A FRAMEWORK FOR EVALUATION OF PUBLIC POLICY ON THE USE OF AGRICULTURAL CHEMICALS

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Although the contribution of chemicals to increased agricultural production is generally recognized, the potentially hazardous side-effects of some of these chemicals are causing a reassessment of their use (National Research Council, 1972; Commoner, 1971; Garman, 1972). For rational public-policy choices to be made, simultaneous account needs to be taken of the contribution of chemicals to agricultural productivity and their potential hazards to various forms of life. The purpose of this paper is to suggest utility analysis as a framework for structuring a systematic decision-making process to determine public policy in this area.

The Nitrogen Fertilizer Case

An example will illustrate the institutional context within which public policy is often determined in issues of this type. The nitrate concentrations of water in certain streams in the state of Illinois have occasionally exceeded those specified by public health standards. The association of these events with increased use of chemical fertilizer containing nitrogen led to a proposed regulation to limit the quantities of chemical fertilizer used by farmers (Illinois Pollution Control Board, 1971). Under current legislation, authority to enact such a regulation is vested in the Illinois Pollution Control Board. This body conducted hearings and considered the testimony along with other evidence in making their decision, a process which, incidentally, took approximately four years and resulted in a recent (October 1975) decision that regulation of fertilizer use was not justified.

The evidence presented to the Board included two types of technical information: the impact of the proposed regulation on (a) the efficiency of the food production system (e.g. Parker, et al., 1974; Swanson, 1971; Taylor and Swanson, 1975; Taylor, 1975), and (b) health and environmental hazards (e.g. National Research Council 1972; Illinois Institute for Environmental Quality, 1974; U.S. Environmental Protection Agency, 1973). Information on the linkages between on-farm fertilizer use and water quality (Parker, et al., 1974) was also presented.

In additon to the technical information, various special interest groups presented their views and recommendations on the proposed regulation, largely in terms of impact on their constituencies. The estimated differential impact of the proposed regulation on various groups (farmers, consumers, environmentalists, etc.) is an important aspect of policy evaluation. One of the difficult tasks of the Board was to distinguish between that testimony which constituted technical information about the impact of the proposed regulation, and that which indicated the preferences of the various groups. Ideally, the decisions made by the Board reflect their judgment of what constitutes the "public interest", and this judgment will depend, in part, on their assessment of information from special interest groups.

Benefit-Cost Analysis

Conventional benefit-cost analysis would need substantial modification in order to be used in analysis of policy alternatives relating to the potential hazards of chemicals used in agriculture. The modifications required go beyond those often suggested (Sewell, 1973). Specific difficulties in using cost-benefit analysis in problems of this nature have been noted previously (Norgaard, 1975).

The crux of many decisions involving the use of hazardous materials lies in balancing the uncertainty of damage to human and animal life with the relatively certain benefits. The social value of the benefits from the use of agricultural chemicals may often be valued directly by the use of market prices or by some adjustment of these prices. However, the hazards cannot often be measured in monetary units.

Although benefit-cost analyses often handle (though not rigorously) the adjustments of benefits and costs by discounting with a risk factor (e.g. Baecher et al., 1975; Hirshleifer and Shapiro, 1969), in the kinds of decisions we are dealing with here, the risk itself is the heart of the matter. (In the adjustment process the risk factor is usually assumed to depend on the standard deviation; this method ignores the fact that preference for risk may depend on more than the mean and standard deviation.) Thus, rather than viewing the choices in terms of conventional benefit-cost analysis, a "benefit-hazard" analysis may provide a better focus on the central issues for policy-makers.

It is also characteristic of these policy decisions that we have not only the problem of incorporating uncertainty into the analysis, but also that of aggregating estimates of different kinds of hazards (disease, death, etc.) to different forms of life. Thus, the public-policy decision framework should provide a means for analyzing and combining various hazards and benefits. In the following sections we present the elements of a framework that a group such as a Pollution Control Board might use in decision problems of the kind outlined. Even if the procedures suggested were not followed in detail, their consideration might lead to improved decision-making.

