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Dealing with Not Knowing:

Evaluating and Communicating Uncertainty at the Science/Policy Interface

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Note from the Series Editor

This policy brief, part of a series by the Institute for Science, Society and Policy (ISSP) at the University of Ottawa, is supported by a SSHRC Public Outreach grant (#604-2011-0007). The goal of the series is to mobilize academic research beyond the walls of universities. The series is directed at public servants operating at the science/policy interface in Canada and abroad. It has been designed to bring forth some themes and findings in academic studies for the purpose of synthesis, knowledge transfer and discussion. This brief is the third in the series. The ISSP also carries out adjacent activities on the topics covered in these briefs. We hope they will be well received and are looking forward to any feedback you may have. You may reach me directly at msaner@uottawa.ca.

Marc Saner

Director, ISSP

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Dealing with Not Knowing:
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Introduction

In any venture in life there are many unknowns. How these unknowns are understood depends on the viewpoint of the observers. How they are communicated further depends on the nature of the unknowns and the questions being asked. A short allegory illustrates this.

Suppose a decision maker needs to decide whether to take the train or to drive from Montreal to Toronto for an important afternoon meeting. She cannot know with absolute certainty how long the trip will take, as there are many known sources of unpredictability that might affect the travel time: Will the weather be clear? Will traffic on the highway be open? How many stops must be made? Will the train leave on time?

Of course, it is entirely possible to scientifically estimate the probability of any foreseen eventuality. What is the weather forecast? Where are the likeliest places that traffic will be encountered along the way? How many stops for gas will be required? In most situations, we can identify some of the known unknowns and estimate an average time along with a measure of significance (for example, driving may take 5.5 ±1 hours; the train may take 5.0 ±2 hours; each with a 95% confidence interval).

Plus, there are outlying possibilities for which one cannot easily account (the unknown unknowns) – a deer on the tracks or a tornado. Our decision maker engages her expert staff to assist in the decision. She asks, "Should I take the train or drive to Toronto?" Some staff suggest more low-probability events: earthquakes, derailments or schedule changes. They also bias this information with their personal preferences; some prefer the independence of car travel, others the comfort of the train. Nevertheless a decision must me made.

Our decision maker is now faced with multiple choices and no clear basis for making a final decision. She takes the train because she prefers the train. The train arrives two hours late and she misses her meeting, thereby inconveniencing her colleagues. The results may have been different had she asked which mode of travel was more likely to get her to the meeting on time.

While this example is simplistic, it is also a pertinent metaphor for how uncertainty is faced at the science/policy interface. How precise the answer needs to be depends largely on the nature of the question, the values of the decision maker and the demands of any stakeholders in the decision. The probabilistic estimate may have sufficed to dissuade the decision maker from her original preference. The additional analysis of low-risk events and the preferences of analysts did little to inform the decision.

As part of a series of policy briefs initiated by the Institute for Science, Society and Policy (ISSP) we are seeking to translate academic knowledge on issues at the interface between science and policy into an accessible form (as described in the box below). In this brief, we address the differences in how uncertainty is understood in the sciences and how it is understood in the policymaking environment. This will be extended to address risk communication in the context of communicating uncertainty. The purpose of this brief is to help to better understand existing literature on the subject and the key considerations in understanding this issue.

Approach and Method

This “state of knowledge” review is the result of an examination of 77 articles and books that relate to science/policy interfaces and issues closely related to this concept. In particular, the closely-related articles mostly deal with literature on organization theory. Of these academic works, this policy brief cites 27 papers that are relevant to issues surrounding knowledge integration at the science/policy interface.

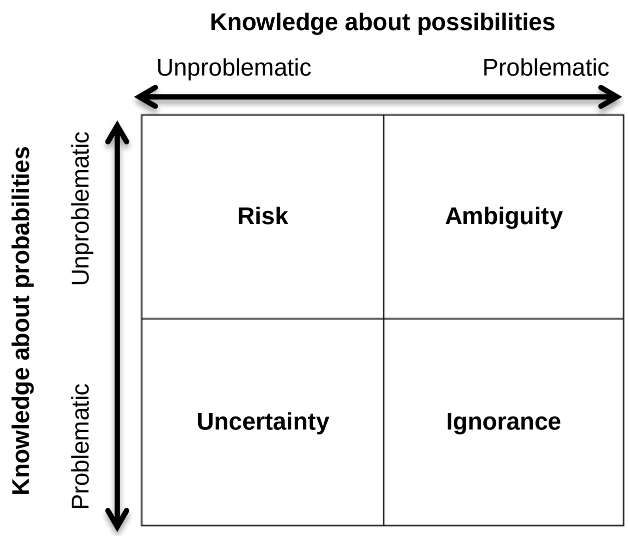
While this review has attempted to discuss as many works as possible, it is certain that there are other groups of literature that discuss knowledge integration and the science/policy interface. For the purpose of coherence, we have selected those works that deal more directly with knowledge forms in the science/policy context.

