MIT Joint Program on the Science and Policy of Global Change

Informing Climate Policy Given Incommensurable Benefits Estimates

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To inform processes of policy development and implementation, climate change research needs to focus on improving the prediction of those variables that are most relevant to economic, social, and environmental effects. In turn, the greenhouse gas and atmospheric aerosol assumptions underlying climate analysis need to be related to the economic, technological, and political forces that drive emissions, and to the results of international agreements and mitigation. Further, assessments of possible societal and ecosystem impacts, and analysis of mitigation strategies, need to be based on realistic evaluation of the uncertainties of climate science.

This report is one of a series intended to communicate research results and improve public understanding of climate issues, thereby contributing to informed debate about the climate issue, the uncertainties, and the economic and social implications of policy alternatives. Titles in the Report Series to date are listed on the inside back cover.

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Henry D. Jacoby[*]

Abstract

The determination of long-term goals for climate policy, or of near-term mitigation effort, requires a shared conception among nations of what is at stake. Unfortunately, because of different attitudes to risk, problems of valuing non-market effects, and disagreements about aggregation across rich and poor nations, no single benefit measure is possible that can provide commonly accepted basis for judgment. In response to this circumstance, a portfolio of estimates is recommended, including global variables that can be represented in probabilistic terms, regional impacts expressed in natural units, and integrated monetary valuation. Development of such a portfolio is a research task, and the needed program of work suggested.

Contents

1. INTRODUCTION

Nations face a continuing struggle to formulate an appropriate response to the threat of climate change, and underlying the resulting policy debates are assessments of benefit and costs—sometimes explicit, but more often implicit. What level of restriction of human emissions is called for, given our understanding of the value of climate impacts avoided? What actions are justified to ease adaptation to change that we may experience in any event? Responses to such questions may reflect the viewpoint of one country, or they may be intended to represent a group like Annex B, or the sum of all nations. They may incorporate uncertainty in different ways, and include different assumptions about future behavior as it influences the benefits of action today.

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But, however it is formulated, any recommendation of limits on human influence in the long term, or of the level of current effort, implies a weighing-up of the benefits expected, for comparison with the costs to be borne. An ability to communicate about perceived benefits thus is essential for authorities seeking a common response to the threat of human-caused change. They need some shared conception of what is at stake in the choice of one level of effort or another, and a common terminology for incorporating these considerations into international negotiations and domestic decision-making.

One approach to meeting this need would be to seek a single estimation procedure, with all benefits converted to a common monetary unit, to allow direct comparison with estimates of the costs of control. Unfortunately, the complexities of the climate issue combine to rule against the formulation of a single, widely accepted measure of this type. Inevitably, governments will be confronted with sets of benefits estimates that are incommensurable—*i.e.*, they will share no common basis for comparison. To deal with this difficulty, it is recommended here that efforts focus on the development of a portfolio of benefits measures, structured to provide transparency when viewing alternative estimates. The development of such a portfolio is a research task, and an effort is made below to outline the work needed.

To limit the scope of this discussion several important issues are laid aside. Most important, the "benefits" considered here are limited to the damage caused by climate change (net of any positive effects) that could be prevented by emissions mitigation. The accounting for adaptation costs, which arises mainly in the context of monetary estimates, are not treated in detail. It is simply assumed that estimates of climate damage (or the benefits of avoiding it) include the effects and costs of economic adaptation. Secondary or ancillary benefits of mitigation actions also are not considered. This last omission is an important one, for many of the issues raised about (net) climate damage apply as well to ancillary benefits and costs. And, although distributional issues will emerge, the discussion does not pretend to cover the range of concerns of developing countries or of sustainable development more broadly. Again, these issues are important, but they as well only add more dimensions to the problem of incommensurability explored here.

Finally, by maintaining the benefits focus of the Organization for Economic Cooperation and Development (OECD) inquiry, problems of cost estimation are overlooked. Given this limited scope, it is worth mentioning that the estimation of costs, of both mitigation efforts and adaptation measures, raises many of the same problems discussed here. Simple aggregations of cost, based on market prices, are commonly accepted. But they nonetheless can involve difficult issues of uncertainty, valuation of non-market effects, and aggregation, as discussed below in relation to benefits.

The climate issue has its own peculiarities, and it is worth putting the benefits question into context. Thus, exploration of this complex topic begins with a quick survey of the role that benefits estimates play in long-term strategy development and in the formulation of near-term policy. Different issues arise depending on the task—whether it is to inform the setting of a current level of mitigation effort, to justify a long-term stabilization target, or to provide information about possible regional effects and guidance for adaptive measures. A summary will follow of limits to our ability to develop commonly accepted, comprehensive measures of climate benefits. Based on the view thus laid out, insights will be drawn about the possible development of a framework for summarizing and presenting benefits information, and the research needed to support it.

2. THE ROLE OF BENEFIT ESTIMATES IN POLICY FORMATION

Projections of the economic and environmental effects of climate change see a wide range of uses in the policy process. These include the presentation of dramatic pictures of specific events (endangered polar bears, shriveled crops) intended to stir public interest in the issue, and projections of effects at regional scale to inform public and private managers about opportunities for effective adaptation. Here, however, the main focus is on the desire for guidance about the benefits attributable to measures to restrict human emissions and their contribution to global radiative forcing. Further, it is assumed that a useful “framework” must yield information that is widely understood and accepted among the diverse set of parties that will participate in discussions of mitigation efforts, now and in future decades. These include not just members of the OECD (diverse enough in itself) but also developing countries and economies in transition.

