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OECD Workshop on the Benefits of Climate Policy:
Improving Information for Policy Makers

Estimating benefits: other issues concerning market impacts

by

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FOREWORD

This paper was prepared for an OECD Workshop on the *Benefits of Climate Policy: Improving Information for Policy Makers*, held 12-13 December 2002. The aim of the Workshop and the underlying Project is to outline a conceptual framework to estimate the benefits of climate change policies, and to help organise information on this topic for policy makers. The Workshop covered both adaptation and mitigation policies, and related to different spatial and temporal scales for decision-making. However, particular emphasis was placed on understanding global benefits at different levels of mitigation -- in other words, on the incremental benefit of going from one level of climate change to another. Participants were also asked to identify gaps in existing information and to recommend areas for improvement, including topics requiring further policy-related research and testing. The Workshop brought representatives from governments together with researchers from a range of disciplines to address these issues. Further background on the workshop, its agenda and participants, can be found on the internet at: www.oecd.org/env/cc

The overall Project is overseen by the OECD Working Party on Global and Structural Policy (Environment Policy Committee). The Secretariat would like to thank the governments of Canada, Germany and the United States for providing extra-budgetary financial support for the work.

This paper is issued as an authored "working paper" -- one of a series emerging from the Project. The ideas expressed in the paper are those of the author alone and do not necessarily represent the views of the OECD or its Member Countries.

As a working paper, this document has received only limited peer review. Some authors will be further refining their papers, either to eventually appear in the peer-reviewed academic literature, or to become part of a forthcoming OECD publication on this Project. The objective of placing these papers on the internet at this stage is to widely disseminate the ideas contained in them, with a view toward facilitating the review process.

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1. INTRODUCTION

Given the privilege of adding "other issues" concerning market impacts to a thorough review general topic, this paper makes no claim to being comprehensive. Indeed, it will read like a collection of short, nearly self-contained essays on five topics that have attracted at least one researcher's interest over the past 20 years. The first section will underscore, yet again because it is so important, the importance of understanding that pervasive uncertainty in evaluating market benefits of climate policy begins its cascade through the analysis with uncertainty about future emissions. A second section begins to focus on adaptation, viewed in its most general context, with an eye toward gleaning some insight into market responses and public interventions into their operation. Section 3 blends the first two in an attempt to convince the reader that pervasive uncertainty can be accommodated in adaptation studies, but only if great care is taken to be clear about who can be expected to know what, and when can they be expected to know it. Section 4 makes a few brief points about discounting in a market context before Section 5 shows how mitigation and adaptation might be complementary responses to the climate problem. Concluding remarks finally bring the threads together to suggest what we can and cannot do with our present knowledge and expertise.

2. UNCERTAINTY AND EVALUATING THE BENEFITS OF CLIMATE POLICY

Uncertainty is ubiquitous in the climate arena. It is therefore critically important, for the sake of evaluating the benefits of climate policy, to recognize that uncertainty begins its cascade through out understanding of the climate system at the source of future climate change. It is, quite simply, a fact of life that the range of “not-implausible” unregulated emissions scenarios along which some sort of climate policy might be imposed is enormous. This section underscores this obvious point by introducing a taxonomy of sources, from an analyst’s perspective, and by offering a sampling of emissions *cum* policy scenarios that clearly illustrate how big the range might be.

2.1 A taxonomy of the sources of uncertainty

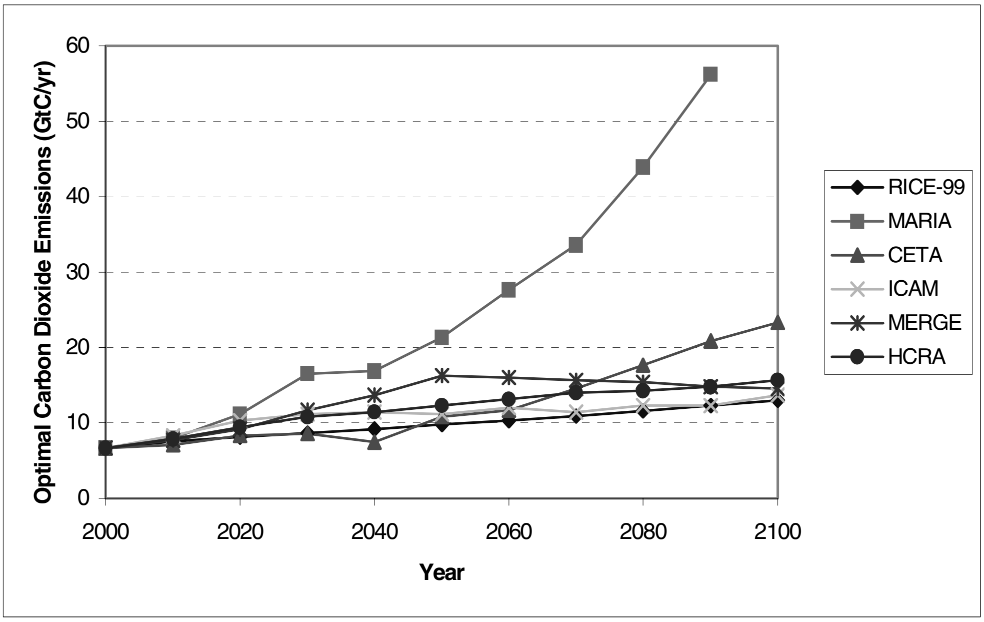
As researchers have looked to their models to produce portraits of how the future might unfold, their community has identified at least five sources of uncertainty. First of all, there is not one accepted model of the climate system. Instead, there are multiple modeling structures – abstractions of the real world – that produce sometime wildly different answers to the very same questions. This simple phenomenon is valuable to examining the relative value of one particular model or another, but it introduces *model uncertainty* for analysts who are looking across model results for a coherent view of the future. In addition, the ability of any particular model to offer credible scenarios is limited by statistical boundaries that surround estimates of the critical parameters upon which it is calibrated (call this *calibration uncertainty).* These limitations are well understood, of course, but they can be exacerbated when any one parameterization (with associated error bounds) is used to produce predictions of critical state variables (call this *prediction uncertainty*). Things get even worse when researchers take account of uncertainty about the track that the critical drivers of the model might take in the future (call this *projection uncertainty*). This compounding effect can be especially troublesome when these drivers move beyond past experience and therefore out of the sample range upon which the model was calibrated. Finally, underlying social and economic structures might change over time; and if they do, this evolution undermines the credibility of using the underlying modeling structure as a representation of future conditions to produce what might be called *contextual uncertainty.*

2.2 Illustrations of the scope of uncertainty

Many of these sources of uncertainty can be noted in even a partial review of some of the literature on emissions scenarios. Nordhaus and Boyer (2000), for example, produced baseline and economically optimal time series for emissions and control rates by running their RICE-99 model on a set of “best guesses” for driving variables like regional population growth, technological change, and fossil fuel availability. Their results depict smooth and modest reductions in emissions that are typical of results drawn from these sorts of dynamic optimization exercises. Specifically, they highlight a 8.2% reduction in cumulative emissions through 2100 that would improve global welfare by something on the order of $250 billion 1990 U.S. dollars (substantially less than one percent of total world product in the year 2100) with a benefit-cost ratio of 3.02. Detailed descriptions of the requisite underlying calibrations for regional production functions, regional damage functions, appropriate equations of motion, and the other model components can be found in their supporting documentation. For present purposes, though, it is sufficient to note simply that all of these calibrations play a critical role in determining their numerical results.

