. Recent advertisements on U.S. television make it clear that many banks are, for example, lending homeowners up to 12.5% of the assessed value of their properties where assessed values approximate market values. Howard Kunreuther of the University of Pennsylvania has observed, in private communication with the authors, that the insurance pool for coastal dwellings in southeastern Florida has long been subsidized by the premia charged from other risk categories scattered all across the state. He is concerned that governments have become the insurer of last resort even when their taxpayer-subsidized rates are deemed to be too high by many exposed individuals. Even the hint that this sort of behavior is being tolerated in market economies leads to questions like:

- Can extreme events trigger market responses that can amplify first-round losses?
- Can routine development as the future evolves lead to overexposure to more routine risks that are not in the extreme?

To see how these questions might matter, consider an insurance industry that must cover losses in an extreme event where (or a series of serious events) in a particular location (along a relatively short time profile when) it has significant exposure. Kunreuther reports, as well, that the Risk Management and Decision Processes Center at the University of Pennsylvania has begun to wonder if such an exposure might be so large that the industry would be forced to liquidate physical or financial assets at a rate which depreciates the assets' market value; and if that were the case, then the required effort to cover actual losses would lead to multiplier effects that would amplify the losses across the broader economy.

Lesson 4: Not all of the possible surprises that deserve analytical attention find their roots in the extremes of natural variability; social, economic, and political systems can, in their accommodation of other issues and risks, conspire to create surprises of their own.

2.5. WELFARE LOSSES ARE TIED TO EXPECTATIONS

Many observers believe that less industrialized nations will suffer terribly in the wake of climate change because of their largely agricultural economies. This is a proposition that needs to be examined carefully. It could easily be the case that these economies could be relatively insulated from change as long as the pattern of their agricultural activity remains largely divorced from market forces so that they can continue to be well served by their traditional diversity of cultivars. The heterogeneous response of their basket of cultivars has evolved over generations of resilient yields against climate variability (which will dwarf climate change over the medium term); and so one key to their remaining unaffected by climate might be that they do not expect a significantly different pattern of life. If, however, they grow to expect ever rising standards of living so that they emulate the populations of industrialized nations, then they are likely to become profoundly unhappy for long periods of time because:

- They will change their cultivation to reduce its diversity and offer more standardized produce into the market.
- Their production will thereby become more vulnerable to climate variability.
- The development of institutions designed to their societies through periods of poor yields will likely lag.

If the loss suffered by individuals is determined by their expectations and if expectations in industrialized nations are higher, then perhaps these are the folks who will suffer more in the wake of climate change. Meanwhile, the highest risks faced by currently less industrialized nations whose socio-economic systems are currently well calibrated to cope with climate variability will likely appear during transition periods to more market oriented economies when they will be able to rely on neither the security of past practices nor the security of well developed markets and insurance structures.

> Lesson 5: Risk needs to be defined in terms of welfare; welfare measures need to be defined in terms of expectations, and so measures of risk need to be defined in terms of existing patterns of behavior, future patterns of behavior, and the uneven dynamics of moving from one to the other.

2.6. POLICY IMPACTS AND CLIMATE IMPACTS MUST BE BALANCED

The pain of the climate change must be weighed against the taste of the medicine designed to mitigate that change; and adaptation in the face of uncertainty is as much of an issue in the later as it is in the former. Studies in which the economy-wide cost of a policy are calculated are helpful, but they are only part of the story. There are tremendous distributional aspects to any policy which tries to remove carbon from the economy. Interestingly, some of those suffering from the greatest potential impacts from climate change, may also be those who would suffer most from the policy. Graetz *et al.*, (1997) have, for example, investigated the Australian agriculture sector. Their work shows that Australian farmers suffer from the most variable precipitation patterns of all OECD agricultural sectors. They are price takers in the world market, and have to move their produce long distances to both their domestic and their international customers. A statistical model estimated from socio-economic and climatic observations over the past 50 years indicates a 90% chance that cereal producers have a net profit in any given year. If climate change influences rainfall in Australia, this estimate is not changed significantly. If on the other hand climate policy aimed at, for example, stabilizing CO_2 concentrations below 500 ppm were implemented, then the increased cost of inputs to their activity, including the distribution of their product, would lead to an estimated 50% chance of net loss for cereal producers in any given year. Clearly, for them, the climate policy medicine is more painful than the impacts of climate change.

