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# Uncertainties in Environmental Modelling and Consequences for Policy Making

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# Communicating uncertainty to policy makers

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## Abstract

As the types of problems that policy-makers attempt to solve grow more complex, they increasingly are turning to scientists for specific advice. A critical challenge in communicating the results of scientific research arises when those results contain a great deal of uncertainty. Different academic disciplines offer diverging advice on how scientists should proceed, based in large part on differences in how the various disciplines view the process of decision-making process itself. In this chapter, the author links the strategies for communicating uncertainty to the decision-making models of economics, psychology, and sociology, respectively. He suggests that the relative strength of each strategy depends on the context within which the decision-maker is operating. To resolve this ambiguity about how best to communicate uncertainty, he offers first-best and second-best approaches. The first-best approach is rooted in a process of dialogue, with attention to two-way communication and the relationship between scientists and policy-makers. The second-best approach is rooted in the goal not of giving all decision-makers all of the information they need, but rather in providing them with just enough information to judge whether they need more. To assist in that latter task, the author suggests particular guidelines for the aspects of uncertainty that scientists need to communicate.

**Keywords:** uncertainty, policy-making, scientific assessment, decision-support systems.

## 1. Introduction

Describing uncertainty, either qualitatively or quantitatively, presents a major challenge to environmental modeling and assessment. Making decisions in cases where uncertainty is a defining feature of the problem likewise presents a major challenge to policy-makers and decision-makers. In between these two tasks lies the area of communication: characterizing uncertainty as scientists have described it in such a way as to assist decision-makers use the information in productive and consistent ways (Risbey and Kandlikar, 2007).

There is increasing consensus that it is important to communicate uncertainty. The United States National Research Council (2006), for example, recently suggested that it is vital for the National Weather Service to communicate the uncertainty associated with weather forecasts, and not just expected weather. The Intergovernmental Panel on Climate Change (IPCC), starting with preparation for its Third Assessment Report, recognized the importance of communicating uncertainty, as well as some of the challenges associated with doing so (Moss and Schneider, 2000).

There is less consensus, however, on the best practices for the process of communicating uncertainty, or even if a single set of best practices exists. There is a widespread recognition that most people working in both private and professional capacities can have major difficulties making important decisions when uncertainty is very high (Thaler, 1991). Breyer (1993), who later went on to become a member of the United States Supreme Court, suggested that regulatory policy faces major problems with issues of risk and uncertainty, leading to policies that actually increase the risks that people face, rather than decreasing them. He suggested special panels made up of experts, insulated from political forces, to make crucial regulatory decisions. Zeckhauser and Viscusi (1990) reached a similar conclusion, and then went on to suggest that issues of risk and uncertainty are a situation where some degree of government paternalism is required, to protect people from their own bad choices (Zeckhauser and Viscusi, 1996). One response has been to avoid communicating probabilities when it is felt that the audience does not have the skills to understand them. Indeed, this has been the approach that was taken for decades with information such as weather and climate forecasts, which reach a newspaper or television audience. Yet there is ample evidence that the divide between educated and non-educated people is not so great, and it would be a mistake to assume that just because an audience is not trained, it is incapable of comprehension. Gordon and Kammen (1996) found that in many cases trained analysts made the same mistakes at estimating probabilities that ordinary people make. Patt (2001) studied uneducated subsistence farmers in Africa, and found that they had essentially the same skills to interpret uncertainties, such as in a probabilistic rainfall forecast, as have been observed among the usual subjects of psychological tests, namely university students in the west. What the farmers, like the students, needed, was a little bit of time to familiarize themselves with the problem, and then their choices responded well to subtle changes in the assessed likelihoods of particular events.

Those who communicate uncertainty need to cope with these issues. In this chapter, I describe some of the suggestions for best practices, by tying these in to the problems that the communicator may be seeking to overcome. I start with this latter set of issues: what are the problems and difficulties associated with using information about uncertainty for decision-making, which communicators have to overcome? From there, I move on to some of the suggested solutions.

## 2. Challenges for communication

There is ample evidence that in some situations of decision-making under uncertainty, people make terrible judgments, both in terms of estimating likelihoods, and in making decisions that respond sensibly to those likelihoods. In one anecdote, a statistic teacher asks a student what the likelihood is that a six-sided die will land on the number 4. The student replies: "Fifty percent. Either it does, or it doesn't." The challenge for communicators is to provide people with information about uncertainty in a form that they will understand, remember, and use. Unfortunately, there is a lack of agreement about how to do so, stemming from a variety of models of how people actually make decisions. Depending on which model the communicator believes to be accurate, there are very different implications for when and how uncertainty ought to be communicated. In this section, I describe three general classes of models, showing how each carries different implications for communicators. I then pose the question of which model is correct.

