CHARACTERIZING CLIMATE-CHANGE UNCERTAINTIES FOR DECISION-MAKERS

An Editorial Essay

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1. Introduction

Climate-change policy-making confronts a wide range of significant scientific and socioeconomic uncertainties. How experts should best characterize such uncertainties for decision-makers has emerged as an important debate within the Intergovernmental Panel on Climate Change (IPCC).

The Special Report on Emissions Scenarios (SRES) (Nakicenovic et al., 2000) developed 40 scenarios of 21st century anthropogenic greenhouse-gas emissions for the IPCC's Third Assessment Report (Houghton et al., 2001). SRES generated the scenarios using six different computer models and a wide range of assumptions about the values of key driving forces. SRES argued that it is not possible to assign a likelihood to any of the emissions scenarios and that the associated uncertainties are best characterized by the full range of scenarios.

Recently, some IPCC contributors have initiated a process to guide the Fourth Assessment report toward characterizing uncertainties with probability distributions that represent the consensus of the scientific community (Giles, 2002). Advocates assert that good decisions under uncertainty are contingent on well-defined probabilities and, lacking experts' judgements, decision-makers will make their own politically motivated estimates of likelihood.

Probability-based estimates are a powerful risk-management tool, but can have serious limitations when applied to a problem such as climate change. To avoid the pitfalls of probability-based methods, the IPCC should also consider approaches to decision-making under conditions of uncertainty that do not depend on expert consensus on probabilities.

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2. Limitations of *Predict-Then-Act* Approach

Uncertainties are typically characterized with probability distributions. For a well constrained problem, such probabilities are first used to assess the likelihood of alternative future states of the world. Then policy alternatives are ranked on the basis of their expected utility, contingent on the probabilities. Where probabilities cannot be derived from empirical data, systematic procedures have been developed for eliciting what are called "subjective probabilities" from experts (Morgan and Henrion, 1990; Moss and Schneider, 2000).

This *predict-then-act* approach has been used in numerous applications, often with great success. For instance, cost-benefit analysis as generally practiced begins by precisely characterizing risks and the costs of reducing them.

However, climate change violates the postulates of *predict-then-act* on two related counts. First, climate change is associated with radically diverse decision contexts, geographic scales, and time scales. It comprises many different types of policy problems involving many different types of actors, and thus is not even theoretically optimizable (Jaeger et al., 1998; Arrow et al., 1996). Second, climate change is associated with conditions of deep uncertainty, where decision-makers do not know or cannot agree on: (i) the system models, (ii) the prior probability distributions for inputs to the system model(s) and their interdependencies, and/or (iii) the value system(s) used to rank alternatives.

Where no single or well-bounded policy problem can be defined and deep uncertainty exists, efforts to characterize uncertainties as a prelude to decision-making may be counterproductive. In particular: (i) elicited probabilities may be a poor description of the real world—decisions based on them may misallocate or too narrowly focus resources and thus erode system resilience; (Rayner, 2000) and (ii) decision-makers will find most credible those expert pronouncements of probability distributions that are compatible with the framework of their own values, policy priorities, and decision contexts (Herrick and Sarewitz, 2000). Fortunately, decision-makers regularly construct successful strategies for dealing with deep uncertainty that avoid such pitfalls. But a focus on generating probability distributions may skew research priorities away from providing information that can support such strategies.

Two general approaches encompass the means for characterizing policy-relevant uncertainty associated with climate change. Some approaches employ the *predict-then-act* framework, often supplementing expert elicitation with new approaches to deriving probability distributions from empirical evidence. Others take a fundamentally different view, assessing the risks associated with particular policy options. The *assess-risk-of-policy* framework seeks to identify the uncertainties most relevant to choosing among alternative policies.

