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NEWS & ANALYSIS

Wresting Environmental Decisions From an Uncertain World

by Pasky Pascual

Editors' Summary: The role of science and law are often at a cross-roads in the world of environmental policymaking. The law imposes legal norms based on what has been generally accepted in scientific circles. In turn, scientific claims are accepted only if they satisfy evidentiary rules prescribed by the law. One may be tempted to postpone decisions until we have all the pertinent scientific evidence before us. But failing to act can be costly—both in terms of financial resources for additional research and of environmental ills that persist while we delay decisions. We must therefore tolerate some degree of uncertainty. But while we may not agree with the decisions, we should know how and why they were made despite the limitations of scientific knowledge. Using a "Bayesian approach," the author demonstrates how policymakers can transparently acknowledge their theoretical and empirical limitations and can communicate the effects of choices they make in certainty's absence.

Within a four-month period in 1905, a 26-year-old Swiss government worker published three pivotal papers that forced scientists to think about the world in entirely new ways. "A storm broke loose in my mind," Albert Einstein later said about his *annus mirabilis*, during which he wrote about the nature of light, the molecular structure of matter, and—in his theory of special relativity—the very essence of time and space.¹

From the present vantage point of this Einstein Year, so billed to recognize the centenary of this triumphant triad of theories, it may be difficult to appreciate the clouds of uncertainty under which Einstein toiled. Mere months after publishing his special relativity, Einstein faced a challenge from the experimental physicist Walter Kaufmann, whose observations on electrons seemed to contradict Einstein's hypothesis.² Capturing the tensions between uncertain theory and ambiguous empiricism, the young Einstein offered this sanguine reply:

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1. For a brief overview of Einstein's accomplishments in 1905, see JOHN S. RIGDEN, *EINSTEIN 1905: THE STANDARD OF GREATNESS 2* (Harvard Univ. Press 2005).
2. Gerald Holton, *Mach, Einstein, and the Search for Reality*, in GERALD HOLTON, *THEMATIC ORIGINS OF SCIENTIFIC THOUGHT: KEPLER TO EINSTEIN 253* (Harvard Univ. Press 1988).

It will be possible to decide whether the foundations of the relativity theory correspond with the facts only if a great variety of observations is at hand. . . . [The alternative hypotheses] have rather slight probability, because their fundamental assumptions . . . are not explainable in terms of theoretical systems which embrace a greater complex of phenomena. A theory is the more impressive the greater the simplicity of its premises, the more different kinds of things it relates, and the more extended is its area of applicability.³

Between the theoretical and the empirical falls the shadow of uncertainty. The shadow looms all the darker in the realm of environmental science, where diverse organisms interact dynamically with a heterogeneous world. Casting light through the gloom, science must often conjecture about the state of environmental affairs. And then, based on science's findings, the law must frequently impose obligations and liabilities.

When uncertain theory clashes with equivocal observations, how should we evaluate the reliability of proposed hypotheses? When this conflict occurs at the nexus of science and law, as in environmental policies, how should we draw inferences so that we satisfy the evidentiary needs of both domains? As described in Part I below, these questions recur in various contexts: when nongovernmental entities ask regulatory agencies to explain their science; when courts evaluate the science underlying regulatory decisions or expert testimony; and when international tribunals assess whether science supports a country's environmental laws.

3. Albert Einstein, *Über das Relativitätsprinzip und die aus demselben gezogenen Folgerungen*, 4 *JAHRBUCH DER RADIOAKTIVITÄT UND ELEKTRONIK* 411-62 (1907), quoted in *id.* Einstein's views on the relationship between evidence and theory is discussed more fully in Part II of this Article.

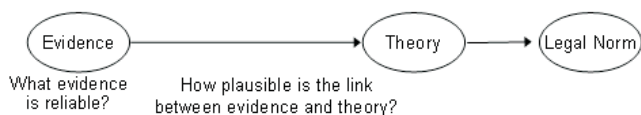
In all these fora, we find it difficult to reason from scientific evidence to appropriate inferences because uncertainty obfuscates knowledge in two distinct ways. As discussed in Part II, not only must we appraise how indeterminate and disparate pieces of evidence are linked to form one integrating theory, but—like denizens of Plato's cave—we must also guess whether we have gathered all the reliable and relevant evidence before us.⁴ Confronted with this twofold uncertainty, we need not engage in Sisyphean pursuits of certainty, nor need we be frozen into solipsistic inaction. Given the ineluctable limits to what we can know about the world, the appropriate policy response to uncertainty is not certitude, but transparent deliberation.

By relying on the Bayesian approach introduced in Part III, society can wrest from uncertainty regulatory decisions that are characterized by *high-information rationality*; we may not agree with the decisions, but we know how and why they were made despite the limitations of scientific knowledge. By relying on transparent, Bayesian models, we may, for example, clearly communicate the policy choices we make to deal with environmental issues replete with scientific uncertainty such as global climate change. In doing so, we can pierce the darkness that may sometimes shroud policymaking, thereby enhancing accountability for decisions made or avoided.

I. Evaluation of Scientific Evidence in Various Legal Fora

For those engaged in environmental policy, evidence and inferential reasoning lie at the cross-roads of science and law, as graphically represented by Figure 1 below. The law imposes legal norms depending on what science theorizes about the state of uncertain spatio-temporal events. In turn, the claims of regulatory science are accepted only if they satisfy evidentiary rules prescribed by the law.

Figure 1



These evidentiary rules focus on questions that are *substantive*—(1) How reliable is the evidence? (2) How plausible is the proposed link between evidence and theory?—as well as *procedural*—(3) How stringently should a reviewing body evaluate a decisionmaker's disposition on these first two questions? The following subsections briefly describe how various institutions have struggled with these questions because they lack a coherent approach to assess the inherent uncertainties underlying scientific evidence.

4. To elucidate the limits of human knowledge, Plato used an allegory about cave dwellers, who—having been shackled so that they see only shadows cast upon the wall—base their concept of reality only on these shadows. *THE COLLECTED DIALOGUES OF PLATO, REPUBLIC*, BOOK VII, 747-48 (Edith Hamilton & Huntington Cairns eds., Pantheon Books 1961).

A. Administrative Review of Science Under the Data Quality Act (DQA)

As part of a series of articles on administrative minutiae that can have inordinate impacts on regulatory policy, the *Washington Post* devoted front-page coverage to the DQA, which has spurred considerable interest on the question: *how reliable is governmental scientific evidence?* A two-sentence piece of legislation written into an appropriations bill in 2000, the Act compels regulatory agencies to establish mechanisms that enable private parties to question government information they believe to be inaccurate.⁵ The article quoted John D. Graham, a high-ranking administrator in President George W. Bush's Office of Management and Budget (OMB), as saying that the Act would compel the government to rely on scientifically based decisions.⁶

Soon after the OMB issued guidelines to implement the DQA, the Competitive Enterprise Institute, a trade association, filed a petition claiming that the Climate Change Action Plan posted on the U.S. Environmental Protection Agency's (EPA's) website was based on a faulty set of models. The petition quoted Patrick Michaels, a professor of environmental sciences at the University of Virginia, who suggested that "the (model) . . . produces much larger errors than the natural noise of the data. That is a simple test of whether or not a model is valid . . ."⁷

It is precisely these types of petitions that disturb some environmental professionals interviewed in the *Washington Post* article. Industry, they suggest, can always fund studies that support industry's interests. "I call this 'manufacturing uncertainty,'" said David Michaels, formerly an administrator at the U.S. Department of Energy under President William J. Clinton and currently a professor of occupational and environmental health.⁸ "They reanalyze the data to make [previously firm] conclusions disappear—poof. Then they say one study says yes and the other says no, so we're nowhere."⁹

As detailed by the OMB, to conform to the DQA a regulatory agency must have issued and implemented guidelines to ensure that the *information it disseminates is of sufficient quality, objectivity, utility, and integrity*.¹⁰ Lewis Carroll's Humpty Dumpty would surely have delighted in the definitional morass that is the DQA and its implementing documents,¹¹ but this Article focuses on only a few choice terms.