Uncertainty

The meaning of the word "uncertainty" is uncertain itself—it has several connotations. As we saw the introductory example, we can always strive to reduce uncertainty by identifying risks and estimating their likelihood (thereby having an approximate answer to the question of travel time or any other question). However there are also unknowns for which we have inadequate knowledge to reduce that uncertainty. Finally, there is the additional uncertainty when engaging the opinion of multiple experts. These themes, in addition to how they are communicated to the public, are the focus of the upcoming sections.

It is useful, however, to begin with a broad definition of uncertainty to have a common understanding. A particularly suitable definition is provided by Pielke (2007), who states that uncertainty, "means that more than one outcome is consistent with our understandings". This may be restated as "any deviation from the unachievable ideal of completely deterministic knowledge of the relevant system" (Walker et al., 2003). These meanings offer two sides of the same coin, where we can visualize multiple outcomes but cannot know the exact future, that is, whether the outcome of a decision will be better than not making a decision. Stirling's (2010) matrix shown in **Figure 1** is an evolution of the risk matrix commonly used in technical disciplines (see, for example Saner, 2010), which plots probability (or likelihood, rate) against consequences (or severity, impact) in order to identifying priorities (the risks that are both likely and severe).

Figure 1. The Uncertainty Matrix



Adapted from Stirling (2010).

Stirling's matrix helps to visualize the relationship among key concepts related to term 'uncertainty', both in the realm of scientific enquiry and policy design. Semantics in the risk analysis context are very complex, however. For example, some authors prefer to give the term 'risk' priority. Risk can be characterized as the attempt to formalize and assess uncertainty—the act of taking into account and measuring unknowns (Gough, 1988). As knowledge about probabilities and possibilities increases, and uncertainty is formalized into risk, it becomes less problematic. In another context – economics – students are trained to think of "Knightian uncertainty" that denotes a risk that cannot be estimated. This is based on a 1921 definition by the University of Chicago economist Frank Knight. The lesson here is not to assume semantic consensus when someone others words such as 'uncertainty' or 'risk'.

In both the production of evidence and the use of evidence, there are multiple reasons why more than one outcome may be consistent with our understanding. In the sections to come, we will review why multiple outcomes are possible (as viewed by scientists), the imperative to reduce uncertainty (among policymakers), and the importance of mutual understanding regarding these perspectives in communicating with each other and the public.

This section will first examine the meanings and sources of uncertainty in the natural and social sciences. This will be followed by a review of how uncertainty is understood in the context of policymaking, and specifically in the way that uncertainty is evaluated at the interface of science and policy.

Uncertainty in Natural and Social Sciences: Evidence Inputs Regarding Uncertainty and Risk

In the natural sciences, uncertainty is understood as being a "familiar companion" in that much of the work undertaken by scientists has recognized sources of error that qualify their findings (Bradshaw & Borchers, 2000:5). In fact, uncertainty (where knowledge about possibilities is unproblematic but knowledge about probabilities is problematic), ambiguity (the reverse) and ignorance (where knowledge about both possibilities and probabilities are problematic, see **Figure 1.**, above) have been described as "intrinsic to scientific definition of risk" (Stirling, 2008; Stirling, 2010).

We find the classification by Pielke (2007) particularly useful. He describes three characteristics of life that explain why uncertainty is fundamentally irreducible in some contexts: *chance*, *myopia* and *intentionality*. That is, while we may know the distribution of the outcomes of multiple rolls of the dice, we cannot predict the outcome of any individual roll due to *chance*. *Myopia* arises when there is insufficient knowledge, for example, one may not know that the dice are biased to produce a specific outcome. *Intentionality* relates to the creation of biases to support a specific outcome, such as the act of biasing the dice to improve one's success rate.

Let us look how the three types of uncertainty—chance, myopia and intentionality—apply to the context of the natural and social sciences. Uncertainty in the form of ***chance*** comes from errors inherent in the variability of the phenomenon being measured and the treatment of those measurements. For example, measurements may be inexact estimates, data may be missing and samples may not have a sufficiently wide timespan (Tallacchini, 2005). Though natural sciences often involve controlled experiments in a laboratory, uncertainty still exists from multiple sources. For example, there is the risk of contamination.