Figure 1 places the Nordhaus and Boyer results into a modeling uncertainty context by contrasting the RICE-99 trajectory with five comparable trajectories authored by other modelers who participated in an experiment conducted by the Energy Modeling Forum (1996); see Gaskins and Weyant (1993) for details of the EMF process. Each of the models identified there was, more specifically, run with consistent calibrations, but they produced different results because they differed significantly in modeling approach and emphasis. The HCRA model [see Hammitt, et al. (1992)], for instance, was based on aggregate, top down construction of aggregate economic activity. Others, like CETA [see Peck and Teisberg (1992 and 1995)], MARIA [see Morita, et al. (1998)] and MERGE [see Manne, et al. (1992)], had relatively elaborate energy sectors; and ICAM [see Dowlatabadi and Morgan (1995)] incorporated an enormous amount of disaggregated detail across multiple economic sectors and multiple household decision-makers. Each of them produced trajectories that are similar to the Nordhaus and Boyer result (also portrayed in the figure for reference); but it is clear that outcomes diverge substantially by the middle of the next century. Model uncertainty clearly matters.

Figure 1. Model uncertainty - optimal carbon emissions with common calibration



Results reported by Yohe and Garvey (1995) showed that prediction, projection, and calibration uncertainties also matter. Figure 2 contrasts the RICE-99 baseline with four representative baseline emission trajectories drawn from a monte-carlo simulation of other possible futures. It displays, in particular, a range of not implausibility (from the 10^{th} through the 90^{th} percentile paths), and it shows that the mean lies slightly above the median. As a result, we can conclude that the distribution of futures is skewed upward. Figure 3 portrays control rates that would promote the economically efficient solution to a global discounted benefit-cost problem along each of these representative scenarios. High emissions trajectories were driven by high population growth, limited technological change in the supply of energy, and low substitutability out of carbon-based energy sources; low emissions trajectories were the result of opposite configurations. Optimal interventions were then computed along each scenario for different climate sensitivities ranging from 1.5^{o} C to 4.5^{o} C for a doubling of carbon equivalent atmospheric concentrations. Both figures show that different assumptions about baseline economic activity derived from different projections of critical drivers and different predictions of critical parameters can produce dramatically different optimal control results from the same model well before the year 2050. For reference, the RICE-99 results set this initial marginal cost equal $9.13 per ton of carbon for its optimally targeted 8.2% cumulative control rate; they therefore fall on the low end of the range depicted in Figure 3

Figure 2. Calibration uncertainty - baseline emissions from RICE-99

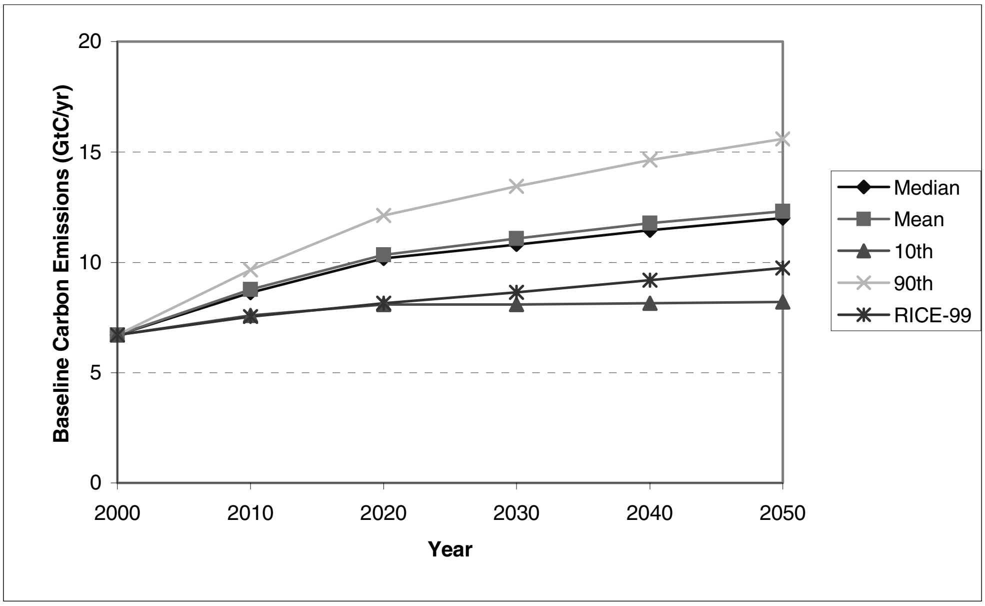
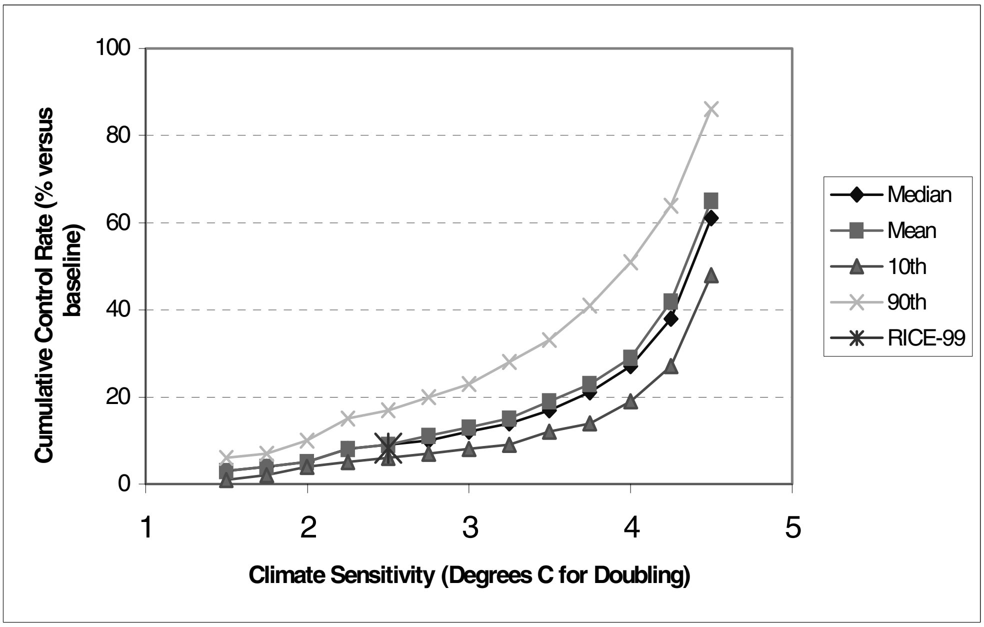
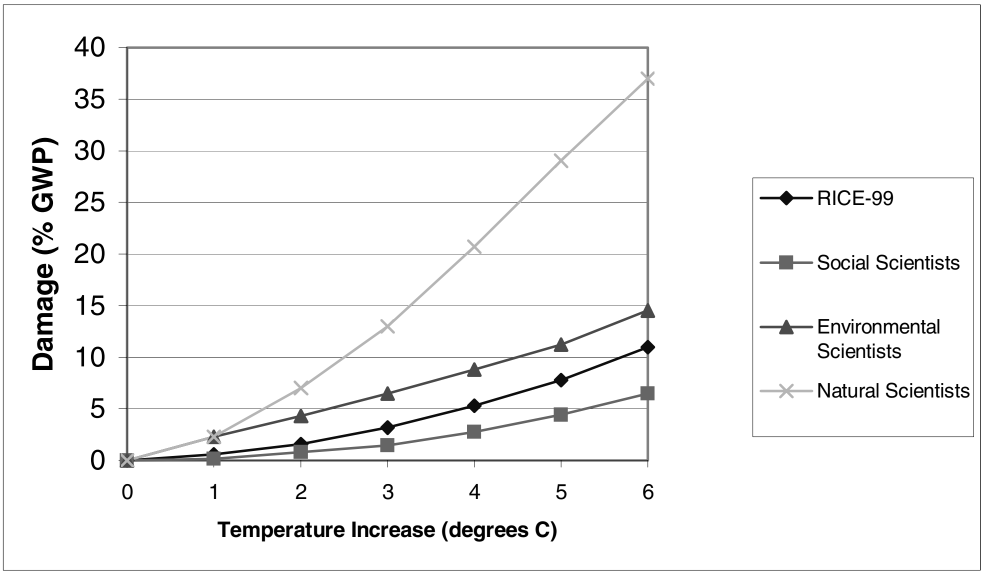