3. New Approaches to Characterizing Uncertainty in the *Predict-Then-Act* Framework

Probability distributions for key climate parameters can be extracted from available data and models. Several research groups have derived probability distributions for climate sensitivity via statistical comparisons of climate model results to recent climate records (Andronova and Schlesinger, 2001; Forest et al., 2001) and for socio-economic and technological driving forces (Gritsevskyi and Nakicenovic, 2000; Nakicenovic and Riahi, 2002). Figure 1 shows a recent estimate of climate sensitivity (Andronova and Schlesinger, 2001) made by simulating the observed hemispheric-mean near-surface temperature changes since 1856 by a simple climate/ocean model forced radiatively by greenhouse gases, sulfate aerosols and solar-irradiance variations. Note that this analysis suggests a much wider spread than the IPCC range, consistent with the observation that experts routinely underestimate uncertainty (Kahneman et al., 1982).

Though valuable for many climate model parameters, such approaches are less compelling for key socioeconomic uncertainties governing future emissions and impacts of climate change. The socioeconomic driving forces may change over time and are interrelated and conditional on each other. Some authors have estimated probability distributions for future emissions by assessing the frequency of results over different emissions models or by propagating subjective probability distributions for key inputs through such emission models (Webster et al., 2003). Such approaches can, along with scenario-based methods, suggest which uncertainties are most important in determining any significant deviations from a base-case projection (Nakicenovic et al., 2000) and can prove particularly important in helping

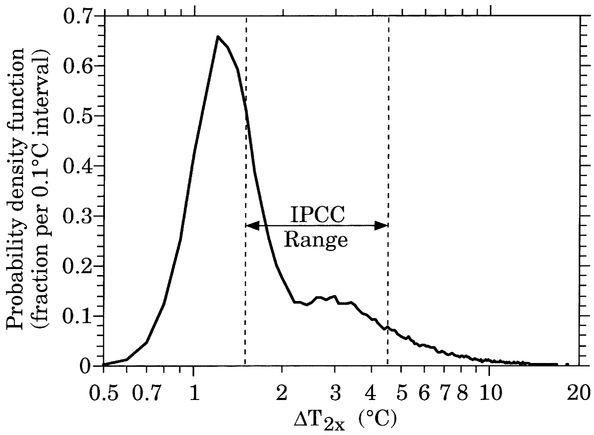

Figure 1. The probability density function for climate sensitivity (from Andronova and Schlesinger, 2001).

to make clear when proposed scenarios differ in important ways from past trends. Given, however, that decision-makers might be justified in anticipating that the 21st century will differ in important ways from the 20th—as the 20th century differed in important ways from the 19th century, etc.—it might well be imprudent for them to treat the specific distributions generated by such methods as a foundation on which to construct policy choices.

4. Characterizing Uncertainty in the *Assess-Risk-of-Policy* Framework

Characterization of uncertainty need not be a prelude to defining policy choices. In recent years a number of new approaches proceed in the opposite direction, starting with available policy options and then assessing and comparing uncertainties associated with these options. Such approaches can be inherently more compatible with the realities of the policy-making process (Jasanoff and Wynne, 1998). Social scientists studying the human dimensions of climate change (Rayner and Malone, 1998; Sarewitz et al., 2000) argue that faced with conditions of deep uncertainty, decision-makers most successfully plan by developing policies that are: (i) based on experience, (ii) relevant to a wide variety of possible climate futures, and (iii) cognizant of the many possible agents of societal change. They suggest that climate-change policy-makers should understand various sources of vulnerability to climate and focus on the technical and political actions that will reduce these vulnerabilities. These include improving the ability to respond to extreme climate events and increasing the efficiency of society's energy use regardless of any expectations about climate change.

New, quantitative methods have recently been developed to assess robust strategies, that is, ones which will reduce vulnerabilities by performing well compared to the alternatives across a wide range of scenarios (Metz et al., 2001). For instance, Ben-Haim (2001) has developed a quantitative representation of structural uncertainty that can be used to characterize the extent of such model uncertainty against which a proposed strategy is robust. Rotmans and van Asselt (van Asselt, 2000) use scenario-based modeling to characterize the futures in which alternative management styles will perform poorly.

Exploratory modeling-based (Bankes, 1993) approaches to robust decision-making (Lempert et al., 2003) use the computer to create a large ensemble of plausible future scenarios, where each scenario represents one guess about how the world works and one choice among many alternative strategies decision-makers might adopt to influence outcomes. Interactive computer visualization, search techniques, and statistical algorithms are then used to help decision-makers identify potential robust strategies, scenarios where those strategies may perform poorly, and potential hedging actions against those adverse scenarios.

