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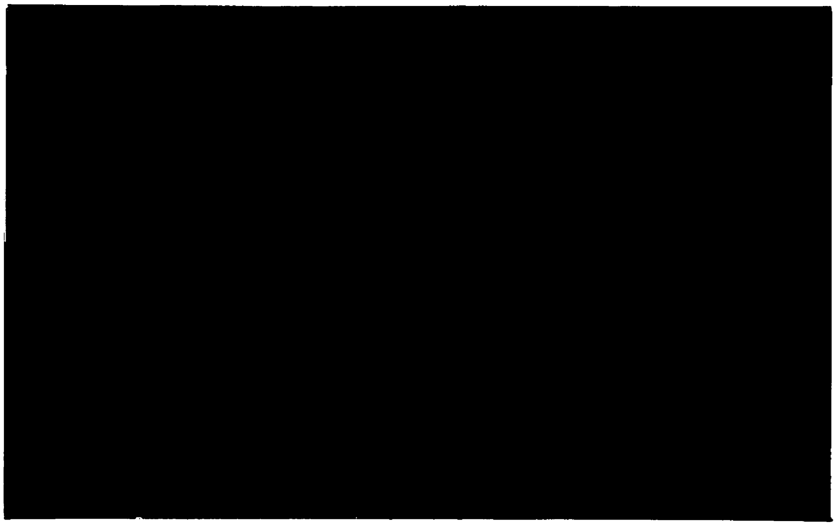

DETERMINATION OF REGIONAL ENVIRONMENTAL POLICY UNDER UNCERTAINTY: THEORY AND CASE STUDIES

by

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Determination of Regional Environmental Policy Under Uncertainty: Theory and Applications

Summary

Uncertainty about environmental effects is a key factor shaping environmental policy decisions. We review alternative approaches to taking uncertainty into account in formal decision methodologies, such as using "conservative" environmental impact estimates, expected utility using multiattribute decision analysis or revealed preference estimation, and the safety rules. Safety rules are more appealing in an empirical context and also correspond to the legal framework guiding environmental regulation. We then present three cases studies involving agricultural drainage and runoff that use the safety rule approach, focusing on the impact of incorporating uncertainty, modeling behavioral responses to policy, the role of heterogeneity in production and the relative importance of long run versus short run distributional effects.

DETERMINATION OF REGIONAL ENVIRONMENTAL POLICY UNDER UNCERTAINTY: THEORY AND CASE STUDIES

I. Introduction

Uncertainty is ubiquitous in environmental policy problems. One reason is simply the complexity typical of environmental problems. Adverse environmental effects typically have multiple causes and are mediated by a multitude of factors. Some of these factors are observable, others are not; thus, science can account for part of observed variations in environmental outcomes. In addition, scientific knowledge is usually limited: There are many things about adverse environmental effects we do not understand fully in a theoretical or empirical sense. For example, little is known about the long term effects of synthetic organic chemicals on human beings and other animal species of interest. The aim of policy is to prevent avoidable damage. At the same time, many adverse environmental effects are quite subtle and are therefore detectable in a reliable way only in cases of extreme damage. Thus, policy makers must generally rely on estimates of these adverse effects derived from indirect evidence that are heavily dependent on the assumptions made in simulation modeling, adding an extra layer of uncertainty. This preventive posture constrains policy makers to issue decisions in a timely manner as well, so that data collection is often not as thorough as might be desired.

The evidence suggests that the public is quite sensitive to these uncertainties. The work of psychologists indicates that the public perceives as more hazardous effects that have greater uncertainty associated with them (for a summary see Slovic, Fischoff and Lichtenstein [1980]). The recent furor over pesticide residues on foods (e.g., Alar on apples) bears this notion out. The best data available suggest that roughly 85 percent of fresh produce in the marketplace have no detectable residues and that almost all of the remaining cases involve residue levels that are extremely small and well below what the U.S. Environmental Protection Agency considers the maximum safe levels. Yet much of the U.S. public believes that pesticide residues on foods pose a serious threat to public health.

Policy makers appear to be quite sensitive to these uncertainties as well, in part because of public demands for taking uncertainty into account in making regulatory decisions, in part (perhaps) because mistakes are the most visible indicator of poor performance. Moreover, much of the legislative governing policy formulation directs decision makers to take uncertainty into account, in that they require policies to safeguard environmental quality with an adequate margin of safety.

To be truly useful in aiding policy determination, then, quantitative decision methodologies should take uncertainty into account explicitly. Cost-benefit or risk-benefit analyses based on expected values are inadequate in this regard, since they make no adjustment for uncertainty. This paper discusses the applicability of several approaches to uncertainty adjustments in quantitative decision methodologies, notably (1) cost-benefit analysis using "conservative" environmental damage estimates, as practiced by the U.S. Environmental Protection Agency and other state and federal regulatory agencies, (2) expected utility analyses, specifically multiattribute decision analysis, and (3) cost-benefit, risk-benefit or cost-efficiency analysis using safety rules. The safety rule approach is illustrated in the final section using problems of agricultural drainage and runoff management, specifically, river discharge of heavy-metal rich drainage water, groundwater contamination by agricultural pesticide use and shellfish contamination by livestock waste runoff.

