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# PROSPECTS AND LIMITATIONS OF OPERATIONS RESEARCH APPLICATIONS IN AGRICULTURE AND AGRICULTURAL POLICY

by

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# PROSPECTS AND LIMITATIONS OF OPERATIONS RESEARCH APPLICATIONS IN AGRICULTURE AND AGRICULTURAL POLICY

## 1. Introduction

Over the years, the inherent dynamic and potential variability of individual country and world agricultural food systems has become increasingly obvious. From resource utilization at the agricultural production level all the way to final consumption of food, a variety of economic, political, and technological forces has continued to evolve with pronounced structural implications. The qualitative implications of these forces are generally known and widely accepted, while the quantitative implications are far less certain.

Conventional wisdom characterizes the qualitative nature of food and agricultural systems by (i) highly inelastic aggregate demand, (ii) low-income elasticity of aggregate demand, (iii) rapid technological change, (iv) asset fixity, (v) atomistic structure of the production sector, (vi) the physical limitations imposed by life cycles of plant and animal growth, (vii) the growing nature of inventories, (viii) the climatic and weather uncertainties, (ix) labor immobility, and (x) the demand for and the propensity of governments to actively intervene in the private sector. These qualitative features result in dynamic paths which are uncertain and contain the potential for much instability.

In addition to the instability properties of agriculture and food systems, the dynamic characteristics are closely related to the "growing" inventory nature of many agricultural commodities. This feature is intimately tied to the life cycle of those commodities, with associated reproductive traits that influence production and supply and thus indirectly influence observed prices and valuations. For example, in the case of beef cattle, the growth cycle requires approximately three years after breeding before a new heifer can be raised to produce an offspring ultimately intended for slaughter. With almost all agricultural crops, the stage at which maturity occurs is largely biologically determined and can be influenced only mildly by economics and managerial decisions. The dynamic lags between a particular market change and the response to that change are thus influenced by biological and physical constraints as well as by the usual economic lags associated with inertia, uncertainty, and adjustment costs. The combination and interaction of these influences often result in both quantity and price cycles for many agricultural commodities.

The inherent dynamics, instabilities, and uncertainties in agriculture and food systems are often offered as justifications for governmental intervention (Blandford and Currie; Rausser and Stonehouse). The governmental policy frequently advanced for dealing with the inherent dynamics, instability, and uncertainty is inventory or buffer stocks. Other instruments of governmental intervention are trade oriented; they include export subsidies, export controls, foreign aid, import tariffs and quotas, concessional sales, and efforts to liberalize trade relations. Still other policies often applied to food and agricultural systems are chiefly oriented toward production and include regulation of output prices, quantity control, input controls, and input taxes and subsidies. In many countries a mixture of these policies is used by national governments in the hope of achieving self-sufficiency; in other countries, marketing boards and marketing orders attempt to influence private sector behavior; and in still other countries, especially planned economies, governments exercise direct control in both the domestic systems and international trade.

In assessing and evaluating such policies, a number of critical uncertainties arise for which little empirical evidence has been accumulated. For example, in the context of trade policy, is the paradigm offered by neoclassical economic theory sufficiently robust, or must governmental behavior and resulting trade distortions be introduced explicitly? In the case of buffer stock policies, the distribution of gains and losses from price stabilization can be drastically altered by various specifications of demand and supply relationships (Just). Moreover, the risk levels within various commodity systems, as well as the distribution of risk and its effects on behavior, have certainly not been precisely quantified. Much remains to be learned about the equity effects of such policies along both qualitative and quantitative dimensions. In general, to provide useful policy assessments, much remains to be learned about (a) the nature of structural change, (b) parameter variation, and (c) expectation formation patterns of various participants in food and agricultural systems.

In the above setting, the lack of dynamic instability and uncertainty measurements have resulted in the selection of policies based on intuition. But dynamic interactions and feedback effects are difficult, if not impossible, to capture on the basis of intuition alone. These effects make the evaluation and ranking of alternative policies a challenging task. We often find that what, in the short run, may seem to be an unqualified desirable policy or strategy from an intuitive standpoint may lead in the long run to undesirable, even deleterious, results.

Conventional wisdom has long held the view that instabilities can and should be confronted by conscious economic policies of national governments. However, due partly to the lack of empirical evidence on dynamic interactions and feedback effects in the evaluation process of alternative policies, instability and imperfections arise in the political-administrative system. As Linbeck argues, the most reasonable approach to policy evaluation is to treat explicitly instabilities and imperfections in both the private sector and the political-administrative sector. This view is substantiated by the historical performance of governmental intervention in agriculture and food commodity systems. At a minimum, differences between various economic forecasts often depend less on the internal functioning of the private sector than on different assumptions of future policies.

Little empirical evidence, unfortunately, has been accumulated on the behavior and instability characteristics of the political-administrative system. The posture of many investigators analyzing this subject is that the specification of these relationships should be "positive" rather than "normative." As Linbeck notes, an eclectic approach is needed which combines proxies for "electability" with more idealistic variables such as producer and consumer welfare in the criterion function of governmental decision-makers. Such a positive approach is entirely consistent with the recent advancements in the theory of economic regulation (Stigler; Peltzman). Much of this literature is concerned with wealth redistributions through the regulatory process. As Peltzman notes, governmental policymakers have not adopted the recommendations of economists which are largely based on normative concepts of efficiency. Instead, his framework views the selection of policies on the basis of governmental policymakers arbitrating among interest groups in seeking to maximize their majority, i.e., their probability of election, reelection, or reappointment.

In the above setting, what is the role of modeling and operations research? To deal with the complexity of agricultural systems, their commodity components, and associated participant interactions, models have long been viewed as a potentially valuable aid to evaluating and forming policy strategies. Obviously, they provide the basis for generating quantitative forecasts and the means of evaluating the effects of alternative decisions or strategies under the direct control of policymakers. In essence, models of the system can offer a framework for conducting laboratory experiments without directly influencing the system. Since these experiments can be conducted with the model rather than the real system, potential mistakes that may result in costly consequences can often be avoided. Perhaps, one of the principal potential advantages of modeling is that it forces analysts or others interested in a particular system to be precise about their perceptions and to examine possible inconsistencies in those perceptions.

For agriculture and food systems or components thereof, many models have been constructed--some for descriptive purposes, some for explanatory or causal purposes, some for forecasting purposes, and others for the express purpose of decision analysis. The latter group of models is of direct interest to operations researchers. An examination of the anatomy of these models provides a basis for reaching the assessment that the potential for such efforts is largely unrealized.

As usually conceived, decision models involve controllable or decision and environmental (uncontrollable, exogenous) variables, performance measures, objective functions, and structures that relate the controllable and environmental variables to the performance measures entering the objective function. Model constructs of these problems are usually advanced in an optimizing mode, and the results obtained from such frameworks provide the basis for system policy prescriptions. As a consequence, efforts in the construction of decision-making models are concerned both with the implications of the optimizing solutions and the accuracy with which the model portrays the system.[1]

In considering the design of decision-making models in agricultural policy, the unfulfilled promise of modeling as an aid and support to policy analysis begins to assume shape. To be sure, the design should begin with the specification of the relevant decision-makers and the control or instrument variables that these decision-makers can manipulate. The relevant decision points and procedures for revising policy actions in the light of new information should also be determined at this early stage of the analysis. Unfortunately, these aspects of policy modeling are often neglected. However, the more challenging aspects of decision-model construction are:

(a) the specification, identification, estimation, and verification of criterion functions

(b) the specification, identification, estimation, and verification of constraint structures

(c) the application of solution algorithms and the design of operational implementation.

It is a basic premise of this paper that the successful implementation of operations research and agricultural policy can be achieved if, and only if, each of the challenges offered by (a), (b), and (c) is squarely addressed. The following sections of this paper deal with the prospects and limitations of a flexible operations research approach to (a), (b), and (c).

## 2. Criterion Functions

Much progress has been made on a conceptual front in specifying, identifying, and estimating criterion functions for general economic policy. It has been recognized on both normative and positive grounds that criterion functions based only on efficiency are inappropriate in operational applications. On a positive front, the work of Stigler and Peltzman has highlighted the growing disenchantment with the economic efficiency objective. They note that the political process is inconsistent with the dichotomous treatment of resource allocation and wealth distribution so beloved by welfare economists. Instead, they view governmental intervention as a political market for redistribution of wealth. On more normative grounds, recent advancements have operationalized the specification, identification, and assessment of multidimensional objective functions. Much of this work is summarized by Keeney and Raiffa.