The nature of available benefit (damage) information has an influence on the broad strategy taken in response to the risk of climate change, and the institutions employed. Such an effect can be seen in Article 2 to the Climate Convention, discussed below. But the main purpose of any analysis of benefits and costs of policy is to inform decisions about actions to be taken *now*. Nations are limited in their capacity to commit to actions in the distant future. Moreover, the climate issue is characterized by the stock pollutant character of the greenhouse gases, long lags in the climate system, and the prospect that some uncertainties will be resolved with time. Under these conditions, nations will decide and re-decide their global response decade by decade. The key decision to be informed, then, is what to do in the near term. Discussion of intended actions over longer time horizons is important, but mainly for what they may imply about desired activity today.

In this circumstance, benefit information comes into play in policy evaluation at two levels: directly in guiding near-term mitigation effort, and indirectly as they inform the setting of long-term goals, which in turn reflect back on the adequacy of efforts today.

2.1 Determining Near-Term Effort

Most often, the benefit side of climate change policy assessments is implicit. Various categories of climate impacts may be presented, but their integration takes place in the mind of the observer. Less often, aggregate benefit assessments are made explicit, perhaps including the calculation of the marginal value of impacts avoided by mitigation effort today. These latter studies have a feature in common: in order to identify the desired level of mitigation today, cost and benefit data are converted to some common measure. Almost universally costs are estimated in monetary units, as noted earlier, so benefits are similarly expressed. These are then summed across diverse effects and the various components of the decision unit of interest (*e.g.*, the sector, the nation, the globe).

In these attempts at explicit analysis, impact estimates usually are summarized by a (net) damage function, stated in terms of a projected change in global average temperature (*e.g.*, Nordhaus and Boyer, 2000). Sometimes, an optimal path of greenhouse gas (GHG) emissions is computed, along with the associated marginal cost or emissions penalty stated in dollars per ton of CO_2 equivalent. Such analyses typically assume that all future mitigation efforts are carried out in an optimal manner, considering the estimated costs and benefits of actions along the way. Usually they are applied at a global level of aggregation, calculating a path of emissions penalties applying to all nations. Less often such work includes features such as uncertainty and learning (*e.g.*, Webster, 2002) and differentiation of mitigation effort among countries. Whatever the method, the main focus of these studies is the optimal level of current effort, and the associated pattern of stringency in the future.

Later this discussion will return to insights to be drawn from such studies. The observation to be made at this point is that this explicit benefit-cost framing of policy choice requires agreement on a single measuring rod, and a means of converting all climate damage effects into these units. Any individual analyst may do this, of course, and draw insight from the results. The difficulty arises in attempts to achieve agreement among nations and interest groups on a common version of this procedure and its underlying values. The problem is illustrated by the IPCC summary of estimates of the proper current (late 1990s) marginal benefit of GHG abatement. The IPCC found a range of \$1.40 to \$35 per ton CO_2 (Pierce *et al.*, 1996).

2.2 Setting Long-Term Goals

Perhaps anticipating the difficulty of direct estimation of the benefits of GHG mitigation, the objective of the Framework Convention on Climate Change (FCCC) was framed (in its Article 2) not as seeking a socially beneficial mix of mitigation and adaptation over time but as avoiding “dangerous” levels of GHG concentrations in the atmosphere. This formulation directs the policy debate to a comparison of the advantages of alternative concentration levels compared to the estimated costs of alternative paths to their achievement. Under any assumed limit on atmospheric concentrations, such cost-effectiveness analysis leads to recommendations of the appropriate path of mitigation effort over time and the level of cost—also frequently stated in terms of dollars per ton CO_2 equivalent—that should be paid now (*e.g.*, Wigley, Richels and Edmonds, 1996; Manne and Richels, 1997).

Also, Article 2 connects to a provision of Article 4 of the FCCC that requires nations to report periodically on the adequacy of efforts, and to continue doing so "until the objective of the Convention is met." Thus the very notion of an Article 2 target provides a basis for debate about whether current efforts are consistent with some particular atmospheric goal. This provision has led to various ways of analyzing what must be done in the short term if an assumed Article 2 goal is to remain within the realm of economic and political feasibility, the most prominent of these being tolerable windows analysis (Toth *et al*., 1998).

Underlying the language of Article 2, and the analyses (formal and otherwise) that follow from it, is the facilitating myth that there exists some scientifically identifiable level of GHG concentration above which there is "danger," and below which there is not.[1] In the absence of summary scientific evidence of such a threshold, there emerges a form of meta benefit-cost assessment about what constitutes the "danger" level, with the debate ranging across levels from 450 ppmv to 750 ppmv.[2] Observers who believe that emissions reductions will be cheap, but climate damage severe, argue that 450 ppmv (or lower) is the correct target. Others who think mitigation will be costly, but climate benefits questionable, argue against any target lower than 650 ppmv.

One key objective of benefits work, then, is guidance regarding the marginal gains of moving from a loose to ever more stringent atmospheric targets. Before turning to a summary of the difficulties underlying this task, it is worth taking a brief look at a couple of recent efforts to represent the climate damage function—one by the IPCC and the other prepared for this OECD project. Both use temperature change as the key variable representing climate as it might influence economies and ecosystems, and each tries to organize available information in a simple expression or functional form.

