Guest Perspective

Building The Black Box Out Of Plexiglass

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By Pasky Pascual

Manifesting an almost childlike capacity for wonder, Albert Einstein in 1926 directed his mind to the question, "Why do rivers meander?" Observing that streams tend to "curve in serpentine shapes," rather than flow linearly down a slope, Einstein mused about the physics of why this must be so.[1] However, it was not until the close of the twentieth century that an earth scientist at Cambridge University calculated a model to describe the mathematical relationship between a river's length as measured along its meandering, loopy path and along a straight line as the crow flies:

Although the ratio varies from river to river, the average value is slightly greater than 3. . . . In fact the ratio is approximately 3.14, which is close to the value of the number B, the ratio between the circumference of a circle and its diameter.[2]

The notion that "nature's great book is written in mathematical language," a startling proclamation by Galileo in the 16th century, now appears firmly embedded in our modern view of the world. We rely on mathematical models to explain the world. And so, for example, we take for granted the complex task of computing the trajectories to land the Mars Rovers on a planet roughly 50 million miles away. Galileo's conviction that we can somehow capture natural phenomena in algorithmic form underlies much of environmental protection. It is what legitimizes Texas's use of a computer model called *CAMx* to deal with ozone problems in one of its most heavily polluted areas, and New York's reliance on the *Reckhow Land Model* to determine how best to protect its residents from phosphorous in its drinking waters. The courts deliberated over EPA's approval of both of these state actions over the past two years partially because of questions regarding the credibility of their underlying environmental models.

What is a model? A model, as EPA defines it in its *Draft Guidance on the Development, Evaluation, and Application of Regulatory Environmental Models* (hereinafter *Draft Guidance on Models*), is "a representation of the behavior of an object or process, often in mathematical or statistical terms."[3] A model is a mental construct. Its construction is driven not only by the thing being modeled, but also by the purposes for which the model is being built and by the particular needs and interests of the model builder.[4] A model is an approximation of reality. If it is true, as the comedienne Lily Tomlin put it, that "reality is a collective hunch," then perhaps it may be said that our mathematical approximations of reality may be considered speculative.

Most people tend to accept the oft-cited cliché that "nothing is certain except uncertainty," and seem to recognize the need to push ahead with decisions despite a lack of certitude. The real issue is how to determine when a model, despite its inherent uncertainties, can be appropriately used in decision-making.

The issue is not trivial. In a recent survey spanning 30 years of court cases, legal scholars Tom McGarity and Wendy Wagner identified numerous instances in which EPA's use of models was subject to judicial challenges.[5] These challenges included allegations that the model in question relied on oversimplifying assumptions, used unrepresentative data, depended on unsound scientific hypotheses and was applied to an inappropriate set of conditions. In general, the courts readily recognized the limits of modeling. The U.S. Court of Appeals for the District of Columbia Circuit articulated the jurisprudence for judicial review of EPA models:

"Any model is an abstraction from and simplification of the real world. . . . We will . . . look for evidence that the agency is conscious of limits of the model. Ultimately, however, we must defer to the agency's decision on how to balance the cost and complexity of a more elaborate model against the oversimplification of a simpler model. We can reverse only if the model is so oversimplified that the agency's conclusions from it are unreasonable.'[6]

The courts do not, therefore, expect that a model perfectly depicts reality, but only that the use of a model is rational and not arbitrary. McGarity and Wagner suggest that when EPA formulates policies based on a model, it should provide detailed descriptions and coherent explanations of its modeling. It would seem that the appropriate policy response to model uncertainty is not necessarily certitude, but transparency.

The goal of transparency is consistent with the scientific community's evolving understanding of model assessment. As the environmental modeler Professor Bruce Beck noted, 10 years ago the term would have meant assessing a model's performance by comparing model output against field data.[7]

Currently, the scientific modeling community is disinclined to use the term "validation" when assessing a model's performance. A model can certainly be *invalidated* for a particular application if the model generates nonsensical results. For example, if a model supposedly predicts salmon weights and begins to generate negative values, we can probably agree that the model is not valid for this use.

However, a model cannot be validated in the sense of ultimately determining a model's "truth." By definition, a model simplifies and approximates reality. We may assume that some true relationship exists between our input and output variables, but we accept that -- because our knowledge of reality is incomplete and because reality is characterized by natural variability -- we can only approximate this relationship. For this reason, it is more appropriate to speak of evaluation rather than validation.

The *Draft Guidance on Models* proffers a definition of model evaluation as a process to generate information to help determine whether a model and its analytical results are sufficient to serve as a basis for a decision. Some of this information can certainly be gleaned by comparing model output to field data, but we should recognize field data for what they are -- single instances, with their own measurement uncertainties, of the larger reality that models are intended to approximate.

This information should be complemented by other information documented throughout the model's life cycle so that we have a model's so-called "pedigree." What is a model's underlying set of hypotheses? What was the quality of the data used to formulate the model? What were the set of conditions under which the model was developed? What are the uncertainties associated with the model and its underlying data? To generate this information, model evaluation encompasses processes such as corroboration, sensitivity analysis, uncertainty analysis, and other methods discussed in greater detail in the appendices of the *Draft Guidance on Models.*

The National Academy of Sciences in 1983 -- by distinguishing the science of risk characterization from the policy of risk management -- recognized the imperative to balance the uncertainties of science against the need for regulatory decisions. Similarly, EPA's proposed framework for model evaluation -- the output of which is information on a model's pedigree -- bifurcates the process of evaluation from that of decision-making. The intent is to enhance transparency by communicating a model's uncertainties and by articulating the choices made in the face of those uncertainties. The intent is, in the words of EPA Science Advisor Paul Gilman, "to build the black box, as models are sometimes called, out of plexiglass."

Through his entire life of building mental models to describe the universe, Einstein continued to be fascinated by the simple fact that one *could* build a model. To him, the most incomprehensible thing about the universe was that it was comprehensible and that it could in part be described by equations. As it must for those who benefit from the work of model builders and users, i.e., for *all* of us, humanity's use of models inspired in Einstein an odd mixture of brashness and humility, as reflected in his remarks to the Prussian Academy of Science.

"How can it be that mathematics, being after all a product of human thought which is independent of experience, is so admirably appropriate to the objects of reality? . . . In my opinion the answer to this question is briefly this: As far as the laws of mathematics refer to reality, they are not certain; and as far as they are certain, they do not refer to reality."

Endnotes

[1] Einstein, A., 1954, The cause of the formation of meanders in the courses of rivers and of the so-called Baer's Law, pp. 249-253 in Ideas and Opinions: New York, Bonanza Books, 337 p.

[2] Singh, S., 1997. *Fermat's Enigma*, p. 17.

[3] The *Guidance on Models*, available at http://www.epa.gov/crem, was publicly released on January 28.

[4] Haag and Kaupenjohann, 2001. *Parameters, prediction, post-normal science and the precautionary principle--a road map for modelling for decision-making*, Ecological Modelling 144, 45-60.

[5] McGarity and Wagner. 2003. *Legal Aspects of the Regulatory Use of Environmental Modeling*, 33 ELR 10751.

[6] *Small Refiner Lead Phase-Down Task Force v. EPA*, 705 F.2d at 535. (DC Cir. 1983)

[7] Beck. 2002. "Model evaluation and performance," in *Encylopedia of Environometrics*. John Wiley & Sons.

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