In agricultural policy analysis, issues of equity are crucial and cannot be neglected. Unfortunately, there is no single widely accepted measure that can be included in an optimization model for the purpose of resolving equity issues. Due to this problem, many public sector planners have argued that this problem must be solved by a political process rather than by applying an optimization model (Brill). Brill argues that most public sector problems are characterized by a multitude of local optimum and noncomparable objectives—the common rubric problem. He goes on to argue that:

> "Parametric analysis would often be required to guarantee obtaining the best solution even if all objectives are known and quantified. In reality, however, it is impossible to capture all the important elements of planning problems within an optimization formulation, and truly optimal solutions are likely to lie in the inferior region of a multiple objective mathematical analysis instead of along the non-inferior frontier."

In light of the above criticism, once again we must return to the basic question: Can economists and operations researchers provide useful insights and assistance in resolving conflicts among multiple objectives? Can they provide intuition, insight, and understanding which supplement that of the decision-makers? In the case of many agricultural public agencies, the multiple objectives include such loosely defined measures as increased income of farmers, increased consumer's welfare, improved distribution of income, self-sufficiency, price stability, improvement in balance of payments, decreased public expenditures, stable flow of supply, and the like. In the face of such multiple concerns, the continued use of single attribute objective criterion functions will result in analyses which fail to deal with actual policy problems. Such an approach will assume an air of unreality that public decision-makers will rightly reject. Hence, if we are concerned with operational implementation, we have no recourse but to deal explicitly with multiple objective criterion functions. There is little doubt that there will be conflicts among the multiple objectives. The definition of a multidimensional objective function neither creates nor resolves such conflicts; instead, it identifies them. The identification of the conflicts is, of course, an important first step in their resolution.

As Steiner argues, however (p. 31):

> "If objectives were genuinely multidiminsional and not immediately comparable, some solution to the weighting problem is implicit or explicit in any choice and that solution reflects someone's value judgment. Put formally, we now accept in principle that the choice of the weights is itself an important dimension of the public interest. This choice is sometimes treated as a prior decision which controls public expenditure decisions (or at least should) and sometimes as a concurrent or joint decision—as an inseparable part of the process of choice."

As is well known, the noncomparability or common rubric problem of multiple objective functions can be dealt with by lexicographic ordering of certain objectives, treating some objectives as constraints, or as a vector maximization criterion. Keeney and Raiffa, however, argue persuasively that, if an analyst in a prescriptive mode is unable to resolve the common rubric problem, sufficient serious thought has not been exercised. In their prescriptive paradigm, the central aspects of choosing policies when faced with multiple objectives are how to define an appropriate measure of each objective and how to resolve conflicts among objectives. They enforce comparability among alternative objectives in terms of their contribution to utility. The resulting scalar measure has been defined as a multiattribute utility function. Construction of such functions involves (1) structuring the objectives; (2) defining performance measures or attributes for each objective; (3) assessing univariate utility functions over each attribute; (4) determining the independence relationships among various attributes, i.e., preferential, utility, or additive independence; (5) specifiying the functional form of the multiattribute utility function; and (6) measuring the scaling constants or weights associated with various attributes. Additive independence results in an additive multiattribute utility function, while preferential independence and utility independence result in a multiplicative multiattribute utility function. The critical problems in the application of this prescriptive approach revolve around consistent assessment of the univariate utility functions and the determination of the independence relationships among attributes. Considerable progress has been made on both these fronts; and, as the work of Keeney and Raiffa clearly demonstrates, the approach is operational.

In a more positive vein, revealed preference has been widely employed to determine the weights associated with various objectives. In the context of water resource policy, the work of Maass and Eckstein treats weights as being generated by the decision process. Both express the view that administrators and project analysts should not abrogate the weighting process and bury the choices within in a single measure of benefit. More recently, in the context of a U. S. agricultural policy problem, Rausser and Freebairn argue that it is both unnecessary and unrealistic to attempt to specify a unique or single-value criterion function. In the environment of public policymaking, the importance of the bargaining process and the resulting compromises between different political groups, the range of preferences of these groups, and the lack of an explicitly stated unambiguous value consensus provide the basis for the construction of several criterion functions. They argue that these functions should reflect the extreme viewpoints and preferences of various decision-makers actively involved in the policymaking process as well as the preference sets lying between these extremes. A parametric treatment of the resulting set of preferences would, of course, provide decision-makers with rational policy outcomes conditional on the representation of policy preferences. The results obtained from such an approach should contribute to the efficiency of the bargaining process in reaching a consensus; should serve each policymaker (i.e., each legislative member) individually; and should serve to make quantitative analysis based on historical data effective for many policymakers even though the composition of a legislative body might change.

The revealed preference approach, of course, imposes some rather restrictive assumptions. The mathematical form of the criterion function must be specified, the constraint structure must be empiricized, and rationality is assumed. Given this structure, past policy actions can be utilized to infer the weights or trade-offs among alternative objectives. This approach has been employed by Zusman in the examination of sugar policy and the Israeli dairy program. The cooperative game framework utilized by Zusman is both theoretically and empirically an elegant formulation of the political process.[2] To obtain an equilibrium solution, Zusman applies the assumption of additive utility to the Harsanyi-Nash cooperative solution to obtain a set of necessary conditions to which the revealed preference methodology can be applied. One of the more interesting aspects of the Zusman framework is that it enables quantification of power exertion of interest groups on public bureaucrats and the responsiveness of those bureaucrats to the exertion of such power. This approach presumes that interest group power issues are settled by the various groups, first dividing up whatever gains may accrue according to their relative strengths; power determines relative shares which neutralizes all antagonisms; and then, and only then, all interest groups strive jointly to maximize total gains. In operational applications of this approach, it is likely that the "cost of power" and "strength functions" are not well defined and that both measure "relative clout" of different groups rather than actual exertion of power.

Still another approach, based on the notion of revealed preference, is the excellent work of McFadden (1975, 1976). In his framework, discreet policy choices are examined; and the weightings in the criterion function are inferred from empirically determined "choice selection probabilities." The qualitative choice model is indeed a useful framework for ex post analysis of public bureaucrats' behavior.

How can the various approaches outlined above be synthesized to obtain a more operational and effective means of specifying, estimating, and verifying public policy criterion functions? The nature of the synthesis depends, of course, on the role or function of the economic or operations research analyst. For a staff analyst working in support of a particular agency or bureaucrat, the approach should involve an operational prescriptive framework. Either the multiattribute utility analysis of Keeney and Raiffa can be employed where policy preferences are determined from direct interviews of public decision-makers or a parametric analysis of alternative attributes can be used where feasible with preferences exercised directly by decision-makers.

For a social analyst working from a positive economic perspective, however, the most appropriate approach seems to be an integrative one which blends the Keeney and Raiffa, Rausser and Freebairn, and Zusman frameworks, recognizing the conceptual contributions of Downs, Stigler, and Peltzman. The key features of the latter conceptual frameworks are that the government is concerned with maximizing political support—the probability of reelection or, in the case of appointed officials, the probability of reappointment. Governmental bureaucrats are viewed as being interested primarily in citizens' votes and only secondarily in their welfare. What counts is not simply aggregate benefits and costs but, also, the distribution of benefits and costs among those who benefit from policy and those who lose. As in the Rausser and Freebairn and Zusman frameworks, interest groups play a major role in the determination of trade-offs and weights assigned to various objectives.

