INTEGRATED ASSESSMENT: IMPLICATIONS OF UNCERTAINTY

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Summary

Integrated assessments (IAs) can be broadly defined as attempts to develop a coherent framework for description and analysis of the salient aspects of a policy issue with considerable social and scientific complexity. Integrated assessments often involve interdisciplinary collaborations, as in the IPCC assessment reports, or a more formal structure, as in mathematical models (IAMs).

Their purpose is to offer an overview of the multiple dimensions of the issue in question. They serve as communication devices between scientists, decisionmakers, and stakeholders. They often reveal critical gaps in the desirable level of knowledge prior to decisions being made.

By ignoring uncertainties and failing to recognize key internal dynamics of global systems, Malthus and the Club of Rome have previously scuttled the ship of systems analysis of global problems. The chances of running the ship of IA aground on the sandbar of myopic arrogance are high. Good practice demands characterization of uncertainties, recognition of their influence in determination of the design of integrated assessments, and methodological approaches to gaining valuable insight from their study.

1. Defining Uncertainty in Integrated Assessments

1.4. Integrated Assessments and Integrated Assessment Models

Integrated assessments (IAs) can be broadly defined as attempts to develop a coherent framework for description and analysis of the salient aspects of a policy issue with considerable social and scientific complexity. Integrated assessments often involve interdisciplinary collaborations, as in the IPCC assessment reports, or a more formal structure, as in mathematical models (IAMs). Their purpose is to offer an overview of the multiple dimensions of the issue in question. They serve as communication devices between scientists, decisionmakers, and stakeholders. They often reveal critical gaps in the desirable level of knowledge prior to decisions being made.

IAs can be designed to follow a *vertical integration* path, a *horizontal integration* path, or, on rare occasions, both. In vertical integration, the goal is to explore and close the chain of causation linking the various elements of change impacting the issue in question. For example, a comprehensive vertical integration of climate change would include explicit interactions between: demographic change and economic development; development and resource mobilization; resource mobilization and biosphere/climate change; and the impact of this biosphere/climate change back on demographics, economic development, and resource mobilization. Such studies often limit themselves to consideration of the direct interactions between different processes. Horizontal integration involves understanding the key processes interacting across the elements of a vertical study. For example, a horizontal integration of water resources would involve the mutual interactions between water quality and quantity and: demographics, economics, energy and food production, land use and land cover, surface and groundwater flows, local and regional climate, transportation, pollution, diseases, and sanitation.

1.5. Different Categories of Uncertainties

The broad scope of IAs and their search for the tissue of knowledge linking different aspects of an issue all lead to frequent struggles with uncertainties. Many different forms of uncertainty can be encountered. In the list below, I use definitions from a mathematical modeling perspective to distinguish these, but these uncertainties are not limited to IAMs:

Parametric uncertainty—where the characteristic behavior of a component of the assessment is known, but not sufficiently to allow us to specify deterministic values for the parameters used to represent the behavior in a mathematical equation. For example, while we have a pretty good understanding of the behavior of light, we do not have a precise measure of its speed. An accurate representation of the state of our knowledge should reflect this uncertainty.

Stochastic uncertainty—where the characteristic behavior is well known, but varies over time and may not be represented by a single draw from a distribution for all time. For example, we may have a relatively good idea of the total precipitation in a given location per year. However, simulating each rainfall event will involve a fresh realization from the statistical representation of possible rainfall patterns. Note that the evolution of statistical representation of rainfall in this location over time is itself uncertain.

Structural uncertainty—where there is insufficient knowledge to distinguish between competing models describing the behavior of the system in question, we should not conduct assessment using only one structural assumption. For example, we know that demographic changes involve altered infant birth rates and survival, along with changing life expectancy for adults. However, how these key drivers of a population change over time is the subject of many competing theories. In exploring the long-term future of the earth, we need to represent these competing models of demographic change to understand their potential interactions with the issues at the focus of the assessment.

