System Theory Applications to Agricultural Modeling

A Proceedings

Edited by A.H. Levis and C.L. Quance

Economics, Statistics, and Cooperatives Service
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CONTENTS

On January 1, 1978, three USDA agencies--the Economic Research Service, the Statistical Reporting Service, and the Farmer Cooperative Service--merged into a new organization, the Economics, Statistics, and Cooperatives Service.

SYSTEM THEORY APPLICATIONS TO

AGRICULTURAL MODELING

A Proceedings

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This volume contains seven papers related to the present and potential contributions of system theory to economic research and policy analysis in food and agriculture. The papers were originally presented at the Conference on Decision and Control in Clearwater, Florida, December 1-3, 1976, and were revised by the authors for inclusion in this volume. The conference was sponsored by the Control Systems Society of the Institute of Electrical and Electronic Engineers (IEEE).

The Economics, Statistics, and Cooperatives Service and National Science Foundation believe these papers to be of sufficient interest and usefulness to warrant their publication in a form widely accessible to public and private researchers and decisionmakers in food and agriculture. Any findings, conclusions, and opinions expressed are those of the authors and do not necessarily represent those of IEEE, the National Science Foundation, or the U.S. Department of Agriculture.

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FOREWORD

Successful attempts to understand and solve complex problems require intense collaboration of researchers from several disciplines. In a world of limited resources it is important to understand the complex dynamic and stochastic interrelationships between several sectors of the economy and technology; such fundamental understanding is crucial for credible policy analysis, decision making and optimization. Agricultural problems and issues represent an extremely important area in which interdisciplinary approaches are required.

System theory is a science that deals with complex interrelationships, including dynamic and stochastic effects. Although a recent discipline, it has broadened its horizons from aerospace and other engineering problems to areas in which a mixture of economics, technological factors and human attitudes are an essential part of the problem. However, in order for system science to have a credible impact upon agricultural problems, a dialog between the different disciplines has to be initiated.

This volume is the first significant step in initiating this important exchange of ideas. I was extremely pleased as General Chairman of the 1976 IEEE Conference on Decision and Control, the main annual forum of the Control Systems Society of the Institute of Electrical and Electronic Engineers, to have had the opportunity to host the presentations by the authors of this publication and the subsequent panel discussions. The two invited sessions were well attended and the subject matter created a great degree of interest within the systems community. The publication of this volume will contribute to the dissemination of this information.

Michael Athans
Professor of Systems Science and Control Engineering
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INTRODUCTION

Leroy Quance and Alexander H. Levis

In 1974, following the most serious shortages of supply relative to quantity demanded for agricultural commodities since the Korean War, a report to Congress by the Comptroller General titled *U.S. Actions Needed to Cope with Commodity Shortages* concluded that "the U.S. Government does not have an effective planning, policy analysis, and policy formulation system for basic commodities." While short supplies and high prices prompted that study, the pendulum has already swung back toward the excess supply extreme with respect to agricultural commodities. Thus, if such a study were to be repeated today, it might be directed at U.S. actions needed to cope with surplus in various commodities.

This situation indicates the need for the further development and improvement of analytical tools that can be used in the planning and analysis of food and agriculture policies, and in program implementation and management. In recognition of this need, two special invited sessions on Agricultural Modeling and on System Theory in Agricultural Economics were included as part of the technical program of the 1976 IEEE Conference on Decision and Control (CDC) held at the Sheraton-Sand Key Hotel in Clearwater Beach, Florida on December 1-3, 1976. This annual conference is sponsored by the Control Systems Society of the Institute of Electrical and Electronic Engineers (IEEE) in cooperation with the Society for Industrial and Applied Mathematics (SIAM). The two sessions were co-chaired by Dr. A. H. Levis of Systems Control, Inc. and Professor D. G. Luenberger of Stanford University.

Six of the seven papers in this proceedings were first presented at the 1976 conference; they have been revised and are published herein to facilitate wider circulation within the community of researchers in agricultural policy analysis and economics. Generally, the authors advocate a strong role for systems theory in food and agricultural modeling and an interdisciplinary approach to the analysis of problems that require global models as well as national, sector, or sub-sector models.

The first paper by Glenn L. Johnson, which also served to set the tone for the discussions between agricultural economists and system theorists at the conference, argues that projections are essential aids in decision or policy making at both the individual firm and the government agency levels and that a credibility gap among decision-makers with respect to modeling provides opportunity for system scientists. But, if system scientists are to fare any better than economists, they must include not only normative feedback loops, but also the strong human interaction in the definition and solution of policy problems.

Alexander and Ilze Levis address the need for a conceptual framework for policy analysis modeling in food and agriculture and for better understanding of the strengths and limitations of the various methodologies. They also point out unresolved methodological and conceptual problems in the broad area of model validation and scenario development for use with simulation models.

Leroy Quance and Yao-Chi Lu advocate a global food and agricultural information system in bringing about a desirable balance between food needs and supplies. They identify historical developments and current events in both the technical and economic workings of food and agriculture, as well as in academic disciplines, which point toward a much greater contribution of systems science and modeling to both private and social decision making. They also advocate an optimistic long-range scenario for the management of supply and demand in food and agriculture. They conclude with a summary of the Economic Projections Program of the U.S. Dept. of Agriculture.

Following these three papers that provide general, but different, views of the role of system theory in modeling food and agriculture, the next three papers present models developed for agricultural policy analysis in the U.S. and in Korea.

George E. Rossmiller summarizes a five year effort to develop, institutionalize, and use a simulation model of the Korean agricultural sector. A unique characteristic of this effort is the close collaboration of the American modeling team with the host country counterparts, so that Korea might have a self-sustaining national analytical capability to aid its food and agricultural planning, policy making, and program management processes when the participation of the Michigan State University team comes to an end.

G. L. Campbell, E. R. Ducot, A. H. Levis, D. G. Luenberger, and D. N. Stengel report on Systems Control, Inc.'s project AGRIMOD, an NSF funded simulation model of the U.S. food production system designed to provide a quick response tool for analyzing the impacts of alternative food and agricultural policies over a 10-20 year planning horizon. The strength of AGRIMOD lies in its use of systems and control theory and the integration of normative and equilibrium submodels that represent production decisions and market economics, respectively.

The third example of application of system theory to food and agriculture reported in this proceedings is the description of GRAIN1, a new simulation model of the wheat production system, and its use in analyzing the growth in size and the decline in the number of farms in the United States. Here, Leonard Brzozowski uses the Systems Dynamics methodology to construct a model that can be used to analyze how public policy can influence growth in farm size and the distribution of farms by size.

The final paper in the proceedings is a summary of the effort by the U.S. Government Accounting Office to inventory current food and agricultural models available for policy analysis. This effort was not yet completed at the time of the IEEE conference, but the preliminary findings of the survey were referred to in the original Quance and Lu paper. This partial inventory of agricultural models by Gary Boss et. al. provides a fitting conclusion to this volume on the application of system theory to agricultural modeling.

In summary, the papers included in this proceedings served as the basis for discussions between agricultural economists and system scientists concerned with the development of an effective planning, policy analysis, and policy formulation system with respect to food and agriculture. While the traditional tools of econometrics and linear programming have made great contributions in the analysis of agricultural systems, additional analytical tools are required to handle the complex problems of agricultural policy. Problems of soft data, validation, and utilization are alluded to in these papers. But the common thread throughout all the presentations included in this volume is a recognition of the strong role and potentially large contribution of system theory in modeling complex food and agricultural phenomena.

Finally, the editors would like to thank the Program Committee of the 1976 IEEE Conference on Decision and Control for providing a forum for the discussion of the ideas presented in these papers. Special acknowledgement is due to the Economics, Statistics, and Cooperatives Service of USDA, the RANN program of the National Science Foundation, and Systems Control, Inc. for providing the support necessary for making this publication possible. The editorial assistance of Ms. Ilze S. Levis and the untiring effort of Ms. Joan Cummins in typing several versions of the manuscripts as well as this volume are greatly appreciated.

OPPORTUNITIES FOR SYSTEMS SCIENTISTS IN MODELING AGRICULTURAL SYSTEMS

Glenn L. Johnson

ABSTRACT

The use of projections in public and private decisions, with emphasis on agricultural decisions, is reviewed. At the public level the decisions deal with agricultural policy, program, and project problems, and at the private level with the problems encountered by farm and agri-business firm managers. There is a discussion of (1) the impact of increased competence in economics and econometrics on the use of specialized projections with respect to agriculture, and (2) the credibility gap which has arisen among decision makers with respect to all quantitative work. The reasons for this credibility gap reveal opportunities for systems scientists in modeling the domains of agrarian problems and further developing systems science techniques to (1) include "man components" and (2) close the normative feedback loops required in iteratively and interactively defining and solving problems.