II. Alternative Approaches to Uncertainty Adjustment

Consider a region in which a productive activity creates spillovers that are believed to have detrimental side effects. Irrigated agriculture in areas with perched water table problems, for example, generates drainage flows that are highly saline and may contain naturally occurring toxic elements such as selenium, arsenic and boron as well as residues of applied chemicals such as pesticides. Surface runoff typically contains fertilizer and pesticide residues as well. Disposal of surface and subsurface runoff into rivers, lakes or artificially created receiving waters may have adverse effects on vegetation, wildlife and human health. The degree to which these adverse effects occur will depend on random factors such as weather that govern the amount of receiving water, breakdown or immobilization of toxic chemicals, uptake of toxic chemicals by vegetation, wildlife population sizes and chemical uptake, and so on. Estimates of the causal linkages between disposal of runoff and these adverse effects will be influenced by errors in model specification and estimation due to incomplete knowledge about the causal processes and incomplete data on causal factors and will thus exhibit greater randomness than the effects themselves.

A decision methodology that takes uncertainty into account must thus begin with an environmental impact assessment that incorporates randomness explicitly. Two different approaches have been taken: (1) adjusting the estimates used to ensure that they contain a suitable margin for error and (2) building an explicitly probabilistic model of environmental impacts. The former has been standard operating procedure for the U.S. Environmental Protection Agency, the Food and Drug Administration, the Fish and Wildlife Service and other federal and state agencies. Its attraction is practicality: Margins for error can be taken from existing engineering rules of thumb. This advantage is its main weakness: Margins for error are derived in an arbitrary way, with no reference to the randomness appearing in the case at hand. These margins for error have no statistical basis and therefore no real meaning. Standardization of protocols for making estimates in this way does note ensure that the resulting estimates provide the same margin for error, because level of error (and inherent randomness) varies from case to case. In addition, margins for error derived in this way cannot be compared in different cases -- or even for different policies designed to address a single environmental impact -- in a rigorous way, making it difficult to evaluate policy alternatives. The latter approach is more difficult to implement. It is more subject to specification error, in the sense that omission of relevant factors can bias the estimates obtained. It does make it possible to ascribe statistical meaning to any adjustments for error, however, and thus makes alternative policy options comparable. It has been growing in popularity - at least for estimating human health risks -- for precisely this reason.

One implication of using probabilistic environmental impact assessments in decision making is that the separation of economic from environmental impact analysis cannot be maintained. It becomes important to incorporate the effects of alternative policy options into ecological models in a complex manner, since effects on estimated outcomes and on the randomness of these estimates are both important. Thus, a policy modeling process that is organically interdisciplinary is a necessity for implementing a more sophisticated approach to policy analysis.

A. *Cost-Benefit Analysis with "Conservative" Damage Estimates*

The approach taken by the U.S. Environmental Protection Agency and other regulatory agencies to adjusting for uncertainty about environmental damage is to make "conservative" estimates of potential damage under alternative policy scenarios that incorporate margins for error using engineering rules of thumb. These estimates are then provided as a rough form of "certainty-equivalent" data for cost-benefit or risk-benefit assessments. As I have argued elsewhere [Lichtenberg, 1990], this procedure does more than bias policy toward more stringent standards, as is intended. It may also bias the type of policy chosen in favor of setting stricter standards and against increased monitoring and enforcement, as the following example indicates.

Consider the case of a rice growing region located upstream of an urban area that uses river water for drinking. Suppose that rice growers use an herbicide believed to pose a human health risk. To control temperature, rice growers find it necessary to lower water levels in their fields. On infrequent occasions (say, a small fraction of the time α) this occurs shortly after applying the herbicide. For convenience, assume that all rice growers discharge simultaneously, so that exposure to the herbicide in drinking water, when it does occur, is always the same. Let the risk from exposure to the herbicide be R, expressed as the number of cases occurring in the population, so that urban residents face an expected health risk αR from exposure to the herbicide in their drinking water. One possible policy is to ban use of the herbicide. Let the social cost of banning this pesticide be C_B. An alternative policy is an enhanced monitoring program that detects the herbicide in time for the city water department to shut off intake until the contaminated water has passed downstream. Suppose that the monitoring program has a cost C_M. If only expected values matter, the pesticide should be banned as long as $C_B < C_M$. A "conservative" risk estimate of the type used by EPA treats the exceptionally high residue levels as normal occurrences and inflates the estimated risk to R. The cost per case avoided under a ban will be C_B/R, while the cost per case avoided under the monitoring program will remain $C_M/\alpha R$, so that the ban will be preferred as long as $C_B < C_M/\alpha$. Thus, whenever $C_M < C_B < C_M/\alpha$, the use of a "conservative" risk estimate will erroneously indicate the superiority of the ban.