> Lesson 6: Risk and uncertainty analyses should be undertaken to contemplate robust adaptive strategies in response to both climate change ***and*** climate change policy.

2.7. POLICY AND ADAPTATION IN A "SECOND BEST" WORLD

It is well known that policies designed to correct a single distortion in an otherwise perfect world are not necessarily the best choices in a world which includes multiple sources of inefficiency; indeed, optimal "first best" policies can actually do more harm than good in such a "second best" world. Perhaps simplest illustration of this phenomenon can be drawn from the economics textbooks. Consider setting an emissions charge designed to limit pollution from a perfectly competitive industry to the point of maximal economic efficiency [denoted Z^*]; i.e., to the point where the marginal social damage [denoted MSD(Z)] caused by the last unit of pollution exactly equals the marginal cost emissions reduction [MC(Z)]. Setting aside all of the measurement issues involved in actually computing such a charge, the theory clearly states that the charge should be set equal to $MSD(Z^*) = MC(Z^*)$ so that polluters efficiently internalize the social damage of their emissions into their output decisions. Industry output would fall appropriately, and the price of the product would accurately reflect the opportunity cost of all of the inputs employed in its production (including the environmental input). If, however, this charge were imposed upon a profit maximizing monopolistic polluter, then the analogous response would see output fall from a level that was already too low and the price rise from a level that was already too high. It is not difficult to see that this could result in a reduction in welfare [see Cropper and Oates, (1992)].

> Lesson 7: Adaptive strategies and policy prescriptions need to be analyzed in ways that include as much of the complicating realism of their social, economic, and political environments as possible. To do so will reveal that some strategies and policies that look good in the abstract can be counterproductive; to do so will, by the same token, uncover alternative strategies drawn from non-climate contexts that could nonetheless have robust and productive climate change impacts across a wide range of possible futures.

2.8. THE FLIP SIDE OF VULNERABILITY IS OPPORTUNITY

The sustainability of any system in the wake of climate change can be modeled to depend upon both the long-term trends in the means of critical variables and associated changes in patterns of short-term variability in those variables. Schimmelpfennig and Yohe (1998) defined an index of sustainability to be the cumulative likelihood that the environment reflected by distributions of variables like temperature and precipitation will, in any given year, lie within the limits of a system's ability to cope. It is expected that these limits can be represented as boundaries of a region of "tolerable experience" that includes a significant but changing portion of these distributions as the future unfolds. Short-term excursions beyond these limits do not necessarily mean disaster for societies dependent upon the system in question, but they do cause hardship. Moreover, repeatedly moving beyond the boundary of tolerable climate with increasing frequency would, in fact, bring the system closer and closer to disaster because systems and the societies that they support become less resilient with each passing crisis. The sustainability index has been applied to traditional maize agriculture in Mexico by Yohe *et al.*, (forthcoming) to show surprising long-term robustness over a wide range of "not-implausible" futures for Mexico drawn from the COSMIC model of Schlesinger and Williams (forthcoming); the variables there were precipitation in July and August and the length of the growing season from spring to fall.