INTRODUCTION

Historically and presently, most public and private decisions are based on projections of the consequences of alternative courses of action. Great military and political leaders have been adept at envisioning the consequences of their actions in such dimensions as time, space (geophysical), and political grouping [6]. On the private side, business leaders and consumers have also used projections in making decisions concerning transportation systems, marketing programs, electrical grids, investments, and intergenerational transfers of property.

In the field of agriculture, projections have also been widely used. At the outset of U.S. participation in World War II, extensive projections were made as to America's wartime capacity to produce farm products. The projections were crucial for the conduct of the war. At the war's end, further projections were made concerning world and U.S. food grain stocks and food needs. These were important in allocating available food grain stocks in the immediate post-peace months. Earlier, the Bureau of Agricultural Economics (BAE), which had developed the U.S. national agricultural accounts, did extensive projections in analyzing the consequences of alternative price support, production control, food stamp, storage, credit, labor, and export promotion programs for farm products. Irrigation, drainage, disease and pest control, marketing, and other projects were studied and projections made to improve practical decisions. At the individual farm level, farm management specialists developed planning techniques to project the consequences of introducing new technologies, institutional arrangements, rotations, and behavioral patterns. As in the case of BAE projections, farm management projections were based on accounting concepts -- in this case, the farm accounting systems developed and taught by farm management specialists. Plant breeders, livestock breeders, ecologists, pesticide experts, and others have been concerned with bio-physical systems important for agriculture. These have been modeled (conceptualized) with varying degrees of specificity [1]. Of particular significance are the models of "ideal" plants used in developing the new miracle varieties.

Much of the projections work for agriculture has been led by agricultural economists -- particularly that concerned with improving policy, program, and project decisions. Prior to World War II, these projections were done largely with pencil, large worksheets, and hand calculators. Where technological, institutional, and human change were important, specialists and disciplinarians concerned with such phenomena also participated.

With World War II as a turning point, the agricultural economists involved in projecting impacts of alternative policy, program, and project decisions began to turn inward towards economics and the associated quantitative techniques of statisticians and econometricians. Public policy analysis by econometricians concentrated mostly on time series data and drew mainly on macro-economic concepts to the neglect of technological, institutional, and behavioral concepts and data, the main exception being a heavy conceptual emphasis on maximizing behavior [6]. In farm management, the emphasis shifted to production economics, again to the neglect of technical and institutional and nonmaximizing behavior. Post-war farm management analysis quickly shifted to maximization on curvilinear production functions fitted to both experimental and cross-sectional data and to linear programming studies. The latter included recursive, quadratic, dynamic, and lexicographic ordering and other refinements. For public projects there have been benefit/cost ratio, internal rate of return, net present value, and other analyses. The upshot of these and other developments has been reduced use (at least proportionally) of the work of agricultural economists by decision makers both public and private. The new post-World War II work of agricultural economists described above did not attain great credibility with real world decision makers.

The interesting question is: why was credibility lost? Decision makers distrust analysis they cannot understand. At the micro level, distrust of the new analyses was found among farmers being served by personnel from the USDA/Land Grant system. Except when farmers blindly follow recommendations, farm advisors and consultants find it necessary to explain to farmers the basis for concluding that so-and-so will happen in such-and-such a sequence if so-and-so is done. Farmers are also quick to ask for evidence. They quickly check up on logic and whether advisors are using the kinds of information they (the farmers) know are relevant. Farmers soon become dissatisfied with neglect of technology, institutions, and people by economists. Also, in public agencies and parliamentary bodies, analyses are not accepted unless the decision makers trust that information known by them to be relevant has been used and that the computations and reasoning are free of logical mistakes [13], [14].

The credibility gap among practical decision makers is readily understood when one compares the interests of many discipline oriented, post-World War II agricultural economists with those of decision makers. Since World War II, such agricultural economists have been increasingly oriented towards improving economic theory and the quantitative techniques used by economists. They are now as interested, or more interested, in favorable evaluations from their disciplinary peer groups than from the decision makers they serve. Those peer groups often denigrate practical, problem solving research as "brush fire research" while glorifying disciplinary research as "basic," "fundamental," and "of lasting value." Quantitative workers among agricultural economists often have vested disciplinary interests in statistics, mathematics, computer science, and related disciplines. These disciplinary orientations cause distrust on the part of decision makers. Also, economists, econometricians, and operations research specialists are specialized on the maximization models of economics. Optimum control theorists among systems scientists use similar models. Such models are used both in seeking prescriptive solutions to problems and in predicting the behavior of producers, consumers, resource owners, and government officials. To the extent that inappropriate values are maximized or minimized, the decision makers have good reasons for rejecting such work. The decision maker looks to researchers for assistance in understanding the domain of a particular problem about which he has to make a decision. He cares little about disciplinary progress and the evaluations of peer group disciplinarians. What he wants is help in deciding which action will solve the problem he faces.

ESSENTIALS FOR CREDIBILITY OF PROBLEM SOLVING RESEARCH

This section summarizes the essentials for credibility with decision makers. Credibility with decision makers requires that problems be realistically defined [6]. Typically, practical problems have domains involving several different disciplines [6]. Furthermore, problems are not usually defined once and for all at the beginning of a problem solving exercise; instead, they are redefined more or less continually during the process of solution. In this process, interaction among investigators, decision makers, executives, and affected persons is an important source of information [5]. Until researchers and decision makers want to understand each other and succeed in doing so, and are agreed concerning the problem and a way of defining it, they lack credibility with each other [6].

Problem definitions ordinarily require positive information concerning conditions, situations, and things. By positive information we mean information about conditions, situations, and things other than about their "goodness" and "badness" [8]. Essential as such positive information is, however, it is only part of a problem definition [6]. Before a practical problem can be defined, information is also required concerning the "goodness" and "badness" of conditions, situations, and things [11]. Solving a problem requires a decision as to a right action [9],[8]. Information about right and wrong actions is prescriptive in nature. The existence of meaningful problems also implies a possibility, at least, that a decision rule could process the relevant positive and normative information into a prescription which would materially improve the existing problematic situation.

There is much confusion in the literature of economics concerning the meanings of the words "positive" and "normative." The confusion has been excellently summarized by Machlup [10]. As soon as it is realized that normative, positive, and prescriptive kinds of information are involved in defining and hence in solving a problem, it becomes clear that researchers must be general enough philosophically to work objectively with normative as well as positive information in seeking prescriptive information [6]. Disciplinary researchers who believe, metaphysically, that objective knowledge is possible only for the positive are bound to have difficulty in objectively defining and solving problems [6], [8]. Fortunately, for the study of decision making units there are other respectable philosophies which grant the possibility of objective, normative knowledge [8], [11], [9]. These include pragmatism which undergrids Wisconsonian institutional economics which has done so much to make U.S. policy making rational [5]. They also include outright normativism not discussed above. G. E. Moore's *Principia Ethica* (1903) [11] is crucial to understanding the possibility of empirical normative knowledge [8]. Moore demonstrates the possibility of normative primitives to use (in the manner of linguistic analysts) [2] to convert analytic statements into synthetic (descriptively empirical) normative statements [11].

It also helps in attaining credibility with decision makers if problem solving researchers are at least as general with respect to disciplines and, hence, types and sources of information as the decision maker they are attempting to assist. Some disciplinarians are so oriented to their own disciplinary peers that they are unable to orient themselves (or to cooperate with others) so as to handle the other disciplinary dimensions of the problem known by the decision maker to be important at the outset of the problem solving process, let alone cover the disciplinary dimensions not yet discovered by the decision maker. It is extremely difficult for a researcher who specializes in one discipline or philosophy to handle the entire domain of a practical problem when that domain involves several different disciplines and philosophies [6].

Generality is also required with respect to techniques. We have already seen that the domains of practical problems involve many different disciplines and many different philosophies [8]. Thus techniques from different disciplines are required, as well as techniques consistent with both normativistic and positivistic philosophies [11],[9]. The techniques developed by the decision making disciplines -- economics, political science, law, and military science -- may also be relevant.

Another kind of generality is that which arises from the iterative and interactive nature of the problem definition and solving process [3],[6]. This is really generality with respect to kind of problem and kind of solution sought. The body of normative and positive information which accumulates from interaction between researchers and decision makers in the problem solving processes leads to adaptive redefinition of problems [3]. These interactive redefinitions of the problem tend to expand or constrain the range of possible solutions and to clarify the values involved [8],[7]. The problem solving process works better in the absence of preconceived concepts of a problem or of its solutions and of the disciplines required to solve it [7].

Generality with respect to dimension is crucial for credibility with decision makers. Decision makers are interested in the consequences of alternative courses of action in several dimensions, including time, income, ownership patterns, age, race, local vs. central control, geographic area, rural vs. urban, sex, and others. Which dimensions are relevant is determined by the evolving definition of the problem being addressed [8].