Figure 3. Implications - optimal cumulative control rates for alternative baselines in RICE-99



Roughgarden and Schneider (2002) added some texture to calibration uncertainty by inserting alternative damage estimates into the aggregate global version of RICE-99. Their alternative damage estimates reflected widely different perceptions about the potential for abrupt climate change, and Figure 4 summarizes both their approach and their results.

Figure 4. Panel A. Calibrating damages from alternative perspectives



Panel A displays different damage functions drawn from a survey conducted by Nordhaus (1994a)) and Morgan and Keith (1994); they reflect different subjective views about the extent to which a changing climate would create economic damage. The RICE-99 calibration lies everywhere above the average social scientist's view but below estimates offered by environmental scientists; and natural scientists were the most pessimistic. Panel B shows a few optimal control rates for a collection of possibilities; these are, again, solutions to the dynamic optimization problem for the different damage functions. Taking 2060 as a snapshot year, for example, the RICE baseline would support less than a 10% reduction in emissions from the uncontrolled baseline while median emissions would need to be reduced by almost 20%, and the 95th percentile case would face more than a 25% reduction. Any of these results pale in comparison to the 30% reduction that would confront the median trajectory if a 1.5% discount rate were chosen or the 36% reduction that would be efficient if the natural scientists' view of severe damages were attached to median emissions. Since similar conclusions hold for any year, it is clear that different perceptions of damages and how they might be discounted have dramatic effects on the efficient reduction of carbon emissions.

This is not a surprise, of course, but two less obvious insights can be drawn from panel B. First of all, two control trajectories are displayed there for the median damage estimate. The lower trajectory would be optimal if the pure rate of time preference were set equal to 3% per year. The higher trajectory (almost 75% higher for every year) would be optimal, though, if nothing changed but the rate of time preference; i.e., the lower median trajectory reflects an economically optimal solution if the pure rate of time preference were 0.015. Lower discount rates mean that future damages cause more harm, in discounted value; and so Panel B shows that lower discount rates mean that increased control rates must be imposed to achieve an optimum. Secondly, optimal control rates from the RICE-99 are the lowest even though the underlying damage function is not. RICE-99 includes both regional diversification and an ability to substitute endogenously out of carbon-based energy as its relative price climbs while the global aggregate does not. These two innovations make it easier to reduce emissions along the regulated scenario, but they also apparently make it easier to reduce emissions along the unregulated baselines against which control rates are measured. As a result, Panel B shows that the optimal control rate need not be as aggressive.

Sensitivity analysis is, of course, only a first step towards handling uncertainty in climate change policy framing. It helps to identify which are the important factors with regard to decision, but it really does not provide much guidance as to which policy finally adopt. Sensitivity analysis does not necessarily consider the interplay between decision and uncertainty primarily because it does not allow for incorporating new information as the future unfolds. More to the point, climate policies will not be one shot decisions. They will, instead, be the products of sequential decisions in which we tailor adjustments to the control trajectory as more information becomes available. As a result, modeling optimal abatement rates within sequential decision framework can provide a more proper representation of decision under uncertainty as long as we keep track of who might know what, and when. In addition, a sequential decision framework provides access to calculations of the value of knowledge, allows the calibration of the relative significance of various sources of uncertainty, and provides indications on the possible existence of a window of opportunity within which resolution of a particular type of uncertainty might be critical. In a cost-efficiency framework with constraints on the global mean temperature rise, for instance, Ambrosi *et al.* (2002) show that additional knowledge about climate sensitivity would be most valuable before 2040 because its value in sequential decision processes rises sharply between 2040 and 2070 (from 13% to 83% of its final value).

Finally, it must be emphasized that uncertainty, *per se*, is not overwhelming in the sense that policy makers should use it as an excuse to do nothing over the near-term. Near-term responses can be based either on even limited confidence in the likely ranges of significant factors (that have been identified) and their companion probability distributions or some notion that a particular initial response, when attached to a suite of contingent “mid-course corrections” is robust across a range of not-implausible futures.

3. ADAPTATION AND THE BENEFITS OF CLIMATE POLICY

The Intergovernmental Panel on Climate Change (IPCC) highlighted five fundamental conclusions with regard to adaptation in the context of equity and sustainable development [IPCC (2001b)]:

1. The vulnerability of any system to an external stress (or collection of stresses) is a function of exposure and sensitivity, and adaptive capacity.

2. Both exposure and sensitivity can be influenced by a system's adaptive capacity.

3. Human and natural systems tend to adapt autonomously to gradual change and to change in variability.

4. Human systems can also plan and implement adaptation strategies in an effort to reduce potential vulnerability or exploit emerging opportunities even further.

5. The economic cost of vulnerability to an external stress is the sum of the incremental cost of adaptation plus any residual damages that cannot be avoided.