5. DQA, §515 of the Department of the Interior and Related Agencies Appropriations Act, 2001, Pub. L. No. 106-554, 114 Stat. 2673 (2000).

6. Rick Weiss, "Data Quality" *Law Is Nemesis of Regulation*, *WASH. POST*, Aug. 16, 2004, at A1.

7. Letter from Christopher C. Horner, to Office of Environmental Information, Request for Response to/Renewal of Federal Data Quality Act Petition Against Further Dissemination of "Climate Action Report 2002" (Feb. 10, 2003), available at <http://www.epa.gov/quality/informationguidelines/documents/7428.pdf> (last visited May 24, 2005).

8. Weiss, *supra* note 6.

9. *Id.*

10. OMB, INFORMATION QUALITY GUIDELINES (2002), available at http://www.whitehouse.gov/omb/infoeq/igq_oct2002.pdf (last visited May 24, 2005).

11. "When I use a word," Humpty Dumpty said, in rather a scornful tone, "it means just what I choose it to mean—neither more nor less." "The question is," said Alice, "whether you *can* make words mean so many different things." "The question is," said Humpty Dumpty, "which is to be master—that's all." LEWIS CARROLL, *THROUGH THE LOOKING-GLASS AND WHAT ALICE FOUND THERE* 94 (Random House 1946) (emphasis in original).

“Information” includes “any communication or representation of knowledge such as facts or data, in any medium or form.”¹² “Objectivity” means that the information must be accurate, reliable, and unbiased; sound statistical research methods must be used to generate original and supporting data and to develop analytical results. If the information has been subjected to the rigors of formal, independent, external peer review, then it is presumptively objective.¹³

While the OMB’s guidelines describe attributes of quality information, they do not lead decisionmakers to an easy demarcation between evidence that is and is not reliable, a fuzzy state of affairs that has wound its inevitable way to the courthouse. In 2003, the Salt Institute submitted a petition under the DQA to question the findings of the National Institutes of Health (NIH) that reducing salt intake reduces blood pressure. The Salt Institute contended that one of the central studies cited by the NIH did not disaggregate the underlying human data by race, sex, age, or any other probable confounding variable; the NIH could not, therefore, issue a recommendation applicable to the general populace.¹⁴ In its response, the NIH emphasized that it did indeed disaggregate data appropriately, that its studies were subjected to extensive independent peer review, and that its recommendations stemmed from “a substantial body of evidence developed over more than a decade show[ing] a clear causal relationship between sodium intake and blood pressure.”¹⁵ After an administrative appeals process, the Salt Institute and the U.S. Chamber of Commerce filed suit against the NIH in the U.S. District Court for the Eastern District of Virginia.

In its decision last November, the court ruled that the scientific issues raised by the Salt Institute were not justiciable.¹⁶ First, deliberating whether the U.S. Congress intended “to create not just a private right but also a private remedy” under the DQA, the court concluded that neither the Act’s language nor its scant legislative history evinced such an intent. Secondly, the court ruled that the NIH studies were not subject to judicial review under the Administrative Procedure Act (APA), which authorizes judicial review of “final agency action for which there is no other adequate remedy in a court.”¹⁷ To be construed as such, the NIH salt recommendations would have to be action “by which rights or obligations have been determined, or from which legal consequences will flow.”¹⁸ The court reasoned that the recommendations were simply statements of scientific findings that in and of themselves, did not have any legal effect behind them.¹⁹

At this writing, the Salt Institute and the U.S. Chamber of Commerce are appealing the lower court’s decision. “Our appeal is for more transparency in the use of science,” said

Salt Institute president Richard L. Hanneman, “[a]nd we are asking the court to banish the games-playing and data manipulation that has compromised implementation of the Data Quality Act. . . .”²⁰

B. Judicial Review of Regulatory Science

1. Sifting Through the Scientific Evidence for a “Rational Basis”

If an Agency decision is subject to judicial review, the questions then arise: (1) *How plausible is the hypothesized link between the evidence and the theory underlying the Agency decision?*; and (2) *How stringently should the courts evaluate this hypothesis?*

Absent specific statutory instructions to the contrary, courts will try to discern a rational relationship between the science and the decision. This standard of review derives ultimately from the APA, which states that unless otherwise specified, courts must limit their review of an agency’s decisions—its rulemaking, informal adjudication, guidance, and policy statements—to whether the decisions are “arbitrary and capricious, an abuse of discretion or not otherwise in accordance with law.”²¹ In *Motor Vehicle Manufacturers Ass’n of the United States v. State Farm Mutual Automobile Insurance Co.*,²² the U.S. Supreme Court ruled that courts can set aside a decision only if, after conducting a “searching and meaningful” review of the administrative record, they conclude that a governmental agency: relied on factors that Congress did not intend; failed to consider an important aspect of the problem; or offered an explanation that ran counter to the evidence or was so implausible that it could not be ascribed to agency expertise or to a difference in view.²³ When called upon to review EPA science under the rational basis standard, the courts have consistently pleaded judicial deference to the Agency’s scientific determinations, asserting that it is not the courts’ role to substitute its judgment for those of EPA’s, particularly when they involve technical and scientific matters that fall within the Agency’s expertise.²⁴

In their survey of legal challenges to EPA’s science, Christopher H. Schroeder and Robert L. Glicksman opine that *State Farm* has never quite achieved the iconic status of *Chevron, U.S.A., Inc. v. Natural Resources Defense Council, Inc.*²⁵ in the legal canon.²⁶ Unlike the latter case, which offers a two-step approach to evaluate EPA’s interpretation of statutory authority, *State Farm*’s

requirement of reasoned decisionmaking contains many subcomponents, such as the obligation to consider reasonable alternatives, to articulate a rational connection

12. INFORMATION QUALITY GUIDELINES, *supra* note 10.

13. *Id.*

14. Letter from William L. Kovaks, U.S. Chamber of Commerce, and Richard L. Hanneman, Salt Institute, to Office of Communications, on Request for Correction Submitted to National Heart, Lung, and Blood Institute (May 14, 2003), available at <http://aspe.hhs.gov/infoquality/request&response/8a.pdf> (last visited May 24, 2005).

15. U.S. Department of Health & Human Services, *Information Requests for Corrections and HHS’ Responses* (Aug. 19, 2003), at http://aspe.hhs.gov/infoquality/request&response/reply_8b.shtml (last visited May 24, 2005).