### 2.1. *Economic models*

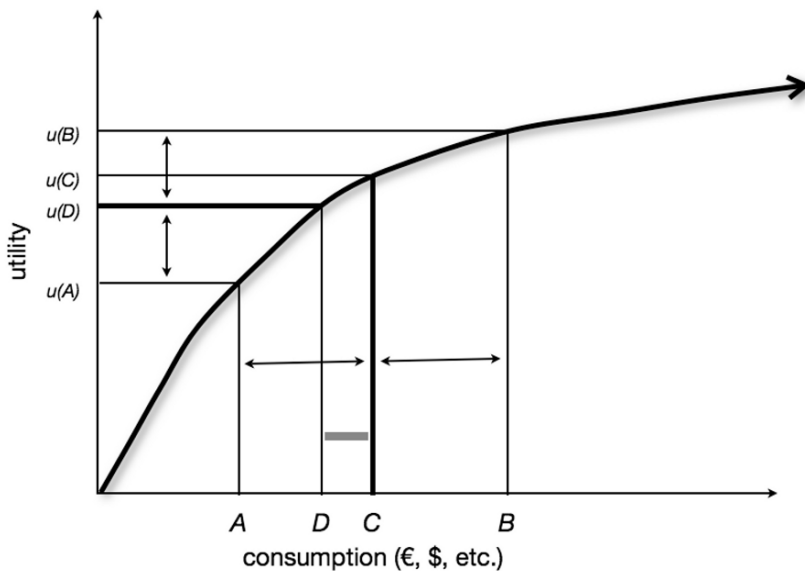
In arguing for more effective communication of uncertainty in the area of climate change, Webster (2003) proposed:

*Uncertainty is not important merely for computing an expected value or 'best guess'. In fact, information on variability and on low-probability high-consequence events allows decision makers to account for society's risk-aversion in their choices. Furthermore, today's decision is not made once now, but will be continually revised in the future as our understanding evolves. The optimal decision today depends not only on current uncertainty, but our expectation of how it will change and how we will respond in the future. This adaptive decision process will be aided by carefully tracking how uncertainties change with new knowledge. Thus, carefully assessing the risks of future climate change impacts is a critical task as a component of scientific support for decision makers.*

While this statement appears to simply reflect common sense, in fact it makes a number of assumptions about how people make decisions, all of which can be described as economic assumptions: people make optimal decisions, based on the information at hand; they change those decisions when new information suggests them to be sub-optimal; they are risk averse. The theory that captures all of these elements is *expected utility theory* (von Neumann and Morgenstern, 1944). According to this model, decision-makers derive utility from different patterns of consumption, and those patterns depend on the outcomes of their choices. Uncertainty implies that that each choice can lead to a range, or distribution, of future outcomes. Decision-makers decide among the choice options by selecting the option that will provide the greatest expected utility associated with its distribution of outcomes, *i.e.*, a weighted average of utility with the probabilities associated with each potential outcome acting as weights. To calculate the expected value

associated with each choice option, they need to integrate the utility function across the distribution of potential outcomes, and this means that they need to know, or make assumptions about, that distribution. It is commonly assumed that people are risk averse, which implies that the relationship between consumption and utility is not linear; if people gain decreasing marginal utility from increasing consumption, then the expected utility associated with a range of uncertain outcomes will be less than the single level of utility associated with the expected, or average outcome. Figure 1 shows an example of this. Since everybody knows – consciously or subconsciously – only their own utility function and their own degree of risk aversion, they need to calculate for themselves the utility associated with each possible outcome, and from that a level of expected utility. If people engage in these processes, again consciously or subconsciously, then it is essential only to provide them with estimates of the probability of different outcomes, and to let them make their own decisions with this information.

A growing number of economists have taken note of the fact that people often make decisions that are apparently inconsistent, such as simultaneously buying insurance (risk averse behavior) and playing the lottery (risk loving behavior).



**Fig. 1.** Utility and risk aversion. The curve shows the relationship between consumption and utility for a person who is risk averse. Consumption levels A and B are the potential outcomes of a lottery, and if each is equally likely, then C is the expected value of that lottery. Because the utility function is concave, the expected utility of the lottery,  $U(D)$ , is less than the utility of the expected value of that lottery,  $U(C)$ . The consumption level D thus provides the same utility as the expected utility of the lottery, and the grey bar between D and C represents the amount of money that this person would be willing to pay for an insurance contract that would convert the lottery into a certain outcome.

