

Into the Jungle: Environmental Decision-Making Under Uncertainty

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Policymaking has never been a simple art form with clear-cut solutions. Although empirical research and quantitative data analysis techniques play pivotal roles in policy formulation, unknown factors can counteract the effectiveness of policies. While the observation that uncertainty is endemic to policymaking is not new, it is a particularly important issue in macro-environmental economic analysis because of the complexity of ecosystems – every environment is unique, and, therefore, must be treated differently. In this sense, the conventional forecasting techniques that policymakers have largely depended on are now becoming obsolete. Due to the magnitude of uncertainty in environmental policymaking, namely the dynamic relationship between the physical and social environment, environmental decision-making requires improved strategies to increase social welfare.

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While even the most advanced economic models are incomplete, they are still quintessential tools for establishing a degree of objectivity in an inherently subjective realm of decision-making. In order to enhance the predictive value of these models, they ought to be augmented with quantified estimates of uncertainty. In this way, policymakers will have a better understanding of the range of feasible scenarios that may result from a given policy. Legislation like the United States Environmental Protection Agency's (EPA) Clean Air Act Amendments (CAAA) are prime examples of policies that would benefit immensely from built-in estimates of uncertainty. While this legislation is successful in some respects, integrating precise estimates of uncertainty would enable the EPA to more accurately anticipate the costs and benefits of regulation, resulting in the implementation of more effective policies. To better understand the magnitude that uncertainty estimates have on cost-benefit analyses, I tested the EPA's model for the 1990 CAAA. Consistent with intuition and economic literature, my findings indicate that uncertainty has an instrumental effect on the EPA's predicted costs and benefits [1,2,3]. Undoubtedly, there will be many

more environmental policies in the upcoming years. Hence, in order to ensure that social welfare is maximized, policymakers would benefit by complementing their models and forecasts with quantified estimates of uncertainty.

Environmental Policymaking & the Role of Uncertainty

A common criticism of risk analysis is that it cannot truly be quantified because each individual has a subjective interpretation of a risky versus safe decision. The stock market is a day-to-day example that illustrates peoples' varying degrees of risk tolerance. While some prefer to purchase stocks over bonds, and vice versa, others prefer to diversify. Likewise, there exist varying degrees of tolerance for environmental quality; individuals that thoroughly enjoy outdoor activities, like camping, will strongly favor public policies that maintain national parks and forests. Conflicting preferences give rise to an inevitable controversy in the literature; however, economics has resolved this dispute by distinguishing between two main environmental approaches: weak and strong sustainability.

Weak Sustainability

- There are substitutes for environmental quality (i.e. higher economic output);
- Society should only maintain current levels of environmental quality for future generations [4].

Strong Sustainability

- There are no environmental substitutes;
- Society should enhance the environment through preservation measures and relatively little resource extraction [5].

Undergirding the defense of weak sustainability is the concept of an individual having a marginal willingness to pay (MWTP) for environmental quality. MWTP refers to the cost that an average consumer is willing to pay, in this instance, for a higher level of environmental quality, at the margin. In this sense, decisions are not made in absolute terms, but rather in comparison with competing alternatives.

In context of the environment, numerous empirical studies have concluded that the public does not have a high marginal willingness to pay for environmental quality [6]. Of course, each country's MWTP varies, with low-income countries having the least. However, in general, individuals' marginal willingness to pay for improvements in environmental quality is, in fact, low enough to warrant the approach of weak sustainability. This realization is monumental for policymaking: attempts to completely eliminate particulate matter are futile because the costs far exceed the benefits, as determined by societies throughout the world. And, this conceptual result is intuitive. On one hand, the marginal cost of removing pollutants increases at an increasing rate; it is more expensive to remove the second ton of pollution than the first. On the other hand, the marginal benefit of decreased pollution increases at a decreasing rate; the sec-

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second ton of removed pollution satisfies people less than the first. As such, there exists an equilibrium point – a “steady state” – that is above the “no pollution level,” such that marginal benefits equal marginal costs. Because resources are scarce and tradeoffs have to be made, weak sustainability has acquired broad academic and political support due to its prudence and versatility over environmental absolutism.