16. *Salt Inst. v. Thompson*, No. 04-CV-359 (E.D. Va. Nov. 15, 2004).

17. 5 U.S.C. §704.

18. *Salt Inst.*, slip op. at 25.

19. *Id.* at 25-26.

20. OMB Watch, *Court Rules Data Quality Act Not Judicially Reviewable*, at <http://www.ombwatch.org/article/articleview/2529/1/231?TopicID=3> (last visited Apr. 13, 2005).

21. 5 U.S.C. §706(2)(A).

22. 463 U.S. 29, 13 ELR 20672 (1983).

23. *Id.* at 42.

24. *Pan Am. Grain Mfg. Co. v. EPA*, 95 F.3d 101, 105, 27 ELR 20184 (1st Cir. 1996) (citing *Mision Indus., Inc. v. EPA*, 547 F.2d 123, 129, 7 ELR 20096 (1st Cir. 1976)).

25. 467 U.S. 837, 14 ELR 20507 (1984).

26. Christopher H. Schroeder & Robert L. Glicksman, *Chevron, State Farm, and EPA in the Courts of Appeals During the 1990s*, 31 ELR 10371 (Apr. 2001).

between facts and conclusion, to respond to significant comments, and to consider only relevant factors. Thus, [rational basis] review requires the court to analyze the agency's application of law and policy judgments to specific facts.²⁷

Given the ad hoc and context-specific nature of their task, it has not been easy for courts to distinguish relationships between evidence and theory that are plausible and that therefore have a rational basis from those that are implausible and therefore do not, particularly when those relationships are obscured by scientific uncertainty. For example, the U.S. Court of Appeals for the District of Columbia (D.C.) Circuit took pains to try and discriminate legitimate and illegitimate emission limits imposed by EPA on air toxics from a variety of sources. Under the Clean Air Act, EPA must derive these limits based on emissions from the best performers within each source.²⁸ Recognizing the uncertainties associated with defining a best performer when emission levels and their causes are highly variable, the court ruled that EPA could use any method to derive these limits²⁹ as long as it led to a "reasonable inference."³⁰

Nebulous, gray lines divide the reasonable from the unreasonable. In upholding EPA's emission limits for cement plants, the court reasoned that while Sierra Club's argument—that EPA must consider industrial processes, not just pollution control technologies, when determining emission limits—had merit, the argument had not been made in the record; therefore, Sierra Club did not "show EPA's [technology-based] estimate was not reasonable."³¹ Upholding EPA's limits for polyvinyl chloride producers, the court agreed with EPA that industrial processes caused too much variability and ruled that EPA could use technology-based limits in light of the fact that EPA presented data indicating a plausible connection between technology-based limits and best performing plants.³² On the other hand, the court rejected EPA's technology-based limits for hazardous waste combustors because EPA presented no data to support its decision.³³

2. Evaluating Science Under a Statutory Call for the Best Available Evidence

When Congress specifies that a regulatory decision must be based on the best available evidence or the best available science, the courts will generally take this as a signal to conduct a more searching evaluation of the decision's scientific basis. In a 5 to 4 decision, the Court, in *Industrial Union Department, AFL-CIO v. American Petroleum Institute (Benzene case)*,³⁴ struck down the Occupational Safety and Health Administration's (OSHA's) proposal to reduce limits

for worker exposure to benzene from 10 to 1 part per million (ppm).³⁵ While it noted that it was not looking to OSHA for scientific certainty, the Court emphasized that Congress required that OSHA's findings be based on the "best available evidence." In a carefully nuanced opinion, the Court explained that this requirement granted OSHA leeway "where its findings must be made on the frontiers of scientific knowledge . . . so long as they are supported by a body of reputable scientific thought."³⁶

Writing for the dissent, Justice Thurgood Marshall surmised: "The critical problem in cases like the ones at bar is scientific uncertainty."³⁷ In essence, the dissent argued that existing information based on current techniques may frequently be inadequate to meet the evidentiary needs set by the majority, thus putting the burden of scientific uncertainty on the workers OSHA was established to protect.³⁸

A few years after the *Benzene* case was decided, the National Research Council issued its report on *Risk Assessment in the Federal Government*, the so-called Red Book, which presented a paradigm for characterizing risk that could serve as a basis for regulatory decisions.³⁹ OSHA relied on this paradigm to eventually issue a 1 ppm benzene standard, and the Red Book's risk assessment paradigm continues to serve as the basis for organizing scientific information about the environmental and public health consequences of pollutants.

Under the Red Book's risk assessment paradigm, the issue arises as to whether risk assessors should or should not consider a threshold dose or intake level below which the risk of a chemical's carcinogenicity is deemed acceptable. This issue lay at the heart of two cases arising from the Safe Drinking Water Act, which specifies that EPA should use the "best available, peer-reviewed science" in its decisions.⁴⁰ The cases involved EPA's decisions not to consider a threshold when it issued standards for radionuclides and chloroform. The reviewing courts struck down EPA's decision as applied to the latter, but upheld it as applied to the former. In the latter case, the court ruled that EPA's rulemaking—which ran counter to recommendations from EPA's own Science Advisory Board—lacked a rational basis because it did not hew to the best available evidence.⁴¹ In the former case, the court explained that while it must determine whether EPA based its decision on the best available science and drew logical inferences from the evidence, the court would still need to treat the Agency's scientific expertise with deference. In the face of uncertain, contradictory data that supported alternative hypotheses, the court would not substitute its judgment for that of the Agency.⁴²

27. *Id.* at 10394.

28. 42 U.S.C. §7412(d).

29. *Mossville Env'tl. Action Now v. EPA*, 370 F.3d 1232 (D.C. Cir. 2004).

30. *Cement Kiln Recycling Coalition v. EPA*, 255 F.3d 855, 31 ELR 20834 (D.C. Cir. 2001).

31. *National Lime Ass'n v. EPA*, 233 F.3d 625, 31 ELR 20494 (D.C. Cir. 2001).

32. *Mossville*, 370 F.3d at 1242.

33. *Northeast Md. Waste Disposal Auth. v. EPA*, 358 F.3d 936 (D.C. Cir. 2004).

34. 448 U.S. 607, 10 ELR 20489 (1980).

35. *Id.*

36. *Id.* at 656.

37. *Id.* at 690.

38. *Id.* at 713-17.

39. NATIONAL RESEARCH COUNCIL, *RISK ASSESSMENT IN THE FEDERAL GOVERNMENT: MANAGING THE PROCESS* (National Academy Press 1983).

40. 42 U.S.C. §300g-1(b)(3)(A).

41. *Chlorine Chemistry Council v. EPA*, 206 F.3d 1286, 30 ELR 20473 (D.C. Cir. 2000).

42. *City of Waukesha v. EPA*, 320 F.3d 228, 33 ELR 20160 (D.C. Cir. 2003).