Moreover, the IPCC noted explicitly that adaptive capacity varies significantly from system to system, sector to sector and region to region, but the IPCC also hypothesized that the sources of this diversity could be explained in terms of a number of underlying determinants:

1. The range of available technological options for adaptation,

2. The availability of resources and their distribution across the population,

3. The structure of critical institutions, the derivative allocation of decision-making authority, and the decision criteria that would be employed,

4. The stock of human capital including education and personal security,

5. The stock of social capital including the definition of property rights,

6. The system's access to risk spreading processes,

7. The ability of decision-makers to manage information, the processes by which these decision-makers determine which information is credible, and the credibility of the decision-makers, themselves, and

8. The public's perceived attribution of the source of stress and the significance of exposure to its local manifestations.

This section will explore these claims, briefly, by first highlighting a few bits of work that have begun the process of putting empirical muscle behind the statement and then by confronting the questions that their content begs. If every adaptation decision is site specific and path dependent, then how can researchers make any progress in identifying methods with which to enhance adaptive capacity? And how can they offer policy makers rules of thumb with which they might gain access to those methods?

3.1. A little empirical support for the hypotheses

Yohe and Tol (2002) report some suggestive empirical results from international comparisons. They found, for example, that poorer people are more likely to fall victim to natural violence than are richer people. They also found that more densely populated areas are more vulnerable. Moreover, they found a positive relationship between income inequality and vulnerability; i.e., people in more egalitarian societies seem to be less likely to fall victim of natural violence than are people in a society with a highly skewed income distribution. A growing body of literature has reached similar conclusions regarding income inequality and mortality (see, for example, Lynch et al. 2000, Kaplan et al. 1996, Ross et al. 2000). Even more recently, McGuire (2002) looked for statistically significant explains for variability in infant mortality across developing countries. Table 1 reports his results, and links each significant explanatory variable to a determinant of adaptive capacity.

Table 1. Significant explanatory variables for infant mortality across 92 developing countries

Variable	Comparable Determinant*
Per capita GDP	Resource Availability
Gini coefficient	Distribution of Resources
Mean schooling for women	Human Capital
% women with prenatal care	Human & Social Capital
% attended deliveries	Social Capital
% infant immunization	Social Capital
% access to adequate sanitation	Social Capital

* All are also related to governance and risk spreading.

Source: 1990 data

Looking even briefly at global experience in public health makes it clear that the determinants of adaptive capacity for climate-related stresses (climate change and climate variability) can be mapped almost directly into well-established prerequisites for prevention (see Yohe and Ebi, 2003). This simple observation strongly suggests that improving the strength of these determinants would also improve a society's ability to respond to a litany of socio-economic and/or other natural stresses. The key to bringing climate issues to the fore in policy discussions related to more pressing issues might therefore lie in focusing attention on those determinants. To do so would offer the possibility of improving welfare relative to a long list of pressing concerns and, at the same time, improving adaptive capacity with respect to current climate variability (with immediate benefits) and long-term climate change (with delayed benefits).

3.2 Markets and adaptation

To an economist, markets may be the paragon of autonomous adaptation. Market responses to price signals of surplus or scarcity need not be orchestrated from above; they happen automatically as rational actors individually pursue their own best interest. To an economic theorist, however, the list of the determinants of adaptive capacity holds special meaning. It is a list of sources for market inefficiency and/or (perhaps) failure. Indeed, weakness in any determinant could doom a market to under-performance or even collapse.

To see how, we can move quickly through the list of determinants. Note, to begin with, that the price elasticities of demand (and supply, for that matter) for any market good increase with time because the list of available response options expands. If energy prices rose, for example, short-term responses might be confined to driving less or lowering the indoor temperature. Over the long-term, though, individuals might add insulation to their house, replace old windows, buy a more fuel-efficient car, and so on; the result would be a larger quantity response to the higher price. We can also rest assured that access to resources with which to underwrite the implementation of alternative responses can increase these critical elasticity. Social capital is required to construct and to sustain the definition of property rights and the institutional foundations upon which market transactions are anchored; and human capital is necessary if market participants are to respond "rationally". Both of these types of capital require appropriately designed institutions as well as decision-makers whose primary goal is to safeguard the integrity of the marketplace. Agents' abilities to process information and to separate signal from noise is equally important; theory tells us that inefficiencies and market failures can result from the application of asymmetric information; these are the realms of moral hazard and principal-agent problems. Moreover, the inability to spread risk, either because of market distortions or the vagaries of adverse selection, can bring a market to a halt. Noting that market efficiency is vulnerable to shortcomings in any of these areas adds credence to the notion that overall adaptive capacity of any system, more generally defined, can be defined by the weakest of its underlying determinants.

3.3 Issues of scope

The introduction to this section ended with two questions whose content is roughly "How can anybody discern general insight from a collection of site-specific and path dependent case studies?" It turns out that the answer to this question might lie in keeping track of the scale at which the various determinants might operate. The set of available, applicable, and appropriate technological options – Determinant 1 for a given exposure at a particular location – should, for example, be defined on a micro-scale even though the complete set of possible remedies might have macro roots. Flood control options might be determined by the local conditions of the river bed and available engineering knowledge, so global knowledge may be restricted to indigenous knowledge on the one hand or informed by worldwide consultants on the other.

By way of contrast, Determinants 2 through 6 should have macro roots, but their micro-scale manifestations could vary from location to location or even from adaptation option to adaptation option. Take Determinant 2 for the moment. Resources are often distributed differently across specific locations. As a result, the adaptive capacities for systems scattered across many locations can be extremely sensitive to the way in which, on a macro-scale, available resources are distributed. Some locations, favored by the distributional process, may not be effected significantly if their funding sources are insulated from macro-scale shocks while other locations that are less favored by the process may see exaggerated variability in resources. In either case, the essential questions in evaluating general insight focus attention on whether sufficient funds are available to pay for adaptation and whether the people who control those funds are prepared to spend them on adaptation (political will).

Macro-scale and even international institutions (Determinant 3) could certainly matter even at a micro level, especially in determining how decisions among various adaptation options might be made and who has access to the decision-making process. For example, the World Bank follows certain procedures in its investment decisions, and adaptation projects in countries seeking World Bank support must satisfy the Bank's criteria before being considered. The European Union also has a framework (on procedures as well as consequences) into which all water management projects must fit, so macro-scale influences can be felt even in developed countries. On the other hand, adaptation projects in other places can be decided and implemented completely according to local customs alone.

The stock of human capital (Determinant 4) could be a local characteristic, as well, but its local manifestation would likely be driven in large measure by macro-scale forces, such as national education programs. The stock of social capital (Determinant 5) and efficacy of risk-spreading processes (Determinant 6) should be largely functions of macro-scale structures and rules; but they could again take different forms from location to location and option to option. Risk can be spread through national markets for commercial insurance and the international reinsurance markets, but some companies refuse to sell flood insurance. Risk can also be spread through mutual obligations in the extended family, the strength of which varies between cultures and city and countryside. By way of contrast, determinants 7 (information management) and 8 (attribution of signals of change) may have some general macro-scale foundations, but their primary import would be felt on a micro-scale. Indeed, decision-rules and public perceptions could take on forms that would be quite particular to the set of available options.