In application of weak sustainability, it is possible to characterize the level of environmental risk that a society is willing to accept based on their MWTP for environmental amenities. For example, in the 1990s, North Carolina’s Cape Hatteras faced the challenge of soil erosion. One proposed solution was a beach renourishment project that would revitalize soil quality. It was determined that individuals that had visited the area and intended on visiting it again would be willing to pay an average of \$174.17 for the renourishment project [7]. While there are many more details underlying the various calculations, it is clear that economists are capable of monetizing individuals’ MWTP for environmental quality and risk. With these displayed preferences, the local government in the Cape Hatteras area had the necessary information to make an informed decision. Even though the most effective policy may not always be implemented, having access to information concerning individuals’ MWTP is a prerequisite to earnest debate about a policy, especially

in a democratic society that hinges on public approval.

While determining individuals’ willingness to pay for improvements in environmental quality is the main source of uncertainty, and indeed the most widely discussed, there are others:

- Measurement error: this results from the device used to collect data and its ability to convey the data to the researcher (i.e. the tracking quality of a receptor monitoring emissions);
- Incomplete data: often, not all data is recorded, resulting in a distorted and/or incomplete depiction of the ecological system;
- Length of the data record: the duration that a measuring device monitors a given event influences the amount of data captured for observation. Poor tracking systems implicate the reliability and timeliness of the observed data, making problem-solving much less precise;
- The method of analysis and presentation of data: data analysis systems are not uniform in their treatment of certain factors; thus, there is a tendency for programs to highlight certain factors at the expense of others. This inevitably influences the interpretation of the data, and eventual presentation of the data for policy action [8].

Undoubtedly, there are flaws in both the models and the tools that researchers apply to conduct cost-benefit valuation. Yet, their imperfection does not imply that economic modelling is not useful. In contrast, models are policymakers' best tool for policy valuation because they introduce objective data analysis techniques to mitigate the probability of bias. For this reason, developing more innovative models that integrate measurements of uncertainty will allow for the informed and optimal implementation of welfare-enhancing policy decisions.

Implications of Uncertainty in Environmental Policy

The wide array of significant logistical and forecasting challenges creates an acute need for the inclusion of uncertainty within every model formulation. Inaccurate predictions not only jeopardize the success of any given policy initiative, but more importantly, guarantee an array of long-term consequences, including a loss of public trust [9].

Unlike conventional goods and services, environmental goods have many overlapping attributes with public goods. By definition, a public good is non-rivalrous (one individual's consumption does not infringe on another individual's consumption) and non-excludable (it is either infeasible, or too expensive, to require payment from individuals for consumption). These two characteristics significantly reduce the incentive for the private market to invest and maintain the relevant goods and services, as demonstrated by ongoing environmental degradation. Because there is no market for preserving clean air, there is little disincentive for emitting pollution. For this reason, the public entrusts the government with the responsibility to maintain public goods, like environmental quality, in the most cost-effective and efficient way. The government may achieve this by empowering the private sector through the creation of new markets, incentives, and/or regulation when necessary. However, government agencies, like the EPA, have often failed to take into account critical factors that influence their models' predicted costs and benefits, resulting in gross over- and under- estimations that adversely affect the efficacy of their policies. For example, the most recent EPA Prospectus Report failed to acknowledge the effects of unemployment on their cost-benefit model. The implicit assumption was that the economy was operating under full employment [3]. This assumption was erroneous because the EPA presupposed that the labor market was in equilibrium, namely that the supply and demand for labor were equal. But, the reality is that unemployment has remained at 9% for the past three years [10]. While inaccuracy alone results in policy failure, citizens no longer have a legitimate reason to trust policymakers in demonstrated instances of blatantly false assumptions. Yet, a successful economic and environmental agenda requires the active support and participation of the public. Indeed, if the public does not approve of legislated actions, logistical implementation is futile [11].

But, the most direct and immediate effect of failing to recognize and act on uncertainty analyses is that policymakers grossly under- or over- estimate an initiative's forecasted costs. Due to the nature of public capital budgeting, enormous quantities of money are at stake and details are particularly important. When the EPA assumed the economy was in full employment, it implicitly assumed that the economy could



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absorb the cost of new regulations more easily, when in reality costs are amplified by higher levels of unemployment [12]. Hence, the EPA's judgment resulted in the imposition of costly regulation at a time when the economy was (and still is) in a very fragile state. While the merits of the regulation can be debated, the EPA unequivocally created a non-optimal outcome by failing to properly account for risk and uncertainty, namely the expected variation in unemployment levels. Hence, it is clear that understanding the sources of uncertainty and taking them into account in modelling and economic analysis is crucial.