C. *Judicial Evaluation of Scientific Evidence Under Daubert v. Merrell Dow Pharmaceuticals, Inc.*⁴³

Unhappy with the courts' general deference to the scientific decisions of regulatory agencies, some commentators have proposed that courts incorporate *Daubert* principles in their review of agency science, which would provide the courts more discretion in determining: *how reliable is the evidence?* In *Daubert*, the Court assigned a gatekeeper role to trial judges, bestowing upon them the responsibility to determine if the science presented through expert testimony is sufficiently reliable and relevant to admit into court.⁴⁴ *Daubert* stated that the scientific evidence proffered by the expert must be "derived by the scientific method" and be "supported by appropriate validation." To assist courts in making this determination, *Daubert* provided a nonexhaustive list of factors to consider: (1) whether the theory or technique in question is subject to empirical testing; (2) whether either has been subject to peer review; (3) whether either is generally accepted by the scientific community; and (4) whether operational standards or known error rates exist for the technique in question.⁴⁵

Daubert emphasized that a court's focus should be on the scientific reliability of an expert's methodology rather than on the conclusions. However, this categorical distinction may be somewhat fuzzy. In *General Electric Co. v. Joiner*,⁴⁶ the Court held that a trial court properly applied *Daubert* principles when the latter ruled as inadmissible evidence that showed a putative link between lung cancer and polychlorinated biphenyls (PCBs).⁴⁷ The Court ruled that the experts could not reliably draw inferences from experiments on infant mice or from inconclusive epidemiological studies. When Joiner counterargued that the district court erred—and the appellate court correctly reversed—by barring testimony based on his experts' *conclusions* rather than their *methodology*, the Court responded that "conclusions and methodology are not entirely distinct from one another."⁴⁸ A court may therefore conclude that the "analytical gap between the [experts'] data and opinion" is simply too great.⁴⁹

D. *Juristic Review of Science by the World Trade Organization (WTO)*

As one might expect, the jurisprudential treatment of scientific uncertainty is even more unsettled under international environmental law. Juristic review of science, an already complex issue at the intersection between law and science, becomes even more problematic when competing national interests are thrown into the mix, as international tribunals struggle with the questions: *How reliable is the evidence?* and *How plausible is the hypothesized link between the evidence and the theory underlying a country's decision?*

The problem stems from the need for the WTO to distinguish between legitimate environmental protection and ille-

gitimate trade protectionism. Under the WTO's Agreement on the Application of Sanitary and Phytosanitary (SPS) Measures, Parties to the agreement must, as a general rule, adopt food safety, agricultural safety, and health measures that conform to international standards.⁵⁰

A nation may adopt more stringent, more protective measures—and may impose these measures on imported products—but only if they are based on *sufficient scientific evidence*,⁵¹ i.e., if there is a *rational relationship* between the measure and a *risk assessment*.⁵² A risk assessment must identify the diseases targeted by the measure, as well as evaluate the probability of entry, establishment, or spread of these diseases (along with their biological and economic consequences) in light of the SPS measure. The risk assessment need not be quantitative, nor need it establish a threshold risk level. Moreover, the risk assessment need not result in a monolithic conclusion to support the view implicit in the SPS measure.⁵³

Regarding the question: *how stringently should the WTO evaluate the sufficiency of scientific evidence cited to support a nation's regulatory decision?*, the WTO will make an "objective assessment of the facts,"⁵⁴ a review process more akin to *Daubert* than to the deferential *State Farm*.

Consider the *Japanese Varietal*⁵⁵ case, brought before a WTO panel in 1997. Japan required exporters of agricultural commodities to fumigate products that may be infested by the nonindigenous codling moth. Additionally, Japan asked exporters to demonstrate fumigation would be successful by submitting laboratory and field tests showing the fumigation dose achieved a 99.99% mortality rate. At issue was whether Japan could also require that these tests be conducted for varieties within a single product.⁵⁶ According to the United States, if it were to comply with Japan's testing requirements, exports of new U.S. varieties would not reach Japanese markets for two to four years.⁵⁷

The United States argued that there were no data supporting Japan's position. Japan argued otherwise, citing independent studies indicating that response to fumigation did in fact differ from variety to variety. To resolve this dispute, the WTO posed the question before an expert panel: did Japan's requirement for varietal testing rest on sufficient scientific evidence?

"The answer is very difficult," attested one of the experts, "[o]therwise perhaps we would not be here."⁵⁸ According to

43. 509 U.S. 579, 23 ELR 20979 (1993).

44. *Id.*

45. *Id.* at 592-95.

46. 522 U.S. 136, 28 ELR 20227 (1997).

47. *Id.*

48. *Id.* at 146.

49. *Id.*

50. WTO, *Agreement on the Application of Sanitary and Phytosanitary Measures*, art. 3, in THE RESULTS OF THE URUGUAY ROUND OF MULTILATERAL TRADE NEGOTIATIONS: THE LEGAL TEXTS (1994), available at http://www.wto.org/english/tratop_e/sps_e/spsagr_e.htm.

51. *Id.* art. 2.

52. *Id.* art. 5.

53. Report of the WTO Panel, Australia—Measures Affecting Importation of Salmon, WT/DS18/R 1-1 (June 12, 1998), modified by Report of the Appellate Body, AB-1998-5 (Oct. 20, 1998).

54. Report of the WTO Panel, EC Measures Concerning Meat and Meat Products (Hormones), WT/DS26 and WT/DS48, modified by Report of the Appellate Body, AB-1997-4, ¶¶ 113-118 (Jan. 16, 1998).

55. Report of the WTO Panel, Japan—Measures Affecting Agricultural Products, WT/DS76/R (Oct. 27, 1998), modified by Report of the Appellate Body, AB-1998-8, WT/DS76/AB/R, 79 (Feb. 22, 1999) [hereinafter *Japanese Varietal* case].

56. *Id.*

57. *Id.* ¶ 4.23.

58. *Id.* ¶ 8.35 n.265.

the panel, it was certainly theoretically plausible that biological differences between varieties could cause them to respond to fumigation in varying ways. The panel also acknowledged there *was* scientific evidence indicating different fumigation results for different varieties.⁵⁹ However, the experts had difficulty discerning the biological and statistical relevance of these differences. There were too many other possible sources for the differences, and it was not clear whether a sufficiently high fumigation dose would render these differences moot.⁶⁰

Ultimately, the WTO dispute panel ruled in favor of the United States. Given the uncertainties raised by the experts, the panel concluded that Japan could not legitimately infer that varietal differences caused a divergence in fumigation efficacy. The panel could not brook Japan's proposed inference in the face of the uncertain evidence before the panel.

E. Toward High-Information Rationality

Because reviewing bodies have been unable to limn a crisp, clear line that distinguishes between regulatory decisions that are appropriately based on science and those that are not, their inquiry into an institution's scientific findings—deferential or not—necessarily tends to be ad hoc. With their reliance on heuristics, the written opinions of these reviewing bodies are tinged with *low-information rationality*, a term coined by the political scientist Samuel Popkin to describe voter behavior. Not entirely irrational, many voters tend to use intellectual short-cuts and cues rather than reasoned thinking to forge connections between a candidate's policies and their consequences. If pressed, these voters would probably be unable to articulate the precise reasons behind their voting preferences.⁶¹

In Part III below, this Article suggests Bayesian inference as a step toward *high-information rationality*, in which policymakers can clearly conceive and communicate the degrees of belief they may have about competing theories and the supporting evidence, as well as the consequences of modifying their beliefs. Rather than forcing reviewing bodies to speculate about the reliability of individual pieces of information, the approach offers a synoptic view of the relationship between uncertain evidence and theory, a topic to which this Article now turns.