A principal limitation of the Keeney and Raiffa prescriptive approach is that it totally neglects the influence of interest groups and committee decision making. Its strengths, of course, are the assessment process and the explicit treatment of uncertainty. The limitations of the Zusman framework are the imposed additivity across individual attributes or performance measures and the difficulty of incorporating uncertainty. Its strengths are the explicit incorporation of interest groups, the costs of their acquiring power, and the associated strength functions. The limitations of the Rausser and Freebairn framework are its vague relationship with the Downs, Stigler, and Peltzman view and the structure on the influence of various interest groups. Its principal relate to the treatment of the common rubric problem via a set of criterion functions, ease of parametric examination of alternative weightings, and its possible influence in an actual bargaining process.[3]

As in the Rausser and Freebairn framework, we shall presume that there is a set of relevant criteria functions. Elements of this set differ in terms of alternative weighting structures. The structuring of performance measures or objectives follows the Keeney and Raiffa approach, with specific performance measures defined for each separately identified interest group. In addition, another performance measure may relate specifically to the governmental policymaker or policymaking body, i.e., reelectability, wealth, or income. For each performance measure or interest group, a univariate utility function is considered. These univariate utility functions are gauged by the perception of the governmental committee or decision-maker. Furthermore, utility or preferential independence can be admitted; and, thus, the multiplicative or interactive multiattribute utility function would result rather than the additive structure imposed by the Zusman framework. The Zusman framework and the conceptual work of Downs, Stigler, and Peltzman become crucial, however, in the determination of the "weights"[4] entering the multidimensional criterion function governing the trade-off among alternative individual attribute utilities. The weights may be viewed as functions of the "cost of power" a la Zusman; hence, consistent with the Zusman framework, the relationship between weights and the cost of power can be regarded as the "strength functions." In this sense the effects of exertion of power on trade-offs made by policymakers reflect the process of political interactions.

The above outline remains incomplete without explicit incorporation of the Downs, Stigler, and Peltzman concepts. These concepts can be introduced by specifying relationships between the costs of power for each interest group with the distribution of benefits derived from alternative policy settings and the distribution of costs across members of the interest group associated with effectively organizing the group to exert power. Hence, the complete framework requires a specification of the multiattribute utility function; the constraint structure which must decompose the system (under the influence of governmental policy) across interest groups as well as within interest groups; relationships between the "cost of power" and the "weights" for each performance measure related to specific interest groups; and functional relationships specifying as arguments for the cost of power the distribution of benefits derived from alternative policies and the costs of interest group organization. As demonstrated in Rausser and Lattimore, if governmental decision-makers are rational, the above framework can be employed to generate necessary conditions which, from past policy actions, can be used to compute the "weights." Introducing certain restrictions on the cost of power along with restrictions on the relationship of costs of power and the distribution of benefits and costs among members of a particular interest group allows the "weights" to be determined which, in turn, allows identification and estimation of the functional relationship between the cost of power, the distribution of benefits within interest groups, and the cost of effectively organizing such groups. This approach provides a complete revealed preference method for estimating the effects of power exertion on policy and for identifying the actual exertion of power. There is little doubt that a high payoff exists for approaches of this sort which integrate prescriptive with substantive positive analysis.[5]

## 3. Constraint Structure

To properly analyze agricultural policy, the theoretical framework for the constraint structure must be developed. This framework should capture the essential elements characterizing the behavior of agricultural firms and the principal properties of agricultural markets. Since the actual affecting of decisions is what operations research is all about, these frameworks must address (i) dynamic interactions, feedback, and linked effects and (ii) equity and efficiency effects. This requires an examination of the returns on both assets and activities and thus the need to treat explicitly both output and input markets. Failure to deal squarely with (i) and (ii) will clearly result in operations research analysis having little impact on the actual selection of policy.

In the context of agricultural production, one theoretical framework that offers the possibility of addressing (i) and (ii) is the so-called putty-clay model. This model, formulated by Salter and Johansen, admits the asset fixity and rapid technological change characteristics noted in the introductory section. It recognizes that technically embodied capital is available for adoption by farmers. Moreover, at least part of the "new" capital is indivisible ~~indivisible~~ which, in turn, leads to unequal degrees of returns to scale in using the new technology for large-scale versus small-scale producers. Particularly in the case of farm machinery, these capital goods are often specialized to the extent that their input-output ratios cannot be altered. Of course, prior to investment decisions, producers can select among alternative technologies (which might be described by conventional neoclassical production functions). But once the investment takes place, flexibility in output capacity and input-output relations for a particular operation is reduced.

The putty-clay approach suggests that the decision-making process of farmers consists of two stages: (1) the long-run choice of technique and (2) the short-run determination of output mix and output use, given the selected technique. A realistic and tractable approach is to assume that the farmer considers only a finite set of distinct production techniques. Therefore, the decision-making process of the farmer includes a mixture of discrete and continuous choices. For example, a farmer has to choose whether or not to purchase a new tractor; given this decision, he has to determine how many acres of wheat and how many acres of soybeans to plant. The putty-clay approach is designed to deal with capital goods that can be bought or sold but for which there is no effective market for services. On the other hand, there might be some capital goods whose services are bought and sold in markets. The services of these capital goods are treated by the farm like any other variable input.

Farmers' decisions are dependent on the nature of the markets in which they operate. Hence, to properly account for (i) and (ii), the characteristics of agricultural markets must be specified correctly in modeling farmers' behavior. Generally, the markets for agricultural products at the farm level are competitive, and farmers can be treated as price takers. But at the time of decisions, output prices are generally uncertain.

Input markets are often more complicated. Agricultural inputs can be categorized into two groups: durable and nondurable inputs. The durables include, inter alia, land, capital goods, financial capital, and human capital. Agricultural processes use service flows derived from the stock of these durable inputs. There are different types of market arrangements for the stocks and flows of services of these durables which must be recognized in modeling farmers' behavior. For example, the amount of land a farmer can utilize depends on the nature of the land markets in the economy. In some cases (especially in developing nations), the amount of land available for utilization to a farmer is fixed since there are no markets for the purchase or rental of land. In other cases there are no rental markets for land, and farmers can extend the amount of land only by purchasing additional land. In many countries, however, farmers can extend the land they utilize either by renting or by purchase of additional land. Different types of land rental arrangements may be used. In some situations, land is rented for a flat fee while in others sharecropping arrangements prevail. Another aspect which should be incorporated in modeling farm behavior is that land is not homogeneous; instead, it is composed of different qualities. Thus, the multitude of land qualities will result in a host of land and land rental markets.

Some of the essential elements of agricultural production, as well as the specific properties of agricultural inputs markets mentioned above, have not been introduced in models used for policy analysis in agriculture. A popular approach is to consider the effects of policy on a representative firm which is assumed to have a neoclassical production function. While representative-firm analysis is simple and easy to apply, it can yield misleading results since it ignores technology and farm size along with specific rigidities of the industry.

A far superior approach is to develop a formal model of an agricultural industry which considers individual responses as depending on the distribution of resources in policy analysis. Such a model can include all the essential ingredients mentioned above. Specifically, assume that an agricultural sector consists of I farms denoted by indexes, $i = 1, \ldots, I$. To reflect the distribution of farm size and land quality, let $L_i = (L_{i1}, \ldots, L_{iJ})'$ represent acreage endowments of qualities $j = 1, \ldots, J$ owned by farm i at the beginning of a production period. Before implementing production decisions, the farmer may choose either to buy additional land or to sell existing land. Thus, let $\Delta L_i = (\Delta L_{i1}, \ldots, \Delta L_{iJ})'$ be a vector representing the change in ownership of various land qualities ($\Delta L_{ij} > 0$ represents net purchases and $\Delta L_{ij} < 0$ represents net sales). In addition, the farmer may choose to augment his landholdings for the duration of the production period by renting additional land from external sources represented by $Z_i = (Z_{i1}, \ldots, Z_{iJ})$ where $Z_{ij} < 0$ corresponds to leasing some of his own land to another farmer.

In this context the vector $A_i$ of acreages of various qualities utilized by farm i in crop production must satisfy

$$0 \leq A_i \leq L_i + \Delta L_i + Z_i; \tag{1}$$

and, of course, the farmer can neither sell nor lease to another farmer more land than is actually owned:

$$\Delta L_i \geq -L_i \tag{2}$$

$$Z_i \geq -L_i - \Delta L_i. \tag{3}$$

To consider the distribution of capital stock and technology in the industry, suppose there are $S_0$ types of existing technologies in the industry and every farm's existing technology, $s_i^0$, may be classified into one of these types denoted by $s = 1, \ldots, S_0$. The technology type thus specifies the complete machinery complement, structures, etc. In addition, with the new production period, $S_1 - S_0$, new technologies become available. Following the putty-clay approach, a farm may continue operating with its existing technology or incur costs of investment $k_s$ in adopting a new technology s; $s = S_0 + 1, \ldots, S_1$ (for simplicity, assume $k_s = 0$ for $s = 1, \ldots, S_0$).[6] The cost of new technological investments attributable to the present production period (annualized cost) is thus $\gamma k_s$ where $\gamma$ reflects the annualized percentage of the investment cost, associated depreciation, deteriorating, etc.