The author introduces three additional sources of uncertainty that could, with some creativity, be subsumed into the categories of uncertainty discussed above. However, they are of such fundamental importance that they need to be discussed individually.

Heterogeneity within aggregate variables—where the model adopted to represent the issue has a scale of representation we know to be too coarse to represent the differences among individuals. For example, fish of the same species and age will still have a distribution of sizes among them. Fishing using a net of a given size selects out smaller fish to be left to produce the next generation.

Analytical representation—there is often a choice of analytical forms that could be adopted for representation of the system in question. Often, classical concepts of continuity, differentiability, and so on, work as an invisible hand to shape the mathematical expressions used to describe the system. These are often chosen even when the assessments rely on numerical simulations, rather than on analytical solutions, to the equations. The adoption of these mathematical forms can be extremely restrictive in reflecting the nature of systems in question. For example, in IAMS climate change damage is often expressed as a quadratic function of global average temperature change. Such expressions have no basis in fact, and are incapable of representing thresholds of impact. Also, by construction they reflect the questionable assumption that current conditions are best and that warmer and colder global temperatures are both equally undesirable.

Paradigmatic differences—application of integrated assessments to policy questions involves the adoption of a paradigm of representation with roots in one or another discipline. This paradigm dictates the key features of the analysis and may, to a great extent, define the outcome of the analysis. For example, in IAs of climate change, the adoption of a welfare economics or an ecological biodiversity perspective leads to distinctly different foci of analysis and policy conclusions. In the former paradigm we often encounter crippling uncertainties about how to put values on natural resources and on living entities. In the latter, the absence of economic considerations driven by basic human needs obscures potential constraints to implementation of policies capable of preserving natural habitats indefinitely. Another widely prevalent example of paradigmatic difference is that in discussions of global climate policy the focus of more affluent countries is addressing the feared environmental problem and the focus of less affluent parties is addressing social and economic development imperatives.

1.6. Links between Integrated Assessment and Uncertainty

Development of integrated assessments poses many intellectual challenges. Not the least among these is the disparate nature of the epistemology of disciplinary knowledge, from which integrated assessments are to be constructed, and the process of integration. The acquisition of disciplinary knowledge has relied heavily on the reductionist approach to scientific understanding. Understanding is achieved by assuming away (or creating isolated environments to sort out) all outside influences on the focus of the inquiry until they are eliminated. This yields useful information about this domain while in isolation, but how much of that understanding is useable in an integrated assessment, where the very purpose of the effort is to explore interactions with outside influences? Thus, the process of integration introduces uncertainties in the core knowledge being integrated.

Many integrated assessments have been assembled from pre-existing models rich in their representation of each domain. The thread that brings them together into integration is a common focus, such as climate change. However, climate may not be the only path (or the strongest path) along which the IA components influence one another. This is a significant challenge to development of coherent IA frameworks. For example, while the IPCC brings together domain expertise in many fields to consider climate change over the next century, few, if any, of the thousands of IPCC contributing scientists believe that climate change is the dominant force of change over that time period. This issue requires careful consideration of the relative importance of interactions and factors of change contained within the assessment and left outside. Where the latter is large and important, the milieu in which the integrated assessment is being conducted is uncertain to the point of losing face validity.

The majority of IAs is constructed to answer specific questions. In providing this answer, by their nature, they are only as strong as their weakest or most uncertain component. Identification of these uncertainties is critical to making better decisions. These decisions can be reflective, i.e. where to expend the marginal effort to gather information relevant to the problem at hand. They can also be the solutions to the problem so that they are robust to uncertainties that may not be resolvable in the time available. To utilize fully these features of a formal integrated assessment, there needs to be systematic characterization of uncertainties in each domain, and in the interactions between the different forces represented in the framework.