Continuing to assume that people are trying to optimize their utility, two alternative explanations are that they get their math wrong working with probabilities, or that they have multiple utility functions. The field of behavioral economics straddles the line between economics and psychology, in that it uses both models and research methods associated with the field of psychology to examine both faulty math and multiple utility functions, while remaining true to economics in terms of still assuming some objective function (or set of objective functions) to be maximized.

Along the former line, behavioral economists have shown that people are often biased in the probability estimates, due to context-specific perceptions and mental shortcuts that they use (Kahneman and Tversky, 1979; Tversky and Kahneman, 1974). Where people are given precise probabilities of relatively abstract events occurring (*e.g.*, the probabilities of winning different sums of money in a lottery), most people appear to over-react to especially small probabilities (close to 0), and under-react to especially large ones (close to 1) (Allais and Hagen, 1979; Kahneman and Tversky, 1979). Similarly, where there are two potential outcomes, the probability of each occurring are adjusted within most people's minds towards 0.5 (Bruine de Bruin *et al.*, 2000). In less abstract settings, most people's estimates are heavily influenced by a set of factors closely associated with the emotional impact of the event itself. Events that are more easily remembered are viewed as more likely than those that are not (Tversky and Kahneman, 1973), and events that generate strong emotional reactions of dread or a loss of control (*e.g.*, a shark attack, a plane crash), not coincidentally because they are then more easily remembered, are also seen as more likely (Covello, 1990). Indeed, even when people are told the probabilities of different events occurring, most of them remember those probabilities differently depending on their emotional reaction to the events and how plausible those probabilities seem (Windschitl and Weber, 1999). The challenge for communicators, given these observed biases, is to provide information that helps people compare the probabilities of different events, to avoid using emotion-laden language that will trigger particular biases, and to help people use the information to calculate optimal strategies. The field of risk communication developed out of these efforts, and is based on the idea that the best way to assist decision-makers coping with risk and uncertainty is to give them information in such a way as to correct their mistaken beliefs (Leiss, 1996). In order to do so, the communicator needs to understand how the decision-maker is using information to form beliefs, and become a partner with the decision-maker in working with the new information to arrive at actual decisions (Fischhoff, 1995).

Along the latter line, economists have shown that the utility people anticipate receiving from the outcomes of choices depends on context-specific issues of perception: the perceived departure of outcomes from the status quo (Kahneman and Tversky, 1979; Munroe and Sugden, 2003; Patt and Zeckhauser, 2000; Samuelson and Zeckhauser, 1988); the agents perceived to be causing those changes (Ritov and Baron, 1992); the perceived fairness of the outcomes (Fehr and Schmidt, 1999; Kahneman *et al.*, 1986; Knetch, 1997); and a long list of other factors.

Often, there are consistent and predictable differences between the utility that people anticipate receiving from particular outcomes before they make a decision, and that which they do in fact experience once those outcomes actually occur. Framing is the inevitable act of describing a decision and the relevant background information to make it understandable and interesting to decision-makers (Kühberger, 1998). There are often many frames that are logically equivalent, but which can trigger different sets of values. For example, most people show different preferences for risk when decisions are framed as affecting either their gains relative to the status quo, or their losses (Kahneman and Tversky, 1979). The challenge for communicators is to be aware that they may be triggering counterproductive values when they frame uncertainty in particular ways. Either, they need to work with people to make sure that the people understand how their values may be influenced, at least temporarily, by the new information, so that they can then make decisions based on their “real” utility function, or the experts (who are presumably not influenced by emotions) need to figure out what the best decision is, and make it for them (Breyer, 1993; Zeckhauser and Viscusi, 1996).

## 2.2. *Psychological models*

Many prominent behavioral economists had their training in psychology, and there is substantial overlap between the psychological literature and the behavioral economics literature in the area of developing confidence judgments and estimating likelihoods. The point of departure is what people’s motivations while making decisions are, and hence how their beliefs actually influence their choices. The psychological models of people’s motivations are too numerous to discuss in detail here, but they share a common feature in that, unlike economic models, they do not assume that individuals make decisions in order to maximize the utility derived from consumption.