Also, following the putty-clay assumption, each technology is associated with fixed input-output coefficients which may be arrayed in an E x J matrix $H_s$ where elements $H_{sej}$ denote the amount of variable input e required per acre of type j land using technology s. In addition, each technology is associated with a 1 x J vector of productivities, $y_s$, where elements $y_{sj}$ give the yield per acre on land of type j under technology s. Yields per acre are assumed to be random variables which depend on weather conditions, variable inputs, and other factors. Finally, each technology is associated with a linear capacity constraint, $\tilde{c}_s A_i \leq b_s$, which may be rewritten without loss of generality as

$$c_s A_i \leq 1 \tag{4}$$

where $c_s = (c_{s1}, \ldots, c_{sJ})$ is a 1 x J vector of constraint coefficients. For example, $1/c_{sj}$ represents the maximum amount of type j land that can be farmed with technology s (e.g., with machine sizes specified by technology s). In addition, the constraint implies that capacity utilization may be substituted proportionally among land types. Of course, realistically, capacity may be doubled by purchasing twice as much machinery, buildings, etc. (incurring investment costs $2k_s$); but this may be simply represented as an alternative technology $s' \neq s$.

Assuming a competitive industry, each farm regards its output price P and the vector of input prices $V = (V_1, \ldots, V_E)$ as given.[7] Thus, with technology s, total revenue from the sale of production is $Py_s A_i$, and variable costs of production (excluding rental expense) are $\mu_s A_i$ where $\mu_s = VH_s$ is a vector of average costs per acre. Suppose, also, that the land and rental markets are competitive with respect to 1 x J price vectors, $W = (W_1, \ldots, W_J)$ and $R = (R_1, \ldots, R_J)$, corresponding to the various land types. Thus, the net investment in new land is $W\Delta L_i$, and net rental expense is $RZ_i$.

Now further suppose each farmer expects land to appreciate and has a subjective distribution of land prices $W_i^*$ at the end of the production period. Capital gains on landholdings are thus given by $[W_i^* - (1 + \theta)W]\ (L_i' + \Delta L_i)$ where $\theta$ is the effective interest rate on the farmer's land investment (including opportunity cost on land held free of debt). Thus, capital gains are random variables the distributions of which can be derived from the distribution of $W_i^*$. Farmer i has a joint distribution for yields per acre under each technology and land prices at the end of the period. The cumulative subjective distribution function is denoted by $F_{si}\ (Y_s, W_i^*)$.

In the above context, suppose the farmer has a myopic objective for the present production period of maximizing his expected utility from total economic gains. The farmer's total gains are denoted by $\pi_{is}$ and consist of the sum of short-run profits less the cost of new capital investments attributable to the current period plus capital gains from land appreciation:

$$(5)\qquad \pi_i = (Py_s - \mu_s)\ A_i - RZ_i - \gamma k_s + [W_i^* - (1 + \theta)\ W]\ (L_i + \Delta L_i).$$

The utility function of the farmer is denoted by $U(\pi)$ (concave and twice differentiable) and the objective of the farmer is to maximize $EU(\pi)$ where E is the expectation operator.

Finally, given the nature of agricultural credit markets, assume that the industry does not have access to a perfect capital market. Suppose that farms have different credit lines available to them possibly depending on their equity, management, etc. Let $m_i$ represent the total funds available to farm i at the beginning of the production period including both internal liquidity and external credit. Then the new investment in land and alternative technologies must satisfy

$$(6)\qquad k_s + W\Delta L_i \le m_i.$$

The farmer's myopic decision problem thus becomes maximization of $E\,[U(\pi_i)]$ in (5) subject to the constraints in (1), (2), (3), (4), and (6). The farmer's decision involves choice of a production technology, the quantities of output and inputs including land rental, and land portfolio adjustment. For conceptual purposes, the decision problem may be broken into two stages. First, optimal production plans and land transactions can be determined by nonlinear programming for a given technology, i.e.,

$$(7) \qquad \max_{A_i, Z_i, \Delta L_i} EU(\pi_i)$$

subject to constraints (1), (2), (3), (4), and (6). Suppose the resulting decisions, which are functions of P, R, V, and W, are denoted by $A_i$, $Z_i$, and $\Delta L_i^*$, and let the resulting maximum under technology s be denoted by $\pi_i(s)$. The optimal technology is then found by maximizing over s,

$$(8) \qquad \max_{s \in \mathcal{S}_i} \pi_i(s)$$

where $\mathcal{S}_i = (0, \ldots, S_1)$ is the set of potential technology choices for farm i. Let the optimal technology choice from the problem in (7), which is also a function of prices P, R, V, and W, be denoted by $\eta_i^*$.

Given the above framework for each individual farm, the farm responses can be simply aggregated into market relationships. Although specific equilibrium conditions can also be developed for output and input markets, they are not given here explicitly for brevity (they may be found in Rausser, Zilberman, and Just).

While input and output prices are determined by the interaction of the agricultural sector with external forces from the rest of the economy, the prices and rental rates of land are determined internally. For example, for given input and output prices and given rental rates, an individual farm's demand for lands of various types (supply if negative) is $\Delta L_i^*(W)$ which is a function of land prices according to the above optimization problem. Supply is equal to demand for each type of land and equilibrium prevails in the industry only if

$$\sum_{i=1}^{I} \Delta L_i^* (W) = 0. \tag{9}$$

Similarly, the demand for rental land of various types (supply if negative) is given by $Z_i^*$ (R) for given prices of land, other inputs, and output. The rental markets are thus in equilibrium only if

$$\sum_{i=1}^{I} Z_i^* (R) = 0. \tag{10}$$

To treat the dynamics of the farming industry and the associated land markets, farm credit must be endogenized in the model. Farm credit generally depends on the farm debt-equity position since loans must be accompanied by sufficient down payments and/or collateral. In this case the availability of funds for investment $m_{it}$ at time t depends on cash on hand, $H_{it}$; the value of nonliquid assets, $N_{it}$; and outstanding debt, $B_{it}$:

$$m_{it} = m_i (H_{it}, N_{it}, B_{it}). \tag{11}$$

Letting $\varepsilon$ denote the rate of down-payment requirement on new investment, cash on hand can be used to finance an investment of $1/\varepsilon\ Y_{it}$ thus requiring an increase in debt of $(1 - \varepsilon)/\varepsilon(Y_{it})$. But also, existing equity, $N_{it} - B_{it}$, can be used as collateral in obtaining new loans. If $1 - \varepsilon$ is the rate at which funds can be borrowed against existing equity, then funds borrowed against equity can be used as a down payment to finance additional investment of $(1 - \varepsilon)/\varepsilon(N_{it} - B_{it})$ with debt increasing by $(1 - \varepsilon)\ (A_{it} - B_{it})$ on existing assets and by $(1 - \varepsilon)^2/\varepsilon(N_{it} - B_{it})$ on new assets. Thus, total funds available for investment are

$$m_{it} = \frac{1}{\varepsilon} H_{it} + \frac{1 - \varepsilon}{\varepsilon} (N_{it} - B_{it}). \tag{12}$$

The value of nonliquid assets may include the value of capital goods, stocks of grains, etc., in addition to land; but consideration of all such possibilities can be added as an obvious extension of the model and would only serve to complicate the present discussion. Thus, suppose the value of assets is simply the value of landholdings, $N_{it} = W'_t L_{it}$.

Cash on hand which can be used as a down payment for current investment includes cash left over from the previous production period after investment plus profits from production, less debt payments due and necessary living expenses, i.e.,

$$\begin{aligned} H_{it} = {} & \left( H_{i,t-1} - I_{\eta_{i,t-1}\eta_{i,t-2}}\, k_{\eta_{i,t-1}} - \Delta W'_{t-1}\, \Delta L_{i,t-1} + G_{i,t-1} \right) (1 + \theta) \\ & + \left( p_{t-1}\, Y_{\eta_{i,t-1}} - \mu_{\eta_{i,t-1}} \right)' A^u_{i,t-1} - \gamma B_{i,t-1} - r'_{t-1}\, Z_{i,t-1} - U_{i,t-1} \end{aligned} \tag{13}$$

where $\theta$ is the discount rate, $I_{ij} = 1$ if $i = j$ and $I_{ij} = 0$ otherwise; $G_{i,t}$ denotes new loans taken out in period t, and $U_{i,t-1}$ is the farmer's living expense for period $t - 1$ (given exogenously). The term $I_{\eta_{i,t-1}\eta_{i,t-2}}k_{\eta_{i,t-1}}$ is the investment associated with the new technology if a new technology were introduced in period $t - 1$; otherwise, it is zero. Of course, in optimization, one must impose the constraint, $H_{it} \geq 0$; i.e., cash on hand is nonnegative. Finally, the outstanding debt at time t follows the equation,

$$N_{it} = N_{i,t-1} + G_{i,t-1} - (\gamma - \theta) B_{i,t-1}, \quad (14)$$

since $\gamma - \theta$ represents the rate of amortization.