Estimates of uncertainty incorporate these potential deviations in the form of statistical errors using measures of significance. Thus, the standards of proof that deal with statistical hypothesis testing (e.g., Type I errors, which result in false positives and Type II errors, which result in false negatives) imply that there is always a window of uncertainty. An hypothesis will typically be accepted at the arbitrary level of 5% significance, implying that 5% of the conclusions will be false positives (Bradshaw & Borchers, 2000).

Statistical measurement errors are also part of social science research, however the contribution of social science research is to "expand the horizon of risk outcomes" to determine potential undesirable effects (Renn, 2008:43). As Raadgever et al. (2011) note, this often includes accounting for the varying perceptions of uncertainty among stakeholders, which has implications for decision making. In taking into account this wide variety of uncertainties for a given problem, there is convergence between social and natural science.

> "Science, well used, holds great potential to improve life on earth. Science, poorly used, can lead to political gridlock, bad decisions, and threaten the sustainability of the scientific enterprise." (Pielke, 2007)

Myopia may result from the characteristics of models used and the nature of the experiments conducted. Studies in the natural sciences make use of models, which are rarely precise, and are therefore subject to prediction errors (Bradshaw & Borchers, 2000). Levins (1966) suggests such models must sacrifice generality, precision or realism. That is, a model that focuses on generality and realism, may give imprecise results. Additionally, the very nature of a laboratory experiment is to perform observations in a closed system. It is possible that in closing a system for observation, some of the realism may be lost. For example, the effects a substance tested on people in the laboratory may not be the same as the effects of that substance outside the laboratory, where conditions are less controlled.

Thus, the knowledge of the unknowns may be insufficient to predict the probability of a specific outcome.

Intentionality arises from (a) the selection of which knowledge to develop and (b) how it is developed and (c) how it is used. It is in fact researchers (and those who decide which lines of research to fund) that decide which experiments to carry out and which hypotheses to test. Knowledge will never be complete and, according to Pielke (2007), additional knowledge may, in fact, detract from a decision since it may uncover more sources of uncertainty and even more options. Further, the outcomes of decisions based on this knowledge are rarely predictable.

On the darker side, there is also the potential for fraud in the form of intentionally falsified results such as in the Korean stem cell scandal (Cyranoski, 2006). As well, decision makers may select only evidence that supports their values.

Based on the concepts of uncertainty in natural and social sciences discussed above, a (non-exhaustive) list of sources can be produced:

- Chance
  - Variability of phenomena
  - Contamination of experiments
  - Measurement error
- Myopia
  - Inappropriate experiments, hypothesis or methodology
  - Complexity of the system (closed system experiments)
  - Model bias (prediction error, lack of generality, precision or realism)
- Intentionality
  - Intentionally falsified experimental results
  - Selective development of knowledge
  - Selective use of evidence

As can be seen from this list, there is a mixture of natural, process-based and human sources of uncertainty related to evidence provided by both the natural and social sciences. These perspectives on uncertainty, as an inevitable part of scientific inquiry, are often in need of reconciliation with the requirements of policy makers and the public.

These concepts are also aligned with the idea of “fitness for use” embodied in statistical quality assurance frameworks (Carson, 2001). The quality assurance criteria of ***relevance***, ***accuracy***, ***timeliness***, ***accessibility, interpretability and coherence*** (consistency) suggest that there is a relationship between *quality assurance* and *purpose alignment* of evidence. For example, some decisions may be more effective if made immediately using current, imperfect evidence rather than being delayed until that evidence is improved.

Uncertainty for Policymakers: Timelines, Values and Norms

In general, the policymaking environment is acknowledged as one in which certainty is desired and uncertainty is not well received (Abt, Rodricks, Levy, Zeise, & Burke, 2010; Bradshaw & Borchers, 2000; Wardekker, van der Sluijs, Janssen, Kloprogge, & Petersen, 2008). For policymakers, deadlines are ultimate realities, reflecting legislative and political timelines that do not match the longer-term schedule of scientific undertakings. As such, there is a gap at the science/policy interface where scientific research often requires more time in which uncertainty might be reduced, and policymakers require the best available information on fixed timelines.

Key point: Each of the quadrants in Stirling's Uncertainty Matrix is associated with appropriate methods. However, the realities of decision making may encourage a focus on risk approaches (probabilistic) rather than approaches better suited to dealing with uncertainty, ambiguity and ignorance.

Stirling (2008) expresses it like this: In real-world politics, the demand for precise quantitative expressions of risk, or an expert judgment of risk is significant and can encourage neglect of the problems of uncertainty, ambiguity and ignorance. In other words, the process of scientific inquiry can be "in competition" with the demands of the political sphere because of their differing timelines and varying acceptance of uncertainties (Bradshaw & Borchers, 2000:5). As such, when it comes to evaluating sources of information, making a decision is more an art than a science.