Bounded rationality, for example, suggests that people engage in a mental search of available options, and choose the first one that is satisfactory (Simon, 1956). This so-called *satisficing* is different from optimizing in that it involves comparing not the outcomes of different choice options, but of each choice option with a set of minimum criteria. Closely linked to bounded rationality is the concept of adaptive heuristics: people develop and use mental shortcuts to identify acceptable options quickly, with a minimal amount of necessary information (Payne *et al.*, 1993). One of the clearest examples is of a person trying to catch a ball hit into the sky, such as in a baseball game. A model based on optimization would have the person calculate where the ball will land, based on an estimation of the speed and direction at which the ball was hit, factoring in the effects of gravity and air resistance. To optimize the chances of catching ball, the person will run to that place as quickly as possible. Actual ball players, however, apparently doesn’t have time for such calculations, and instead rely on the “fast and frugal” *gaze heuristic*: they keep their eye on the ball and observe the angle at

which it appears above the horizon. When that angle appears to be decreasing, they accelerate towards the ball; when the angle is increasing, they accelerate away from the ball. If they can accelerate quickly enough, their path will always intercept that of the ball before it hits the ground, without their ever knowing where that point of interception will be (which is why they sometimes crash into walls while running) (Gigerenzer and Selten, 2001). People continually develop and improve upon such heuristics as they gain familiarity with a decision-domain; they use and refine the techniques that work.

Information can change people's beliefs and judgments of confidence, but as a result of not only the content of the information, but also its source (Weber *et al.*, 2000). Most people weight information gained from personal experience quite differently than they do information gained from third parties, and the form of the personal experience can also make a difference (Edgell *et al.*, 2004; Griffin and Tversky, 1992). People are more likely to trust expert opinion when they fully understand it, and when they perceive it coming from a source with an obligation to be honest, such as arising out of a previous social relationship (Birnbaum and Mellers, 1983; Birnbaum and Stegner, 1979; Birnbaum *et al.*, 1976; Darr and Kurtzberg, 2000; Patt *et al.*, 2006; Sniezek *et al.*, 2004). Indeed, many people modify their choices in response to new information not necessarily because they believe the information itself to be true, but rather in order to signal that they have accepted the help that was offered by the information provider (Harvey and Fischer, 1997). Perhaps most importantly, information can affect not only beliefs, but also the motivation to act on the basis of those beliefs. For example, information that ought to be most valuable from the perspective of belief updating—that which is quite different from their prior beliefs – often has little effect on people's actions, either because they reject it out of hand in order to preserve their own self-confidence (Petty and Cacioppo, 1986), or because accepting it reduces their self-confidence and motivation to take any action at all (Prentice-Dunn and Rogers, 1986). By contrast, offering people information that confirms their prior beliefs can provide additional motivation to act.

If people are not optimizing, then helping them to understand the precise probabilities associated with different possible outcomes of decisions is not a productive exercise. Rather, it is important for communicators to help them explore the consequences of their own actions on different future scenarios, and to see which decisions make them happiest given how their actions will change their future. Some types of information can lead them to withdraw from a decision, while other types of information can lead them to engage.

### **2.3. Political models**

While both economic and psychological theories of decision-making explain people's actions in social settings, their focus is still on the individual. A separate set of models, which one can loosely label social (although they are rooted in a

number of disciplines, including sociology, anthropology, and geography), centers of the social context for decision-making and action. Historically, scholars in these fields have reached very different conclusions from economists and risk communicators about the role of scientific information in decision-making processes.

The role that scientific information plays in decision-making depends critically on the social processes through which that information is transmitted and processed (Jasanoff *et al.*, 2002), and Kasperson and Kasperson (1996) show how particular social institutions can amplify or attenuate the perception of risk. Proponents of the cultural theory of risk, for example, suggest that there are several distinct worldviews, or discourses, and that people interpret information in ways that are consistent with their own view (Douglas and Wildavsky, 1982; Thompson *et al.*, 1990). The same piece of information about a particular risk may to a *heirarchist* suggest great need for control, to an *egalitarian* greater need for caution, to an *individualist* greater need for individual autonomy, and to a *fatalist* greater cause for resignation. People can continue to believe that they are ignorant of a particular subject, even after having received a great deal of information about it, in order to maintain their social identity (Michael, 1996). People see their own type of knowledge as tied to their social identity, and often cannot communicate effectively with scientists, whose social identity is quite different (Wynne, 1996). The fault need not lie with the lay decision-makers, but with the scientists who assume that their own interpretation of evidence is more reliable.

Scientific uncertainty influences decision-making by altering political discourse. Policy-makers rely on scientific evidence to add legitimacy to their actions (Ezrahi, 1990). When the scientific community admits the it does not know the answer to policy relevant questions, it may bolster the credibility of scientists themselves (Shackley and Wynne, 1996), but at the same time it undercuts the legitimizing function that they provide, and becomes a publicly accepted justification for postponing action (Funtowicz and Ravetz, 1990, 1993). It is not surprising, then, that groups interested in maintaining the status quo in the climate change policy arena do not simply of deny the problem exists, but rather claim that the science is too uncertain to base any actions upon (Gelbspan, 1997). Conflict about issues of science does not necessarily have the same sedative effect (Dryzek, 1997; Lee, 1993). In highly contested issue areas, experts commonly line up on both sides of the political fence, each group playing a legitimizing role, with the media then highlighting these differences of scientific opinion (Boykoff and Boykoff, 2004). Conflict-based uncertainty may be a signal to the public that a particular issue is important and politically contested, and hence that policy actions may be necessary (Patt, 2007).