Working through issues of scope in this way shows that policy-makers must recognize that variation in adaptive capacity across diverse locations may (or may not) be determined by common factors. In cases where common underlying sources of weaknesses in the ability to respond to climate-related stresses across a wide range of locations can be identified, sensitivities and exposures of varying degrees could be ameliorated by macro-scale interventions that work in parallel throughout the region; these could be the targets of macro-scale policy. In other cases, however, particular locations could be quite idiosyncratic in their inability to cope so that policy interventions would have to be constructed on a site-by-site basis. In a world of constrained resources, therefore, the choice for policy-makers may be between working at the macro-scale to support improvements of varying significance across multiple locations and working at a specific location where a severe weakness would respond only to focused intervention. In either case, keeping track of how strengthening one or more determinant of adaptive capacity across a large a growing set of locations can provide general insight into how each works to reduce exposure and/or sensitivity.

4. ADAPTATION DECISIONS IN THE FACE OF ENORMOUS UNCERTAINTY

There are, in the parlance of the IPCC (2001c), a large number of decision-analytic tools with which agents in market-based sectors confront their choices. Since these tools have been discussed elsewhere during the workshop, this section begins by doing little more than make the point that various tools are better at handling uncertainty then others, particularly when public adaptations envision planned interventions into the marketplace. It continues, though, to review an illustration of how the effectiveness of adaptation options might be examined under conditions of extraordinarily profound uncertainty. In this, and in fact every case, though, analysts must heed the warning authored by Smit, et al. (1999 and 2000); i.e., they must clearly understand who is adapting or planning to adapt to what. And when this lesson is applied to situations dominated by enormous uncertainty, it can be expressed as keeping careful track of who knows what and when do they know it. Economic agents are neither dumb, in the "dumb-farmer" sense of never responding to any change in a critical source of stress; but they are not clairvoyant, either.

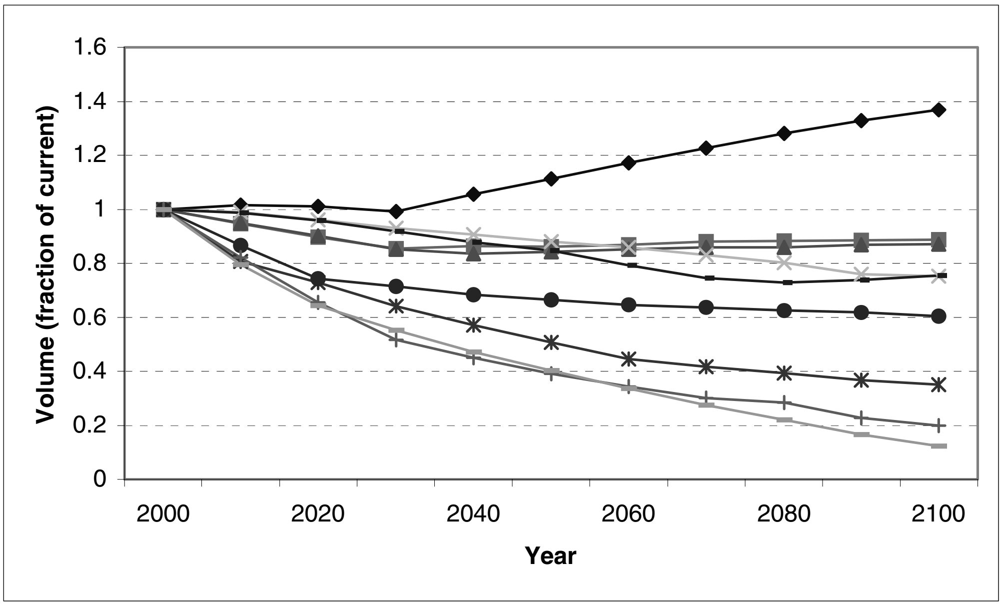
4.1. A simple comparison of decision rules under uncertainty

Cost-benefit techniques designed to reflect calculations of net present value can be used to describe the actions of individuals in the market and/or public actions that alter market outcomes in cases where the uncertainty can be represented by well-defined probability distributions (see Chapter 2 of IPCC (2001b), Chapter 10 or IPCC (2001c) or Jones (2001). When the uncertainty is more pervasive, however, straightforward cost-benefit analysis may be less appropriate. For instance, economic agents may look for robust strategies that do reasonably well over a wide range of possible circumstances. They may also construct contingent, adaptive management strategies if they are convinced that they can effectively distinguish the signal of a change from the noise that surrounds it. Market systems can handle each of these possibilities. When the sensitivity to an exposure might be abrupt, markets may have some trouble accommodating the needs of economic agents who ignore the contribution of their individual actions to that sensitivity. In such a case, public decision-makers might pursue a variant of the precautionary principle – enacting policies that encourage, entice, or coerce individuals into behaving in ways that minimize the likelihood of crossing some critical threshold. But what if uncertainty about the future were so pervasive that it was difficult to do much more than span a range of "not-implausible" trajectories to across which it is almost impossible to assign relative likelihoods? Would markets lead to efficient outcomes? Not if economic agents did not have access to information that could guide them to make decisions that were, *ex post*, correct. Could public adaptation options be examined in such a case? Perhaps. The next section provides an example in which this daunting task was accomplished; it is drawn from the work of Strzepek, et al (2001).

4.2 Analyzing adaptation when uncertainty is enormous – an example

Strzepek, *et al*. (2001) described a process by which "not implausible" climate scenarios were selected for Egypt as the first step of a project designed ultimately to conduct detailed integrated assessments of their impacts across a range of similarly "not implausible" socio-economic scenarios. Figure 5 is drawn from that work; it displays nine representative climate scenarios in terms of flow into Lake Nasser. Each was driven by specific assumptions about greenhouse gas and sulfate emissions, climate and sulfate aerosol sensitivities, and the results of some specific global circulation model; but each was selected for its value in representing a wide range of futures that cannot, as yet, be discarded as completely impossible. Taken together, they span a range of outputs produced by running COSMIC for rainfall and temperature for nine upstream countries through a hydrological model authored by Yates and Strzepek (1998).