Generality with respect to the decision rules used to select a right action is also required. The selection of a right action to solve a problem maximizes human interest in some sense. Among the preconditions which must be met for maximization is the selection of a decision rule. Among the decision rules are those of maximizing the discounted values of expected future net monetary returns, satisfying, minimizing, maximizing, and random choice [7].

There is a special kind of generality required with respect to information from decision makers and others affected by the results of problem solving research. The iterative process of defining and solving a problem is participatory with decision makers and affected persons. Investigators play but one role in the total process. As the process moves progressively from problem definitions to solutions, questions arise repeatedly as to whether the tentative solutions will "work." In testing problem solutions for their workability, interaction with decision makers and the affected persons continues to be an important source of information. It is the decision makers and the affected persons who will experience the "goodnesses" and avoid the "badnesses" which the solution is designed to attain and avoid. Initially, at least, their normative knowledge is likely to be at least as good if not better than that of the research investigators.

Some of the prerequisites for credibility with decision makers were discussed above. The meaning of credibilility with decision makers can now be defined more formally. Problem solving analyses are credible with decision makers if they pass four tests [8], [7], [6], [13], [14]:

1. coherence
2. correspondence
3. clarity
4. workability.

The coherence test is simply the test of logic. Decision makers apply it when they insist that the analysis and models used in problem solving exercises be logically consistent. Some methodologists regard passing of this test as validation. The correspondence test is applied by decision makers when they insist that analyses be consistent with their empirical knowledge of the real world. Some methodologists regard the passing of this test as verification. As decision makers are typically eclectic and not particularly "hung-up" on philosophic specializations, they typically regard their knowledge of the real world as being both normative and positive. The clarity test is one of understandability. The analyses and models have to be explained in terms which decision makers can understand. Ambiguous concepts and models cannot be validated or verified either by scientists or decision makers. When the decision maker applies the test of workability, he checks the proposed solution and projected consequence of the solution to see if he thinks the outcomes would actually result from the prescribed action and, if they result, whether they will solve the problem before him [5]. Such tests can be applied to both the positive and normative information used to reach prescriptive decisions. Prescriptive knowledge can also be subjected to such tests. The latter includes decisions as to which decision rule to use in processing positive and normative information into prescriptive knowledge [11], [9], [2], [8], [6], [7].

OPPORTUNITIES FOR SYSTEMS SCIENTISTS IN AGRICULTURE

The opportunities for systems scientists in agriculture are with respect to three kinds of research: problem solving, subject matter, and disciplinary [6]. The specific problems of public decision makers are time, space, and institution specific. Problems are defined interactively with decision makers as they arise. Stable classifications of such problems do not exist and are probably impossible [7]. However, the evolving stream of problems is so large that we can have confidence that extensive opportunities to do problem solving research for public and private decision makers will continue to exist [13].

Problems arise, abroad, in planning agricultural programs and in designing particular projects [6]. Domestically, problems arise in the same areas, although the U.S. does not develop agricultural sectoral plans. Also, in the U.S., most state governments have well developed departments of agriculture which have policy, program, and project problems. Further, each state college of agriculture engages in problem solving research for its state. At the national level, such research is supported mainly by the United States Department of Agriculture, NSF's RANN, NAS, The Office of Technology Assessment, and others. An important example is "AGRIMOD," a national agricultural sector study done by Systems Control, Inc. with NSF support. In the private sector, problems arise from agri-business firms, consumers, and farmers [4]. Such agribusiness firms as Caterpillar, John Deere, the meat packing companies, pharmaceutical companies, and seed companies all face problems having domains which systems scientists can help model. Another important study is the national agricultural sector study at Michigan State University which is partially funded by Deere and Company. Significant progress has also been made in modeling the domains of problems of individual farmers [7]. In Michigan, for instance, it is possible to call the Michigan State University/University of Michigan combined computers by touch-tone telephone from individual farms to solve investment, income tax, fruit tree spraying, and other problems.

Subject matter research is defined as that designed to produce information on a certain subject germane to a set of problems [6]. Such research is multidisciplinary, for if the subject is confined to one discipline, it is disciplinary research of known relevance. It should be noted that the domains of individual problems in a set are so unique that, typically, information about the subject is not fully adequate to solve any given problem.

Subject matter research includes conceptualizations or models of phenomena as well as descriptive data. Both the models and data should be relevant to solve a well identified set of problems faced by a well identified set of decision makers. Generally speaking, subject matter models work best if componentized so that they can be taken apart and reassembled along with still other components in configurations corresponding to the domain of each specific problem [6]. Subject matter research is needed on such important subjects (not problems) as: food, various aspects of energy, income distributions, distributive justice, technological advance and adoption, environmental quality, agricultural education, capital generation, agricultural credit, and employment generation. Effective work on these subjects requires focusing in on fairly well defined sets of problems faced by well defined sets of decision makers. This focus is necessary as such subjects are so broad as to be capable of consuming almost any conceivable budget unless constrained or focused on sets of problems.

Disciplinary research also provides many opportunities for systems scientists in agriculture. In economics, systems science models have important contributions to make to our understanding of the dynamic consequences of alternative decision theories [6]. In the technical agricultural departments and disciplines such as agronomy, plant breeding, animal husbandry, entomology, or irrigation and drainage engineering many important systems and components need to be modeled [1].

Among the disciplinary contributions needed from systems scientists is increased attention to formalizing the iterative interactions between decision makers, executives, and affected persons, one one hand, and computerized model components, on the other. Until these iterative interactions are formalized so that "man components" are part of well integrated and well articulated overall models, we will have to get along on the basis of an "ad hocery" which puts essentially separate models together in crude, subjective, not fully reproduceable ways. In putting such components together, it would be helpful if systems scientists approached the task in a less positivistic way than is customary among them. Decision makers monitor environments normatively as well as positively. The interaction between the machine and man components needs to be modeled so that both positive and normative learning takes place in the total model as a result of the normative monitoring by decision makers, executives, and affected persons as they interact iteratively both (1) experimentally with the environment and (2) as a result of experimenting with alternative model scenarios [7], [8], [11], [10], [9], [12], [14].

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TOWARD A CONCEPTUAL FRAMEWORK FOR POLICY ANALYSIS MODELING

Alexander H. Levis and Ilze S. Levis

ABSTRACT

The increasing number of simulation models being developed promises to provide policy analysts and decision makers with versatile, quick-response tools for analyzing the effects of alternative policies. A general conceptual framework for such models is described and issues related to model validation and use are discussed. It is concluded that substantial research effort is required to resolve some of the fundamental issues of modeling for policy analysis.

INTRODUCTION

The development of versatile and comprehensive simulation models suitable for policy analysis demands the reconciling of two essentially conflicting objectives. If the results are to be of use in decision making, *accuracy* is essential; if the model is to allow for structural changes of the type that occur in a socio-economic system, an *adaptive structure* is necessary. The traditional modeling of socio-economic systems usually emphasizes one of these two objectives; their integration into a balanced methodological approach is the essential challenge in designing dynamic simulation models for policy analysis.

Models have been described as explanations of the systems modeled [1]. However, the question arises as to what structural properties a model should possess in order to be able to explain. The definition of explanation is one of the unresolved problems of the philosophy of science (i.e., explanation as derivation of facts from general premises vs. explanation as analysis). To quote C. West Churchman: "One wishes to discuss a concept, and hence must try to make clear what concept is being discussed, but the purpose of the discussion is to enlighten the meaning of the concept." [2]. Another question is whether it is possible to derive, from the description of the function to be fulfilled, the features a model should have to achieve its purpose. The issue is further complicated because of the conflicting philosophical bases underlying scientific methodologies: rationalism (the method of establishing propositions by reason, or deductions, involving premises stating general ideas or principles) vs. empiricism (the doctrine that all knowledge must be validated in experience and that whatever is knowable is based on sense data), or, alternatively, analytic truth (which can be validated simply by examining the meaning of the symbols and the logic of the language) vs. synthetic truth (which must be verified empirically) [3].

The preliminary exploration of those two approaches and the proposition that a synthetic framework that integrates elements of both is most appropriate for modeling for policy analysis are presented in the next two sections. Finally, some comments on validation and use of large scale computer models in the policy making process are also included.

TWO POINTS OF VIEW

Rationalism (Leibnizian inquiry) underlies much of modern theoretical science. Leibniz believed that the universe is a harmonious whole, and that truth can proceed deductively from the clear, mathematical, and logical principles that govern the universe. The key concepts of Leibnizian philosophy are *necessity* and *absoluteness*. To know absolutely is to know what *has* to be, while to know something absolutely is to know its reason for existing and to realize that the essential connection of all its past, present, and future characteristics, of everything that has happened to it and will happen to it, is an expression of what the thing itself is. "From this source," (writes Leibniz) "springs immediately the received axiom that nothing is without a reason, or that no effect is without a cause." [4].