The observation that people will not take an action when the motivation for it is uncertain has led to the strategy of communicating the most likely outcome as relatively certain, rather than reveal uncertainty (Irwin and Wynne, 1996). But when events are uncertain, and scientists do not reveal them to be so, there is a chance that the scientists will appear to be wrong. This in turn can lead to a major loss of credibility. For example, in the early 1990s, the government of the state of

Ceará in Brazil began to warn farmers about upcoming droughts associated with El Niño, a pattern of warm water off the coast of South America. Farmers were happy to take the government's advice, and to plant drought tolerant crop varieties when they were warned of a bad year. But then 1 year the government warned of a bad year, and the rains turned out to be good. After that, the farmers were unwilling to follow the advice they were given (Orlove and Tosteson, 1999). Several years later, exactly the same story repeated itself in Zimbabwe (Glantz, 2000). Research has shown that the perception of error can destroy the credibility of some fragile mechanisms to generate trust in information, but has less of an effect when the decision-maker has good reason to believe that the communicator is being honest (Patt *et al.*, 2006).

#### **2.4. Which model is correct?**

One can argue that economic models offer a normatively correct model for making decisions, even if they do not accurately describe how people actually operate. One might suspect that well intentioned individuals, given enough time to consider all available information, and aware of the biases potentially inherent in psychology and politics, would adopt an economic approach. But this view is not universal. Gigerenzer (2000), for example, suggests that the heuristics associated with bounded rationality actually improve decision-making over what economic models can offer, given real constraints in information and processing ability. Supporting this view, a well-known story concerns a particular professor of economic decision-theory, who was faced with an especially life altering choice. His student asked him how he intended to make the decision, expecting him to say that he had assigned a value to all of the possible outcomes, considered the likelihoods of each, and calculated the expected utility associated with the two possible choices. The professor surprised him: "Normally I would do that, but this decision is important, so I need to follow my gut instinct."

Decision strategies are often context specific, and the strategies people adopt are the ones that can, in the relevant social context, provide a legitimate justification for their ultimate actions. When people are making individual decisions that touch their core values and that are laden with emotion, the psychological models likely do provide the best explanation of their behavior. In market situations, and when people are making decisions for an organization with prescribed rules, then the economic models may provide a more accurate description. When their decisions affect their social standing and power, then the political models may be more accurate. What is important for communicators is that each decision-making style responds to a different set of information concerning uncertainty. This suggests that there is no single best way to communicate uncertainty associated with a particular phenomenon to all decision-makers all the time.

### 3. Solutions

Ideally, communicators will understand their audience well enough to match their communication style to the relevant decision-making style. Research has identified features of good communication practice that make this possible, an indeed in some cases the conventional wisdom has evolved substantially. For example, it is now well accepted that uncertainty with respect to the weather ought to be communicated, whereas 20 years ago this was not the case. Advice for communication now centers on processes of communication, rather than exclusively on the information content.

#### 3.1. *Processes of communication*

A constant theme in the recent literature is that it is essential for science communicators, especially when uncertainty plays a substantial role, to engage in practical and ongoing decision support (Cash *et al.*, 2003). Two factors help to promote this. First, it is essential that communication is participatory, flowing in both directions between scientists and decision-makers. Second, it is increasingly seen as important that trustworthy organizations fill the role of mediators.

Participation of stakeholders in assessment and decision-support processes is now recognized as the gold standard for efforts to bridge the gap between scientists and decision-makers (Cash *et al.*, 2003, 2006), drawing from findings concerning risk communication (Fischhoff, 1995) and social learning (Social Learning Group, 2001). This involves designing a forum in an assessment process where stakeholders can express both their concerns over outcome, and their own local knowledge, and be confident that the content of the assessment responds to both types of information. Participation serves several functions. First, scholars have argued that it is the means by which scientists and analysts discover what the concerns of their audience are and what information they will consider using (Cash, 2001; Michael, 1996; Moss *et al.*, 2002). It can allow the analysts to discover whether, in this particular context, economic, psychological, or political models better describe their audience, and within each of those classes what their goals for the decision are, and provide the type of information about uncertainty that is most relevant, which in turn is a function of the decision making model being used. Indeed, one would not enter into a stakeholder dialogue asking decision makers which model they use, but rather would explore, through the process of dialogue, the factors that are most relevant to them. Second, participation is the means for scientists to learn about locally relevant facts that could play a role in their analysis (Wynne, 1996). Often, scientists conduct their analysis at a coarse spatial scale, and participation is the means to obtain the local knowledge necessary to downscale their models. Third, through the participatory process of questions and answers, scientists can learn which parts of their message are difficult to understand, and

focus their communication on those points, correcting initial misperceptions and misunderstandings (Suarez and Patt, 2004). Fourth, participation is a way of developing an implicit connection between scientists and decision-makers that is necessary to improve trust in the information (Patt *et al.*, 2006).