Utility Analysis

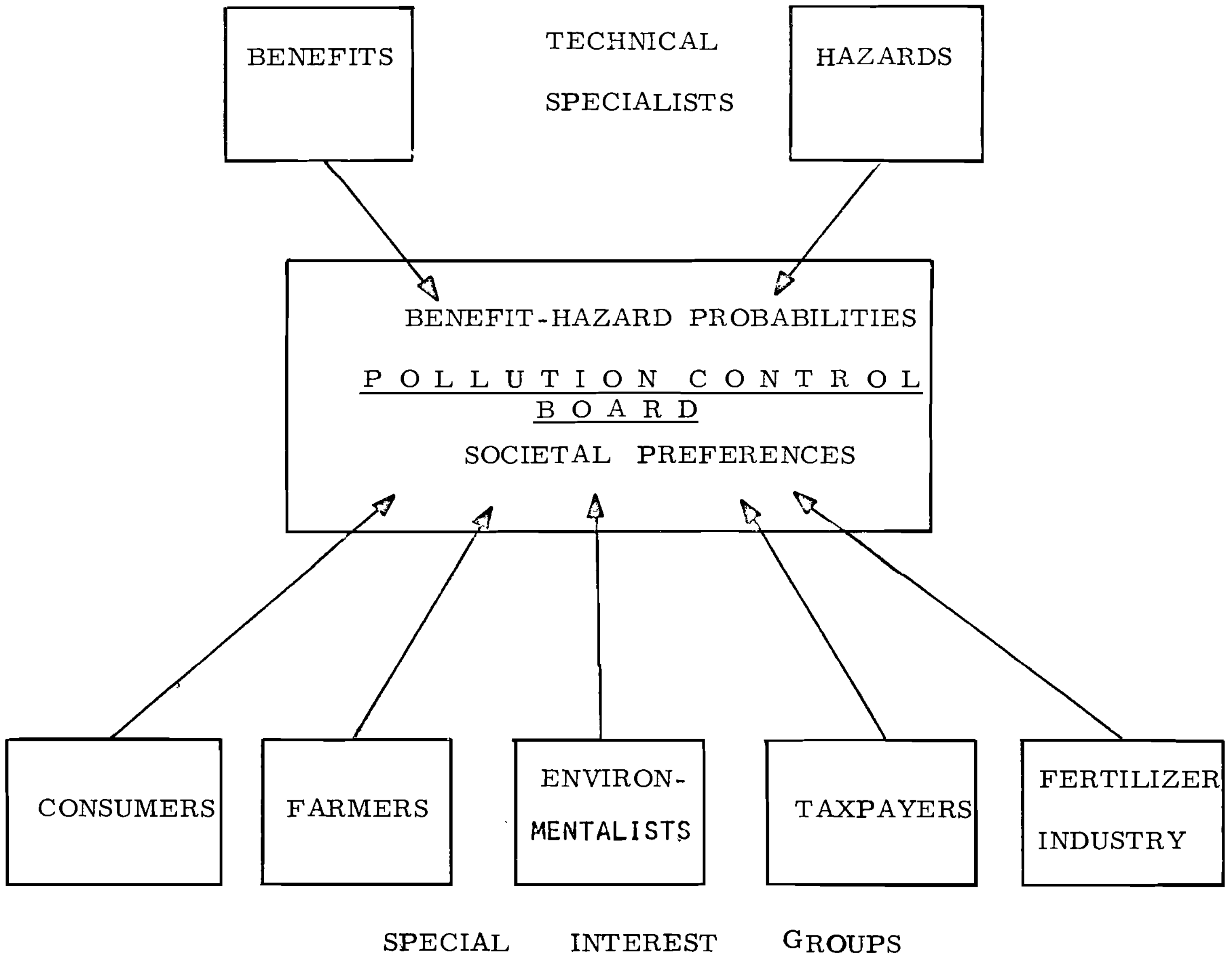
The analytic framework provided by utility theory is chosen because of the central role of uncertainty in decisions of the kind described. Two components of this framework may be identified. One deals with estimation of the relevant outcomes of various actions, and the other concerns the preferences of the decision-makers.

Estimation of Benefits and Hazards

In order to best use the analytic framework of utility analysis, it is necessary for benefits, B, in the form of efficiency of food production to be related in a probabilistic fashion to the quantity of agricultural chemicals, x, used in the production process. Similarly, the hazard, H (for expository purposes confined to a single species at a specified location and point in time) from such use of chemicals must be related to the level of x in probabilistic terms.

During a hearing, expert witnesses, one set concerned with benefits and another with hazards, might be required to present evidence (Figure 1) on the structure of probability distributions. Information in this form would facilitate communication and permit the analysis suggested below. Normally, one would expect witnesses to specify no more than the mean and the variance of B or H as a function of x, and possibly the family of the distribution. The Board might assist witnesses in preparing their testimony to facilitate subsequent analysis by Board members. The estimates of the probability distributions of B and H, expressed as functions of x, would then be combined by the Board into a joint density function, which we write as $p(B,H|x)$.