To Leibniz, knowledge consists of universal and necessary truths based on principles, and not derived from experience. Reason alone can decipher the mathematical-logical order of the universe; knowledge cannot come from without, but must arise within the mind. All knowledge lies implicit in the mind; experience does not create it, but only makes it explicit. It can even be proved that knowledge does not come from the senses. If it did, universal knowledge would be impossible. Empirical truths do not possess necessity; they are accidental propositions, and just because something has happened, there can be no assertion that it must always happen the same way. However numerous the examples of an occurrence may be, they do not prove that the event will necessarily always take place. In sum, without basic principles there would be no science at all, but only a collection of factual details.

It is evident that many models possess Leibnizian characteristics. According to Mitroff and Turoff [5], the underlying assumption of such models is that they embody the fundamental, structural features of reality and can thus be relied on for projecting into the future.

Thus Leibnizian inquiry emphasizes theory: Leibnizian models make possible the data that are fitted to them; the data do not make possible the models [5]. In fact, a Leibnizian system might permit the input of any kind of information whatsoever, and "show no discrimination, no filtering of obviously irrelevant or false data." [2].

Policy analysis models developed by engineers fall usually within the Leibnizian framework. These models have an underlying structure which is essentially that of an engineering system. Often, they can be reduced to either a resource allocation problem or a materials flow problem, or a combination of the two (energy models, LP agricultural models, etc.). The causal relationships between the variables are deduced from basic principles, e.g., conservation laws. The strength of these models is in that they can have an adaptive structure and, in the case of dynamic ones, they can easily incorporate technological change. They can provide useful information as long as the socioeconomic environment within which the physical system functions remains essentially unchanged. This is not the case when socio-economic conditions affect not only the parameters, but also modify the objective function in a resource allocation problem: the explicit relationships cannot be deduced from basic principles.

In contrast to the above modeling framework is the one based on the empiricism of Bacon, Hume, and Locke. The latter, in the *Essay Concerning Human Understanding*, set out to negate the Platonic theory that the mind comes into the world already in possession of certain innate truths--a theory handed on to medieval thought by Augustine, and accepted by Descartes, Spinoza, and Leibniz. There are, says Locke, no such things as innate moral or logical principles, already fortified by which the intellect begins its operation of thinking about the world. In fact, the mind has no built-in preconceptions or information about nature. It begins by learning the simplest things first, and builds up to complex matters from elementary forms of knowledge. The truth of specific propositions is recognized before general maxims are accepted; many of the most necessary and valid propositions are not recognized until attention is drawn to them, and then only if the observer has been so trained by previous education as to be able to understand them. Knowledge is acquired only through the accumulation of sense impressions (data), not derived from innate truths (laws). However, David Hume argued that the mind cannot learn the necessary connection between events by means of experience. Consequently, empiricists adopted a skeptical attitude regarding causal connections of events, and especially regarding the ability to predict future sequences of events [2].

A Lockean model is based on an inductive use of accumulated data, not on deductions from abstract axiomatic theories. The collected data are analyzed, compared, classified, correlated, and through progressive elimination, a relationship describing a phenomenon is obtained. The truth content of the Lockean models is associated entirely with their empirical content [5]. It can be argued that no group of inquirers could collect all the relevant data or examine all the relevant interconnections. From a large set of choices, only a relatively small amount can be examined or analyzed.

Churchman, in contrasting Leibnizian and Lockean inquirers, argues that "the famous debate between Leibniz and Locke on the subject of innate ideas could be considered a debate about whether the optimal inquiring system has inputs from "outside" or not. Leibniz's inquirer does not, Locke's does. That is, Locke *seems* to insist that some outside influence will dictate which contingent truths should be taken most seriously, and it is not up to the executive to control this influence. Leibniz, on the other hand, wants the executive to do his own deciding internally." Furthermore, "in the Leibnizian inquirer, the goal is to create a network that will take precedence over all competing networks, whereas in the Lockean inquirer, the goal is to create as large or as elegant a network as possible based solely on the basically acceptable empirical data." [2].

The Lockean framework is used extensively in economics, in the social sciences, as well as in science and engineering. For example, econometric models are particularly well suited for short term forecasting, provided the underlying system will not move away from its "operating point" or previously unobserved modes will not be excited during the interval of time over which the model is used. It follows from these remarks that Lockean models are accurate, when used properly, but do not exhibit an adaptive structure.

Policy analysis models must be both accurate and structurally adaptive. They must integrate the desirable features of both Leibnizian and Lockean approaches. The conceptual framework for achieving this synthesis is the Kantian one.

A SYNTHETIC APPROACH

Immanuel Kant's early philosophic views were shaped by his interest in science and mathematics and influenced by Leibniz and Wolff; thus, he was pre-disposed to rationalism, but he was also influenced by Locke and Hume. However, he perceived that the empiricists, in spite of their desire to derive everything from experience, had invented a new metaphysical concept, the *mind*, which received and organized experience. It was the innate nature of the mind to perceive, remember, and associate its impressions in a certain way and establish certain relations between them.

Kant defined genuine knowledge as universal and necessary knowledge. He agreed with the rationalists that such knowledge exists, but limited it to the basic assumptions of the sciences of mathematics and physics; a rational metaphysics including cosmology, theology, or psychology be considered impossible. He agreed with the empiricists that only what can be experienced can be known, and that sensation provides the matter of knowledge. He agreed with both the rationalists and Hume that universal and necessary truth cannot be derived from experience. Kant's view was that the senses furnish the materials of our knowledge, and the mind arranges them in ways made necessary by its own nature. The contents of our knowledge are derived from experience (empiricism), but the mind thinks its experiences, and conceives them according to its native *a priori*, namely, rational, ways (rationalism). Kant states that to assert objective reality of a phenomenon, the phenomenon must be perceptible as well as conceivable, since "perception, which supplies the material of a concept, is the only characteristic of reality." At the same time, reality may be attributed to things as yet unperceived, provided these possible perceptions "hang together with some other perceptions according to the principles of empirical connection." Hence "it is possible...even before the perception of a thing and..in a certain sense, *a priori*, to know its existence." On this fact rests the ability to make valid predictions regarding the future [6, 7].

From the last paragraph one can, then, deduce Kant's answer to such questions as: What permits us to extrapolate from the past or present to the future? What guarantees are there that the future will behave like the past? What assurance do we have that the future will behave as our models indicate? Likewise, it is the Kantian combining of rationalism and empiricism that underlies the characterization of a Kantian system as one whose truth content is located in both its theoretical and its empirical components. And, even as the contents of our knowledge are derived from experience, but the mind *thinks* its experiences, so are "theories or general propositions built up from data, but data cannot be collected without the prior assumption of some theory of data collection...Hence, *theory and data are inseparable*...The guarantor of a Kantian system is the degree of fit or match between the underlying theory and the data collected under the presumption of that theory." [5].

The use of policy analysis models is not for the accurate projection of the future (forecasting), but rather for analyzing the effects of alternative policies by observing the qualitative changes in the system's behavior. It is precisely those policies which affect change in the socio-economic system that are of particular significance to policy makers. Although quantitative information is necessary to measure the change, neither purely Lockean nor Leibnizian approaches provide a satisfactory framework for designing models of socio-economic systems. As stated earlier, the need for a methodology that reconciles the two conflicting objectives in model design - accuracy and structural adaptivity - leads to the synthetic or Kantian conceptual framework for policy analysis modeling. However, research is required to develop the conceptual framework and formulate a set of guidelines for the design of dynamic simulation models based on the synthetic or Kantian point of view. Concurrently, a better understanding of the relative strengths and weaknesses and of the inherent limitations of the existing methodologies is essential. The need for this perspective becomes acute when the questions of validation and use of models in the policy process arise.

VALIDATION AND USE OF MODELS

Concern regarding validation is often expressed about large scale models of socio-economic systems; it ranks as high in the discussions [8] as documentation, transferability, and communication, whether between model builders themselves - no easy task - or between modelers and decision makers. The issue becomes particularly thorny in the context of policy analysis models. While various procedures for "model validation" have been proposed, the fundamental underlying problem remains still unresolved. Recent books [9], [10], [11] have started to shed some needed light on the issues by presenting a wealth of information on models, modelers, and their successes and failures in the public decision making environment. At the same time, modeling of socio-economic systems has inspired an ever growing list of opprobrius treatises which could serve as a constant reminder to over-zealous model builders of the thousand errors they are prone to make.