Combining these relationships (12)-(14) with the basic model in (1)-(10) provides a model of the farming industry with associated land and product markets where farmers operate myopically and technological change is imposed exogenously. In the context of this model, land price expectations can be specified either according to an adaptive expectations mechanism, an extrapolative expectations mechanism, or a rational expectations mechanism. Endogenizing land price expectations in this manner, the model becomes capable of explaining land appreciation and the associated role of product prices, production costs, technological developments, etc.

A more complete dynamic representation of the system requires formulation of the individual farmer choice alternatives as a dynamic optimization problem. The use of the myopic formulation is appealing, however, since it simplifies the analysis immensely and in most instances should capture the essential elements of the dynamic optimization criteria. Firm footing for the degree of approximation involved in the use of myopic formulations has been provided by Tesfatsion who has investigated the use of myopic economic decision rules in approximating the outcome of dynamic optimization problems. The degree of approximation is improved the smaller the uncertainty in the system and the higher the correlation among the gains of different periods. Note that in agriculture the latter correlation under each technique can be high indeed. Moreover, Tesfatsion finds that bounds for the approximation error can be expressed in terms of absolute risk aversion, variance of the stochastic element, and the marginal gain. The principal value of these important results is that they allow us to determine the nature of approximation for intermediate or myopic return functions to their global counterparts. In an operational setting, frequent use of such results can be very advantageous.

This conceptual framework suggested above for analyzing the behavior of an agricultural industry seems cumbersome, but it is tractable and has been applied both theoretically and empirically in emphasizing the importance of distributional effects of policy in agriculture. In a recent paper, Rausser, Zilberman, and Just have used this approach in its greatest applied generality thus far to theoretically analyze the diversion policies of the U. S. Food and Agriculture Act of 1977. These policies are designed to limit the aggregate production of crops in the United States by controlling the acreage devoted to the different crops. Participation in the diversion programs is voluntary, and the programs are defined by two instruments. One instrument is the diversion requirement, namely, the percentage of land controlled by a participant farmer that should be set aside and not utilized. The second instrument is the diversion payment—the incentive offered to participants. These two instruments are determined for each crop every year by the Secretary of Agriculture. The diversion payments vary among different regions of the country reflecting the variation in average land productivity in these regions. The first policy issue is the determination of the participation rate in the program as a function of the policy instruments and investigation of the characteristics of the participants in terms of technology, farm size, landownership, etc. The second policy issue relates to the distributional effects of the diversion programs. To attain these answers, the theoretical analysis investigates the effect of diversion programs on output prices, land rental fees and prices by land type or quality, and the quasi rent attributed to capital goods.

For the case of fixed technology, results show that the key determinant of compliance is the diversion payment per diversion acre and the minimum rental rate $\overline{R}$ (the rental rate of diverted land in case of some compliance). Moreover, it was found that an increase in the diversion payment $\tilde{P}$ tends to increase diversion (measured in acres diverted), while the impact of an increase in the diversion requirement, $1 - \omega$, on acreage diverted is more complex. In case of full compliance, an increase in the diversion requirement will increase diversion. However, in case of partial compliance, an increase in the diversion requirement tends to decrease total diversion. The latter result might be considered counterintuitive; however, note that, while an increase in the diversion requirement will increase the land diverted by each participating farm, it will also <u>reduce</u> the number of participants. Thus, the effect of the reduction in the number of participants on total diversion is greater than the effect of the increase in the diversion for each participant. Since the number of participants depends critically on the distribution of resources among farmers, the analysis demonstrates that distributional issues may be of critical importance in determining the overall effectiveness of agricultural policy.

The above framework is especially useful for modeling constraint structures which admit the adoption of new technologies by agricultural firms. Under risk neutrality, this possibility leads to the following optimal solution:

$$(15) \qquad \pi_i(s) = \phi_{1i} - (\gamma + \phi_{2i})\, k_s + \phi_{2i}\, W\, (L_i + \Delta L_i) \quad ,$$

where $\phi_{1i}$ denotes the shadow price of the capacity constraint, $\phi_{2i}$ the shadow price of the credit constraint, and $\gamma$ is as defined above. For this case, Rausser, Zilberman, and Just show that an increase in the diversion payment tends to discourage the adoption of new technologies which were previously feasible with existing credit sources but may encourage the adoption of new technology which was not previously feasible because of insufficient credit. When a reduction in diversion requirement increases rental rates, then adoption of feasible technology with larger capacity is discouraged; but adoption of technology for which credit was previously insufficient or for which capacity is smaller may be encouraged. Hence, diversion policies have three major effects on the adoption of new technology:

1. Reductions in utilized land tend to improve the marginal technology so that the opportunity gains from operation are reduced (at least when new technology increases capacity).
2. The increased returns through diversion payments tend to increase rental rates and land prices (although a tightening of diversion requirements may work in the opposite direction) in which case wealth increases, perhaps making some new technology affordable.
3. For the typical case of partial participation, the short-run effects of holding diversion requirement constant and increasing the diversion payments can be significantly different from the long-run effects.

The effects are particularly important in selecting actual policies. For example, a desire to reduce output and enhance farmers' income could lead to increased diversion payments for given diversion requirements which, in turn, would cause R/W to rise, thus reducing the shadow price of credit and making new investments more attractive.

The above results presume risk neutrality. Understanding the process of technological adoption, however, requires the explicit recognition of uncertainty and risk aversion. This is a major policy issue in both developed and developing countries.

Numerous approaches are available for appropriately characterizing the constraint structure under risk including the multiplicative risk framework (Sandmo); mean-variance formulation (Tobin, Markowitz, Freund); stochastic dominance (Hadar and Russel; Anderson, 1974a); safety-first frameworks (Roy, Telser, Kataoka, Roumasset); prospect theory (Kahneman and Tversky); and skewed distributions and moment-generating function frameworks (Rausser and Lattimore). Space precludes an assessment of each of these approaches; clearly, their relevance depends upon the problem under examination.

An application of the general framework (1)-(8), in the context of risk aversion and technological adoption, is presented in another paper of this volume by Just, Zilberman, and Rausser. Concentrating on agricultural development, they treat two major issues: barriers to adoption and distributional effects. Land markets are not considered because of their general inactivity in developing countries. Moreover, only two technologies are considered so as to provide sharp focus to some specific economic development issues.

In the Just et al. analysis, a number of implications of new technology are apparent which have been observed casually but which are not evident in representative firm models. Results show how adoption depends on the distribution of resources and thus how distributional considerations can explain different rates of adoption in different regions or countries. The framework also shows how income distribution is impacted by new technology and thus provides important necessary information for policy selection. Finally, by endogenizing product and input prices (including wage rates), the results show that the spread of incomes among individuals may either improve or worsen depending on the particular characteristics of the new technology. These types of considerations, which are of crucial policy importance, can generally not be made on the basis of either representative firm models or ordinary aggregate industry models.

## 4. Empirical Applications and Solution Algorithms

To be sure for agricultural policy analysis to be useful, accurate knowledge of how the agricultural economy works—fortified by reliable quantification of key relationships in the system—is a necessity. Awareness of values basic to what people want from the agricultural sector and from the political processes by which policy is made is also essential for meritorious work in political economy. The former relates to the specification and estimation of a constraint structure while the latter pertains to the criterion function. In each of these two areas, much of the research required is not properly viewed as policy analysis nor should it be; but most certainly policy analysis and prescription can make little of any progress without these two components.