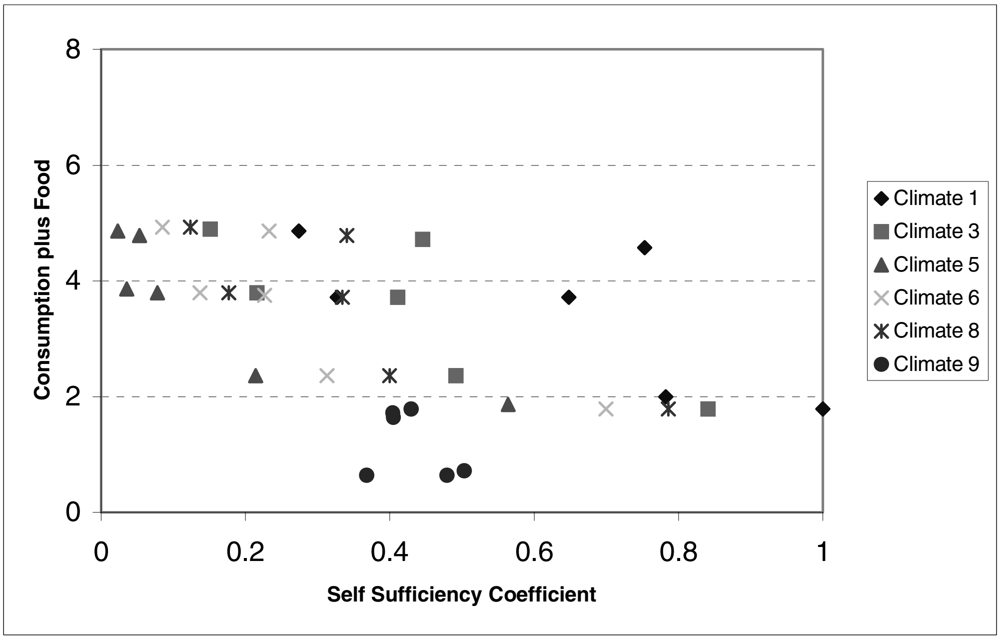
Figure 5. Not-implausible flows into Lake Nasser (fraction of 2000 flow)



A careful review of Figure 5 also sets the stage for thinking about the ramifications of alternative socioeconomic scenarios, especially with a view towards framing experiments designed to investigate the role of three possible macro-scale adaptations: municipal recycling, drip irrigation, and groundwater pumping. Scenario 1 could produce favorable outcomes from climate change as long as potential floodwaters could be diverted into vacant and domestic regions of the Sahara Desert. Flow into Lake Nasser would be stable along this scenario through 2030 and then climb over the next 70 years. Scenarios 2 and 3 would be relatively benign. Flow would fall by roughly 8% by 2030, but that level would be maintained across the rest of the 22nd century. Scenarios 4 and 8 would also portend modest climate change with a gradual decline by 2100 of approximately 12%. Scenario 6 offers the first portrait of serious shortfall in Nile flow. Flow would fall by 25% by 2025, thereby tracking even the worst climate outcomes over the near-term; but it would decline only gradually thereafter for a total reduction of 40% by 2100. Scenario 5 tracks scenario 6 through 2025, but subsequent reductions would be more severe. Indeed, flow into Lake Nasser would be 55% and 65% lower then the present value by 2067 and 2100, respectively. Finally, scenarios 7 and 9 would produce the worst outcomes in terms of climate change. Near-term reductions of 30% by 2025 are not much worse than 5 and 6; but flow falls by 75% by 2067 and by 80% around the turn of the next century.

Motivated by an understanding of the critical role played by the determinants of adaptive capacity, Strzepek, et al. (2001) highlighted the potential significance of high-capital and low-capital futures in evaluating the potential for effective adaptation. Variation across socio-economic futures captured this distinction in a Ramsey-style growth model with three different population trajectories and high or low settings for three critical parameters: nonagricultural productivity growth, growth in agricultural yields, and investment efficiency. Since domestic food security is a critical policy objective of the Egyptian government, favorable and unfavorable terms of trade were also considered. Figure 6 displays outcomes that reflect the diversity of the results created by running the growth model without adaptation for 600 combinations of climate and socio-economic futures in terms of an index of Egyptian food self-sufficiency and total food plus consumable good consumption in the year 2067.

Figure 6. Representations of not-implausible outcomes absent adaptation



Allowing adaptation to climate along the 36 scenarios reflected in Figure 6 showed that adaptation could make a significant difference in Egypt, especially for pessimistic climate scenarios. Panel A of Figure 7, for example, links outcomes in 2067 with and without adaptation for four socio-economic scenarios for the middle population trajectory along climate scenario 3. Notice that the value of adaptation is seen most clearly in terms of increased food self-sufficiency, sometimes at the expense of some economic activity. Panel B meanwhile links outcomes for the same scenarios for the same population trajectory along the most pessimistic climate future – scenario 9. Here, adaptation was devoted to increasing economic activity. Moreover, food security suffers in three cases, and quite substantially in the two cases where economic robustness is hampered by inefficient investment. In fact, only along the one scenario marked by high efficiency in investment and the agricultural sector could both policy objectives (food security and economic development) improve with adaptation. The results therefore show that socio-economic context of the sort suggested by the determinants of adaptive capacity mattered. Indeed, scenarios hampered by inefficient investment displayed diminished capacities to adapt along either the food security or the economic activity scale, or both. It is, finally, significant that food security was the major beneficiary of adaptation to all climates but the most severe.