In developing integrated assessments covering global change issues there is significant heterogeneity in the extent of knowledge available about different parts of the world. For example, whereas commercial energy markets dominate the supply in industrialized nations, noncommercial fuels, often collected communally, meet the needs of a sizable fraction of the world's population. Economic models of production are often specified for industrialized nations where capital is plentiful and labor is scarce (or needs to be made less important to limit union power). These models are often adopted as being representative of production patterns in less industrialized settings—even where there may be a desire to increase employment for social reasons and there is a dearth of capital. These systematic errors and uncertainties in representatives of IAs make their insights about the distribution impacts of policies involving the developed world and other nations highly uncertain if not fundamentally suspect.

2. Implications of Uncertainty for Policy Formation

2.1. Uncertainty, Its Resolution, and the Policy Imperative

One may think it is wiser to delay action until key uncertainties have been resolved. For example, it would be foolish to decide on the flavor of ice cream to purchase at the store before visiting the store and learning which flavors are in stock. But this approach to dealing with uncertainty is hardly a panacea to all ambiguous circumstances. The magnitude and impact of anthropogenic climate change is uncertain, as is the cost and efficacy of various intervention programs. Can we delay to reduce uncertainties before we act or will delay commit us to environmental damage that is difficult to reverse? Interestingly enough, delay is likely to be counterproductive in resolving the climate policy dilemma for three reasons:

1. Right now, we do not know who would benefit and who would suffer from climate change. Risk aversion forces us to focus on adverse outcomes and unites us into a coalition for interventions reducing future climate change and impact. Let us assume that decisionmakers chose to delay until such time that we know not only the extent of climate change but also the identities of winners and losers. Once this uncertainty is resolved, the coalition for intervention is destroyed.
2. Climate change involves systems with uncertain but possibly high sensitivity to anthropogenic perturbation and uncertain but possibly long time constants. We can delay interventions to track climate change for a longer period. Even at a later time, the dual nature of uncertainties will not permit assured proclamations about the severity of climate change and its impact. Furthermore, any marginal learning about this system will not be of value if we discover that the anticipated impact will be devastating, and it has taken us so long to learn this fact that we now have insufficient time to change course.
3. Intervention strategies to limit climate change involve technological, social, and behavioral changes that are relatively novel. The uncertainty in their cost to society is related to the lack of experience with their implementation. If intervention policy is delayed, we will not create the conditions where new information about the costs of intervention will be forthcoming. Hence, delay will lead to a continued gross uncertainty in our understanding of the costs of intervention.

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Biographical Sketch

Hadi Dowlatabadi is Director, Center for Integrated Study of the Human Dimensions of Global Change, Department of Engineering and Public Policy, Carnegie Mellon University, and University Fellow, Resources for the Future. He hold B.Sc. and Ph.D. degrees in physics from Edinburgh and Cambridge Universities, respectively. He came to the US in 1984 as a post-doc at CMU to study acid rain. In 1987 he joined Resources for the Future to gain a better understanding of economics. In 1991 He returned to CMU to coordinate an integrated assessment of climate change. Since 1996 He has been Director of the Center for Integrated Study of the Human Dimensions of Global Change, an NSF Center of Excellence focused on interdisciplinary research on the interactions between managed and natural systems. He is interested in interdisciplinary research. He relies on mathematical models to organize his thoughts and help him explore the uncertainties and complex dynamics of natural and social systems. He developed models of diverse issues such as: energy markets and investment strategy, ecology, economics, technical change, demographics, tropospheric air pollution, climate change, sea level rise, coastal storms and their impact, HIV/AIDS in New York and in Sub-Saharan Africa, geo-engineering of the Earth's climate, and agricultural impacts of climate change. Much of his current agenda involves trying to model how we (humanity) engage in the processes of system identification (environment and community) and response. Along the way he spent a year at the Rockefeller Foundation where along with Tim Weiskel he designed a program called LEAD (Leaders for Environment and Development). LEAD since 1991 has helped more than 1000 fellows around the world be better positioned to understand environmental issues and represent their region's needs in international negotiations. His view of the world can be captured in three questions: How should we deal with uncertainty? How can we represent and solve real world problems? How can we improve human response to a changing environment? You can read his musings about these issues in more than 80 papers and two books.