Changes in the agricultural production structure—size of farm units, ownership, forward contracting, vertical relationships with nonagricultural firms, and the like—will continue to cause discontent among entrepreneurs participating in this sector and to raise issues about efficiency and the distribution of power in the economy. This, of course, raises questions bearing on personal income distribution, which we have argued throughout this paper are indeed important but are notably difficult to resolve. There are many approaches here as there are value judgments. One approach advocated by

George Brandow is for economist to forthrightly adopt A. C. Pigou's proposition that a narrowing of the personal distribution of income increases welfare if the national product is not reduced. These and other equity considerations regarding the distribution of wealth are indeed demanding in terms of data requirements. Time series data which reflect the dynamic interactions, feedback, and linked effects regarded as crucial in section 3 are generally not available across wealth categories of various participant groups (e.g., consumers, producers, intermediaries, and input suppliers). This is perhaps the major reason why issues of distribution and equity resulting from various policies are often examined by economists and operations researchers as an afterthought. Nevertheless, as we argued in section 2, the neglect of such distributional effects on various groups within the major components of agricultural systems will doom to failure any policy analysis that is conducted—failure, that is, with regard to the actual selection and implementation of policies. Hence, an approach to empirical confrontation and model solutions is required which recognizes such data limitations <u>but is not constrained</u> by such restrictions. In fact, one of the principal policy issues facing many public sector decision-making bodies is the dimensions of the data support system that should be maintained to perform policy impact analysis.[8]

We too often neglect the importance of fully integrating the array of various quantitative approaches to policy analysis and testing of theoretical constructs. Econometric methods, optimization, systems analysis, and simulation as well as more pragmatic data collection efforts should not be viewed as separable tasks. Instead, problem-oriented research requires that these apparently separate tasks and associated methods be effectively integrated. It is our view that, without an effective integration, the potential for operations research efforts in public policy related to agricultural systems will remain largely unrealized.

A modeling approach for effectively integrating the array of quantitative approaches could be based on one of the three classes of models identified by Bellman or independently by Feldbaum. They distinguish three types of models: deterministic, stochastic, and adaptive. It is well known that deterministic models are those with all components and relationships assumed known with probability one. Stochastic models are those with some random components and relationships but with the distributions of the associated random variables assumed to be known. Adaptive models are those with components and relationships about which there is initially some uncertainty (for example, the parameters of the relevant probability distributions may be unknown). Most importantly, however, the uncertainty on the structure and components changes by learning as the process evolves.[9]

Adaptive models can incorporate learning processes which are either passive or active (Rausser). Passive learning processes are those in which information has accumulated about the system or model strictly as a byproduct. Active learning processes are those in which the learning and the operation of the system are treated as joint products. This feature is referred to as dual or adaptive control. Unknown quantities about which no data are available can be characterized by probability distributions which are altered by learning as the process evolves. The active accumulation of data and information does not take place independently of the policy process. Formally stated, optimal adaptive control procedures require a simultaneous solution to the control problem and the sequential design of experiments problem.

In the context of data collection and the net value of information, adaptive control is nothing more than a multiperiod generalization of preposterior analysis (Rausser and Hochman). Preposterior analysis, the two-period form of adaptive control, has been widely used in agricultural economics to examine questions of the information value of additional research and data collection efforts (for an illustrative application, see Anderson and Dillon). The problem is to properly characterize the unknown parameter probability distributions after the research or additional data are available but before such efforts are undertaken. To be sure, this approach recognizes that attempts to obtain more reliable estimates of various interactions, delayed effects, and causal mechanism itself presents a resource allocation problem. One way of formally dealing with this problem is preposterior analysis for the two-period planning horizon or adaptive control for the multiperiod horizon with the result of providing guidelines for the design of experiments to capture the information content of additional sample data.

In pursuing the above modeling approach, a judicious use of sensitivitity analysis and an examination of questions related to robustness must be constantly addressed. If a particular policy or set of policies is insensitive to a clausal or linked effect, presumably the value of data or information related to this effect need not be examined. In other words, the value of such information is outweighed by its associated cost to investigate such questions. To be sure, computational rationality dictates that models be tractable and interpretable. Moreover, models must admit the possibility of formally deriving reliability statistics related to the uncertainty of impacts associated with particular policies. In using models for policy analysis, a number of difficulties arise due to model dimensions and problems of numerical accuracy.

The issue of accuracy is particularly important when the structural model representation is nonlinear in the variable space. In agricultural systems which address dynamic, linked and feedback relationships, we often find model representations which involve simultaneous interactions of large systems. For nonlinear representations in these model forms, it is not possible to obtain a unique reduced form. In computing the necessary derivatives to obtain this form in such models, issues of approximation and round-off problems naturally arise. Analysts operating with such models often sweep under the rug the problem of measuring the variability or risk associated with policy actions under examination. It is noted in Rausser, Mundlak, and Johnson that these problems can be largely avoided by specifying models which are linear in the variable space but in essence nonlinear in the parameter space. This requires the specification of models in which the parameter effects are not constant but instead are treated as time-varying and random. Their approach allows forecast probability distributions, conditional on alternative policy actions, to be generated for particular points in the parameter space. This approach also simplifies the validation and verification procedures, especially the derivation of dynamic properties of the constraint structures. When such model representations are combined with adaptive control approach to modeling, we still arrive at a nonlinear policy model due to the need for simultaneously examining the conventional policy problem and the sequential design of experiments as data collection problem. Here again, judicious use of sensitivity analysis and appropriate solution algorithms are required.

## Solution Algorithms

There are a number of possible methods for solving dynamic, stochastic models of the sort envisaged here; they can be categorized in terms of analytical, analytical simulation, and ad hoc simulation methods. Although identified as alternatives, it is important to recognized that these three general options are simply points on a continuum—ranging from completely analytical (in the sense of close form solutions) to ad hoc or exploratory simulations.

Analytical methods generate information from isomorphic representations of the model structure as optimal solutions. The optimizing algorithm must be consistent with the structural characteristics of the model (constraint structure) and the criterion function. In terms of the adaptive modeling approach suggested above, such solution algorithms are not available. Only by approximating the original model structure or the decision rules can policy results be obtained. In either of these two instances, we have, in effect, turned to some form of analytical simulation.

Analytical simulation methods are generally applied to models sufficiently complex that exact solutions for isomorphic representations for capturing optimal decisions are not feasible. Viewed from the opposite end of the aforementioned continuum, analytical simulation algorithms are operational when the structure and objectives of the modeling process are sufficiently identified to suggest systematized experimental processes. Information developed through experiments with combinations of policy and noncontrollable variables selected according to grid coordinance are often used to approximate optimal solutions or strategies. Optimum seeking or policy improvement procedures used in connection with model experiments may also be viewed as types of analytic simulation solutions.

Another form of analytical simulation, suggested as early as 1965 by Dorfman, involves the joint use of optimization and simulation methods; namely, by simplifying model representations to enable the derivation of an optimal solution, a simulation model for the more complex structure is then used to examine that solution as well as minor modifications in more detail.[10] Other approaches use simulation methods to discard dominated alternatives and subsequently employ policy improvement solution algorithm to select strategies from the reduced set (Johnson and Rausser). Moreover, a number of recent applications have shown how optimization and simulation can be employed recursively. Numerous examples have implemented optimal programming algorithms for allowable ranges of decision variables values in conjunction with simulation models to generate (performance) outcome probability distributions. On the basis of insights from the simulation model, allowable ranges for the decision variables values are modified, and the optimization model is again applied. Such recursive approaches make sense if properties of convergence can be established (Johnson and Rausser).

In the case of exploratory or ad hoc simulation methods, the performance of various alternatives are usually inferred on the basis of experiments chosen in an intuitive rather than a structured fashion. In applications of this approach, we generally find that there is no explicit criterion function. Thus, policies are somehow selected on the basis of the comparative performance of experiments or simulations conducted. To be sure, the analytical content of the results that have been generated by such methods is minimal. However, for complex representations in which very little prior information is available, such methods often provide the basis for useful insights.

As noted above, an adaptive modeling approach to policy analysis requires the intregration of econometric, operations research, systems analysis, and the value of information assessment methods. An effective integration of these methods will often dictate the use of a "toolbox" of solution algorithms. In other words, it will often prove desirable to use multiple models to develop, evaluate, and elaborate alternative solutions. The toolbox perspective, although certaintly inelegant, increases the likelihood of tailoring available algorithms to provide significant information and insights rather than just "answers." Such algorithms should be designed to store and calculate as well as to display additional intermediate information to facilitate the learning and planning process. Such intermediate information often serves to stimulate creativity if generated via an interactive process. For example, an analytical simulation algorithm can first be employed to generate an initial design that meets specified criteria. The planners and analysts then provide human reaction by introducing desirable refinements resulting in locally optimal designs. In this fashion creative sparks may be ignited. Operationally, it will often prove difficult for planners to implement such designs and without examining alternative designs.