Figure 7. Panel A. Effect of adaptation along a moderate climate scenario

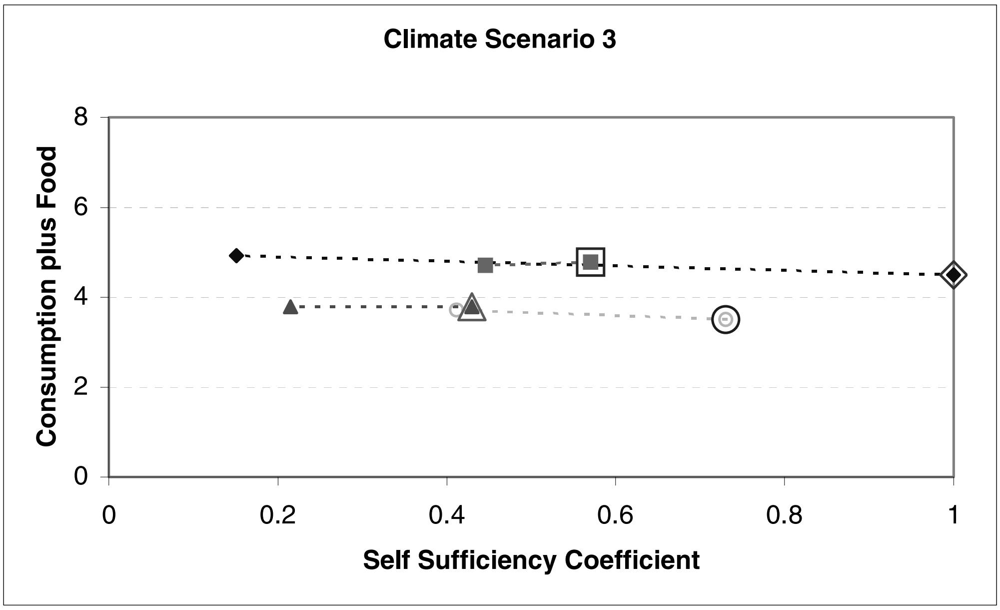
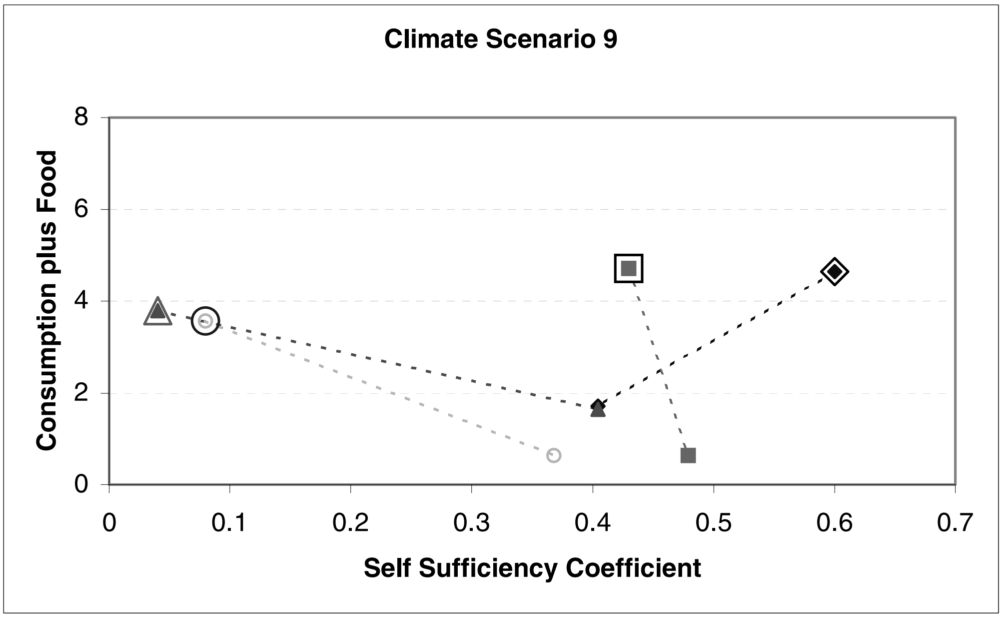


Figure 8. Panel B. Effect of adaptation along an extreme climate scenario



How much would it be worth to the Egyptian economy to be able to determine which scenario was unfolding in a timely fashion? To explore this question, we can contemplate the value of knowing if climate change would be modest or severe by asking how much it would be worth to know that climate scenario 3 (a modest reduction in Nile flow) would materialize rather than scenario 9 (a dramatic reduction in flow even in the relatively near-term); and we can also ask how much it would be worth to know that scenario 9 was emerging rather than scenario 3. The value of this sort of information is critically dependent upon the specific properties of the adaptive response under consideration. Improved *ex ante* information can hold negligible value for adaptations that can be triggered by direct observations of current circumstances as the future unfolds *as long as the appropriate signal of change can be effectively distinguished from the surrounding noise.* Improved information can, by way of contrast, be enormously valuable for adaptations that involve significant investment in infrastructure and/or significant reallocations of resources in anticipation of that investment. Drip irrigation and municipal recycling fell relatively well into the first category; either would involve modest investment in small projects that could efficiently come on line as climate change produced incremental need. Drilling for groundwater below the Sahara and pumping it to where it would be needed would, however, lie squarely in the second.

Reflecting current expectations of the Egyptian Ministry of Water and Irrigation, the growth model undertook direct investment in pumping groundwater only when five-year average flows into Lake Nasser fell 25% below current levels, but that turned out to be only half of the story. The perfect foresight assumed in its Ramsey formulation allowed the economy to reallocate capital between the agricultural and non-agricultural sectors well in advance of that date. As a result, information that could support early differentiation between two strikingly different climate futures could be expressed as measurable fractions of current GDP – roughly 0.5% of current GDP in present value. In addition, planning for bad news and adapting to good was shown to be a better choice than the other way around. Indeed, increased climate variability made it even better to "plan for the worst" because it made the climate signal more difficult to detect and therefore delayed possible "midcourse" corrections in adaptation and investment plans.

5. ADAPTATION AND DISCOUNTING

Choosing the correct discount rate is, of course, an enormous issue on the mitigation side of the climate policy agenda. Why? Because the stakes are so high. Recall that Panel B of Figure 4 showed that an efficient policy computed when costs and damages, net of adaptation benefits, are discounted at a lower discount rate (1.5%) would restrict emissions much more strenuously than a comparable policy for the same baseline emissions trajectory computed with the future discounted at a higher discount rate of 3%; but this simple observation begs the question of whether or not 1.5% or 3.0% were more appropriate.

What do we know about which rate would be more justifiable in evaluating mitigation policy? IPCC (1995b) spent an entire chapter making a distinction between descriptive (lower) and prescriptive (higher) discounting – a distinction whose fundamental content is perhaps best exhibited by the Ramsey rule for intertemporal optimization. According to this rule, discounted utility would be maximized if per capita consumption at the end of year t (net of all social damages attributable to climate change) should be discounted relative to consumption at the end of year (t-1) by

$$r(t) = \rho + \theta\, g_c(t),$$

where ρ represents a pure rate of time preference (a measure of impatience in consumption), θ is the elasticity of the marginal utility of consumption (the rate at which utility changes as consumption grows), and $g_c(t)$ represents the rate of growth of per capital consumption in year t.

Many analysts find the second term convincing, especially for commonly applied logarithmic utility functions for which $\theta = 1$. In that case, the second term is simply the anticipated rate of growth of per capita consumption. The key to their conviction is that wealthier generations who will inhabit the future will attach smaller utility values to marginal reductions in per capita consumption caused by devoting resources to mitigation. But what should be done about the pure rate of time preference? Most attempts to measure it have focused attention on individuals' decisions over time, and those decisions do not shed much light on how society should weight the relative welfare of successive generations. Debate continues, to be sure, but many scholars are coming to the conclusion that this rate should be set at or close to zero when, as in the case of mitigation, costs and benefits are extended well into the future.

It turns out, though, that the discount rate may no longer be the most important uncertain parameter for early decades abatement rates. For instance, Lecocq *et al.* (2002) show that the impact of the discount rate on short-term response is strongly dependent on the value of the time derivative of damages. More specifically, abrupt shifts in climate change damages (either because of a sudden climate surprise or because we happen cross some threshold in the response of ecosystems or human settlements to climate change stress), uncertainty regarding the discount rate matters much less than uncertainty regarding the date of sudden acceleration of damages. It may also be more appropriate to introduce the environment directly into the utility function so that we can express values placed on the environment as a purveyor of amenities. From a practical perspective, this inclusion would amount to adding a (negative) depreciation term to the Ramsey rule that would lower the overall discount rate.

Regardless of how one views these concerns on the mitigation side of the climate policy equation, the choice of a discount rate is far less controversial for autonomous or planned adaptations to external stress for which benefits and (opportunity) costs are more completely understood in large measure because they extend over (relatively) shorter time frames. Autonomous, market-based adaptations and planned adaptations will be taken in turn.