In considering the role of models and the issues associated with their use in the policy process, three functional groups can be identified: (a) *the modeler,* or model builder, who conceives, designs, and implements a model; (b) *the model user* who is concerned with obtaining quantitative and qualitative information on specific policy issues (he is either a policy analyst or on the staff of the decision maker); and (c) *the decision maker*, who requires pertinent, timely analyses and recommendations from his staff. Much of the argument regarding poor communication between modelers and decision makers results from inadequate appreciation of the important role of the model user/policy analyst. Problems arise when modelers attempt to carry out both functions and especially when they attempt to influence the decision maker in a direct, personal way. This is not meant to imply that decision makers or model users cannot be modelers or vice versa; it is meant to stress the different functions that have to be performed in incorporating models in the policy development and decision making mechanisms.

If the identification of the three functional groups is accepted, then the issues of validity, verification, and credibility can be put in perspective. The following definitions have been adapted from [9] and [12]:

> *Verification* is a test of whether the model behaves exactly as its designer intended.
>
> *Validation* is a test of whether the model behavior is in agreement with the real system it represents with respect to the specific purposes for which the model has been designed.

The question of verification is of great concern to the members of the model building team and to their peers. Verification includes debugging of computer programs, testing algorithms for convergence, checking that data are entered properly and used correctly and, generally, ensuring that the implemented model is true to its conception and error free, "irrespective of whether or not it and its conception are valid" [9]. Verification of the model is a necessary requirement by reviewers, by model users, and by peers. The discovery of errors usually ellicits quick corrective action by the modeling team.

Validation is an issue between the model user and the modeler because validity is closely tied to the function the model will perform: will it be used to forecast or to project? Will it be used to explore the impacts of specific alternative policies? Will it be used to simulate policies or to determine policy options? A model may be "valid" for one set of uses and invalid for many others that appear to be very similar. While the differences may seem minor, they may violate some of the implicit assumptions in the model; the intuitive understanding of these differences may be one reason why models perform better when the model builders are involved in their use.

In considering validation tests for a model, it is important that its philosophical basis be understood. The formal procedures that have been established for Lockean models may be totally inappropriate or irrelevant when applied to Leibnizian models. Even the commonly required test for a model to reproduce the behavior of the real system over a specified historical period is fraught with conceptual difficulties. It is not really a test for validity, but rather for verification. The authors of [9] correctly point out that validation procedures are at best "tests aimed more at invalidating than validating the model."

What is important in considering a "verified" model for use in policy analysis is whether its underlying assumptions and theories, or the approximations regarding the model's boundaries and the interactions between the subsystems are compatible with the issue to be analyzed and with the policies to be evaluated. The interaction between the model builder and the model user (not the decision maker) in defining the scope of each policy analysis study is an essential component for effective utilization of models in the policy process. And it is at this point, when the model builder bypasses this step and acts as policy analyst without the necessary experience and perspective, that communication between decision maker and modeler breaks down with a possible loss of confidence in modeling by the decision maker.

Even though a model may have been verified by the modeler and considered valid by the model user for a specific study, there is still a third issue: credibility of the model with decision makers. G. L. Johnson states in the preceding paper that "problem solving analyses are credible with decision makers, if they pass four tests: (1) *coherence*, (2) *correspondence*, (3) *clarity*, (4) *workability*."* The first two, coherence and correspondence, can be interpreted as tests for validation and verification while the clarity test is one of understandability. "When the decision maker applies the test of workability, he checks the proposed solution and projected consequence of the solution to see if he thinks the outcomes would actually result from the prescribed action and, if they result, whether they will solve the problem before him."* A fifth test, that of *reliability*, has been proposed by W. Fishel [13]. Reliability measures the consistency over time with which a model generates understandable and workable results; reliability, however, can only be established with repeated use of the model.

This concept of credibility, with its attendant objective and subjective tests, forms interactive links between the three functional entities - the modeler, the user, and the decision maker. The establishment of that interaction is essential, if large scale models are to serve a useful function in the policy making process.

In order to use models in policy analysis, three types of input data are required to spefify a model completely and carry out a simulation: the numerical values of the model parameters, the time functions that represent the exogenous variables - deterministic or random - and the time functions that represent the policy variables. It is quite often difficult to differentiate between the three; the classification of the input data as model parameters, exogenous variables, and policy variables depends on the model user's objectives, attitudes, and the policy issues to be analyzed.

The exogenous variables and the policy variables constitute, together, the *scenario* for each specific simulation. The set of parameters used for each simulation determine the specific model realization. Consequently, an important consideration in the use of dynamic simulation models is the determination of scenarios. This problem is often addressed by first defining a baseline scenario and then considering extreme variants (high-low, max-min) in the pertinent variables. Essentially, a high dimensional space is defined in which the baseline scenario is only a trajectory. The variants with respect to one variable define a strip on a hyperplane that includes the baseline trajectory. Variants in several independent variables define a rectangular tube that contains the baseline trajectory.

The use of a simulation model can be thought of as a process that maps the tube in the scenario space into some region in the output space. Since carrying out simulations of many scenarios (and the attendant "sensitivity" analyses) using a large scale model is both prohibitively costly and impractical, what becomes important is the ability to bound the space of output trajectories by selecting only a small set of input scenarios. Alternatively, the methodological problem can be expressed as the determination of a small set of possible input scenarios that can characterize the reachable set of outputs. It should be noted that the relevant concept is that of *possible* rather than *probable* scenarios. The idea of evaluating scenarios in terms of their possibility is not new, if it is realized that the idea of consistency, so often discussed in the context of scenario development, can be related to possibility (an inconsistent set of exogenous variables represents an impossible scenario). Recent developments in the theory of fuzzy sets [14, 16] and of the calculus of possibilities [15] may lead both to new insights in the relationship between the input scenario space and the reachable set in the output space, as well as provide a language for defining the boundaries of the regions in question. While probabilistic methods are well suited to forecasting problems, a possibilistic approach seems better suited to policy analysis.

CONCLUSIONS

While a very substantial effort is being expended in developing models for use in the policy and decision making process, the effort is meeting with very limited success. In this paper, an attempt has been made to describe a conceptual framework for policy analysis modeling and indicate the importance of understanding the inherent limitations of various methodological approaches. The question of model credibility is then addressed and finally the need for a theory for scenario development in the context of dynamic simulation models is stressed. Each of the above areas contains a host of unresolved issues and unsolved problems that must be addressed if models are to be used successfully in policy analysis.

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APPLICATIONS OF SYSTEMS SCIENCE IN PROJECTING ALTERNATIVE FOOD AND AGRICULTURAL FUTURES

Leroy Quance and Yao-Chi Lu

ABSTRACT

Public and private policy decisions, program planning and management, and expenditures of limited federal and state funds affect food production capacity, commodity supply-demand, resource development and use, the environment, economic development, and the world food situation. In dealing with the long-run aspects of these problems, public decision makers are increasingly turning to anticipator analyses for which they need more and better information about alternatives, tradeoffs, and impacts on social value functions. Providing private and public decision makers timely futuristic information about U.S. food and agriculture is the mission of the Economic Projections Program of the Economics, Statistics, and Cooperatives Service of USDA. Its approach is a "dual thrust man-machine simulation system" which provides futuristic information and analysis about the U.S. food and agricultural system and its major linkages with the general and world economies.

INTRODUCTION

Man has always been fascinated by the future and made efforts to predict future developments. Recently, interest in the future seems to permeate every aspect of human endeavor with renewed frenzy. Alvin Toffler [14] probably put his finger on the most important reason--change. The area of change we want to concentrate on is change in food and agricultural systems and change in the way we study them to aid public policies dealing with food and agriculture.

The scriptures speak of feast and famine, and historically we have had a feast or famine attitude about the world food situation. With amazing regularity, the public attitude swings from the position that agriculture has an inherent and chronic capacity for overproduction to the other extreme of viewing scarcity as a permanent characteristic of food production. Recently, the pendulum has swung from the chronic overproduction hypothesis held by Heady et. al., [4] and Johnson, Quance, and Associates [6], for example, to the other extreme of the scarcity theme held by such analysts as Brown [1] and Renshaw [11].

A LONG-RANGE WORLD FOOD SCENARIO

Let us look back over the past 200 years of U.S. history to develop a scenario for the next 100 years based on the major long-run food parameters--population and income growth on the demand side and technological change and productivity growth on the supply side. Although this brief summary emphasizes supply capacity in the United States, it has world implications.

Demand

Herman Kahn and associates [7] identify an upswing in world population and a gap opening between incomes of the rich and poor nations beginning at about the time of the American Revolution. During the first 100 years of U.S. history, world population almost doubled, while the income gap, measured by the ratio of income between the richest and the poorest nations, increased from 5 to 1 at the beginning of the period to 25 to 1 by 1875.