Numerous case studies have suggested that participation increases the likelihood that decision-makers will use information containing uncertainty. A meta-analysis of studies looking at how uncertain climate information was communicated reached the conclusion that important decisions involving probabilistic information are only made when the decision-makers have the opportunity to talk with climate experts, who can answer their questions concerning the sources and other features of uncertainty (Patt *et al.*, 2007). One of the few controlled experiments involved subsistence farmers in Zimbabwe, who were being provided probabilistic seasonal climate forecasts, to which they could respond by changing particular planting decisions. The forecasts themselves were not locally specific, but required further analysis taking local conditions into account, such as historical variations in seasonal rainfall, soil types, and farmers' marketing opportunities. At the time of the study, the farmers had access to the forecasts over the radio, a non-participatory method of communication. The researchers invited a random selection of farmers from two communities to attend participatory workshops at the same time that the forecasts were being broadcast over the radio, shortly before planting decisions needed to be made. Several months later, after the harvest, the researchers interviewed a random sample of workshop attendees and non-attendees, asking them whether they had used the forecast information to make different decisions. The farmers who had attended the workshops were more than five times as likely as those who had received the same information, but via radio, to use the information for their farming (Patt *et al.*, 2005b).

It is also important for information to reach decision-makers through appropriate channels, ones that generate an appropriate amount of trust in the information. For example, consider a commercial farmer in North America or Europe, who wants to learn about whether climate change will have a significant impact on her business. She might use the Internet, and discover the report of the Intergovernmental Panel on Climate Change (IPCC), and even go so far as to read the relevant parts of it. The next day, however, she may see a program on television, or read an article in a magazine, that delivers a contradictory message. Which will she trust more? Probably the message from the source with which she is familiar, which is likely not the IPCC.

Social scientists have described organizations that facilitate the transfer of knowledge from the scientific community to the policy and decision-making communities "boundary organizations," because they span the boundary between science and action (Gieryn, 1995; Jasanoff, 1987). The most important feature of successful boundary organizations, ones that engender levels of trust that are appropriate for the information content, is that they have responsibility, or accountability, to both the science and action communities (Guston, 1999, 2001). A good example would be an agricultural extension service, which is located in a university setting,

but funded in part by an agricultural ministry, and which relies on the help of an agricultural member organization to reach out to farmers. Numerous case studies have shown that these types of organizations tend to communicate information that is relevant to their target audience, and which draws off of social connections and implicit obligations, in addition to a track record of success, for its reputation of trustworthiness (Cash, 2001; Cash and Buizer, 2005; Jasanoff *et al.*, 2002).

A study by Patt *et al.* (2006) examined whether the greater trust these organizations enjoy is rooted in their social connections, or in the fact that these organizations, partly because of their social connections, produce more relevant information. They conducted an experiment in which decision-makers could earn money by playing a probabilistic game two times. The game they used was the so-called Monty Hall Three Door Game, which is interesting because most people (about 80–90%) follow an intuitive decision-making strategy that generates the winning outcome one-third of the time, rather than the other decision-making strategy, which wins two-thirds of the time (Friedman, 1998; Granberg and Brown, 1995). In their experiment, the researchers randomly assigned participants to a control group, which played the game without advice, and to three experimental groups, all of which received advice from a third party, who was drawn from the same pool of people as the people participating as the decision-makers. The advice was always the same, namely that the counter-intuitive strategy would win with a much higher likelihood. In the first experimental group (“simple advice”), the experimenter did not reveal any information about the terms under which the advisor was participating, and indeed the advisor received no compensation for participating. In the second experimental group (“aligned incentives”), the advisor would be paid some money if and only if the decision-maker won the game. The experimenter described this to the decision-makers, and thus it was clear that the advisor had an obvious incentive to provide high quality advice. In the third experimental group (“purchased advice”), the advisor would participate only if the decision-maker paid him a small fee (a fraction of the money that everybody received for agreeing to participate in the first place). The results were interesting. There was no significant difference in decision-making strategy between the “control” group (no advice), and the “simple advice” group. Initially, only people in the “purchased advice” group were more likely to adopt the superior strategy. Over successive rounds, however, the “aligned incentives” group became more likely to adopt the correct strategy, and the “purchased advice” group settled back towards the “control” and “simple advice” groups. These results suggest that the relationship between the advisor and the decision-maker can make a large difference.