As Renn (2008:43) has stated, "there is no universally accepted or rationally required strategy for evaluating different options with uncertain consequences…In a democratic society, scientists cannot claim more power in making this decision than anyone else." Indeed, the subjective nature of evaluating risk has been noted (Stirling, 2008). Further, it has been observed that the way in which evidence from natural sciences and social sciences is integrated can vary depending on country and issue context (Falck-Zepeda & Zambrano, 2011).

This lack of coherence in evaluating uncertainty is a point that has also been discussed in empirical examples of science/policy interface functioning. Hauge (2011) found that scientific advice to inform North-East Atlantic fisheries policy had mistreated and misunderstood sources of uncertainty. In providing advice with improperly treated or improperly acknowledged uncertainty, the basis of policy decisions is compromised. Wardekker et al. (2008) found that policymakers were not aware of the many forms of uncertainty that exist in scientific research, and tended to see numbers as reliable. Also, there was a difference between policy advisors and policymakers – where policymakers wanted less information on uncertainty in reports they were given, and policy advisors wanted to include more.

Key point: Evaluating risk is often subjective. There are many examples of bias where uncertainty in its fullest sense is misunderstood, mistreated or simply excluded from the final decision.

Knol et al. (2009) investigate a metric used to assist policymakers in evaluating and comparing environmental health problems in order to inform policy. They find that estimates provided by Disability Adjusted Life Years (DALY) contained uncertainties that were not disclosed and were therefore potentially misleading. Walker et al. (2003:16) also indicated that the inability to properly communicate the meaning and sources of uncertainty at the science/policy interface results in "confusion and frequent lack of mutual understanding".

To deal with these difficulties, governments have devised two different approaches of consistently considering uncertainty in issues of regulation. The **precautionary approach** emphasizes early regulatory action under uncertainty. The precautionary principle[1] was first made internationally known in the Convention on Biological Biodiversity (United Nations General Assembly, 1992). It is now commonly used, especially in Europe and Canada. In contrast, the **risk-based approach** emphasizes thorough assessment to reduce uncertainty prior to regulatory action. It seeks to monitor the impact of a technology after implementation and to implement restrictions if a product is later found to be unsafe (Williams, Kulinowski, White, & Louis, 2010). These approaches can be interpreted as the contrast in priorities between ensuring public safety and allowing economies to innovate.

[1] The precautionary principle states that "In order to protect the environment, the precautionary approach shall be widely applied by States according to their capabilities. Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation." (United Nations General Assembly, 1992)

Communicating Uncertainty to the Public

While it is clear that there are different needs related to uncertainty in the scientific and policy spheres (Bradshaw & Borchers, 2000), a misunderstanding at the science/policy interface can be felt rather severely in communication with the public. As Bucchi (2009) indicates, in the past we may have been able to treat the science/policy interface as a closed relationship, but this is no longer possible given the consistent scrutiny of public actors.

For instance, misunderstandings or dysfunction at the science/policy interface can result in public whistleblowing, which has the effect of fostering distrust between scientists, policymakers and the public (DeMaria, 2008). In addition, incomplete understanding of sources of uncertainty and how uncertainty is evaluated in policymaking can compromise scientific authority in the public (Morton, Rabinovich, Marshall, & Bretschneider, 2011).

There are multiple examples of public engagement in issues of science and policy that have negative repercussions on the actors involved. For example, when studies are published that indicate a negative environmental condition that may affect the public (e.g., tainted soil in a schoolyard), media coverage of the article may not fully elaborate on the qualification of the findings (i.e., perhaps the chemical concentrations were statistically significant only at a level below current regulatory standards) (Pohl, 2008). Further, reporting on the study may not include current government plans to address new regulatory standards. As studies have pointed out, communication itself is not neutral and often involves multiple actors with multiple agendas or messages (Pohl, 2008; Stocking & Holstein, 2009).

Even if the uncertainty naturally present in scientific study is conveyed to the public, it has been argued that from the public perspective this may undermine scientific findings by admitting to not knowing for certain (Morton et al., 2011). As such, much like in the policymaker’s desire for certainty, the public places similar demands on scientists. Though it has been advocated that uncertainty should be treated as information (rather than the lack of information) (Bradshaw & Borchers, 2000), this may not help to create a helpful perception of risk if questions remain unanswered (Williams et al., 2010). That is, a comprehensive assessment of knowns and unknowns may not be conducive to making a timely decision. Williams et al. (2010) suggest, for example, that misplaced concerns about the risk of the technology led to a failure to adopt food irradiation policies that would have reduced the risk of food poisoning.