Exploratory modeling-based methods are not averse to the use of probabilities, but distinguish between their two roles as: (i) factual statements about the world—e.g., a climate sensitivity of 4.5 °C is less likely than one of 2.5 °C—and (ii) a coherent mathematical framework for summarizing information—e.g., given a uniform distribution over a some large ensemble of scenarios, policy A has better expected utility than policy B. A key difference between these two roles is that the first suggests a single, correct answer—e.g., the probability distribution shown in Figure 1 is an accurate representation of our current knowledge about the state of the world—whereas the latter admits of many plausible representations—e.g., policy A dominates policy B for any probability distribution that puts more weight on climate sensitivities above 3.5 °C than below. From a policy perspective, this difference is important because of what Whitehead (1929) termed the "fallacy of misplaced concreteness," that is, the tendency of decision makers to invest the concreteness of reality in numbers representing abstract ideas—in this case, the tendency to look on any probability distribution as a true indicator of the likelihood of a future set of events.

In contrast to the *predict-then-act* framework, which envisions a large number of consensus probability distributions (one for each important uncertainty) as inputs to a process that generates policy recommendations contingent on these probabilistic statements about the world, the *assess-risk-of-policy* framework envisions a process that generates policy options whose satisfactory performance is maximally insensitive to uncertainties and outputs a small number of probabilities to characterize the residual risks of choosing such a policy. For instance, Figure 2 shows the likelihoods one would need to ascribe to drastic climate damages and high climate variability to justify abandoning the proposed robust strategy described in the shaded region in favor of one of the other strategies shown on the figure (Lempert and Schlesinger, 2002). The study from which these results derive claims that choice of near-term climate-abatement strategy is contingent on the uncertainties shown on the two axes, but is largely insensitive to the other uncertainties considered in the analysis. That is, the *assess-risk-of-policy* framework aims to characterize hard-to-quantify uncertainties, including those that might be considered "surprises" (Lempert et al., 2002), by identifying for policy-makers a set of well-hedged strategies and the small number of key residual risks to which they are still most vulnerable.

We emphasize that our point is not that the *assess-risk-of-policy* framework somehow avoids "subjectivity" that detrimentally afflicts *predict-then-act*. Rather, we claim that the former supports a different characterization of deep uncertainty that decision-makers may find more useful in many of the choices they confront over climate change policy.

The *assess-risk-of-policy* framework requires several types of subjective judgments, that is choices potentially particular to the individual analysts involved. These include the choice of simulation models and the range of input parameters to these models used to create the scenario ensemble. Clearly, not all plausible models or input ranges can be considered for any but the simplest problems. In addition, the analysts' perception of political possibilities may influence the choice of strategies considered and thus the uncertainties ultimately judged most important. Any critical reviewer of such an *assess-risk-of-policy* analysis should ask—what plausible