The report of Working Group II of the IPCC's Third Assessment Report (TAR) represents a massive effort, summarizing a huge body of data, research and analysis on the impacts of potential anthropogenic climate change (McCarthy *et al*., 2001). One of the tasks of this Working Group was to help answer the leading question addressed to the TAR: "What can scientific, technical, and socio-economic analysis contribute to the determination of what constitutes dangerous anthropogenic interference with the climate system?" The TAR's Synthesis Report states that the IPCC could not produce a coherent answer to the question: "Comprehensive, quantitative estimates of the benefits of stabilization at various levels of atmospheric concentrations of greenhouse gases do not *yet* exist" [emphasis added] (Watson *et al*., 2001, p. 22). In part this situation results from uncertainties in the link between atmospheric

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[1] In analysis under certainty, GHG levels may be identified that are associated with abrupt, non-linear change, such as shutdown of the thermohaline circulation, that is easily identified as a "danger" threshold (Schneider, 2003). Many analysts would argue for a limit far below the levels so calculated, however, and even the abrupt-change threshold loses clear definition in the face of uncertainty.

[2] For simplicity, I ignore the problem of defining an atmospheric target if multiple greenhouse gases are considered. See Reilly, Jacoby and Prinn (2003).

concentrations and radiative forcing, climate response, etc. But more relevant for this discussion, the Synthesis Report states,

> . . . impacts such as the changes in the composition and function of ecological systems, species extinction, and changes in human health, and disparity in the distribution of impacts across different populations, are not readily expressed in monetary or other common units.

Nonetheless the authors made an attempt at a summary representation of what is at stake. Apparently hoping that colors have the same meaning across cultures, they employed the palate in **Figure 1** to express in a qualitative way where “danger” lies. It is a creative attempt to deal with a daunting problem, but literally the interpretation lies in the eye of the beholder. One conclusion can safely be drawn from the figure, however. There is in this representation scant guidance for setting a “danger” threshold for policy purposes, or for estimating a marginal benefit function.

The OECD-sponsored study by Smith and Hitz (2002) draws on analyses reviewed in the TAR and others published since the TAR was completed. It also makes no attempt at conversion to a common metric. Instead, the authors seek to reveal the shape of the various damage relations (*e.g.*, damage increasing monotonically with temperature change, showing first some net benefits then increasing damages, or unknown), and to identify the level of temperature change where damages seem to increase significantly. Available studies allow them to so classify some sectors, but not others.

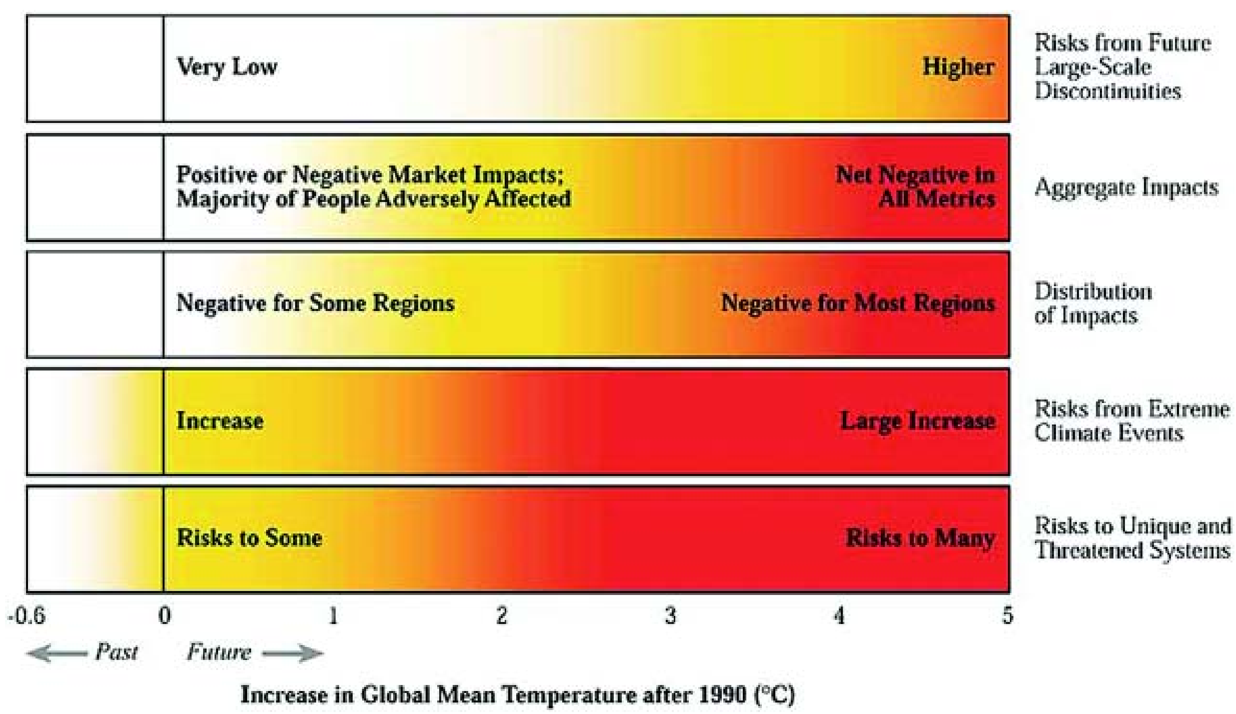

Figure 1. IPCC Representation of Impacts and Risks of Temperature Change
(Source: McCarthy *et al*., 2001, Fig. TS-12)