World population growth and the income gap accelerated during the second 100 years of American history. Kahn and associates believe that from 1950 to 1990, the rates of growth in population and gross world production (GWP) will be somewhat above 2 and 5 percent per year, respectively. While world population and the income gap will continue to grow, the income gap will reach a maximum of about 200 to 1 by 1990. Furthermore, 1975 would probably mark a transition point when world population growth would switch from increasing at an increasing rate to increasing at a decreasing rate.

Thus, Kahn and associates see the present as the inflection point or a "real transition" in world demand for food. Growth in world population and GWP will now begin a gradual leveling-off process, eventually stabilizing at very high levels (about 15 billion people and $300 trillion GWP) late in the 21st century. And the income gap between rich and poor countries should begin rapidly closing at about the time of the U.S. Tricentennial.

Supply

Although the quantity of food supplied can be increased by using larger acreage and/or increasing non-land capital and labor inputs, the major long-range shift factor effecting expansion in the food supply will be technological change and producitivity growth in agricultural production.

A backward glimpse shows that at the time of the American Revolution, most farming tools differed little from those used for the previous two centuries. After the Revolution, however, American farmers had invented and adopted many improved farming practices, tools, and machinery including the cotton gin, cast iron ploughs, mechanical reapers, and mixed fertilizers [10]. As a result, productivity increased. But because farming practices, tools, and machinery were basically hand-powered, productivity growth reached the limit imposed by hand power by the Civil War.

The Civil War stimulated change from hand power to animal power and thrust American agriculture into the first American agricultural revolution [10]. War-induced labor shortages, high demand, and resulting high food prices encouraged farmers to adopt labor-saving horse-drawn machines. During this period, several farm programs and policies were implemented to generate new knowledge and to disseminate it to farmers. Thus, productivity accelerated after the Civil War until about 1880 and then tapered off toward World War I as the full potential of horse power was reached.

Although the first practical self-propelled gasoline tractor was built in 1892, internal combustion engine tractors were not widely adopted until the outbreak of World War I. During the War, high farm prices and high wages relative to machinery prices caused rapid conversion from horsepower to mechanical power.

Mechanization was only the first phase of the phenomenal growth in agricultural productivity since World War I. Through genetic and chemical as well as mechanical engineering research, many new technologies were developed. After World War II, with widespread use of chemical fertilizers, the complementary potential for such technologies began to be realized. Each new technology tended to shift the productivity growth curve upward before the curve leveled off toward the limit imposed by mechanical power. Continuing mechanization of farming operations and rapid adoption of a host of other major technological breakthroughs caused productivity to continue to grow throughout this period.

We might call our present epoch "early science power" with respect to growth in agricultural productivity. Whereas earlier epochs were characterized by a single power source with definite limits of substitution and growth, the characteristic of science power is that production processes employ major technologies that tend to be more complementary--their combined use tends to create greater productivity than the sum of the productivities of each used in isolation. Other things have happened also. As a technology or family of technological breakthroughs signal a new epoch, the epochs tend to be shorter and to occasion significantly greater productivity impacts. We do not believe that we have reached the limits to productivity growth from mechanization, improved plant varieties, and agricultural chemicals. Even so, before the limits of such known technologies are reached, a new family of technologies will likely emerge in the period between 1985 and 2000. This new epoch we might label "intermediate science power," with the new technologies likely to include such unprecedented technological breakthroughs as bioregulators, photosynthesis enhancement, twinning in beef cattle, and single cell protein. Before productivity reaches its limits to growth from these new and existing technologies, controlled environment agriculture could be making a major impact in an epoch we might call "advanced science power." Not only could this epoch further the complementary relationships among advanced technologies, but it could also significantly reduce the strain on our natural resources and the environment. Moreover, the impacts endured from random and unpredictable weather could all but be eliminated.

In the epoch of controlled environment agriculture, the limiting factor would be the finite earth. But long before the earth-bound scenario provides a limit to agricultural productivity growth, space colonies could emerge with agricultural enterprises [9]. Controlled environment agriculture and advanced hydroponics such as the nutrient film technique of the advanced science power epoch could complement space technology to make possible a "space power" epoch in the growth of agricultural productivity.

We do not want to underestimate, however, the role of economics. Well in advance of reaching the limits of an earth-bound scenario, economic forces could, at least temporarily, cause the world society to alter drastically its social and economic order. Stabilizing the world's population could be the first priority. Such change could reduce the economic incentive to move into the technically feasible but extremely costly space power epoch, or at least significantly alter its dimensions [6].

Furthermore, the causal relationship may be reversed. Rather than controlled environment agriculture enhancing space colonization, research relating to the problems of sustaining life in space and the development of solar energy may greatly reduce the cost and make controlled environment agriculture more feasible in otherwise hostile earth environments, according to the typical "spinoff" principle.

To summarize our world food scenario, food demand, although continuing to increase to very high levels, should do so at decreasing rates. But technological change and productivity growth coupled with resource development and increases in conventional inputs should permit the world food supply to not only keep pace with demand, but should also permit significant increases in the real cost of food as measured by the share of per capita income spent for food.

THE CHALLENGE

We hear responsible people projecting futures for the United States and the world ranging from doomsday to a scenario of plenty. Perhaps, though, the real significance is not the inconsistency with which analysts of different disciplines and perspectives view the future, but the consistency of those voices in recognizing the need to study the future--to rephrase Santayana, those who neglect the future risk losing it.

World population and income growth have the potential for creating a soaring food demand. On the other hand, finite natural resources, environmental degradation, and possible "limits to growth" in agricultural productivity raise the possibility of severe problems in maintaining a desired balance between the demand and supply of food and fiber without starvation playing the equilibrating role.

However, we believe the evidence strongly suggests the unfolding of a supply-demand management scenario wherein man succeeds in controlling himself and his environment--a world in which both technologies and human values change. Rather than concentrating on either technological change to increase food supplies or population and resource control and conservation to decrease food needs, a balanced future is sought in which both the quantity and quality of human existence are valued. Rather than reject the machine, have blind faith in science, or throw up our hands in hopelessness, we have reasoned faith in a future where science and man are adaptive to a common rhythm in tune with our environment.

Our unfolding scenario calls for bracketing food supply and demand determinants such as technological change, inflation, environmental conditions, population and income growth, and world trade in likely ranges, estimating the probabilities of each reasonable combination, and simulating the resulting alternative food and agricultural futures through various planning horizons. But we are not constrained to accept the results. Should some projected events appear undesirable, we can stop the simulation as it advances through time, rewrite the "second act" of the scenario, make new policy decisions, and continue our journey through time with man in control of his destiny.

With the U.S.'s comparative advantage in natural resources, science, and technology, we could truly insure an adequately full breadbasket for the world. Problems we could solve would be very diverse--ranging from the extreme of providing adequate calories to prevent starvation in the poorest food deficit country to improving dietary quality in the U.S. and other wealthier nations to extend life expectancy a few days, months, or years. Accomplishing such diverse tasks as well as all those lying in between requires a very complex systems approach. We must integrate natural resources, technology, and human components into a highly sensitive food information system. Information about these components flowing throughout the system would be its lifeblood. A man-nature-machine partnership would exist with each element participating according to its comparative advantage: man the thinker, nature the provider, and machine the doer.

Such a food information system could change our sequence of acting on food problems from reactionary to anticipatory. Rather than correcting our course and repairing the damage after a problem had occurred, we could sense problems before they happened, provide evasive measures, and continue on course with man in control of his destiny.

Thus, we would be capitalizing on the opportunity to make man, nature, and machine part of a single super-sensitive life supporting system. Some would carry this thought further. Some scientists believe the destiny of man lies in expanding this concept to space--to scatter life throughout the universe much the same way that a dandelion's seed is scattered across a field [12].

This life supporting system could include such diverse elements as a hydro-meterological station in the Soviet Ukraine monitoring the winter wheat crop to an international food game serving as an Adam Smith-like "invisible hand" guiding nations toward enlightened long-range food policies, serving not only each individual nation's self interest, but the interest of the world in total.

Let us turn again to history for some insights into the problems and potential for accepting the challenge.

A HISTORICAL SUMMARY OF ECONOMIC RESEARCH IN AGRICULTURE

The market structure of the agricultural economics profession is as dynamic as the food and agricultural system we study. With respect to demand structure, there has been a shift in relative emphasis from micro-economic or "firm" research to macro-economic or "economy at large" research. We are realizing that, as James D. Shaffer [13] expressed it, we have been overly concerned about the efficiency of an already fairly efficient pea-packing plant when there are more pressing social problems. Emerging social problems such as maintaining adequate and low-cost food and fiber for domestic population, public services, environmental quality, the energy crisis, and the critical world food balance require more aggregative economic analyses of the whole or major sectors of our society and world.