Figure 1. SOURCES OF INFORMATION FOR BENEFIT - HAZARD DECISIONS



The problem is how the uncertainty can be rigorously incorporated in the analysis. A well-chosen objective function on B and H is required. It would be convenient if the expected value of the objective function could serve as the guide for decision-making. Fortunately, the expected value is what should be maximized in the case of the von Neumann - Morgenstern utility function (Friedman and Savage, 1952; Pratt, et al., 1965). The assessment and use of these functions depends on whether certain axioms are satisfied (Baecher, et al., 1975; Pratt et al., 1965). It is reasonable to expect that they would be satisfied in most rational decision-making problems of the type we are considering; the mathematical problem is to maximize with respect to x,

$$\iint U(B,H)p(B,H|x)dBdH \quad ,$$

where U(B,H) is the utility function over B and H. (Standard calculus techniques can be used to find the value of x that maximizes the integral. We assume that U(B,H) is an increasing function of people's preferences as reflected by the Board.) By following the above procedure, the uncertainties involved are taken into account in a systematic manner.

Assessment of Social Preference

Although, in principle, the Board members are selected because of their ability to represent the "public interest," it is likely in practice that each member will have a constituency. In any event, the perceptions of the societal preferences held by Board members before the hearings may be modified as a result of testimony from special interest groups (Figure 1), and provision should be made for such modification. (Several techniques are available to aid Board members in assessing their utility functions [Fishburn, 1967].)

While the exact values of these two utility functions, one for hazards and one for benefits, should be determined by an assessment, we can say something about their shape. They will often be of one of two forms: concave everywhere (Figure 2), or S-shaped (Figure 3). Concave everywhere corresponds to the situation where, when faced with (a) a lottery or (b) the expected value of the lottery, the expected value will be chosen (preferred). A concave function might be expected in the following case related to benefits. The level of agricultural chemical use affects the index of the cost of food (CF), a proxy for benefits. (Thus CF would replace B in the joint probability density function which relates hazards and benefits to levels of use of agricultural chemicals.) Suppose that a choice exists between an index value of 100 with certainty, or a 50% chance of an index value of 70 or 130 (Figure 2). A choice of the certain value of 100 would imply a concave shape for the utility function. The concave shape also corresponds to the case where, given the same mean, the situation with a lower variance will be preferred.

The S-shaped utility function exhibits different preference patterns over different ranges of hazards (Figure 3).