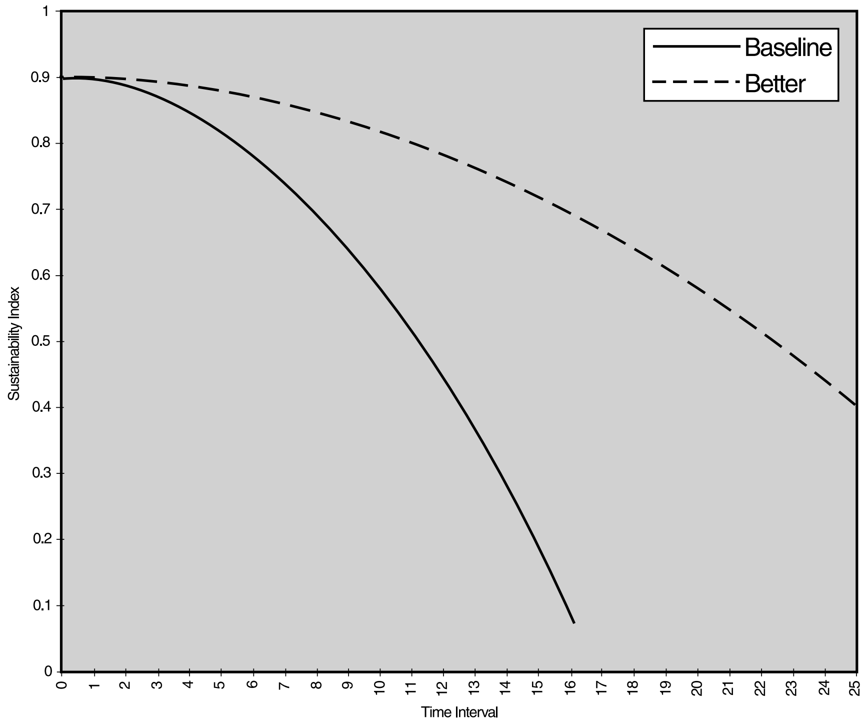

Figure 1. Trajectories of sustainability for a system vulnerable to climate change.

Systems thus become increasingly vulnerable to change and ultimately collapse as the sustainability index falls. Figure 1 portrays two possible trajectories for a vulnerable system; both trajectories fall, perhaps because the climate change moves the means of the critical variables toward the limiting boundaries (without contemporaneous and accommodating evolution of those limits), perhaps because climate change increases the "width" of the tails of the distributions of those variables, or perhaps because climate change does both. The "Better" trajectory falls less slowly to demonstrate that adaptation strategies under conditions of risk and uncertainty for societies dependent upon the system in question can, in this context, work to improve sustainability of the system and thus the welfare of the (supported) society. How? By helping the system cope with the trends in the means (i.e., by expanding the limits for critical variables in the same direction as the climate change), by making the system more robust to short-term variability (by expanding the limits in all directions), or both.

There is, however, a third type of adaptive strategy for system-dependent societies that is not reflected in Figure 1. Climate change can, for many reasons, make alternative systems that could also support societal welfare ***more*** sustainable over time. Analyses of the adaptive options should therefore include searching for creative constructive alternatives; and strategies designed to accelerate the improving sustainability of alternatives and societies' abilities to switch from one means of support to another should be investigated. Figure 2 depicts two trajectories for such an alternative with the "BETTER" trajectory now depicting facilitated acceleration. The society in question can switch its reliance from the declining system to the rising system when the sustainability index of the second exceeds the first. Notice that working both to prolong the existing supporting system and accelerating the development of the alternative reduces the period where the index might be uncomfortably low (i.e., period over which the frequency of short-term experiences beyond the limits of coping is relatively high); but working both has an ambiguous effect on the timing of the switch. The potential of switching processes is one of the fundamental points of the Mendelsohn and Neumann (1998) volume.

> Lesson 8: Societies can be vulnerable to climate change, but they can perhaps diminish the associated welfare effects by effective anticipation of new opportunities that change might offer.

2.9. GALILEO AND THE IPCC

Two more lessons can be drawn from asking, perhaps whimsically, "How would Galileo have done in the IPCC process?" A quick review of Galileo's confrontations with the Council of Trent drawn from Pederson (1983) helps in this regard. The first hint of trouble for Galileo and his belief in the Copernican system of planetary dynamics emerged on February 7, 1616 when Dominican Niccolo Lorini wrote a private letter to Cardinal Millino in Rome to express his concern about "Galileisti" who were teaching that the Earth was moving around the sun and not the other way around. The Holy Office of the Vatican decided on February 24th, after three days of consideration, that Copernicus's book, *De revolutionibus orbium coelestium*, was to be suspended and, along with two other supporting volumes, forbidden. Galileo was not mentioned in any of the official documents, and he was freed of any retribution in a private audience with the Pope as long as he refrained from holding or defending the motion of the Earth. It is worth noting, though, that the Holy Office worked with remarkable and alarming speed to decide a critical issue of then contemporary science and that it actually passed judgment on the scientific merits of the Copernican view of planetary dynamics. They declared that the Earth's moving was not only heretical and in conflict with the Faith, but also "stupid and absurd".