II. Uncertain Theoretical and Empirical Underpinnings of Scientific Evidence

In the decade following his miracle year, Einstein worked through a theory of general relativity to plumb the full consequences of his ideas, including the intriguing notion that space curved because of gravity. In 1919, he received word that the astrophysicist Arthur Eddington corroborated general relativity by measuring the deflection of distant starlight as it streamed past the sun's gravitational pull during an eclipse. Asked how he would have felt if the experiment indicated otherwise, Einstein replied: "Then I would have been sorry for the dear Lord—the theory *is* correct."⁶²

Such wry observations and other similarly playful comments: ("If facts don't fit the theory, change the facts")⁶³ may lead some to misapprehend Einstein as an opportunistic empiricist, one who conveniently embraced Eddington's confirmatory astral evidence while rejecting Kaufmann's disconfirming measurements on electrons. However, to do so would be to ignore Einstein's abiding view on the relationship between theory and evidence, a view influenced by the writings of the French philosopher and scientist Pierre Duhem.⁶⁴

For Einstein, as it was for Duhem, scientific theory was based on empirical evidence, but such evidence was itself based on all manner of auxiliary hypotheses, such as assumptions about the physics and chemistry underlying one's observations. If, for example, Kaufmann's laboratory results seemed to disconfirm Einstein's theory, it may have been because Kaufmann's measurements were faulty (as indeed, they were ultimately shown to be). For Einstein, corroboration of a theory should be based *not* on an *atomistic*, point-by-point correspondence between theory and each observed data point or sets of data points, but rather on a *holistic* assessment of the fit between theory and the entire body of evidence.⁶⁵ In Einstein's words:

We establish a conceptual system whose individual parts do not correspond immediately to experiential facts. Only a certain totality of theoretical materials corresponds again to a certain totality of experimental facts. . . . It is a part of a theoretical construction that is true or false, i.e., corresponding or not corresponding to experience, only *as a whole*.⁶⁶

Take, as an example, Eddington's observations of 1919. Eddington's measurements seem straightforward enough: compare photographs of reference stars taken during the eclipse with those taken at other times. However, consider that in order to corroborate general relativity, Eddington needed to show positional differences that corresponded to 0.01 millimeters on his photographs. Consider as well that this miniscule difference was affected by light's refraction in the earth's atmosphere and by perturbations to Eddington's optical equipment caused by temperature changes. Consider any number of the drudging details associated with the 1919 expedition—the transport of equipment to observation sites in Africa and Brazil, the cloud conditions on the day of the eclipse, the state of photography—and one recognizes that Eddington's empirical results were predi-

63. This quote has been attributed to Einstein. See, e.g., Famous Quotations Network, at <http://www.famous-quotations.com> (last visited June 13, 2005).

64. Einstein seems to have been first exposed to Duhem in 1909 or 1910 when he was at the University of Zurich, during which he was a neighbor and colleague of Duhem's German translator, Don Howard, *Einstein, Kant, and the Origins of Logical Empiricism, in LOGIC, LANGUAGE, AND THE STRUCTURE OF SCIENTIFIC THEORIES, PROCEEDINGS OF THE CARNAP-REICHENBACH CENTENNIAL, UNIVERSITY OF KONSTANZ, 21-24 MAY 1991*, at 91-98 (Wesley C. Salmon & Gereon Wolters eds., University of Pittsburgh Press 1994) [hereinafter Howard, *Einstein & Kant*]. See also Don Howard, *Einstein and Duhem*, 83 *SYNTHESE* 363 (1990) [hereinafter Howard, *Einstein & Duhem*].

65. Howard, *Einstein & Kant*, *supra* note 64.

66. 3 *THE COLLECTED PAPERS OF ALBERT EINSTEIN, THE SWISS YEARS: WRITINGS, 1909-1912* (M. Klein et al. eds., Princeton Univ. Press 1993), cited in *id.* at 92 (emphasis in original).

59. *Id.* ¶ 8.37.

60. *Id.* ¶¶ 8.42 to 8.47.

61. Louis Menand, *The Unpolitical Mind*, *NEW YORKER*, Aug. 30, 2004, at 92-96.

62. The account is given by Ilse Rosenthal-Schneider in *Reminiscences of Conversation With Einstein*, dated July 23, 1957, cited by HOLTON, *supra* note 2, at 254-55.

cated on panoplies of auxiliary hypotheses.⁶⁷ One gleans an appreciation for Einstein's view that scientific inference can only be conducted by sifting holistically through the congeries of data and hypotheses that constitute one's theory.

Einstein and Duhem would no doubt have seen Figure 1 (a portion of which is repeated below as Figure 2A) as an oversimplification and misrepresentation of scientific inference. Perhaps they might have found Figure 2B more acceptable: theory and evidence are part of an interrelated system based on auxiliary hypotheses. Conflicts between theory and evidence can therefore be accommodated through any number of indeterminate ways by modifying any of the auxiliary hypotheses. It follows that alternative theories can explain the same set of evidence. Einstein wrote:

[T]he *truth* of a theory can never be proven. For one never knows that even in the future no experience will be encountered that contradicts its consequences; and still other systems of thought are always conceivable that are capable of joining together the same given facts. If two theories are available, both of which are compatible with the given factual material, then there is no criterion for preferring the one or the other than the intuitive view of the researcher.⁶⁸

Figure 2A

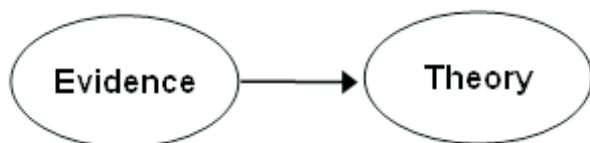
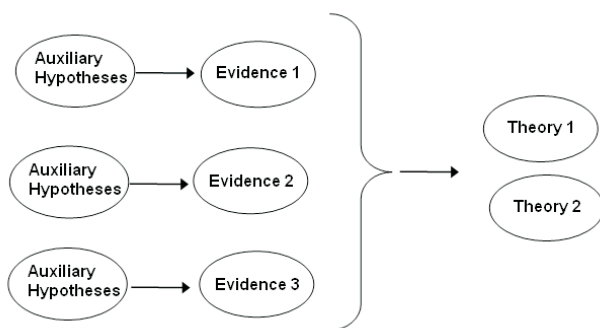


Figure 2B



Einstein's and Duhem's views on scientific inference have profound implications for the legal evaluation of scientific evidence. First, such evaluations may lead to entirely different results, depending upon whether one views scientific evidence through a holistic or atomistic prism. In its

written opinion, the district court in the *Joiner* case reviewed six of the experts' studies one by one to conclude that none was sufficient to show a link between PCBs and lung cancer. Contrariwise, the appellate court attempted to analyze all of the evidence taken together to determine whether the cumulative "weight of evidence" provided adequate support for the experts' opinion. In his dissenting Court opinion, Justice John Paul Stevens stated his preference for the latter approach, noting that it was a perfectly appropriate use of science, one that EPA uses to assess risks.⁶⁹