This shortcoming of economics is currently visible in our failure to anticipate recent events in the world economy and our lack of clear perspective of what is to come. We have perhaps fallen short of our potential contribution to social management because there is a lack of preciseness about societies' food and agricultural goals and thus no clear set of alternatives for policy analysts to explore. These related problems result from rapid changes in agriculture and in food and agricultural institutions.

In the early 1900's, the United States was completing the settlement of our frontiers. Under subsistence agriculture, the farm family was the principal institution and food policy was basically family policy. Thus, there were no conflicts between policy goals or areas such as food policy, rural welfare, and farm policy.

With the technological revolution in agriculture, commercial agriculture came into existence. Each farm family began to supply more and more people with food and food policy became commercial agricultural policy. The tripartition of food, farm, and rural welfare policy began to separate, but there was such a large overlapping area that there were no serious conflicts. It was during this period that most of our agricultural data series originated. Agricultural policy research became a separate identity from farm management and agricultural economists began studying relationships between food policy, farm policy, and rural welfare.

As we advanced into industrialized agriculture, a managerial revolution took place. Emphasis turned to firm growth and the combining of units into larger and more complex businesses. This resulted in the vertical integration of many food and agricultural processes. Policy goals became less compatible; national food policy became different from family food policy and commercial agricultural policy. In our public institutions, we entered a period of strained relationships between old allies. Not only have policy goals greatly diverged, but they are becoming blurred; our traditional data series are proving inadequate and our basic conception and processes for conducting policy research are fragmented. Many concerned individuals and groups sense a void--and are scurrying to fill it.

The changing supply structure for economic research in agriculture reflects responses to developments in the scientific method, increasing cost of research, and technological developments in automated data processing. Early emphasis was on farm management and the collection of data in keeping with the inductive scientific philosophy. But over time, our general research philosophy has come to give more equal treatment to all sub-stages of research in a cyclical inductive-deductive scientific method.

As described by Cohen and Nagel [2], modern scientific method involves five generally recognized sub-stages of research: recognizing and defining a problem, formulating a hypothesis, designing empirical procedures, assembling and analyzing data, and interpreting findings. Completion of one research cycle leads to new generalizations, new problems, and the need for new data. Data and analytical requirements are interrelated with other sub-stages of research, are specified more in terms of a preconceived body of theory, and are applied to a particular research problem in the form of a cause and effect hypothesis. As progressive research cycles have been completed, a "model" of technical and economic relationships in food and agricultural systems has begun to evolve in keeping with the more systematic, additive, and recurring nature of economic information needs.

Public support for agricultural research and extension programs has not increased as rapidly as some analysts thought it should, but salary and other related costs have accelerated. And historically, most economic research has been supplied by a large number of individuals operating as entrepreneurs, producing small bits of analysis that they hope will be demanded. Hathaway [3] observes that this analysis has not added up to an adequate understanding of solutions to larger social issues, even though a large portion of economic research is paid for by the public. As the cost structure for research resources and the demand for aggregative social and global research increases, economizing principles are being applied. Research resources are beginning to be combined along an expansion path of least-cost combination.

A third major supply development is the advance in automated data processing and accompanying growth in simulation and systems analysis. This development enhances both (1) evolution of a more complete scientific method involving research cycling with each round becoming more complex, more realistic, and increasingly sophisticated and (2) integrative research including not only net social benefit or macro-economic analysis, but also connecting links to disaggregate levels such as firms, individuals, and/or households.

Large scale systems analysis enables an additive and integrative approach to research needs and the simulation of many relevant alternatives with respect to technical and economic uncertainties and policy choices. Advances in automated data processing technology, both hard- and software, constitute a major, but as yet only partially realized, positive shift in the supply curve for economic research. Originally, computers were used merely to replace routine and costly manual data processing and storage activities. But as more sophisticated economic systems are translated into machine language and combined with data systems, the researcher's imagination provides the only real limiting factor to the size and complexity of a simulated food and agricultural system.

Although the economic research element of social management is our first concern, economic information is of limited value unless it is based on the best available technical relationships and coefficients that the physical sciences can provide and unless it is communicated in a usable and timely form. As food and agriculture systems and the institutions concerned with their operations become larger and more complex, these necessary aspects of economic research will undoubtedly become more difficult, even given our modern data processing and communications technologies.

As we participate in efforts to improve economic information, we hear many observations that, somehow, we modern-day participants in economic research and policy evaluation in U.S. agriculture have lost the unique capability of the old Bureau of Agricultural Economics (BAE) to communicate effectively with action or technical science program-based agencies, the Administration, and Congress. Perhaps this is merely an expression of nostalgia on the part of our senior cohorts in keeping with the natural proclivity for looking back. But this is one more reminder that in looking at economic information systems, sources of technical and program data, as well as communications with policy decision makers, are equally important to economic research in the context of a generalized social management cycle.

The physical sciences and action agencies provide technical and program information and coefficients. Economists add information and coefficients about input and product markets and develop models of the appropriate sectors or subsectors of the food and agricultural system. The economic analysis and information generated are transmitted to policy makers, decisions are made, new or modified programs initiated, and new information generated. This constitutes a new knowledge state with potential new problems and one social management cycle is complete. Economic research is not generally the "answer" generating component of this process, but provides one significant kind of information that is considered with all other relevant information in the social decision making process.

Those who fondly reminisce about BAE's place in history would probably describe that agency's "charisma" quite differently from the above, but some such cycling of information is essential with regular and recognized interaction among participants at both the working and policy management levels. Both suppliers and demanders must communicate their side of the market if it is to be effective in helping with continual adjustment toward a new equilibrium in a dynamic world.

FOOD AND AGRICULTURAL MODELING

Since Adam Smith, in his *Wealth of Nations*, laid bare the market mechanism by which a society is provided stability, economists have struggled with the problem of quantifying technical and economic relationships to aid public and private policy making and planning processes. As statistical and mathematical tools have been added to economic theory in simulating economic forces, modeling has had its ups and downs, but has generally assumed an increasingly greater role in economic research.

Current ESCS Efforts in Long-Range Projections

Any concept of an ideal food and agricultural information system is subject to much error and continual revision as the future unfolds. But it is necessary to conjecture about the ideal system--identify principal ideas and label components with terms that we can relate to or understand with our present knowledge. As we proceed from general concept to identifying specific components and possible relationships, the discussion becomes increasingly tentative and subject to change.

The ideal economic Projections Research-Management Information System (PRMIS) for ESCS as we now see it is illustrated in Figure 1. This system involves a continuing food and agricultural research, policy making, and planning cycle in the public management process. Generally, the cycle involves: 1) perceiving long-range issues and questions; 2) researching the issues and questions; 3) disseminating the information to policy and decision making institutions (both public and private); and, 4) receiving program and policy institutions' feedback and observing the new situation. And in the anticipatory spirit, the new situation with new food problems does not have to be real. Rather, problems can be anticipated in the simulation and analysis of alternative futures and evasive action taken before an anticipated problem becomes real.

Through the interaction of the Agency's Projections Review Board, coordinated projection teams and analysts in the core program area, Economic Projections and Analytical Systems (EPAS), long-range food and agricultural issues and questions are identified. A theoretical model of food and agriculture specifies these issues and questions in the form of cause and effect relationships and links the issues and questions to the analytical research capability.

The analytical research capability consists of a data base, judgment synthesizer, international food game, and the National Interregional Agricultural Projections (NIRAP) system. Both the theoretical model and NIRAP system are supply-demand oriented.

The data base plays the conventional role of providing a historical perspective, basis for estimating NIRAP system coefficients, and a current base to which we can compare projections.

The judgment synthesizer provides an automated capability to process systematically judgmental information about any aspect of PRMIS, such as the likelihood that specific scenario attributes will grow at a specified rate, or the probability that an unprecedented technology will come on stream with specific adoption and impact patterns over time. But the scenario development component of NIRAP will generally be the heaviest user of the synthesizer.

The World Food Game (WFG) will perhaps for some time be only a symbol of the long-range potential of a simulated food information system such as PRMIS. However, in early 1977, we had the privilege of participating in early testing of a "first generation" international food game developed by the Center for Futures Research, Graduate School of Business Administration, University of Southern California as the current effort under their 20-year forecast project. In PRMIS, we believe the WFG can serve the dual purpose of helping the game players to gain greater awareness and perception of real or potential world food problems and assist in giving our scenarios a global perspective.

The NIRAP system, a computerized simulation of U.S. agriculture, is the central analytical capability of PRMIS. It is used to project and analyze alternative futures based on scenarios differing with respect to rates of growth in major uncertainties affecting food and agriculture and policy options. Later, we will discuss NIRAP in greater detail.