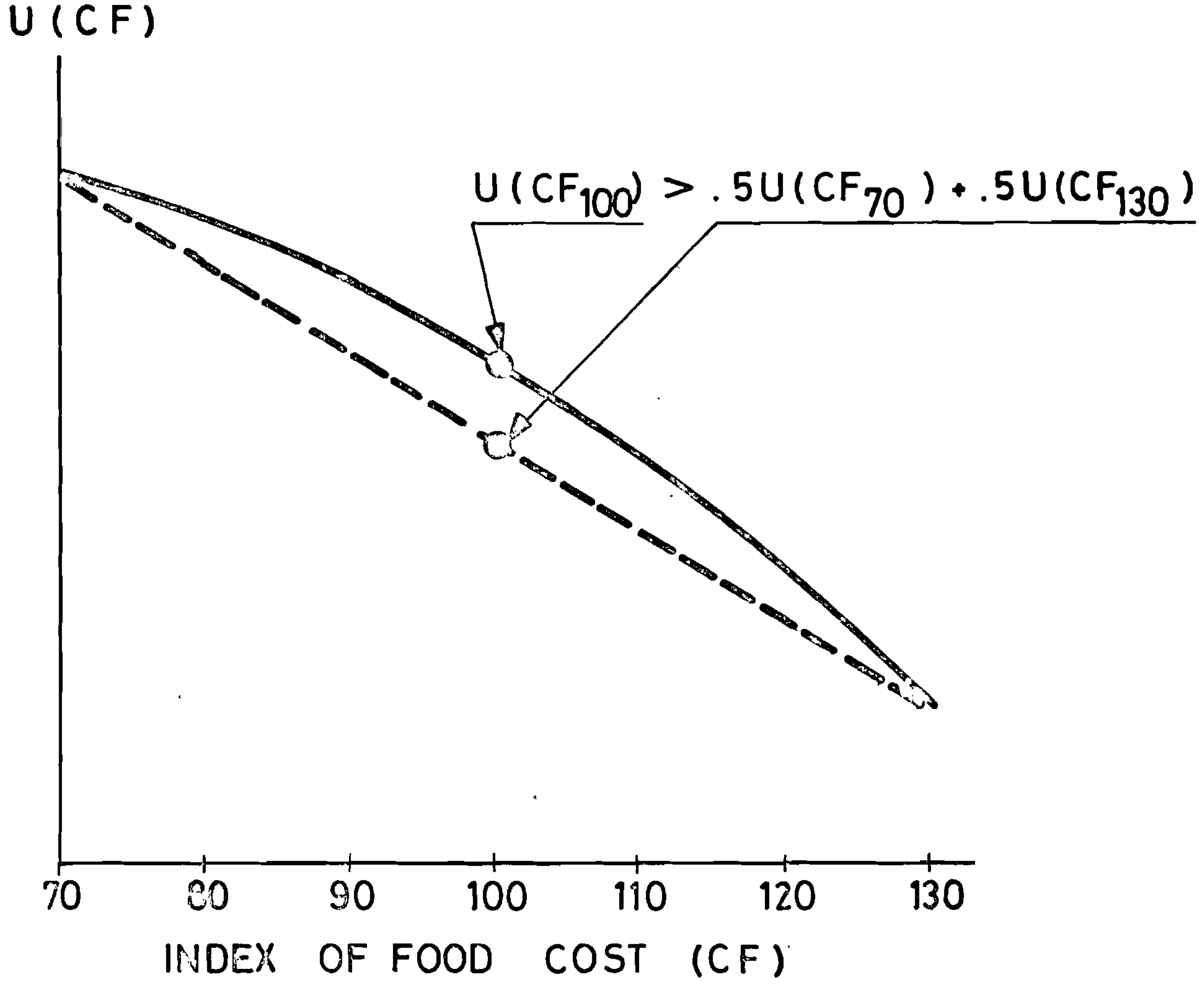


Figure 2. A CONCAVE UTILITY FUNCTION

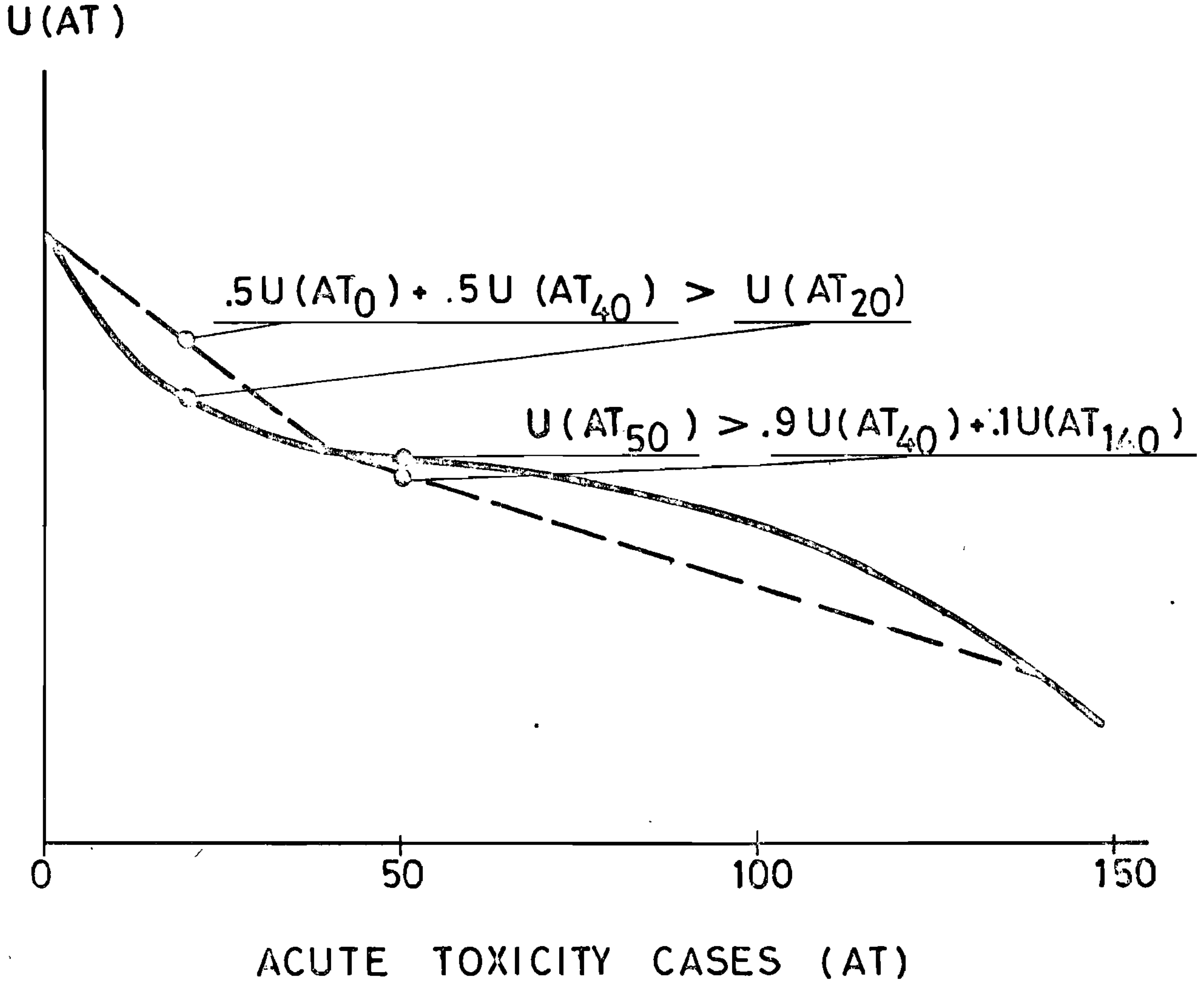


Figure 3. AN S-SHAPED UTILITY FUNCTION

This shape of function may characterize a situation in which there is a rather clearly defined level of hazards around which the decision-maker is more willing to take risks than he is at much higher hazard levels.

Suppose that in a given watershed the number of persons suffering acute toxicity (AT) from the use of agricultural chemicals are accepted as a proxy for hazards. (AT would then be substituted for H in the joint probability density function which relates hazards and benefits to levels of agricultural chemical use.) Consider the choice between (a) a 50% chance of having 40 persons suffering acute toxicity (judged to be a bad situation) and a 50% chance of no persons affected (a value certainly below that of a serious problem), and (b) prior knowledge that 20 persons will be affected, a value somewhat higher than the one where the situation is judged to deteriorate in terms of public response. In this case, the decision-maker might prefer the uncertain situation (where there is a good chance for a relatively satisfactory situation) to the certain one that is unsatisfactory. Such behavior would correspond to the convex portion of the utility function (upper portion of utility function in Figure 3).

The concave portion of the utility function in Figure 3 might correspond to the following situation. Suppose that in the same watershed the choice is between (a) a 10% chance of having 140 persons so affected and a 90% chance of having 40 persons affected, and (b) having 50 persons so affected for certain. A concave shape reflects that the certain alternative (50 persons) will be chosen (see the lower portion of the utility function in Figure 3).

Joint Utility Function

The two utility functions (one relating to CF and one to AT) developed by Board members would be discussed and combined into a joint utility function. Preferences of Board members can provide the logic for doing this, and special forms for this joint utility function (and those of higher dimension) have been described (Keeney, 1969).

Consideration of Multiple Hazards and Benefits