B. Expected Utility and Multiattribute Decision Analysis

Expected utility has long been the preferred paradigm in economics for treating issues of choice under uncertainty. Recent criticisms of this approach have focused on its inability to capture some common aspects of individuals' actual choice behavior, that is, its performance as a descriptive model [Machina, 1987]. It remains attractive as a normative model, although some argue that it sets too strict a standard for rationality.

Empirical applications of expected utility depend on estimation of multiattribute utility functions describing preferences over relevant outcomes, to be combined with estimated outcome probabilities. Multiattribute utility functions can be estimated in two ways. The first involves elicitation of utility function parameters by questioning a crucial decision maker, the second utilizes the revealed preference approach to estimate the parameters from past decisions.

Elicitation of the preferences of a key decision maker has been used successfully in a number of business applications (see for example Keeney and Raiffa, 1976). Such an approach is problematic in a public policy context because it is not at all clear that any single decision maker can or should speak for the body politic.

An alternative is to derive information on public preferences by analyzing past decisions. Several studies have employed such a revealed preference approach to estimate the relative social welfare weights on producer welfare, consumer welfare and similar outcomes in cases involving agricultural policies, trade policies and highway construction (for a survey see Rausser, Lichtenberg and Lattimore [1983]).

A number of difficulties arise in connection with the use of this approach, especially for environmental policies. First, information on key variables involved in environmental policy decisions may not be available. Second, public preferences regarding policy outcomes such as environmental quality and agricultural income may change over time, so that past decisions are poor indicators of current welfare weights. For example, policy decisions in California have historically favored agriculture over urban income in cases such as water subsidies. More recent decisions appear to have reversed the situation, as evidenced by the defeat of the Peripheral Canal, the imposition of stringent standards for water quality from agricultural drainage and the imposition of strict pesticide use reporting requirements. Third, public preferences regarding policy outcomes may also vary from case to case, so that decisions from one situation will give erroneous information about preferences in another. Decisions about development of a Yosemite Valley or a Glen Canyon may have little bearing on situations involving agricultural drainage. Finally, theory and empirical evidences suggest that past decisions are in large measure determined by the relative political clout exercised by different sets of agents active in political markets. Revealed preference approaches thus tend to conflate public preferences and past relative political power. It is by no means clear that the parameters estimated in this way can or should be interpreted as expressions of true social preferences.

In sum, it appears that practical difficulties in deriving estimates of parameters expressing social preferences make application of the expected utility framework to public policy issues quite questionable.

C. Safety Rules

A third alternative is to assess tradeoffs between productivity losses and environmental quality using safety rules to adjust for uncertainty, as proposed by Lichtenberg and Zilberman [1988a]. Such an approach has several advantages. First, it is essentially a way of deriving a "conservative" estimate of risk that has formal statistical meaning. As a result, it is likely to be appealing to regulators and scientists accustomed to dealing with "conservative" estimates while bringing some rigor to the definition of "conservative", so that the criticisms raised above do not apply. Second, the safety rule approach conforms closely to the stricture contained in much environmental legislation that posits a goal of providing adequate protection of public health and/or the environment with a sufficient margin of safety, as well as corresponding to a "disaster avoidance" approach that is often felt to characterize bureaucratic decision making. In other words, it corresponds to public preference structures codified in law and in regulatory practice. Third, it can be thought of as an extension of the Baumol and Oates [1971] standards-and-charges approach to cases involving uncertainty. Finally, safety rules have been used in a variety of economic applications; they are well understood and have been shown to give good approximations of expected utility decisions in several empirical contexts [Thomson and Hazell, 1972].

This approach views the government as having two objectives: maximizing net market benefits and minimizing environmental damage. Net market benefits refers to the real incomes of producers and consumers derived from production and consumption of items affected by regulation, less government expenditures. To account for uncertainty about environmental damage estimates, the environmental quality objective is defined as an upper bound that is not exceeded with a certain degree of confidence, for example, the level below which environmental damage is estimated to fall, say, 95 percent of the time. This corresponds to the use of confidence intervals from classical statistics to adjust for uncertainty and addresses the need for allowing a margin for error raised in the legislation.

The tradeoffs between these two objectives can be estimated by solving a constrained optimization problem of maximizing net market benefits subject to the constraint on the environmental quality objective. Solving the problem while varying the constraint repeatedly yields a set of tradeoffs between market welfare and environmental quality and an associated set of policies.

Formally, let X be a vector indicating the extent of use of the policies to be considered. For example, X_1 may be the level of a tax on emissions of toxic elements into a body of water, X_2 may indicate the severity of restrictions on pesticide use, etc. Net market benefits are a function of these policies B(X). Environmental quality is similarly a function of these policies R(X) and is a random variable. Let R_0 be the desired environmental quality level and P be the desired margin for error. The optimization problem is

$$\max_{X} B(X)$$

$$\text{s.t. } \Pr\{R(X) < R_0\} > P.$$

The solution is an optimal policy vector $X^*(R_0,P)$ that is a function of the environmental quality target and the desired confidence level, which measures the margin for error. Substituting into the net market benefits function gives