



Coping with uncertainties-examples of modeling approaches at IIASA[☆]



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ABSTRACT

Uncertainty is a pervasive characteristic of all research addressed at the International Institute for Applied Systems Analysis (IIASA) which is at the core of this Special Issue. The role of science in better coping with uncertainty is twofold. First, to describe uncertainties as comprehensively and well as possible, both quantitatively and qualitatively; second, to develop methods that can lead to improved decision-making under uncertainty. Here increasingly the concept of “optimal” is replaced by one of “robust” decisions, i.e. decisions that make sense vis à vis multiple uncertainties. This paper illustrates selective examples from IIASA research that contribute to the twin objectives of a better description of uncertainty and improved decision-making under uncertainty, drawing from research in the fields of technology dynamics, climate change policy, as well as catastrophic risk management and portfolio analysis. The conclusions emphasize the need for a basic research strategy aimed at elucidating uncertainties in parameters as well as in alternative model representations, and in developing improved models for robust decision-making. Models of robust decision making emphasize risk hedging spatially and through a portfolio of policies and technology options.

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1. Introduction

Uncertainty is one of the key challenges addressed by systems analysis and a pervasive characteristic of the human dimensions of global change. The systems analysis of global change is at the

☆ “The expansion of economic, technological, and ecological interdependence has stimulated a growing volume of research on its implications and consequences. The International Institute for Applied Systems Analysis (IIASA) itself is one institutional manifestation of this expansion. Much of the work to date has been based, implicitly or explicitly, on an evolutionary paradigm – the gradual, incremental unfolding of the world system in a manner that can be described by surprise-free models, with parameters derived from a combination of time series and cross-sectional analyses of the existing system.... The focus on surprise-free models and projections is not the results of ignorance or reductionism so much as of the lack of practically usable methodologies to deal with discontinuities and random events.” (Brooks, 1986).

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heart of the research mission of the International Institute for Applied Systems Analysis, IIASA, a non-governmental think tank located in Laxenburg, Austria. IIASA was founded in 1972 upon initiative of the USA and the then Soviet Union to provide a scientific bridge to study universal and global problems using the tools of the then nascent field of systems analysis. The Institute is now supported by academies of sciences or equivalent bodies from 23 countries, East and West, North and South.

This Special Issue is devoted to research at IIASA, with its papers aiming to provide a wider readership with an opportunity to become familiar with current research themes, methods, and applications. Yet even an entire Special Issue cannot provide a comprehensive picture of all research performed at IIASA and thus represents a selection. Uncertainty and Social and Technological Transformation were thus selected as overarching themes of this Special Issue. This paper leads into the first of the overarching themes of this Special Issue: uncertainty.

It is not possible in a single paper to provide a comprehensive overview of more than 40 years of uncertainty-related research at IIASA, not to mention of the entire research field, a review that could easily fill a voluminous monograph. Instead, we set out

more modest objectives for this paper: to provide a non-technical (i.e. non-mathematical) and accessible illustration of IIASA's research in the domains of dealing with uncertainties both descriptively as well as prescriptively in modeling applications. The term descriptive refers to methods aiming to representing salient uncertainties fully; the term prescriptive refers to improved models of decisions under uncertainty. The selected examples were chosen with the twin objective in mind to provide accessible illustrations of novel methods or novel applications to both descriptive and prescriptive uncertainty approaches. Their commonality arises that they all deal with the human dimensions of global change and that they have been developed at IIASA.

The role of science in better coping with uncertainty is twofold. The first role is to describe uncertainties as comprehensively and accurately as possible, both quantitatively as well as qualitatively. A hallmark of IIASA's research is a keen interest in methods and empirical analysis of "long-tailed" distributions and extreme event analysis in the development of scenarios. These probe into an uncertainty space that often is beyond reach of deterministic projections and surprise-free model representations.

The second role of science is to develop methods that can lead to improved decision making under uncertainty. Let us recall that the intellectual/scientific traditions that led to the creation of IIASA were strongly influenced by perceptions of the possibilities of forecasting and new methods of operations research developed for optimal planning and decision making after WWII. In its methodological (e.g. the gradual extension of linear programming to stochastic optimization approaches) as well as in its applied research (extending over ever longer time horizons, and evolving to the study of ever larger, complex, interrelated phenomena such as global change) IIASA's science itself reflects an increasing awareness on the need of new decision paradigms. Increasingly concepts such as "rationality" or "optimality" are complemented by new concepts such as "robust" decision making (e.g. Ermoliev and Hordijk, 2006), i.e. decisions that make sense vis à vis multiple (type of) uncertainties.