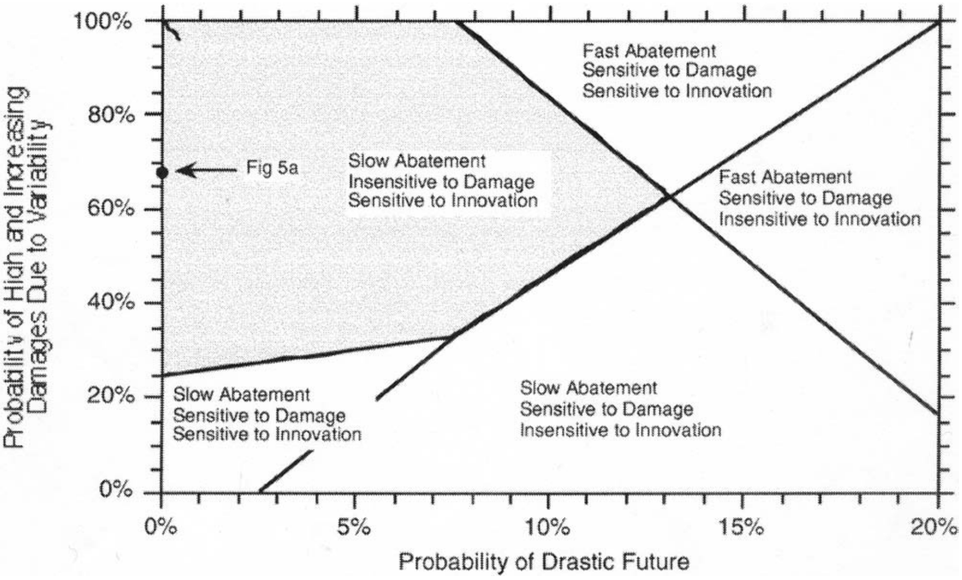

Figure 2. The most robust emissions abatement strategy as a function of expectations about two key uncertainties—the probability of large future climate impacts and large future climate variability (source: Lempert and Schlesinger, 2002). Strategies are described by near-term abatement rate and the near-term indicators used to signal the need for any change in abatement rate. Shaded region characterizes range of uncertainty over which one strategy of interest is robust.

models, parameter values, and alternative strategies have been neglected that might make a proposed robust strategy vulnerable?

We claim, however, that this question can provide a potentially important change in the rules of the game. *Predict-then-act* presumes that the ultimate goal of the analytic exercise is to characterize uncertainty for decision-makers so that they can make informed choices. This process can suggest implicit criteria that scientists and analysts do the best job when they reduce uncertainty as much as possible. These criteria can pose a danger that the analysis will underestimate the uncertainties or focus on those parts of the problem where the uncertainties are most precisely characterized (Metlay, 2000). *Assess-risk-of-policy* presumes that the ultimate goal of the exercise it to suggest all possible vulnerabilities of chosen strategies and help decision-makers choose the strategy with the most acceptable vulnerabilities. Analysts are encouraged to consider a wider range of plausible futures.

In many respects, *assess-risk-of-policy* is more subjective then *predict-then-act* because it forces analysts and decision-makers to explicitly decide, through their choice of strategy, the futures to which they remain vulnerable. In situations where existing or attainable scientific understanding can rigorously define the boundaries of a decision challenge or where there are limited opportunities for simultaneously hedging against different vulnerabilities, the *predict-then-act* framework is less extravagant with computational resources and is probably more useful and reassuring for decision-makers. But in situations where the future retains some capacity for surprise and careful consideration of the available science may reveal heretofore unrecognized or difficult to articulate hedging options against a wide range of different types of vulnerabilities, *assess-risk-of-policy* may provide more policy relevant results.

The differing uses of Monte Carlo sampling in the two frameworks provide a concrete example. Both *predict-then-act* and *assess-risk-of-policy* might employ a sample of many thousands of cases of randomly chosen input parameter values for some simulation model. The former would extract information from this sample by reporting the probability density function of some model outputs of interest, for instance the global-mean surface temperature in 2100 or the expected utility of some policy option, contingent on probability weightings on the input parameters. The latter might sort the cases into two sets—one where some strategy performed well and one where it performed poorly—and characterize the poorly performing set such that decision-makers could attempt to identify low-cost hedging options and, if necessary, understand the futures to which their chosen strategy remained vulnerable. Depending on the nature of the uncertainty and the possible hedging options, decision-makers might find that assess-risk-of-policy provides a more useful summary of the available scientific information.

5. Characterizing Uncertainty in the IPCC

Methods enabled by advances in computer capabilities and by improved understanding of decision-making processes offer new ways to characterize and confront scientific and socioeconomic uncertainties for climate-change decision-makers. Implementing these new approaches could require some changes in the IPCC process, which currently reflects the *predict-then-act* framework. *Predict-then-act* is certainly crucial for addressing those uncertainties which can be properly characterized by probability distributions of one sort or another. But giving heightened attention to *assess-risk-of-policy* approaches may give the IPCC an alternative to inappropriate uses of consensus probabilities, and provide climate-change decision-makers with a firmer foundation for action in this contentious and deeply uncertain policy realm.

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