It is a carefully prepared survey, with studious qualification of its results. But even so there remains a danger of over-interpretation of its conclusions. One of the key results is that:

> Almost all of the studies we examined estimated that there will be increasing damages beyond approximately 3 to 4°C increase in global mean temperature. The studies do not show a consistent relationship between impacts and global mean temperature between 0 and 3 to 4°C. (Smith and Hitz, 2002, p. 54)

When setting an environmental constraint in the face of poorly quantified benefits, it is natural to look for an "elbow" in the benefits relation. Even if the level of benefits is not known, it is a good place to consider setting the constraint, because there seems a better chance here than elsewhere in the possible span of control that marginal benefit (lower below the elbow, higher above) will intersect the marginal cost of mitigation. The authors do not suggest this interpretation, but it is there to be made by the unsuspecting reader. Since most sectors covered in the study are not quantified using a common metric, there is no way to weigh up the relative damage among sectors. Even if such an "elbow" could be identified within a range of hypothesized temperature changes, it would vanish with the introduction of uncertainty in the relations of emissions, or even atmospheric concentrations, to climate outcomes. Thus the survey cannot provide a basis, at an aggregate level, for saying what the aggregate damage function looks like.

Note should be taken of the severe limits of the studies that were available to Smith and Hitz. They were very few in number. Also, they tend to use global average temperature as the climate change indicator, even though in many cases precipitation and dryness, and change in variability (droughts and floods), may be more important. And most are based on changes in equilibrium climate, with no capacity to consider the effects of transient change. As emphasized below, any effort to meet the OECD's objective of improved benefits estimates should begin with an increased allocation of resources to the correction of these inadequacies in the fundamental science.

Thus, even after earnest effort, summaries of available climate effects studies offer little quantitative guidance to global policy setting either for the choice of an atmospheric target or for the level of near-term effort. There are fundamental reasons why the task of providing better aggregate benefit estimates will be difficult, if even if the needed work on the underlying science were available. They are largely evident from the discussion to this point, but it is worth reviewing three in particular, in order to bolster an argument made later that much of what governments justifiably want, in the way of scientific information to guide policy development, is not to be had, at least not in a single "comprehensive, quantitative" measure. It is not just that such analysis is not available "yet," as in the quote above from the TAR Synthesis Report. The need is for a benefits framework that will serve in a world where a single, widely understood and commonly accepted benefit estimate will not be available *ever*. This expectation leads to a portfolio approach, outlined below.

3. THE CHALLENGE OF AGGREGATE BENEFIT ESTIMATION

This essay began with the proposition that, in any policy choice, benefit-cost considerations are inescapable. Decisions about a climate response—stringent or relaxed policies now, tight or loose atmospheric constraints for the future—imply some weight of the likely climate benefits. That argument reflects a view that the concepts and analysis methods of economics, and its sub-field of welfare economics, provide the best approach to clear thinking about choices in this domain. Included in this approach is the understanding that value is human mitigated, the acceptance of notions of willingness to pay as an appropriate basis for economic valuation, and the parsing of value into different categories (use, option, existence).[3] These concepts help provide a common language, one that is essential for domestic and international debate about an appropriate response.

The challenge presented by the climate issue is that these ideas must be adapted to choices of a scope, magnitude, and complexity never foreseen by earlier generations of thinkers. The underlying economic theory is sound, but severe problems of empirical estimation are revealed in application to the climate issue, as will be evident in the discussion below. Of course, any one analyst or analytical group, or perhaps the responsible authorities of one national party to the Climate Convention, can always agree on benefit estimates, and on a functional form for their inclusion in a model or other process for deciding mitigation policy. Unfortunately, the task is not to guide a single decision-maker or interest group but to help inform multiple-nation negotiations where participants have different understandings of the world, and national decisions where different segments of the population hold widely varying views of the issue.

3.1 Uncertainty and Risk Preferences

Considered choices about climate policy require the formation of a link between actions that could be taken and the climate change effects they might prevent. Unfortunately it is a lengthy chain that connects the two, and the first link is the physics, chemistry and biology of the climate system and the human and natural systems with which it interacts. Uncertainty in these phenomena creates serious problems for those trying to construct a measure of the benefits of efforts to reduce human interference. The difficulty is not just in quantifying the physical[4] aspects of climate change, but also in the differences among relevant groups in their perceptions of the risks that such analysis may reveal.

Informing the choice of an atmospheric concentration target under FCCC Article 2 of the Climate Convention provides an example of the challenge. At our current level of understanding, we cannot specify the precise degree of emissions control that would be required to achieve a particular "danger" level of change, even if such a level could be defined in terms of global

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[3] For an introduction to the concepts at issue, see Kolstad (2000).