In the above setting planners and analysts are not wedded to the first design, and there are implicit incentives to pursue other distinct alternatives. In this environment, artificial intelligence and heuristic methods will prove particularly worthwhile. These methods place emphasis on problem solving, optimum-seeking solution and search procedures rather than optimum solutions. Thus, the "answer" seeking mentality is avoided, and learning and inductive inference is highlighted. These features will one day become completely operational in the context of computer-oriented heuristics designed to accomplish such functions as search, pattern recognition, and organizational planning.

To facilitate on learning and inductive inference, operations researchers investigating various policy issues in agricultural systems will have to develop an expertise in experimental design and response surface procedures. Relevant experimental designs must be sequential (Anderson, 1974b) and squarely address "policy improvement" algorithms. Such algorithms involving sequential designs typically begin with an extensive search via simple exploratory experiments which converge toward some peak (or valley) of the surface and then switch to an intensive search as the optimum is approached.[11]

To implement such sequential experiments and policy improvement methods, the appropriate response surfaces must be constructed. Fortunately, an excellent survey is available for operations researchers to familiarize themselves with response surface investigations from the standpoint of sequential analysis and optimal designs (Chernoff).

In designing operational solution algorithms, the special problems confronted in the use of multiple objective functions and the need to to reflect equity; and distributional effects (section 2) must be explicitly recognized. For policy improvement algorithms and associated analytical simulation methods, we are often faced with a plethora of local optimum. Analysts frequently deal with these problems by employing incomplete or partial multiple objective criteria functions, i.e., they perform a partial analysis. The limitation of such partial analyses is that superior solutions often lie in "inferior" regions. Given the limitations of operating with complete, as well as incomplete multiple objective criteria functions, there should be serious attempts on the part of operations researchers to generate alternative weightings or trade-off relationships. To be sure, it will often prove difficult to communicate important trade-off relationships; but, nevertheless, from a researcher's strategy standpoint, benefits appear to outweight the associated costs.

Theory and intuitive reasoning can be heavily utilized in isolating those trade-offs which allow a set of scalar criterion functions to be examined by a parametric analysis. When such criterion functions cannot be captured, again, parametric analysis can be utilized with some objectives expressed as constraints motivated perhaps by a lexicographic ordering and/or as satisficing arguments. Recent advances in effectively combined measures such as consumer, intermediary, and producer surpluses along with risk effects and general equilibrium effects such as exchange rates, balance-of-payment considerations, and other factors are indeed encouraging (Hueth, Just, and Schmitz). These advancements are suggestive of appropriate ways of dealing with the multiplicity of objective functions problem and allow effective parametric analysis to be performed.

In the final analysis, major benefits from modeling public policy problems depends critically upon the sound judgment and experience of the public decision-makers and the analysts involved. Only through such judgment and experience will it be possible to balance the value of simplicity with the cost of complexity. Given the appropriate balance, the principal benefits of quantitative modeling will be achieved. These beneftis include: (1) forcing the users or public decision-makers and the analysts to be precise about perceptions of the system they are attempting to influence (testing these perceptions with available evidence); (2) providing structure to the analysis; (3) extending the decision-makers' information processing ability; (4) facilitating concept formation, (5) providing cues and insights to decision-makers; (6) stimulating the collection, organization, and utilization of data (which are often neglected); (7) freezing the decision-maker and analyst from a rigid mental posture; and (8) becoming an effective tool for negotiation, bargaining, and as a basis for persuasion.

These and other benefits can accrue to such efforts provided the obstacles to achieving such potential benefits are avoided. These obstacles include: (a) timeliness, solving the wrong problem or solving the right problem too late; (b) allowing improper expectations to form by not clearly delineating what the model can and cannot accomplish (the role of modeling efforts should always be supplemental rather than supplant the normal decision process); (c) failure to differentiate the characteristics of the public decision-maker or user and the analyst (these are often very different types of people with different roles, responsibilities, expertise, cognitive style, etc.); and (d) failure to treat the development and use of models as a process not as the recreation of a product. If These observations are constantly kept in mind, design of effective policy models and associated decision support systems will be immeasurably enhanced. Such model support systems must be diligently maintained and nurtured if successful implementations are to be achieved.

## Footnotes

[1] Of course, in a dynamic setting there is an explicit trade-off between the design of policies that result in optimal levels of the performance in the current period and those policies that provide the basis for measuring the system accurately; more on this later.

[2] This work follows the earlier suggestions of Rothenberg who views the legislative process as an n person, nonzero sum, repeated cooperative game of strategy for which no general solution exists. In general, game theory is appropriate for providing a vocabulary for treating a multiplicity of outcomes rather than providing a tool for predicting particular outcomes.

[3] If a social analyst is also examining alternative institutions or "instrument sets," then the McFadden qualitative model of revealed preference must also be blended with the integrative approach suggested here. This approach could be used to select the instrument mix followed by the approach outlined in the text. Hence, it should be clear that we are concerned with policy settings on prespecified instrument variables; i.e., the form of governmental intervention is predetermined.

[4] In the Keeney and Raiffa framework, it is not strictly correct to view the scaling constants as measuring the relative importance of performance measures since such constants are not invariate with respect to choice of origin. Hence, unless some origin can be captured which serves as an objective and neutral measure, one cannot infer that the relative sizes of the scaling constants reflect relative power of various interest groups. This, of course, is another reason for operating with a set of criterion functions, different

elements of which may refer to alternative origins. Hence, for the framework suggested here, weights reflecting tradeoffs rather than scaling constants are employed.

[5] For the supervisory analyst, viz., an analyst concerned with evaluating a "subordinate" decision-making body, an approach very similar to the one described above for the social analyst can be employed. The principal difference here relates to the accessibility of the supervisory analyst to the policymaking body. Specifically, once the approach for the social analyst has been implemented by the supervisory analyst, the resulting estimated set of public policy criterion functions could be viewed as a prior distribution across the parameters of the univariate utility functions and/or the weights. Implementing a Bayesian framework, additional sample information would relate to observed actions which, in turn, would result in a revision of the initial prior distributions. Such an analyst could also play a staff role by assisting the policy body in selecting an objective neutral origin along with influencing or attempting to counteract the strength functions emanating from particular interest groups. Such a framework might also be effectively integrated with decentralization concepts of rewards and penalties to make the governing preference structure of subordinate policy bodies consistent with those of the supervising body.

[6] The assumption here is that a farm will only incur investment costs to adopt new technologies because of expectations of obsolescence of existing technologies.

[7] For simplicity, assume that input prices include capital costs associated with operating debt.

[8] We often find that national governments and various public agencies simply accept what data are reported on a secondary basis and failed to recognize that existing computer technology and data processing procedures allows them to feasibly entertain the collection, summarization, and maintenance of primary data support systems.

[9] Clearly, the first two model types are special cases of adaptive models.

[10] An empirical illustration of this approach in context of river basin planning is available in Jacoby and Loucks.

[11] Intensive searches are often based on two-level complete factorials and "equilateral triangle" designs. Of course, the surface is characterized by irregularities and discontinuities; exhaustive search is required (Conlisk and Watts).

## References

[1] Anderson, J. R. "Risk Efficiency in the Interpretation of the Agricultural Production of Research," Review of Marketing and Agricultural Economics, Vol. 42, No. 3 (1974a), pp. 131-184.

[2] __________. "Simulation: Methodology and Applications in Agricultural Economics," Review of Marketing in Agricultural Economics, Vol. 43 (1974b), pp. 3-55.

[3] Anderson, J. R., and J. L. Dillon. "Economic Considerations in Response Research," American Journal of Agricultural Economics, Vol. 50 (February, 1968), pp. 130-142.

[4] Bellman, R. Adaptive Control Processes: A Guided Tour. Princeton: Princeton University Press, 1961.

[5] Blandford, D., and M. Currie. "Price Uncertainty: The Case for Governmental Intervention," Journal of Agricultural Economics, Vol. 26 (January, 1975), pp. 37-51.