2. Types of uncertainties

Uncertainties can take many identities and forms. They range from "parametric" uncertainties (e.g. uncertain parameters and thresholds of otherwise well-established relationships, abundant especially in the environmental field), to "functional" uncertainties (where a relationship between two variables is ascertained, but the parameters and the direction of influence remain uncertain; e.g. does the availability of new communication technologies and telecommuting lead to less or more travel?). Lastly, there are "unknown unknowns – [things] we don't know we don't know" (Rumsfeld, 2002).⁴

⁴ "Reports that say something hasn't happened are interesting to me, because as we know, there are known knowns; there are things we know we know. We also know there are known unknowns; that is to say we know there are some things we do not know. But there are also unknown unknowns – the ones we don't know we don't know." (Rumsfeld, 2002). Quite ironically, Donald Rumsfeld seems to have paraphrased an old anonymous Arab proverb: He who knows not and knows not that he knows not is a fool. Shun him. He who knows not and knows that he knows not is simple. Teach him. He who knows and knows not that he knows is asleep. Wake him. He who knows and knows that he knows is wise. Follow him. <http://www.chara.gsu.edu/~gudehus/Quotations/>.

Despite being known to science since the end of the 19th century, climate change might in fact be a good illustration of an "unknown unknown" to policy makers. What Brooks (1986) calls "sudden emergence into political consciousness" constituted a genuine surprise to policy makers, when climate change was first proposed for deliberations at a G-8 summit back in 1978 (Schelling, 1996).⁵ It is beyond the scope of this paper to propose a comprehensive taxonomy of uncertainties.⁶ For the subsequent discussion, we differentiate between three main classes of uncertainty as relevant for modeling applications in systems analysis: *epistemic* (e.g. uncertain data and/or models), *linguistic* (e.g. vagueness in problem formulation and/or failure to precise context specificity), and finally *contingency/agency* (uncertainties arising from human intentionality, i.e. the very policy decisions a particular study aims to contribute to).

The domain of *epistemic* uncertainty comprises uncertainties in both data and models. While well known to science, it continues to be a major stumbling block in communicating science to policy makers and the public at large, frequently being subject to *linguistic* uncertainty (discussed below). Data and model uncertainties interact in important ways for all those phenomena that are not directly observable/measurable, thus not lending themselves to the traditional statistical tools of handling measurement errors (imperfect observations) or systematic errors (bias in sampling or in measurement devices) and their ensuing communication via empirical distribution functions (probability density functions). Consider as an example the issue of the detection of historical climate change (subject to measurement and systematic errors) vs. the issue of describing uncertainty of future, projected climate change (involving in addition also substantial modeling uncertainties) in which the ensuing probability density functions become themselves *conditional* on the particular model used or to *subjective* model interpretations, reflecting different "degrees of belief" of expert opinions. Dependence on a single model (or on a too restricted group of experts polled) will lead to an undesirable compression of uncertainty (overconfidence). Evidently, the above example deals only with some uncertainty aspects. It is important to note that the evolution of the climate system is inherently uncertain and thus much larger than the uncertainties involved in modeling particular aspects of climate change, past or future.

Recent developments (with important contributions from IIASA, particularly in the field of technology studies) that complement traditional techniques for describing uncertainty such as expert opinion polling or Monte Carlo simulation techniques based on a single model, include: the comparative use of model ensembles and the use of massive computation techniques either via parallel processing (e.g. Gritsevskiy and Nakicenovic, 2000) or agent-based simulations (e.g. Ma et al., 2008), which, it should be noted however, can introduce new uncertainties themselves. Common to them all is the aim to generate distributions of to-date unobserved states of a

⁵ For a vivid account see Schelling (1996). Schelling, Nobel Laureate in Economics and IIASA alumnus, also highlights that back in 1978 "only at IIASA the topic [of climate change] seems to have organized itself... [resulting] in integrated work on the subject".

⁶ For a good introduction see e.g. Regen et al. (2002).

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