[4] The term "physical" is used to describe impacts of climate change including physical, chemical and biological measures. That is, it refers to impacts stated in their own natural units, and not converted into a monetary measure.

average temperature. **Figure 2**, adapted from work by Webster *et al*. (2003), illustrates the problem. Shown there are two PDFs of global change. One shows an estimate of the distribution of temperature change assuming no emissions control, taking account of uncertainty in both human emissions and the response of the climate system. The other is the same distribution under a profile of global emissions control that would (under central tendency estimates) lead to a stabilization of greenhouse gases at roughly 550 ppmv. The insight to be drawn from the figure is that it is not possible to make a one-to-one link between policy action over time and the climate change avoided. At best the policy outcome can be stated in terms of a confidence interval, or the odds that a particular climate result will be achieved.

More troublesome, the need is to pursue the analysis to the regional level, where most of climate change effects must be studied. Uncertainty grows substantially at regional scale, even for climate variables such as temperature, precipitation, dryness, etc. One can still think in terms of the odds of outcomes, but existing climate models cannot even crudely quantify the uncertainty at regional scale. Finally, even with certain knowledge of future regional climate conditions, there remain the limits to our knowledge of adaptive response and ultimate impact, particularly for unmanaged ecosystems. The benefits of an emissions mitigation policy—even when impacts are measured in their natural units—are thus also most appropriately thought of in probabilistic terms. Because of the difficulty of uncertainty analysis at regional scale, however, studies tend to use distant proxies, like global average temperature, and to collapse the analysis to “reference” values of uncertain emissions and climate system parameters. Nonetheless, there is no “solution” to be found to the threat of climate change, only the hope of identifying the appropriate level of risk reduction.

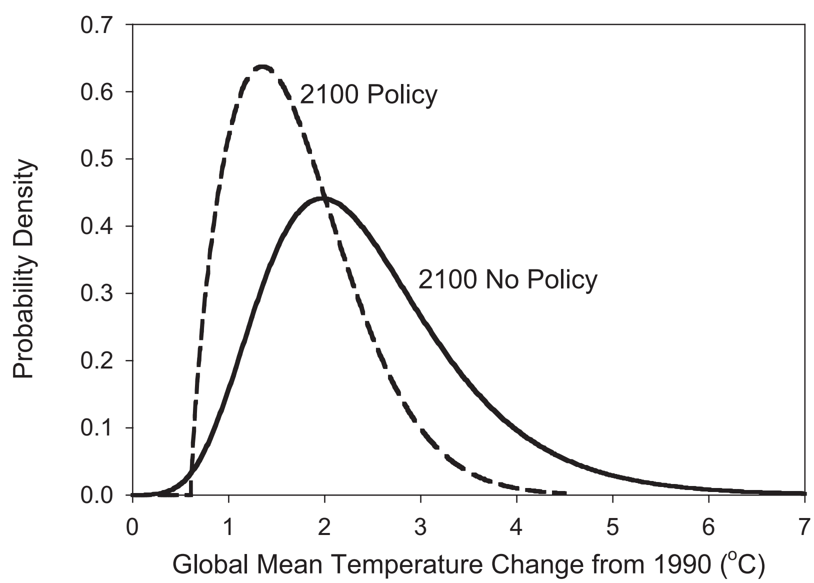

Figure 2. Temperature Change Under No-Policy and Stabilization Cases
(Adapted from Webster *et al*., 2003)

Furthermore, even where such estimates of the risk-reducing effect of a policy path can be calculated, the construction of a commonly accepted single benefit function faces another challenge. Attitudes to risk differ among cultures and across individuals within a culture or nation (Renn and Rohrmann, 2000; Slovic, 2002). People have different views of what it would be worth to reduce a particular risk, even if they agree on the magnitude of the effect under various outcomes. Thus it is difficult to imagine a single benefit function—say, expressing the benefit of reducing the future atmospheric concentration from 650 to 550 ppmv—that will communicate across the diverse parties to climate policy negotiations. There may be many ways to summarize such information, each with meaning to a particular party, but there may be no way to reach agreement on a common estimate, and perhaps even a difficulty in achieving a common measuring rod.

3.2 Valuation of Non-Market Impacts

The next link in the chain from mitigation action to benefit would be the conversion of the many physical, chemical and biological effects into a common measure that can be directly compared with cost. The issue is valuation, and the task falls into two familiar categories: effects that can be reasonably represented by calculations using market prices (or near-market analogies) and those that cannot. Several types of climate impacts can be credibly formulated in monetary terms, because market prices are available to value the physical changes that may be estimated to occur. Effects of environmental change on agriculture and commercial forestry are obvious examples. When prices are not available, valuation can sometimes be achieved by appeal to what in economic analysis is called the "revealed preference" of consumers—monetary value being imputed from observed behavior in markets that do exist. Data for such analysis may be found in closely related markets, as when the value of clean air is estimated from variations in property values. The value of an environmental bad also may be imputed from expenditure on defensive measures (sound proofing to avoid noise pollution), or of an environmental good by analysis of spending that allows full use of the good (travel expenditure to enjoy a park).[5]

Unfortunately, only a small number of all climate change impacts are candidates for revealed preference treatment, and the ones where data are available for many countries are still more limited. Where direct market-origin data are absent, another approach is to apply contingent valuation—seeking an estimate of what consumers would pay for an environmental good contingent on the assumption a market existed. A couple of techniques are in use. In one, people are surveyed to try to determine their willingness to pay for an environmental improvement, or what they would have to be paid to be willing to accept the loss of some aspect of environmental quality they already enjoy (Hanemann, 1994). In a similar approach, laboratory experiments are conducted wherein subjects are put into an artificial market where a non-market good is actually traded, and behavior is observed in the search for underlying preferences.