[6] Brandow, G. E. "Policy for Commercial Agriculture, 1945-71," in A Survey of Agricultural Economics Literature, Vol. 1, edited by L. Martin. Minneapolis: University of Minnesota Press, 1977, pp. 209-292.

[7] Brill, E. D., Jr. "The Use of Optimization Models in Public Sector Planning," Management Science, Vol. 25 (May, 1979), pp. 413-422.

[8] Chernoff, H. Sequential Analysis and Optimal Design. Philadelphia: SIAM, 1972.

[9] Conlisk, J., and H. Watts. "A Model for Optimizing Experimental Design for Estimating Response Services," American Statistical Association Proceedings: Social Statistics, Section 64 (1969), pp. 150-156.

[10] Dorfman, R. "Formal Models in the Design of Water Resource Systems," Water Resources Research, Vol. 1 (1965), pp. 329-336.

[11] Downs, Anthony. An Economic Theory of Democracy. New York: Harper and Row, 1957.

[12] Eckstein, O. "A Survey of the Theory of Public Expenditure Criteria," in Public Finances: Needs, Sources, and Utilization, edited by James N. Buchanan. National Bureau of Economic Research. Princeton: Princeton University Press, 1961.

[13] Feldbaum, A. A. Optimal Control Systems. New York: Academic Press, 1965.

[14] Freund, R. J. "The Introduction of Risk into a Programming Model," Econometrica, Vol. 24, No. 2 (1956), pp. 253-263.

[15] Hadar, J., and W. R. Russel. "Rules for Ordering Uncertain Prospects," American Economic Review, Vol. 59, No. 1 (1969), pp. 25-34.

[16] Harsanyi, J. C. "A Simplified Bargaining Model for the n-Person Cooperative Gain," International Economic Review, Vol. 4 (May, 1953), pp. 194-220.

[17] Hueth, Darrell L., R. E. Just, and A. Schmitz. Welfare Economics: Theory and Application. Englewood Cliffs, N. J.: Prentice-Hall, Inc., 1980.

[18] Jacoby, H. D., and D. B. Loucks. "Combined Use of Optimization and Simulation Models in River Basin Planning," Water Resources Research, Vol. 9 (1972), pp. 1401-1414.

[19] Johansen, L. Production Functions: An Integration of Micro and Macro, Short Run and Long Run. Amsterdam: North-Holland Publishing Company, 1972.

[20] Johnson, S. R., and Gordon C. Rausser. "Systems Analysis and Simulation: The Survey of Applications in Agriculture and Resource Economics," in A Survey of Agricultural Economics Literature, Vol. 2, edited by G. G. Judge, R. H. Day, S. R. Johnson, G. C. Rausser, and L. Martin. Minneapolis: University of Minnesota Press, 1977, pp. 157-301.

[21] Just, R. E. "Theoretical and Empirical Possibilities for Determining the Distribution of Welfare Gains from Stabilization," American Journal of Agricultural Economics, Vol. 59 (December, 1977), pp. 912-917.

[22] Just, R. E., D. Zilberman, and G. C. Rausser. "A Putty-Clay Approach to the Distributional Effects of New Technology Under Risk," in Proceedings of Operations Research in Agriculture and Water Resources, edited by D. Yaron and C. Tapiero. Amsterdam: North-Holland Publishing Company, 1980.

[23] Kahneman, D., and A. Tversky. "Prospect Theory: An Analysis of Decisions Under Uncertainty," Econometrica, Vol. 47, No. 2 (March, 1979), pp. 263-292.

[24] Kataoka, S. "A Stochastic Programming Model," Econometrica, Vol. 31, Nos. 1-2 (1963), pp. 181-196.

[25] Keeney, R. L., and H. Raiffa. Decisions With Multiple Objectives: Preferences and Value Tradeoffs. New York: John Wiley and Sons, Inc., 1976.

[26] Linbeck, A. "Stabilization Policy and Open Economies With Endogenous Politicians," American Economic Review, Vol. 66 (May, 1976), pp. 1-19.

[27] Maass, A. "System Design and the Political Process: A General Statement," Design of Water Resource Systems. Cambridge, Mass.: Harvard University Press, 1962, pp. 565-604.

[28] Markowitz, H. M. Portfolio Selection: Efficient Diversification of Investments. Cowles Foundation Monograph 16. New York: Yale University Press, 1959.

[29] McFadden, D. "The Revealed Preference of a Public Bureaucracy: Theory," Bell Journal of Economics, Vol. 6 (Autumn, 1975), pp. 401-416.

[30] __________. "The Revealed Preferences of Government Bureaucracy: Empirical Evidence," Bell Journal of Economics, Vol. 7 (Spring, 1976), pp. 55-72.

[31] Nash, J. F., Jr. "Two-Person Cooperative Gains," Econometrica, Vol. 21 (January, 1953), pp. 128-140.

[32] Peltzman, S. "Toward a More General Theory of Regulation," Journal of Law and Economics, Vol. 19 (1976), pp. 211-240.

[33] Pigou, A. C. The Economics of Welfare. 4th ed. London: Macmillan, 1962.

[34] Rausser, G. C. "Active Learning Control Theory in Agricultural Policy," American Journal of Agricultural Economics, Vol. 60 (August, 1978), pp. 476-490.

[35] Rausser, G. C., and J. W. Freebairn. "Estimation of Policy Preference Functions: An Application to U. S. Beef Import Policy," Review of Economics and Statistics, Vol. 56 (1974), pp. 437-449.

[36] Rausser, G. C., and Eithan Hochman. Dynamic Agricultural Systems: Economic Prediction and Control. Amsterdam: North-Holland Book Publishing Company, 1979.

[37] Rausser, G. C., and Ralph Lattimore. "New Developments in Theory and Empirical Applications of Endogenous Governmental Behavior," in New Directions in Econometric Modeling and Forecasting in U. S. Agriculture, edited by Gordon C. Rausser. Amsterdam: North Holland Book Company, 1980.

[38] Rausser, G. C., Y. Mundlak, and S. R. Johnson. "Structural Change, Parameter Variation, and Forecasting," in New Directions in Econometric Modeling and Forecasting in U. S. Agriculture, edited by Gordon C. Rausser. North-Holland Book Publishing Company, 1980.

[39] Rausser, G. C., and E. P. Stonehouse. "Public Intervention and Producer Supply Response," American Journal of Agricultural Economics, Vol. 60 (December, 1978), pp. 885-890.

[40] Rausser, G. C., D. Zilberman, and R. E. Just. "The Distributional Effects of U. S. Agricultural Policy: Deficiency Payments and Input Control," Department of Agricultural and Resource Economics, Working Paper No. 80, University of California, Berkeley (March, 1980).

[41] Rothenberg, J. "A Model of Economic and Political Decision Making," Harvard Seminar in Political Economic Decisions (March, 1967).

[42] Roumasset, J. A. Rice and Risk: Decision Making Among Low-Income Farmers. Amsterdam: North-Holland Publishing Company, 1976.

[43] Roy, A. D. "Safety First and the Holding of Assets," Econometrica, Vol. 20, No. 3 (1952), pp. 431-449.

[44] Salter, W. E. G. Productivity and Technical Change. 2d ed. Cambridge: England: Cambridge University Press, 1966.

[45] Sandmo, A. "On the Theory of the Competitive Firm Under Price Uncertainty," American Economic Review, Vol. 61 (1971), pp. 65-73.

[46] Steiner, P. O. The Public Sector in the Public Interest, The Analysis and Evaluation of Public Expenditures: The PPB System. A condominium of papers submitted to the Subcommittee on Economy and Government of the Joint Economic Committee, Congress of the United States. Vol. 1, 1969, pp. 14-45.

[47] Stigler, G. E. "The Theory of Economic Regulation," Bell Journal of Economics and Management Science, Vol. 2 (1971), pp. 3-21.

[48] Telser, L. "Safety First and Hedging," Review of Economic Studies, Vol. 23, No. 1 (1955-56), pp. 1-16.

[49] Tesfatsion, L. "Global and Approximate Global Optimality of Myopic Economic Decisions," Journal of Economic Dynamics and Control (forthcoming).

[50] Tobin, J. "Liquidity Preference as Behavior Towards Risk," Review of Economic Studies, Vol. 25, No. 2 (1958), pp. 65-86.

[51] Zusman, P. "The Incorporation Measurement of Social Power in Economic Models," International Economic Review, Vol. 17 (June, 1976), pp. 447-462.