Secondly, evaluation of evidence will differ depending on whether one views theory and empiricism as categorically distinct—with the latter serving a superior evidentiary function—or whether one shares Einstein's and Duhem's view that a link exists between theory and observations that is mediated by auxiliary hypotheses. The former view was espoused by the appellants in *Tozzi v. Department of Health & Human Services*⁷⁰ who asserted that the government arbitrarily and capriciously classified dioxin as a known carcinogen. Tozzi argued that only epidemiological studies based on data drawn from human populations would provide sufficiently distinct causal arrows between dioxin and cancer; mechanistic studies based on an understanding of the cancer's etiology were unreliable.⁷¹ In matters of environmental policy, Naomi Oreskes argues for the latter view; Oreskes cautions against the—some might say deliberately—naïve expectation that with *just* the right amount of data and *just* the right empirical proof, the "correct" theory will emerge to guide us to the "correct" environmental policy.⁷²

Einstein refused to simplistically dichotomize scientific evidence into data and theory because he charily regarded two distinct types of uncertainties. He certainly recognized the nature of uncertain data—*aleatory uncertainty*—resulting from errors in empirical measurements or from the world's inherent stochasticity. But he also recognized that the sources of aleatory uncertainty are, to a degree, indeterminate. Because we do not know what we do not know—because of *epistemic uncertainty*—Einstein preferred to think of the theoretical and the empirical as complementary, albeit uncertain, pieces of information to gain insight into the universe. How to gain insight from such uncertain evidence has been a long-standing source of consternation, one that haunted a Presbyterian minister in the mid-18th century, Rev. Thomas Bayes.

III. Bayes and Inference Under Uncertainty

The reverend's intellectual milieu was permeated by musings about how "chances," i.e., probabilities, yielded insights about everything from games to God. Correspondence among Bayes and his contemporaries reveal that they applied their mathematical reasoning in efforts to comprehend the uncertainties underlying whist, billiards, and the existence of the Divine.

69. 522 U.S. at 153.

70. 271 F.3d 30, 32 ELR 20335 (D.C. Cir. 2001). Reasoning that the Department of Health and Human Services' authorizing statute allowed it to rely on *both* mechanistic and epidemiological studies, the court upheld the government's decision.

71. *Id.*

72. Naomi Oreskes, *Science and Public Policy: What's Proof Got to Do With It?*, 7 ENVTL. SCI. & POL'Y 369 (2004).

67. For a historical account of some of Eddington's methodological problems, see Ian McCausland, *Anomalies in the History of Relativity*, 13 J. SCI. EXPLORATION 271 (1999).

68. Howard, *Einstein & Duhem*, *supra* note 64, at 371 (emphasis in original).

Bayes was particularly interested in what kind of inferences could be drawn on the basis of imperfect evidence. For example, Bayes criticized his contemporary, the mathematician Thomas Simpson, for suggesting that the average of many observations was a better estimate of an astronomical body's location than a single observation. Bayes, the "Doubting Thomas,"⁷³ pointed out that this was not necessarily true in light of measurement bias:

Now that the errors arising from the imperfection of the instruments & the organs of sense should be reduced to nothing or next to nothing only by multiplying the number of observations seems to me extremely incredible. On the contrary the more observations you make with an imperfect instrument the more certain it seems to be that the error in your conclusion will be proportional to the imperfection of the instrument made use of.⁷⁴

To put it another way, if one were to flip a coin many times, one would expect the coin to come up heads 50% of the time, but only if the coin was fair. If the coin was fixed so that its outcome was biased but not guaranteed, how would one then determine this probability? This question goes to the heart of Bayes' major scholarly contribution. Bayes' intellectual predecessors approached games of chance by predicting the likeliest outcomes, given what one believed to be the probabilities of the game. Bayes agonized over the *inverse* issue, as much philosophical as it was mathematical: how should he update his beliefs based on new, but ambiguous, evidence?

Bayes' answer to this question is an approach that suggests how contemporary scientists—and legal analysts—might reconcile uncertain theory and evidence, particularly when two theories compete to explain the same body of evidence. The essence of the approach is to acknowledge that theoretical reliability is a matter of belief and that one can formally assess how one's beliefs should be updated based on unfolding evidence according to the following axiom:

$$\text{Prob}(\text{Theory}/\text{Evidence}) \propto \text{Prob}(\text{Evidence}/\text{Theory}) \text{Prob}(\text{Theory}).$$

In words, the probability of a theory being true, given the evidence that has been observed, is proportional to the probability of the evidence when the theory is true times the *prior* probability of the theory, i.e., one's belief in the theory absent any evidence. Bayes' genius was in realizing that there was a symmetry to evidence and theory: as one can evaluate the probability of the evidence, assuming that a theory is true, so can one evaluate the probabilities of two competing theories in the face of available evidence.

A. Bayes and the Prosecutor's Fallacy

One way to grasp the utility of Bayesianism is by thinking through what legal scholars call the *Prosecutor's Fallacy*, for which the Sally Clark murder case serves as a widely cited exemplar. A prosecution team in the United Kingdom charged Clark with murdering her two infant children—first in 1998 and then again in 1999. Clark insisted that both her children had succumbed to Sudden Infant

Death Syndrome (SIDS). In its counterargument, the prosecution relied heavily on expert testimony from pediatrician Roy Meadow, who asserted that two random crib deaths within a single family were so improbable—a 1 in 73 million chance—that foul play was the likelier cause. The prosecution won its case, primarily because of the argument summarized by what has come to be known as Meadow's Law: "One cot death is a tragedy, two is suspicious, and three is murder."⁷⁵

As with any juristic review of scientific evidence, the central challenge in the Clark case was to evaluate the probability of a theory (that SIDS caused the deaths), given the uncertain evidence. The fallacy in the prosecution's reasoning was to ignore what Einstein might have called this theory's auxiliary hypotheses. The fallacy was to treat the theory's uncertain components—the alternative hypotheses and the evidence—as *independent* rather than *conditional*.

Conditional probabilities are an important concept to Bayesians. Like Tom Stoppard's Guildenstern,⁷⁶ a Bayesian might initially believe that a given coin was fair. However, following a long string of coin flips that yielded heads, the Bayesian would begin to suspect the coin was biased. Before flipping her coin for the 86th time, the Bayesian might view the outcome of her next coin flip as dependent or conditioned upon knowledge gained from the previous 85 flips, adjusting upward her initial expectations of a 50% chance of heads.

Meadow estimated that the chance of SIDS-related death in a family like Clark's was 1 out of 8,500. Meadow then computed the probability of two SIDS-related deaths as 1/8,500 squared, or roughly, 1 in 73 million. The United Kingdom Royal Statistical Society's response to Meadow's thinking encapsulates how Bayesians would have approached the case:

[Meadow's] approach is, in general, statistically invalid. It would only be valid if SIDS cases arose independently within families . . . [T]here are very strong a priori reasons for supposing that the assumption [is] false. There may well be unknown genetic or environmental factors that predispose families to SIDS, so that a second case within the family becomes much more likely . . .