Quantifying Uncertainty in the Clean Air Act Amendment

The Environmental Protection Agency (EPA) is required, under Section 812 of the 1990 Clean Air Act Amendments, to develop periodic reports for Congress to determine the benefits and costs resulting from reductions in particulate matter. Because of the legislation's importance, it serves as one of the best examples for demonstrating the value of uncertainty analysis in policymaking. The common approach to uncertainty estimation is the implementation of Monte Carlo simulations. By simulating thousands of repeated and arbitrary samples on a given model, this technique allows researchers to ascertain the effect that uncertainty has on expected costs and benefits. In this sense, some models may have significant variation in their costs and benefits (i.e. the outcome of the policy could be either very good or very bad), while others do not. In either case, it is vital for policymakers to understand the monetized consequences of variation.

In context of the CAAA analysis, the primary focus was the number of deaths avoided by reductions in particulate matter since that is the objective of the legislation. In brief, I created a series of Monte Carlo simulations using a uniform distribution for an established metric of relative risk. Using this, the uncertainty analysis indicates that there is a material effect on the expected costs and benefits of the CAAA, namely billions of dollars. In this sense, the assumptions that are made underlying the relationship between particulate matter and human health are fundamental to the outcome of the analysis. Simply put, if the models that policymakers are using have material variation in them – uncertainty regarding the subject of interest – then the Monte Carlo uncertainty estimation will demonstrate significant variation in the costs and benefits of the proposed policy. What complicates this situation even further is that researchers are often not aware of the implicit assumptions that are made. For example, systematic risk is omnipresent, but its effects are not always easily identifiable due to political and international uncertainty, in addition to other miscellaneous factors. In these instances, models may not even reflect a particular type of risk, making the entire procedure for uncertainty estimation of costs and benefits somewhat ineffective. Nonetheless, it is clear that the CAAA exhibits significant variation in costs and benefits due to the imprecise relationship between particulate matter and human health.

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Policy Recommendations for Decisions Amidst Uncertainty

While models become increasingly more complex in

order to accurately and effectively resolve concerns in environmental analysis, there is immense value concomitant with identifying sources of uncertainty. The case of the CAAA is merely one environmental economic example that highlights the effects of uncertainty in policy analysis. Indeed, one of the most valuable responsibilities of the EPA is its monitoring and regulation of particulate matter to ensure that national ambient air quality does not reach dangerous levels. That said, investigating the role of uncertainty in environmental decision-making allows for two overriding conclusions.

Firstly, tradeoffs are inevitable. By applying an economic analysis to the issue of environmental policy, it is clear that there are tradeoffs that policymakers must make. For example, one may invest billions of dollars for a small project in order to reduce risk to approximately zero, but is that a profitable investment? When conducting a cost-benefit study for evaluating a given project, policymakers must determine the level of risk that they – and society at large – are willing to adhere to as well as the relationship between risk and net benefits. For example, constructing a nuclear reactor necessitates nearly a complete understanding of relevant risks because the consequences of making an error are massive. Nonetheless, as stewards of the public's wealth, governing agencies should ensure that every environmental project takes into account accurate estimates of the public's marginal willingness to pay for environmental quality [6].

Secondly, details matter in modelling. Whether the assumptions are simple or complex, ranging from the choice of the model's error distribution to the estimate of marginal willingness to pay for varying levels of risk, details fundamentally influence the results of a model. For this reason, model assumptions form the foundation of economic and policy analysis, and, therefore, must be clearly stated and thoughtfully scrutinized.

While the challenges posed by uncertainty are omnipresent, its consequences can be mitigated through policymakers' use of advanced techniques that clearly quantify it in context of the level that society is willing to accept. Even though risk will never be completely eliminated, modelling the appropriate amount of risk allows policymakers to understand not only the locations of major risk sources, but also the extent to which it influences the policy evaluation. With this knowledge, policymakers can ensure that only the most effective and prudent policies are implemented to achieve the desired objectives. ■

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