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[5] For a summary of method used for this type of analysis, see Kolstad (2000) or Smith (1993).

Continuing and sharp controversy surrounds the use of these methods, with serious questions raised as to whether responses to imaginary situations can ever yield information consistent from that revealed by real choices (*e.g.*, see Diamond and Hausman, 1994). But whatever one's taste in these analytical methods, the scale of the impacts of climate change, and poor respondent understanding of the implications of changes at regional and global scale, means that any such applications are going to be partial in coverage. It is hard to imagine the application of such a process to a relevant question such as, "What would you be willing to pay to prevent the loss of all arctic tundra?" More important for this discussion, it is questionable whether such applications can produce estimates that are commensurable across regions or realms of climate change impact.

3.3 Aggregation

Finally, different participants in the search for a climate solution will add up effects in different ways, whether expressed in natural units or dollar amounts. The aggregation problem is the same as that faced in valuing any public good, but it is particularly troublesome in the climate case. In the classic solution to public goods valuation, benefits are determined by eliciting estimates of willingness to pay from each party affected, then summing them up. The approach is consistent in theory; the difficulties arise in practical application. The procedure assumes that the income distribution underlying the estimates is optimal, or at least acceptable. But in application to climate change, with its conflict between North and South, this is not the case. The issue was painfully explored in preparation of the IPCC's Second Assessment Report, in the debate over the use of willingness-to-pay measures of the value of human life (Pierce *et al.*, 1996). Without correction, the same human loss in a rich country receives much greater weight than in poor a one. There is an extensive literature on the correction of estimates by some form of global welfare function, with a computation of weights by region, but in the climate context this approach only pushes the issue back one step to the selection of the weights, for which there is no widely accepted process. Different parties will have different weighing schemes, and their summary estimates will be incommensurable.

A further difficulty arises because benefits estimates are not constructed by the textbook method of summing individual valuations. Rather, analysis groups in one country or another prepare estimates for the whole, applying willingness-to-pay estimates and relative weights as they see fit. Even with the best intentions, aggregation methods will differ, and alternative estimates will be incommensurable for this reason alone. This aggregation issue arises at all scales from the individual upward to various social aggregates, and in all benefit estimation problems. But it is particularly troublesome for climate change, which is so fraught with inter-country equity issues, not to mention the need to aggregate the (imagined) preferences of future generations.

4. A FRAMEWORK FOR FUTURE BENEFIT STUDIES

The conclusion to be drawn from the discussion thus far is that no single benefits measure is going to be universally applicable.[6] By extension, no single method for calculating the magnitude of the marginal benefits of greenhouse gas mitigation, stated in the same units as marginal costs, is going to be widely accepted. As a result, there is no single analytical basis for selecting a target level of atmospheric concentrations or other climate variables like global mean temperature rise. As in other areas of public decision, governments necessarily face the limits of neutral assessments as a guide to political decision, and they best prepare to deal with this situation by structuring benefits research so that the results are transparent, and as universal as possible in their acceptance.

In this circumstance the desired "framework" for benefits estimation will involve a portfolio of estimates, related to one another but at different scales, in different units, and with alternative degrees of aggregation. Discussion of this approach begins with information needed to inform the debate over long-term atmospheric goals. The proposed set of benefits measures includes global physical variables, regional indicators in natural units, and monetary aggregates. Their development involves a set of parallel tasks, because the different indicators need to be coordinated with one another. Thus while the discussion to follow makes some tentative recommendations regarding the content of such a portfolio of measures, it should be emphasized that what is proposed here is best seen as the outline of a research agenda.

4.1 The Selection of Long-Term Atmospheric Goals

A benefits portfolio would include estimates at a global aggregate level, with (1) global variables that can be analyzed in probabilistic terms, (2) impacts that can be measured at regional scale—most likely in natural units, and (3) exercises in monetary valuation. With this structure, variables that might gain broad acceptance are given prominence, and a foundation of common information is laid for the more problematic matters of non-market valuation and aggregation.

4.1.1 Global Physical Variables, Uncertainty and Risk Reduction

Considering the overwhelming uncertainty that pervades the climate issue, the ideal would be to formulate climate policy as a way of reducing the risk of damage, in analysis at all levels of aggregation. Unfortunately, as noted earlier, climate models cannot support this type of analysis at a regional level. The risk reduction perspective is nonetheless very important to convey, and thus the first level of benefit representation should be at a global level, expressed in those variables that can be analyzed in probabilistic terms. Climate variables at this level are usually thought of as drivers of benefits estimates, but here it is proposed that they themselves serve as the basis for a benefits measure.

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[6] For a similar argument, see Schneider, Kuntz-Duriseti and Azar (2000).

Several efforts have been made to estimate probability density functions (PDFs) for temperature change under non-policy conditions (Webster *et al*., 2003; Wigley and Raper, 2001). These same analyses can be extended to estimate PDFs of climate change under specified policy paths, as illustrated by the work of Webster *et al*. (2003), shown in Figure 2. Such analysis could be applied to important variables besides global mean temperature, such as temperature by latitude (*e.g.*, distinguishing risks among polar, temperate and tropical regions) and sea level rise.