Aside from its invalidity, figures such as the 1 in 73 million are very easily misinterpreted. Some press reports at the time stated that this was the chance that the deaths of Sally Clark's two children were accidental. This . . . is a serious error of logic known as the Prosecutor's Fallacy. The jury needs to weigh up two competing explanations for the babies' deaths: SIDS or murder. . . . What matters is the relative likelihood of the deaths under each explanation, not just how unlikely they are under one explanation. . . .⁷⁷

73. "Doubting Thomas" refers to St. Thomas, the last one of the apostles to become convinced of Jesus' resurrection.

74. David R. Bellhouse, *The Reverend Thomas Bayes, FRS: A Biography to Celebrate the Tercentenary of His Birth*, 19 STAT. SCI. 3, 20 (2004).

75. Ray Hill, *Reflections on the Cot Death Cases*, SIGNIFICANCE, Mar. 2005, at 13.

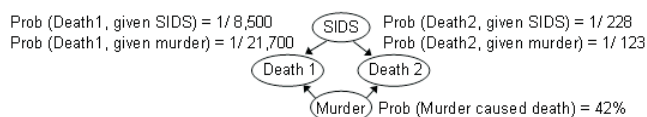
76. Tom Stoppard's play, *Rosencrantz and Guildenstern Are Dead* (Grove Press, Inc. 1967), opens with the title characters placing bets on the toss of a coin while on their way to visit their childhood friend Hamlet. Guildenstern is disturbed that the coin turns up heads 85 times in a row.

77. Press Release, Royal Statistical Society, Royal Statistical Society Concerned by Issues Raised in Sally Clark Case (Oct. 23, 2001), available at <http://www.rss.org.uk/docs/Royal%20Statistical%20Society.doc> (last visited June 1, 2005).

B. Bayesian Networks as an Aid to Inferential Logic

To wrest understanding from uncertainty, decisionmakers from various domains—economists, ecologists, financial analysts, computer scientists—have relied on *Bayesian networks* (BNets), which couple Bayesianism with a graphical representation of the relationship among probabilistic events. Figure 3 below features the Clark case, as told by way of a BNet. Three components make up the BNet: circles, causal arrows, and conditional probabilities. The circles, called nodes, represent those elements—the various hypotheses and evidence—that constitute a theory. The *qualitative* relationship among them is represented by arrows that connect the nodes in the direction of causality. The *quantitative* relationship among them is captured through an algorithm based on Baye’s axiom. In essence, the BNet serves as a schematic narrative of the Clark case, told in all its stochastic glory.

Figure 3



By considering all available information, the BNet treats Clark as the Royal Statistical Society recommended. It accepts Meadow’s premise that the likelihood of SIDS causing an infant’s death are 1 in 8,500, but complements this with information indicating that this likelihood increases to 1 in 228 for a second such death. It also relies on data suggesting that the probability of murder causing an infant’s death is an unlikely 1 in 21,700, which increases to 1 in 123 for a second such death.⁷⁸ Therefore, while both SIDS and murder are unlikely events, murder is the more unlikely of the two, and SIDS more likely caused the death of the two Clark children.⁷⁹

The beauty of BNets lies in their explanatory power: observations about any node generates knowledge about all other nodes, providing one with a tool to draw transparent, rational inferences in a probabilistic world. Clearly, these inferences depend a great deal on a BNet’s structure and underlying probabilities, the characterization about which two reasonable people might differ. But the point of using BNets is not freedom from uncertainty, but rather, *high-information rationality*. One could disagree with any element in the analysis presented above, but this is precisely the point of high-information rationality. It provides a level of transparency that facilitates discussion of a theory’s underlying basis.

78. These data were taken from Ray Hill, *Multiple Sudden Infant Deaths—Coincidence or Beyond Coincidence?*, 18 PEDIATRIC & PERINATAL EPIDEMIOLOGY 320-26 (2004).

79. The BNets featured in this Article, with the exception of the Borsuk model, were developed using the software BNet Builder, developed by Charles River Analytics, Inc.

C. Applying Bayesianism to the Japanese Varietal Case

Consider once again the WTO’s *Japanese Varietal* case in the light of Bayesian thought. The gravamen in the *Japanese Varietal* case was whether U.S. fumigation effectively reduced Japan’s risk of codling moth infestation. As the United States pointed out, all scientific evidence before the WTO panel was pertinent only in “the contributions that (the evidence) made to scientists’ conclusions about the fumigant dosage”⁸⁰ To put it in Bayesian terms, the panel needed to determine the probability of the hypothesis—that U.S. fumigation met Japan’s safety levels—given the indeterminate evidence.

Figure 4A

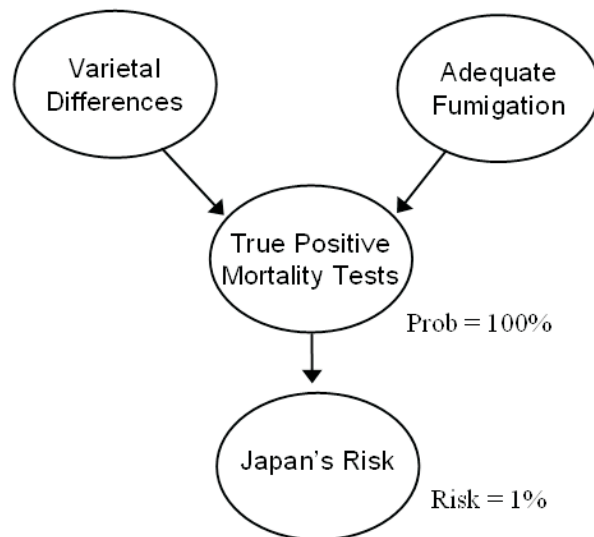
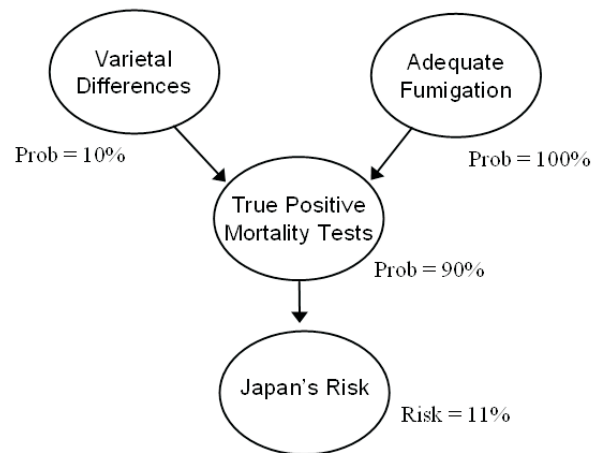


Figure 4B



Figures 4A and 4B present the *Japanese Varietal* case as a BNet composed of uncertain evidence: *varietal differences*

80. *Japanese Varietal* case, *supra* note 55, ¶ 4.66.

might (or might not) affect the efficacy of the *fumigant dose* to perhaps (or perhaps not) influence the outcome of the *mortality test*, which (maybe) serves as an indicator of Japan's risk of codling moth. Both the U.S. and the WTO panel recognized that under international law, this risk level was a policy call within Japan's sovereign right; Japan could have even adopted a zero tolerance level for risk if it chose to do so. This risk level was never explicitly quantified in the *Japanese Varietal* case. However, given its insistence that fumigation result in an almost 100% mortality rate, it seems fair to assume that Japan established a fairly low tolerance for risk, which this Article assumes to be 1%.