The utility analysis can be extended to situations where more than one hazard or benefit must be considered, or where impacts are unquantifiable. Most real-world evaluations of hazards of actions involving agricultural chemicals are not confined to a single species suffering a specific type of damage. Benefits may also take a variety of forms, including, for example, differential impact of changes in real cost of food on various income groups, impact on farm income, and the chemical industry, etc. On the other hand, some toxic substances may enter the food chain and create hazards in a wide variety of species and locations. (The unevenness of the quality of information concerning hazards should be reflected in the associated probability distributions.) The dynamics of the movement of the chemical substance, including changes in its form, as well as its location over periods of time, may well be the most important part of hazard evaluation. Thus, the relations among and between species, locations, and time periods must be recognized. These interrelations are of two types: one is technological--the relationship of impacts, both benefits and hazards, over time and space, and the other preferential--people's preference rankings over some impact depending on the values of other impacts. Aggregation of multiple risks in the context of the market and technical aspects of project appraisal have been addressed, for example, in a World Bank publication (Reutlinger, 1970). Work is in progress on how some of these preference patterns can be conveniently handled in a utility function framework (for example, preference patterns for impacts over time are being studied by Meyer [1969] and Bell [1975]).

Concluding Comments

In this paper we suggest that utility analysis be used as an organizing concept in making public-policy decisions involving benefits and hazards. We recognize that a Pollution Control Board may not be able to spend the time necessary to insure that the testimony they receive contains estimates of benefits and hazards in the form of a probability distribution function. Nevertheless, we view this as a first step toward an improved decision-making procedure, regardless of whether the formal estimation of utility functions follows the receipt of this information. Further, the delineation of information into (a) technical data dealing with outcomes of alternative actions, and (b) the preferences of society and its various groups suggests a systematic sequence in considering the information received. Again, this view of the testimony would increase the scope for improved procedures even if assessment of utility functions did not follow.

Finally, some experimentation should be done with actual assessment of utility functions in situations such as those described; this may operationally prove to be the most effective way to indicate the need for the kinds and forms of information indicated.

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