All went well for Galileo until 1632 when, after careful planning and skillful politicking, Galileo published *Dialogo sopra i due massimi sistemi del mondo* in an attempt to reopen the scientific question and in the hope of having the 1616 decision annulled. Galileo offered a weak scientific "proof" and spent most of his effort trying to argue how the Earth's moving might be consistent with careful reading of the Scriptures. His science was ignored, and his theology only resulted in his being suspected of heresy.

There are lessons, here, for the IPCC process. The IPCC is not the Council of Trent; nor does it function like the Holy Office of the Vatican. It does, however, work toward consensus in preparing its assessment reports. In so doing, it risks focusing attention so firmly on widely held "canonical" views of how the climate might change and how people might react that the research community ignores alternative views that might turn out to be right. The IPCC must, in other words, not dismiss alternative views without due and proper scientific consideration; and it must not belittle researchers who come to the table with plausible alternatives. The IPCC should, more to the point of the historical analogy, stand ready to do more than invite a modern-day Galileo to one workshop and then dismiss what he has to say by commission or omission. Each perspective deserves a shot at "Can that be?" and "If so, so what?"

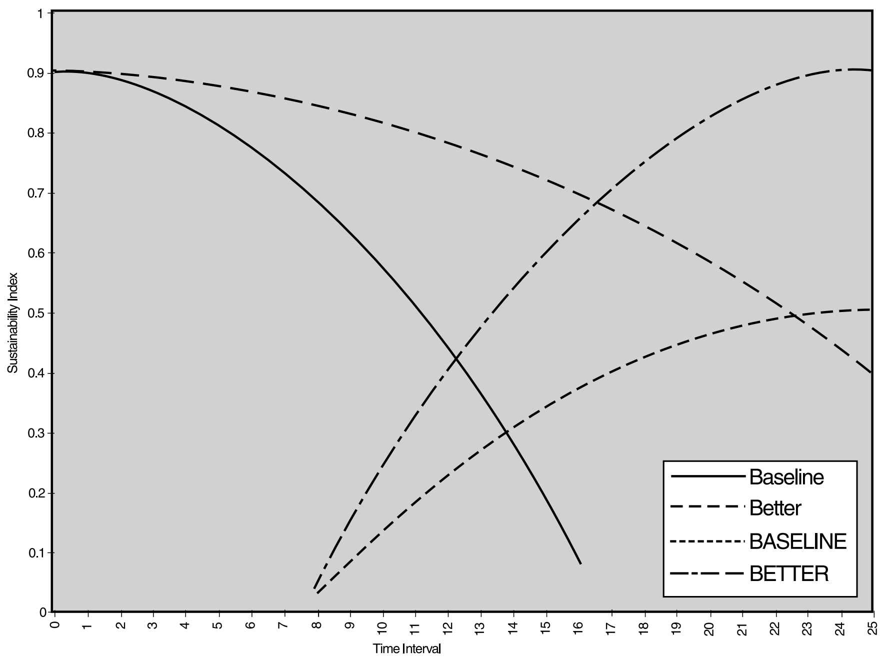

Figure 2. Trajectories of sustainability for an alternative system given climate change.

Perhaps more importantly, the IPCC should not force its scientists to argue for their perspectives within arenas that lie outside of their expertise by working the problem with only one methodological approach. Disciplinary perspectives are essential if science is to be evaluated critically. Alternatives that pass the tests of scientific review can be discounted if they are not particularly significant sources of variance in the next level of integration, but significant sources of complication cannot be whisked away by a methodological brush that requires consistent sets of output and aggregated outcomes.

> Lesson 9: The full range of climate change possibilities should be examined carefully and honestly so that plausible futures can be examined carefully.

> Lesson 10: Multiple methodological approaches to the framing of the problem should be applied so that the robustness of adaptation can be examined thoroughly at every level and in the proper context.