Research is needed to better understand which way of representing such results is likely to be most widely understood by target audiences. Alternatives include PDFs like the ones in Figure 2, statements of the odds of avoiding certain specific conditions (*e.g.*, sea level rise exceeding 30 cm), or big-loss vs. small-loss segments of roulette wheels. However done, the objective would be to express the benefits in terms of variables that do not run afoul of the controversies over valuation and aggregation, and that cast benefits in a proper risk-reduction framework. In addition, a framework might be provided so that differences in risk perception and tolerance could at least be discussed.

A question remains as to where in this framework the prospect of abrupt climate change should be addressed (Alley, 2002; Schneider, 2003). Possible events such as a significant slowing of the thermohaline circulation, or the loss of permafrost regions and the associated the release of greenhouse emissions, are too important to be left out of any system. Analyses attempting to support estimates of likelihood are extremely weak, however, and the potential effects at regional scale are poorly understood. A tentative recommendation is that they nonetheless be included in benefit representation at this high level of aggregation, even if stated only in qualitative terms.

4.1.2 Effects at Regional Scale, In Natural Units

A second component of a benefits portfolio would be measures of impact at regional scale. In general these measures would be stated in natural units, short of monetary valuation, although in some cases economic valuation may in fact provide the most convenient measuring rod. For example, useful market measures have been achieved for sectors like agriculture, commercial forestry, and energy use, and these monetary measures would be preferred to physical measures. Here as well the need is for uncertainty analysis, but for the time being estimates at this level would likely have to be made on an expected magnitude basis. This has been a common approach among analysts of climate impacts.[7]

The challenge is to develop a small number of indicators, in natural units, that together convey as comprehensive a picture as possible of what different levels of climate change might involve. There are several aspects to the task. First is research on the best regional aggregation for this purpose. Most studies use an aggregation chosen to be consistent with integrated

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[7] For example, see Fankhauser (1995), Nordhaus and Boyer (2001), Fussel and van Minnen (2001), and a summary of work as of 1995 by the IPCC (Pierce *et al*., 1996).

assessment models, and so their structure is strongly influenced by the data available for cost analysis and the assessments at hand for market-price based impacts studies. For example, for physical indicators (to be discussed below) the identification of polar regions would seem important, although they are usually missing from such studies.

Next is the identification of physical measures or indices that are mutually consistent (in terms defined below) and that have high information content. Several examples can be seen in the papers prepared for this OECD project and in other effects research. A number of studies use numbers of people subjected to one or another hardship (risk of hunger, flooding, water stress, disease) as seen the summary by Smith and Hitz (2002). Also, various studies have used biogeography models to calculate terrestrial impacts measures in terms of pixels where climate change leads to change in ecotone (Leemans and Eickhout, 2002; Toth, Cramer and Hizsnyik, 2000). In developing a set of such measures, a number of criteria seem important:

- **Definition.** There should be a clear definition, to allow consistent measurement across regions.
- **Independence.** Such measures or indices should be independent of one another, and of impacts that may be estimated in monetary units at this level of aggregation. The objective would be to preserve additivity, to facilitate integration with one another and incorporation in attempts at wide-scale monetary valuation and aggregation.
- **Global application.** The measure or index should have application to all, or at least most, regions.
- **Baseline comparison.** There should be some basis for comparison, so observers have an idea whether a change is large or small. For example, the measures of change in terrestrial ecosystems might be calibrated on a regional basis with an estimate of the last 100 years of anthropogenic change, caused by the conversion of natural ecosystems to agriculture and urban use.

What is involved here is a stretch toward multi-attribute analysis, and coverage would be partial at best. Clearly there is no fully satisfactory approach to this task, only more or less disappointing compromises. But recall the need: it is for indicators at regional level that lie somewhere in between the color diagram of Figure 1 and a thousand measurements of effects like hectares of coral reef, numbers of alpine meadows, and days of trout fishing.

4.1.3 Market and Non-Market Valuation and Aggregation

A third component of the portfolio should be the construction of benefit functions, at regional and global level, aggregated in monetary units. Estimates of this type bring together two rough categories of analysis and judgment: market and non-market effects. Useful market estimation has been achieved for several sectors, as noted above. Others, like recreation, have simulated-market analogies that may prove widely acceptable.[8] More problematic are health impacts, where

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[8] For discussion of the boundaries, see Nordhaus and Kokkelenberg (2000).

economic estimates of pain and suffering and value of human life may be common practice in some countries and anathema in others. Estimation of effects even further removed from market measures—like ecosystem change, species loss, and amenity values—present still greater difficulties, as noted above.

However, despite the difficulties, estimates of monetary aggregates belong in the portfolio of measures. They are needed to serve two important functions in climate analysis: imposing discipline on benefit estimates and indicating efficient time patterns of response. On the first point: without some means of adding up effects—which requires a common measuring rod—it is difficult limit the claims for one or another physical effect of change, or the mitigation cost justified to prevent it. Whatever one's view of the valuation issue, there are tradeoffs to be faced. The construction of aggregate benefit functions provides a framework for testing the reasonableness of the total of benefit claims, including a transparent accounting of possible substitutes for good and services, or environmental conditions, that may be lost or displaced due to climate change.

The second advantage is the insights to be gained about climate policy, even if no more than the general shape of a global benefit function is accepted. A number of studies impose a benefit function that presumes that climate damage increases more than proportionally to temperature change. Some of these applications calibrate these relations with benefit estimates from individual sectors and countries (*e.g.*, Nordhaus and Boyer, 2000). The procedure is subject to question given the concerns summarized above, but the precise parameters are not crucial to the essential insight to be drawn from these studies. It is that, for climate change, an efficient mitigation response will start small and increase in stringency over time. The precise level of current effort may still be left unresolved, but the nature of the desired path is not, and it is an insight missing from much current climate discussion and policymaking.