The challenge of communicating uncertainty has given rise to the field of *risk communication*, which has been developed since the 1970s (Fischhoff, 1995; Plough & Krimsky, 1987; Powell & Leiss, 1997). There is a vast literature that focuses on communication between scientists and policymakers as well as communicating with the public. This has tended towards a more unidirectional view of public communication that treats the public as a subject rather than partner (Fischhoff, 1995). This implies that risk communication has focused on trying to guess how the public may react and to prepare responses for it – as opposed to a true partnership with the public (see Morgan, 2002). In essence, given the issues described above arising from multiple messages, risk communication seeks to consolidate opinions to give a single coherent answer or set of answers (FAO/WHO, 1998).

Beyond traditional notions of risk communication, more recent research focuses on alternative methods of public engagement in the evaluation of uncertainty. Much like discussed in Brief #2 "Integration of Knowledge and Values in Decision-making", recent literature has pointed to including affected communities in the process at an early stage. This means not only introducing aspects of uncertainty from a scientific viewpoint, but also incorporating an open understanding of policy timelines and local perceptions. At its core, however, the idea of public participation allows for previously undiscovered sources of uncertainty to be integrated into the process (Cockerill, Daniel, Malczynski, & Tidwell, 2009; Morehouse, O'Brien, Christopherson, & Johnson, 2010; van Aalst, Cannon, & Burton, 2008).

Key point: Engagement between scientists, decision makers and the public in the evaluation of uncertainty has been found to improve not only the quality of the decisions but also their acceptability.

To avoid the shortcomings of traditional risk communication, which focuses mainly on a one-way flow of information, *participatory risk assessment* is a method that has been put forward to assist with a more publically-engaged risk evaluation and communication. Morehouse et al. (2010) have found that public perception of risk has an effect on the willingness of stakeholders to change behaviour and form opinions. Relatedly, it has been observed that including public stakeholders in risk assessments can lead to a better understanding both of the nature of uncertainty and also of public perceptions and concerns (Cockerill et al., 2009). Therefore, the inclusion of the public in a participatory assessment of potential risks results in a coproduced risk portfolio that may include new risks that previously went unnoticed by scientists and policymakers (van Aalst et al., 2008).

While this approach benefits from its inclusive nature, it also has limitations. Cockerill et al. (2009) point out that there can be a high level of variability in public perception – as well as variation in priorities and values among individuals. In addition, timeframes and available resources can differ. While this variability is desirable in that the purpose of participatory risk assessment is to take it into account, too high a variability in values can have the opposite effect of creating irreconcilable divisions among participants. Nevertheless, in applicable situations, there is much promise in an inclusive and bidirectional process of risk management with affected members of the public. Arguably, taking on such an endeavour would require a strong collaboration between the scientists and policymakers already working on the issue at hand to deal with these new (and potentially intellectually disruptive) perspectives.

Some Key Findings

As we have seen, there are multiple sources of uncertainty and how these are understood differs among actors at the science/policy interface. These uncertainties can arise from chance, myopia or intentionality. They can differ among disciplines, functional groups and individuals. Creating a common understanding of uncertainty can facilitate communication and build trust among the actors. Knowing what we don't know is often the first step to reducing uncertainty and improving the quality of decisions.

Rather than focussing on risk communication to minimize negative public responses to decisions, approaches are being developed that include the public as partners in the decision making process. These approaches can not only improve acceptance of the resulting decisions but also further reduce their uncertainty by broadening the base of stakeholders early in the decision making process.

It should be helpful to see the interrelationships between the challenge to communicate appropriately (at the interface of science and policy) and the challenge of selecting appropriate information in the first place. The latter has been well described in the concept of fitness for use in quality control contexts.

The following key findings are an attempt to highlight common messages from the literature we reviewed:

- When engaging the scientific community, decision makers should ask questions that can be answered
- It is important to develop a common understanding among all those involved in informing a decision of the knowns and unknowns that could affect the decision and its outcomes.
- Based on this common understanding of uncertainty, decision makers should consider whether or not a decision at this time is warranted. Decisions can be divided into adaptive stages wherein the results of one stage inform the next.
- Scientists should be explicit about sources of variability and what is not known when providing the "best available evidence".
- The sources of variability and unknowns should be communicated to the public along with the results of the decision.
- Public participation early in the decision making process should be considered when risks are high and values diverge.
- The precautionary principle should be considered if decisions may cause irreversible negative impacts.

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