### ***3.2. Information content and form***

If one views participatory communication of uncertainty, involving trusted sources of information, is a prerequisite for decision-makers’ making difficult decisions wisely, then it becomes clear that one of the purposes of scientific assessment is to

stimulate that type of communication where it is appropriate. This is not a trivial point. Participatory communication is time consuming and expensive for all parties concerned. The goal of scientific assessment, when communicating uncertainty, ought not to give the right information to guide all decisions, but to provide enough background understanding of the nature of the uncertainty so as to stimulate those decision-makers whose decisions are particularly sensitive to the uncertainty to seek further help. There are a few features of the uncertainty that are, for most decision-makers, of central importance, and which can be communicated quickly and fairly easily. Some of these are statistical in nature, while others pertain more to the system being described. In this section I list some of these, and with them some guidelines about what form to provide the information in.

### 3.2.1. Shape of the distribution

From an economic standpoint, the most important piece of information to convey is the shape of the distribution, to the extent that this is, or can be, known. Some argue that for climate change, for example, it is not possible to attach any likelihood estimates on various possible future scenarios, and the best that can be done is to suggest a range over which uncertainty likely operates (Betz, 2007). Others, by contrast, argue that it is possible to describe some outcomes as more likely than others, even if it is not possible to describe a full probability density function (Risbey, 2007). These debates aside, it probably is relevant for decision-makers what the likely range of values that they might face actually is, and secondarily relevant what the distribution is within that range. If their decision is sensitive to the range of values within that distribution, then they will seek out more information about its precise shape.

People remember and use information about uncertainty differently, depending on whether they learn it through personal experience, or from a description (Weber, 2006). Thus, it may be relevant to use some example to describe the practical significance of this range, in such a way as to relate to people's personal experience. For example, the current range of climate sensitivity (amount of warming given a doubling of atmospheric CO<sub>2</sub> concentration) could be described as being between 0°C and 10°C. It is relatively obvious what the 0°C implies (*i.e.*, no change from the present), but could be worthwhile pointing out what a 10°C shift would mean, such as that the city of Boston would come to experience the climate now experienced in Houston.

To the extent possible, it is useful to convey information on the shape of the distribution, in the form of what ranges are more likely than others. Anecdotal evidence suggests that it can be dangerous to convey the mean value of a distribution, for people will place a great deal of emphasis on that, and in the process forget about the rest of the distribution, which might be more relevant. Statistics such as the variance or standard error are probably irrelevant for most people, who do not understand what they represent.

### 3.2.2. Likelihood of particular events

There are some singular events that people are very worried about, and their likelihood can be very relevant for decision-making. For example, if the West Antarctic Ice Sheet were to collapse quite quickly, this would be catastrophic for all coastal cities; the likelihood of this event alone should have an influence on climate policy (O'Neill and Oppenheimer, 2002). To the extent that it is possible to clarify this likelihood, it should be communicated.

In doing so, however, it is important to remember that people remember likelihoods in qualitative terms, rather than quantitative terms (Windschitl and Weber, 1999). The IPCC dealt with this issue by developing a confidence scale, which uses precise words matched to ranges of likelihood. While there are some problems with this approach (Patt and Dessai, 2005; Patt and Schrag, 2003), it has been praised almost uniformly (Risbey and Kandlikar, 2007).

### 3.2.3. When and if uncertainty will be resolved

The presence of uncertainty can be one of the strongest reasons for inaction (Funtowicz and Ravetz, 1993). If people believe that the uncertainty will be resolved in the foreseeable future, they will use that as a rationale for avoiding making a firm decision before then (Patt, 2007). This is consistent with the idea that maintaining freedom in the presence of uncertainty and the potential for learning has a real option value (Fleten *et al.*, 2007; Schatzki, 2003). Often it is assumed that uncertainty can and will be resolved fairly quickly. For example, in the climate change literature, there are many papers exploring what the optimal decision strategy is, given uncertainty about climate sensitivity that will be resolved within the next decade (Jones, 2000). But studies have suggested that such uncertainty is likely to be resolved very slowly (Andronova and Schlesinger, 2001), or potentially not at all (Roe and Baker, 2007). This in turn carries implications for the policy approach that is adopted (Allen and Frame, 2007; Lempert, 2002). Clearly, giving some indication of the pace at which uncertainty will be resolved is important.