3. Some "Mega"-Lessons from the State of the Art

Concentrating on robust adaptive strategies will make it clear that most of the potentially severe difficulties with climate change will lie in the tails of the distributions of potential impacts. In its past incarnations, however, the IPCC process has led naturally to a chapter by chapter convergence toward a consensus of what is most likely to happen. Careful consideration of these tails has, as a result, been systematically cast aside as report deadlines have drawn near, especially in preparing the executive summary reports that attract to greatest attention. The IPCC Third Assessment Report (TAR) cannot afford to continue in that tradition; and so each chapter produced in Working Groups II and III should include careful consideration of the extreme impacts that might be contained in the tails.

- Are they feasible, or are there feedbacks that might offer natural protection?
- If they are feasible, what are the precursors of the extremes that might offer advanced warning?
- How much momentum is there in a climate that is moving toward an extreme?
- How much advanced warning would be required to overcome that momentum?
- Is there a role for hedging strategies, or would they be too disruptive if the more likely scenarios of the future emerge?

Perhaps the TAR should include an associated activity that would examine the tails and pose these questions of low probability-high consequence events regardless of their source; it is certainly true that the social science of climate change will be the source of as many surprises as the natural sciences.

Finally, careful inclusion of these lessons across the full range of analyses will makes it clear that continued single-minded reliance on full-blown integrated assessments as the unifying methodology will be less and less attractive. Integrated assessment will continue to provide context for valuable analyses of response options in the aggregate, but they will never accommodate adequately the richness of climate adaptation and climate policy across the full range of critical sectors distributed fully around the world. The administrators of the TAR should therefore make certain that it include alternative representations of the problem that go beyond the confining limits of integrated assessment and that the process of producing the TAR systematically considers the mechanisms by which interactive mitigation and adaptation policies might be contemplated and enacted. As argued by Schellnhuber and Yohe (in press) before the World Climate Research Program, only then can the IPCC examine the plausible boundaries that define "non-dangerous" interference with the climate system.

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References

Cropper, M.L. and Oates, W.A.: 1992, 'Environmental Economics: A Survey', *Journal of Economic Literature* **30,** 675-740.

Graetz, D., Dowlatabadi, H., Risbey, J. and Kandlikar, M., 1997, 'Applying a Framework for Assessing Agricultural Adaptation to Climate Change in Australia', *Earth Observing Center, CSRIO Report* #97/1.

Mendelsohn, R. and Neumann, J. (eds): 1998, *The Economic Impact of Climate Change on the United States Economy*. Cambridge University Press, Cambridge, United Kingdom.

Moser, S.C. and Cash, D.W., forthcoming, 'Global Science for Local Action: The Case of Climate Change Assessments', *Global Environmental Change.*

Pedersen, O.: 1983, 'Galileo and the Council of Trent: The Galileo Affair Revisited', *Journal for the History of Astronomy* **14**, 1-29.

Schellnhuber, J. and Yohe, G.: 1998, 'Comprehending the Economic and Social Dimensions of Climate Change by Integrated Assessment', *Conference on the World Climate Research Programme: Achievements, Benefits and Challenges*, Geneva, Switzerland.

Schimmelpfennig, D. and Yohe, G.: 1998, 'Vulnerability of Agricultural Crops to Climate Change: A Practical Method of Indexing Vulnerability', in *Global Environmental Change and Agriculture: Assessing the Impacts*, Edward Elgar Publishing, New York.

Schlesinger, M. and Williams, L., forthcoming, 'Country Specific Model for Intertemporal Climate' *Climatic Change*

West, J.J. and Dowlatabadi, H.: in press, 'On Assessing the Economic Impacts of Sea Level Rise on Developed Coasts' in Downing, T.E., Olsthoorn, A.A. and Tol, R.S.J. (eds.) *Climate, Change and Risk*, Routledge, London.

Yohe, G.W., Neumann, J., Marshall, P. and Ameden, H.: 1996, `The Economics Costs of Sea Level Rise on US Coastal Properties', *Climatic Change*, **32**, 387-410.

Yohe, G.W. and Schlesinger, M.E.: 1998, 'Sea Level Change: The Expected Economic Cost of Protection or Abandonment in the United States', *Climatic Change*, 38, 337-72

Yohe, G.W., Jacobson, M. and Gapotchenko, T., forthcoming, 'Spanning 'Not-Implausible' Futures to Assess Relative Vulnerability to Climate Change and Climate Variability', *Global Environmental Change.*