As gleaned from Figure 4A, one can assure Japan of this 1% risk, i.e., $\text{Prob}(\text{Risk}) = 1\%$, level if one assumes that the mortality test results were certain and non-stochastic, i.e., $\text{Prob}(\text{True Positive Mortality Tests}) = 100\%$. Making this assumption buffers Japan's 1% risk level from all upstream uncertainties.

However, if one acknowledges that the mortality test results depend on the interplay of uncertain factors and that their interpretation is therefore uncertain, this risk level rises precipitously to 11%. As indicated by Figure 4B, *even if* one were to assume conservative probabilities that favor the WTO panel's ultimate disposition of the *Japanese Varietal* case—a 100% probability that the fumigation dose is adequate and a 10% probability that there are biologically significant varietal differences—the risk to Japan rises far above the 1% level which, as a matter of international law, Japan had the right to set.

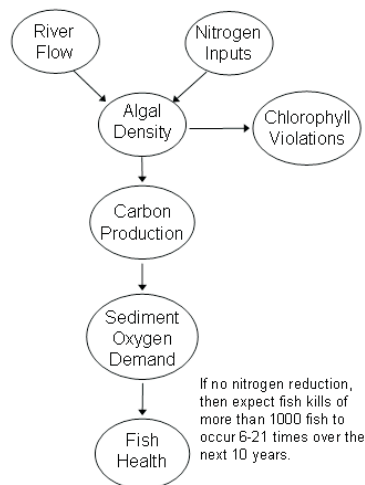
D. An Exemplar of High-Information Rationality in a Regulatory Context

In the face of unavoidable uncertainty, Oreskes has argued that science can never provide the level of proof for which self-proclaimed environmental skeptics clamor because scientific proof is rarely what is at stake in contested environmental issues.⁸¹ When a scientific basis is tendered to support a regulatory decision, commentators such as Prof. Wendy Wagner have accused EPA of engaging in a "science charade": decisions based on policy calls are sometimes rationalized on scientific grounds because the courts defer more to the Agency when it successfully wraps decisions within the mantle of science.⁸² To reconcile this tension between unavoidable—or worse, contrived—uncertainty and obfuscatory science, this author has argued elsewhere that the appropriate policy response to uncertainty is not certitude, but transparency.⁸³ In an exemplar of high-information rationality that managed to deal intelligently with uncertainty in a regulatory context, Mark Borsuk and others developed a BNet, a simplified version of which appears in Figure 5, to help decisionmakers assess a state legislation's impact on the water quality.⁸⁴

In response to public concern over water quality, the North Carolina legislature in 1998 mandated a 30% reduc-

tion in nitrogen load.⁸⁵ By eliciting the concerns of local stakeholders, Borsuk and his colleagues first derived a list of attributes—fish health, algae levels, dissolved oxygen—that were deemed most critical. They then used a BNet to relate these attributes to the pollutants—nitrogen and chlorophyll levels—for which North Carolina imposed regulatory limits.⁸⁶

Figure 5



The transparency of the Borsuk model manifests itself at multiple levels. First, nodes and arrows serve as a graphical narrative to help stakeholders understand the environmental system: nitrogen loadings stimulate algal growth; algae die and are consumed by bacteria, a process that uses up dissolved oxygen; low oxygen levels kill fish directly or indirectly by making fish susceptible to disease.⁸⁷ Second, conditional probabilities allow decisionmakers to communicate the underlying beliefs that inform their policy calls: assuming a baseline scenario of no nitrogen reduction (the likelihood of which one can assign a value), then North Carolina's ambient concentration limit for chlorophyll will likely be exceeded between 9.8% and 18.8% (given a 90% confidence interval) of the time, and one would expect fish kills exceeding 1,000 fish to occur 6 to 21 times (given a 90% confidence interval) over the next 10 years.⁸⁸ Third, the Borsuk model makes no pretense of omniscience; in light of imperfect information, the conditional probabilities and the functional relationships relating different nodes were based on an evidentiary mix of empirical studies, mechanistic models, expert opinion, and policy calls, and the Borsuk model communicates how this amalgam of uncertain information was used.⁸⁹ One may disagree with the model's version of reality, but one knows the structure of that reality, how it came about, the degrees of belief underlying the structural components, and whence they came.

81. Oreskes, *supra* note 72.

82. Wendy E. Wagner, *The Science Charade in Toxic Risk Regulation*, 95 COLUM. L. REV. 1613 (1995).

83. Pasky Pascual, *Guest Perspective, Building the Black Box Out of Plexiglass*, RISK POL'Y REP., Feb. 17, 2004, at 29-30.

84. Mark Borsuk et al., *Stakeholder Values and Scientific Modeling in the Neuse River Watershed*, 10 GROUP DECISION & NEGOTIATION 355-73 (2001).

85. *Id.*

86. *Id.*

87. *Id.*

88. Mark Borsuk et al., *A Bayesian Network of Eutrophication Models for Synthesis, Prediction, and Uncertain Analysis*, 173 ECOLOGICAL MODELING 219-39 (2004).

89. *Id.*

IV. Conclusion

Environmental policymaking is often guided by economic notions of efficiency—by the notion that we should make rational choices that balance the costs and benefits of economic activity and environmental protection. The economist Herbert Simon coined the term *bounded rationality* to describe those situations in which rational decisionmakers reach inefficient results because epistemic uncertainty blinds them to relevant exogenous events, available alternatives, and future consequences.⁹⁰ In a delusional pursuit of efficiency, we may be tempted to postpone decisions until we have all the pertinent scientific evidence before us. But epistemic uncertainty is ever-present, rationality is inevitably bounded, and gathering information can be costly—both in terms of financial resources for additional research and of environmental ills that persist while we delay decisions. It is therefore optimal in these

situations to be less than fully informed and to tolerate some degree of uncertainty.⁹¹

It is one thing to tolerate uncertainty and quite another to disregard it. As the *Japanese Varietal* case suggests, failing to formally account for uncertainty's role can lead to possibly erroneous legal decisions. By using Bayesian inference, policymakers—governmental as well as nongovernmental entities—can transparently acknowledge their theoretical and empirical limitations and can communicate the effects of choices they make in certainty's absence.

In her search for intelligent life in the universe, Lily Tomlin described reality as a “collective hunch.”⁹² In the face of environmental risks about which—for epistemic and stochastic reasons—we can never be certain, it would behoove all of us to forego the illusory pursuit of “slam-dunk,” empirical proof and proceed—transparently, prudently—with environmental solutions based on the collective hunch that the best available evidence can bring us.

90. Herbert A. Simon, Rational Decisionmaking in Business Organizations, Nobel Memorial Lecture (1978).

91. George J. Stigler, *The Economics of Information*, 69 J. POL. ECON. 213-25 (1961).

92. JANE WAGNER, *THE SEARCH FOR SIGNS OF INTELLIGENT LIFE IN THE UNIVERSE* (First Perennial Library ed. 1987).