### 3.2.4. Sources of uncertainty

Quite closely related is the issue of the sources of uncertainty. This is because while there may not be progress in eliminating the uncertainty, there may be major changes in the estimates of it in the near term, because one or more of the sources of uncertainty are resolved. An example of this was described by Suarez and Patt (2004). They were communicating probabilistic climate forecasts to forecasts, in a year where there was a great deal of uncertainty about the future development of El Niño, the most important predictor of seasonal climate. They were communicating the forecast, for the December to March rainy season, in September. The

uncertainty about El Niño would likely be resolved by October, which could substantially change the likelihood estimates. As they described, they found it useful to describe these two sources of uncertainty – uncertainty concerning the magnitude of El Niño, and uncertainty about the effect of El Niño on local rainfall – as a means to suggest to farmers that they should find out, in October, how the first of these uncertainty issues had been resolved. Moreover, they found it effective to explain this problem of joint probability using an analogy. They described the problem of betting on a football game, at a time when it was unclear whether the star player for one of the teams would be able to play, or would be injured. Clearly, the odds for the game would change after that player completed his medical check!

### 3.2.5. Characterizing the sensitivity of different decisions to uncertainty

Finally, it can be useful to provide general guidance for decision-makers on whether the particular decisions they face are sensitive to the range of uncertainty. Within the climate change issue, for example, there are two broad classes of decisions: mitigation, which is the reduction of emissions and of atmospheric CO<sub>2</sub> concentrations; and adaptation, which is the act of managing climate impacts in order to reduce their negative consequences, and to take advantage of opportunities (McCarthy *et al.*, 2001). Each type of action may be sensitive to different ranges and types of uncertainty. For example, the Stern Review (2007) made the somewhat controversial claims that the potential cost to society of failing to mitigate would be between 5% and 20% of global consumption, whereas the cost of mitigating to avoid most of those costs would be less than 2%. By offering ranges of uncertainty that do not overlap, the Stern Review thus suggests quite clearly that the decision to engage in at least this amount of mitigation is not sensitive to remaining uncertainties. By contrast, the types of decisions that can be made for adaptation are quite diverse, and many of them are very sensitive to uncertainties (Patt *et al.*, 2005a). It is important to tell climate change policy makers that they need more detailed information about uncertainty and adaptation than can fit in an assessment report, whereas for mitigation they do not.

## 4. Conclusions

Uncertainty needs to be communicated to policy makers, yet doing so in a way that the most important details are made salient is a task that can only be achieved through interactive dialog. There are several reasons for this.

First, different decision-makers, operating in different choice contexts, make decisions through very different sets of thought processes. The standard assumption in normative decision models is that people follow an economic model, which is based around the maximization of expected utility or value. In fact, people seldom do this. In most cases, they follow processes described by psychologists, or by

sociologists. When doing so, the types of information that might change their decisions, and the effects of that information, can be quite different. The process of dialog can identify which decision making pattern is in play, and in turn the information that is most salient.

Second, uncertainty has several dimensions, and it is difficult to communicate all of these quickly and easily in a one-way process. Some measure of the uncertainty is a result of ambiguity in existing theory, another part coming from measurement error, and a third from conflicting beliefs about what model is the more appropriate characterization. Moreover, people respond differently to the different dimensions, and often do so in ways that are counter productive. It is important to help people apply information to a salient choice problem, in order to guide them through the process of deciphering the uncertainty and identifying appropriate response strategies.

Third, the presence of uncertainty creates a large opportunity for the loss of credibility of the communicators of that information. If they identify a best response strategy to a problem that is sensitive to the uncertainty, that strategy will appear sub-optimal with some probability greater than zero. People need to participate in arriving at response strategies, taking some responsibility for their development, in order to see them as the best option given the conditions. Moreover, they are more likely to trust communicators who demonstrate that they have a real incentive to provide accurate information.

For all of these reasons, it has been observed that participatory communication is the *sine qua non* of effective decision-support and scientific assessment in the context of high uncertainty. Modelers need to be ready to be engaged by decision-makers, to help them arrive at good decisions. At the same time, however, modelers need to publish their results in non-participatory media, such as a published scientific assessment. What is the best way to do so? I have argued in this paper that the most important consideration is giving decision-makers enough information to know when they need to invest the time and resources to take part in a participatory process, and when they do not.

To do this, there are some basic pieces of information that need to be conveyed. First, the range of potential outcomes is of vital importance. Less important is the shape of that distribution, and even less importance still are the mean and variance. Second, qualitative verbal descriptions of the likelihoods of important outcomes are important. Third, it is essential to identify whether uncertainty can be expected to be resolved quickly. Fourth, it is often important to identify some of the sources of uncertainty, since these may influence whether uncertainty estimates will change over time. Fifth, it can be useful to offer guidance on specific classes of problems, and whether these are sensitive or not to the range of uncertainty.

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