4.2 Informing Short-Term Effort

If the analysis is extended to the benefits that can be attributed to action taken today (the most important issue at stake), additional considerations and uncertainties intrude. The effects on climate risk of actions taken today are not independent of what future generations of policymakers may decide to do along the way. As noted already, many calculations of desired near-term effort are based on the assumption that all future generations will make choices that are socially optimal given the assumed cost and benefit functions (*e.g.*, Nordhaus and Boyer, 2001). Even those calculating the minimal effort required now to keep open the option of meeting of some future goal (*e.g.*, Toth *et al*., 1998) must impose assumptions about future behavior. Further complicating the analysis of these choices at each step is the fact that the options that future decision makers will face are influenced by actions of their predecessors. Today's actions influence not only the available set of future technological options, but also the inheritance of institutional capability and public understanding. Thus, except where analysis can be based on a single monetary benefit function, or the benefit analysis yields an atmospheric constraint, the distance between estimates of climate change effect and the choices made today is great. The condition is, unfortunately, characteristic of a stock pollutant emitted by many sources, and the direct guidance to political decisions about current mitigation effort is at best indirect.

5. RESEARCH DIRECTIONS

Most of the components of a framework for benefit estimation, at least as discussed here, are not new. Work is under way on almost every topic, building on years of research and analysis stimulated by the climate change issue. A couple of points from the discussion above should be emphasized however. First, what is suggested here is a more formal structuring of climate effects estimates according to region and the level of detail. The objective is to provide a portfolio of information that can be further analyzed and aggregated according to the abilities and values of the various participants in climate policy discussions.[9] Second, the development of such a structure is a research task—requiring a focusing of effort and redirection of available resources to climate change impacts and the benefits of emissions mitigation. The overriding priority in meeting these needs is research on the fundamental science of climate change impacts, with a special focus on natural ecosystems, their ability to adapt, and potential damage when they cannot. The discussion above, and the survey by Smith and Hitz (2002) highlight the inadequacy of current knowledge. In part the lack is attributable to the great complexity of these systems, but unfortunately our ignorance also results from the inadequate allocation of funds to research in these areas by the major national and regional research organizations. Most of the other specific tasks suggested below depend on progress on the basic science of terrestrial and ocean ecosystems.

If the portfolio concept emphasized here is to be pursued, several other areas of research are of high priority. Climate change is a century-scale problem, and by the same token the development of a limited portfolio of measures, to help inform the policy process, should be seen as requiring continuous, long-term effort as well. The needed actions include the following.

Design of a Portfolio Benefits Measures. Based on analysis of available information and a forecast of the possible results of future research, a template should be designed, covering the three elements of the portfolio above. It should consist of a limited set of indicators—no more than ten. This might include two or three measures of global climate (*e.g.*, probability of temperature rise greater than 2°C by 2100), four or five summary indicators of regional impact, and one global monetary measure. The portfolio of measures would not be the only information generated and made available, but it would be a set of variables continuously maintained and used to describe the results of various policy choices.

Encouragement of Uncertainty Analysis. Analysis of uncertainty in climate projections, and in the effects of policy measures, is being pursued, as noted above. These efforts

[9] There are limits to this approach, of course. If key parties are poles apart in their view of the nature of climate risk, then even a minimal portfolio of commonly shared information may be difficult to achieve.

should be encouraged, and supported where possible. Also, a process for incorporating this work into benefits measures at the level of global climate should be developed, perhaps including involvement of the IPCC.

Development of Regional Impact Indicators. A research program should be formulated with the purpose of developing the best set of impacts indicators (which may include market measures) that can be supported by current research and anticipated future results. The work would involve a process of sorting and testing, using the criteria proposed above, in a search for a set of indicators that captures as many of the implications of change as possible without causing sensory overload.

Estimation of Market Impacts in Developing Countries. Most analyses of the market effects of climate change have been carried out in the richer countries, and very crude methods have been applied to extend the results to the developing world. Research directed specifically at impacts in developing countries should be increased, in order to fill out those regional indicators where monetary quantities are a natural unit of measure. Particularly important in such an effort will be consideration of potential improvements over time in adaptive capacity.

Formulation of Global Climate Damage Functions. Global damage functions are an essential input to many forms of analysis applied to the climate issue. Yet the number of efforts to prepare such estimates is very small. Moreover, they focus very heavily on available market-based estimates, with minimal research on ways of incorporating effects on unmanaged ecosystems. Research should be supported to improve these aggregate functions, particularly the representation of developing country impacts and the consideration of non-market, ecosystem effects.

Finally, one message of this exploration of the benefits question is that policymakers can reasonably expect benefits work to yield insight into the seriousness of climate change, and rough guidance as to actions that are justified today and leading into the future, but they cannot expect the problem of incommensurability of benefit estimates to be overcome. Clear, widely accepted estimates of marginal benefits are not likely to become available to dramatically narrow the range of choices regarding what to do today. They must prepare as best they can for extracting a basis for judgment from a (one hopes well-constructed) framework for summarizing diverse forms of information.

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