5.1 Autonomous, market-based adaptation

Markets are driven by private agents who discount future income and consumption at the return to private capital – the opportunity cost of financial capital. If capital markets were perfect, then this discount rate would match the (short-term) pure rate of time preference. Capital markets are not perfect, of course. The rate of return to private capital can exceed the pure rate of time preference for risky responses to market stresses (add a risk premium) or because the return to private capital is subject to (corporate) income taxation. In either case, and many others, the appropriate discount rate simply adds the effect of whatever distortion exists (risk, taxation, etc…) to the pure rate of time preference.

5.2 Planned adaptation

Planned adaptation is typically publicly financed, but should costs and benefits of publicly financed investments (in adaptation projects) be discounted at the rate of return to private investment? Following Arrow and Lind (1970), Ogura and Yohe (1977) were able to demonstrate that the answer to this question is "Maybe, but probably not." More precisely, Ogura and Yohe demonstrated that the marginal return to government investment (i.e., the rate at which future costs and benefits of such an investment are discounted) could fall below the pure rate of time preference only if public investment would complement private investment (i.e., make it more productive as in, for example, improving a pier or heightening protection against floods and other extreme events), but only if the marginal gross return to public capital exceeded the pure rate of time preference (because of taxation of privately generated profits, for example). The opposite result would hold, however, if public investment would substitute for private investment that would have otherwise been undertaken. The idea behind this result is to recognize that lower discount rates encourage investment by making it more likely that discounted benefits exceed costs. It follows immediately that adjusting the discount rate can exaggerate or inhibit public investment in ways that can diminish the efficiency losses caused existing economic distortions. Indeed, the appropriate discount rate for a public investment in a planned adaptation could be less than the pure rate of time preference and even be close to zero in a second-best world if it would improve the productivity of private capital.

6. ADAPTATION AND MITIGATION

It has been argued frequently that adaptation is the enemy of climate (mitigation) policy in the sense that reducing damages through adaptation reduces the need for mitigation. While this argument may hold some truth in the political arena, it need not hold even in practice if one focuses attention on the determinants of adaptive capacity. We have seen that a system's adaptive capacity depends on a list of determinants. The availability of technological (or policy) options, the availability of resources, the distribution of those resources, the relative empowerment of various segments of the population, the credibility of empowered decision-makers, the degree to which climate objectives complement their other objectives, the ability to access to credible information and the will to act on that information, and the ability to spread risk all made the list. Yohe (2001) and the IPCC (2001c) also noted that a system's mitigative capacity (the ability to diminish exposure or sensitivity by reducing emissions and, hopefully, the magnitude of the stress) is dependent on a list of determinants that is largely the same. Recognizing the coincidence of multiple determinants for adaptive and mitigative capacity can therefore helps to identify relevant policy domains within which policy makers can work to improve both mitigation and adaptation.

Enhancing each of the determinants of both capacities can be policy objectives in and of themselves. It follows that the set of determinants goes a long way in defining the degree to which the set of policy domains can profitably be expanded. Understanding their interaction can provide insight into when and under what circumstances enhancing one or another determinant might pay the most dividends and/or when it might prove ineffective because of deficiencies in other areas. Indeed, looking for the synergies underscores the notion that coping with the climate problem is not a question of mitigating and then adapting. Nor is it a question of adapting and then mitigating. It is a more holistic question of doing both at the same time. Focusing attention on the common determinants of mitigative and adaptive capacities can lead productively to understanding of exactly how to meet these coincident challenges.

It should be emphasized, however, that a single country might simultaneously display high adaptive capacity and low mitigative capacity (or visa versa) even though both capacities share the same list of determinants. To see how, note that a nation's capacity either to mitigate or to adapt would be low if it is weak in any one of the underlying determinants [see Yohe and Tol (2002)]. Consider, then, a wealthy nation like the United States where the damages associated with climate change would be focused on a small but well-connected group of people while the cost of a wide range of adaptation options might, through a well established tax system, be distributed across the entire population. Adaptive capacity could then be high because the people at risk from climate change would have a strong incentive to push for adopting one or more of the available adaptation options while the people paying the bills would see almost no effect on their own well-being. Their taxes might be slightly higher, or existing revenues might be redirected in a complicated appropriations process that few follow and fewer understand.

The population of the United States does, on the other hand, include another small group of people who see themselves threatened by most, if not all, of the wide range of available mitigation options and/or policies available to its government. The benefits of mitigation would meanwhile be marginal for most people and distributed well into the future. They would surely be distributed widely across the country and spread far into the future. Mitigative capacity in the United States could then be small, not because lists of technological options or mitigative policies were short and not because resources were lacking. Rather, a collective will to mitigate might be undone because the potential losers had effective access to the governance structure in the United States Senate through which they could block any attempt to do so.

7. CONCLUDING REMARKS

What conclusions can be drawn from a collection of short observations that were summarized one by one in the introduction? And what do they tell us, collectively, about what we know about the value of climate policy? It may be a stretch based on the experience from which these observations were drawn, but this researcher thinks that they tell us that we cannot answer that question. We cannot say what the value of climate policy might be. Given that we cannot really quantify distributions of uncertainty over emissions futures, not to mention site specific and (socio-economic) path dependent exposure and sensitivity, we cannot even say what the expected value of climate policy might be. Indeed, even if we could agree on an emissions future and an associated climate prediction, we could not say what the value would be because of the intricacies of exposure, sensitive, and adaptation across the globe.

We can, however, say that we have begun to understand the determinants of adaptive and mitigative capacity. We can, as well, declare identifying these critical determinants offers the promise of connecting considerations of climate policy with considerations of sustainable development. Future research will be most productive if it responds to this possibility by examining how development might strengthen resilience, on the one hand, or worsen exposure or vulnerability to climate change stress (the so called contingent damages), on the other. In so doing, we will make progress in understanding how to link adaptation strategies with development projects in the context of huge climate uncertainties

Taking a broader view of where we are, it is not unreasonable to claim that it may now be productive to turn some of our research effort to questions of how to design the new institutions of the 21st century. These will, of course, be institutions constructed to span the diversity of the globe in an effort to enhance both mitigative and adaptive capacity around the world without doing damage to (if not also enhancing) equity and sustainability. What will these institutions look like? That is really not for an economist to say. Indeed, we may only learn by doing – trying a little of this and a little of that to see what works and what does not. But an economist can assert that it is far more likely that this learning by doing process will be far less contentious and therefore far more productive in the near-term when the requisite international and intergenerational transfers of resources can be denominated in tens of millions of dollars than it would be several decades from now when those transfers will amount to tens of billions of dollars. Time is, therefore, of the essence.

And how do we set climate policy in the meantime? Perhaps by looking at it as buying insurance that reduces the risk of an intolerable or a barely comprehensible impact – the abrupt impacts surveyed elsewhere in this volume by Steve Schneider.

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