Dissemination of information has perhaps been the greatest shortcoming of agricultural model developers and users. We often become so preoccupied with the model that it becomes an end itself, rather than a means to good analysis. Dissemination of information generated by our models in turn suffers, and we get poor marks for our efforts. The analyses and reports are typically so lengthy and technical that even other economists seldom take time to read or understand them, let alone people in policy making institutions with less technical backgrounds. Dissemination needs to take the form of a pyramid with a very brief statement of not more than two pages summarizing the problem and relevant information as the apex. In PRMIS, we call this encapsulated dissemination outlet *Future Facts*--About Food and Agriculture--and expect to publish the first issues in early 1978. But eventually, this activity will result in a comprehensive food information matrix.

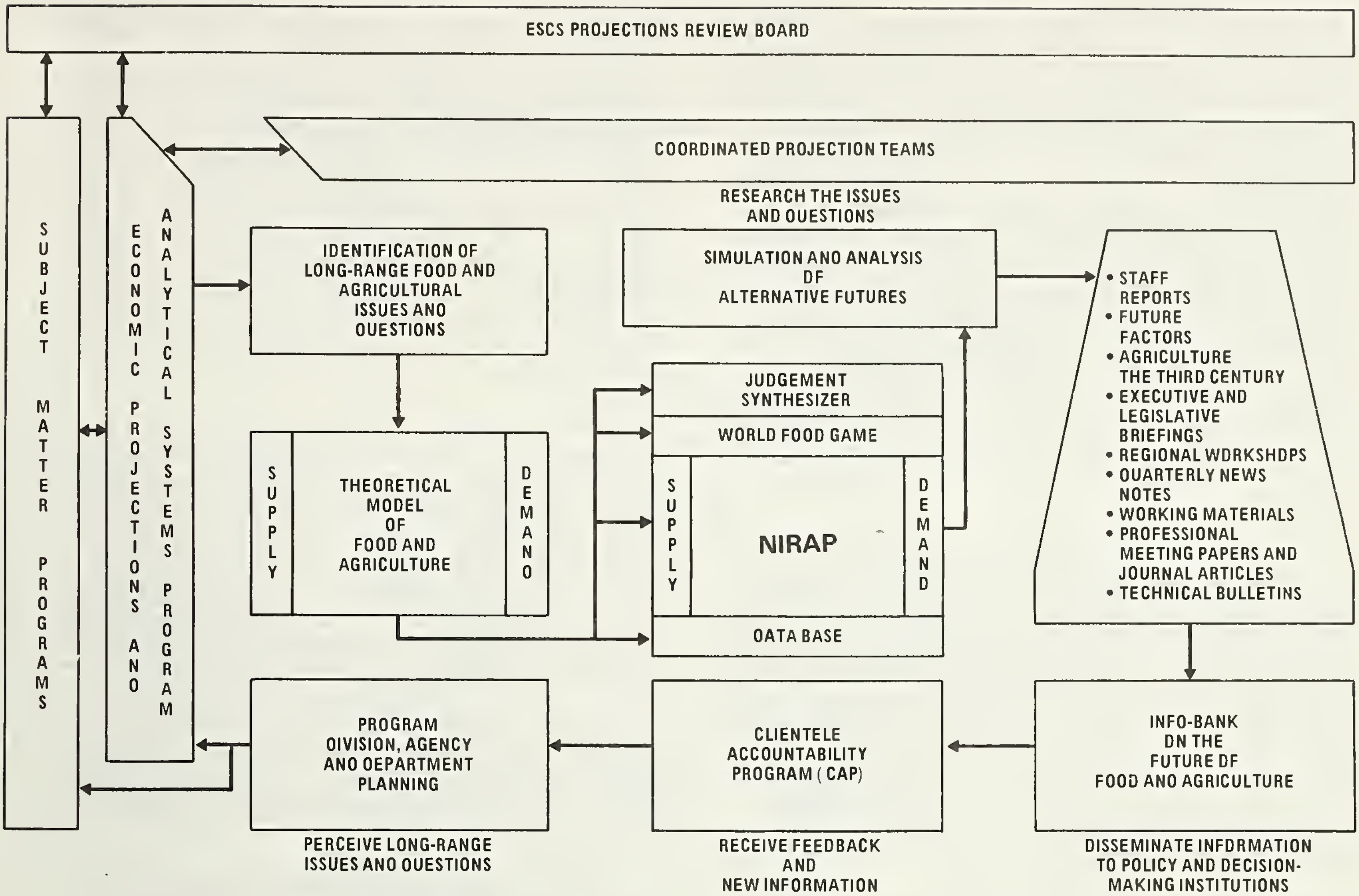


FIGURE 1. TOWARD AN IDEAL ECONOMIC PROJECTIONS RESEARCH MANAGEMENT INFORMATION SYSTEMS (PRMIS)

Matrix output, as indicated earlier, would be very concise, consisting of not more than two pages of published text or a 5-minute video tape. In published form, the matrix output could be contained in loose-leaf notebooks conducive to easy revision.

A second, more visionary but perhaps more useful output mode, would be "food rooms" in ESCS, the USDA Administration Building, the Executive Office Building, and the Senate and House Office Buildings. These food rooms would consist of displays describing the food information matrix, viewing chairs, and a television screen connected to a video tape bank. The viewers, upon selecting the issue and question of concern, would receive a five-minute analysis structured to give a precise definition of the concept under question, a historical perspective, alternative possibilities, sensitivity analysis of policy options, and references to more in-depth technical ESCS research.

Further down the dissemination pyramid, information outlets would become progressively more conventional and more detailed. One exception would be the executive and legislative briefing. This briefing would be held each time a significant portion of our "core" projections were revised--probably every other year. It would give key staff economists or other interested parties in the executive and legislative branches of government an opportunity to see and hear the preliminary results of our updated long-range appraisals for food and agriculture before they are published.

To date, most dissemination activities have been speeches, professional papers, and unpublished working materials. However, we have published four issues of *Agriculture the Third Century* under four subtitles: *Introduction to the Economic Projections Program* (Number 1), *Commodity Production and Utilization Projections to 1985* (Number 2), *Historical Perspective on Demand and Supply Projections in the USDA* (Number 3), and *The Metric System* (Number 4).

The information bank on the future of food and agriculture (INFO-BANK) would be an interactive computerized storage and retrieval system with video capability. INFO-BANK would contain a bibliography of literature related to food and agricultural projections; access to the data base; a statistical computation package; the current ESCS core projections of alternative futures; other agricultural projections generated in ESCS and elsewhere; independent forecasts of future events affecting food and agriculture; a listing of all analysts in ESCS and elsewhere with experience and interest in projections; definitions of projections terminology; all ESCS project objectives and accountability factors relating to projections; and an inventory of current models relating to agricultural projections. An analyst could sit at the INFO-BANK console and develop a draft of almost any document relating to projections such as a project proposal, annual plan of work, *Future Facts, Agriculture the Third Century*, or a special clientele request for ESCS projections.

One of the most difficult tasks a government agency with some public service responsibility such as ESCS has is to measure the inputs and outputs from the clientele service activity. Our Clientele Accountability Program (CAP) will be designed to document who our clientele are, the volume of service we provide, and how good or bad our capability is for fulfilling clientele needs. A computerized CAP will periodically and rapidly tabulate clientele service information and provide needed inputs into annual planning efforts.

Program, Division, and Agency planning include the preparation of routine ESCS Management Information System (MIS), Program Area Statement (MIS-1), Project Statements (MIS-2's), and Annual Plans of Work (MIS-3's). In addition, an annual Economic Projections Program evaluation and review technique (PERT) chart is prepared to integrate and link important research tasks, determine the critical path, estimate time required for each research task, and routinely monitor and adjust research schedules.

The Present Analytical Capability

Figure 2 is a general flow diagram of the National-Interregional Agricultural Projections (NIRAP) system. To date, and in one model system, it has not been feasible to study systematically all technical, economic, and political interactions in and between food production, the general and world economies, and the environment. But hopefully the NIRAP system provides an abstract simulation of major cause and effect relationships necessary to provide realistic analysis of some important issues. We are far from satisfied, though, but are continually working to expand the NIRAP system capability.

Simulation of the future begins in the NIRAP system with a synthesis of professional judgment and exogenous projections of variables that cause shifts in the supply and/or demand functions for individual farm commodities and aggregate farm output. We call this process scenario development. Variables, such as public expenditures for agricultural research and extension programs and environmental controls, provide shifts for agricultural supply functions via the agricultural productivity simulator. On the demand side, shifts in demand for farm output arising from population and GNP growth in the domestic economy and changing attributes of world agricultural trade are estimated via the constant price commodity demand component.

Market disequilibriums generated by shifting demand and supply functions are eliminated in the aggregate farm output and commodity production and utilization components via own price and cross price elasticities of supply and demand. The aggregate farm output component projects "absolute" aggregate supply and demand responses, while the commodity production and utilization component projects "relative" commodity prices and quantities.

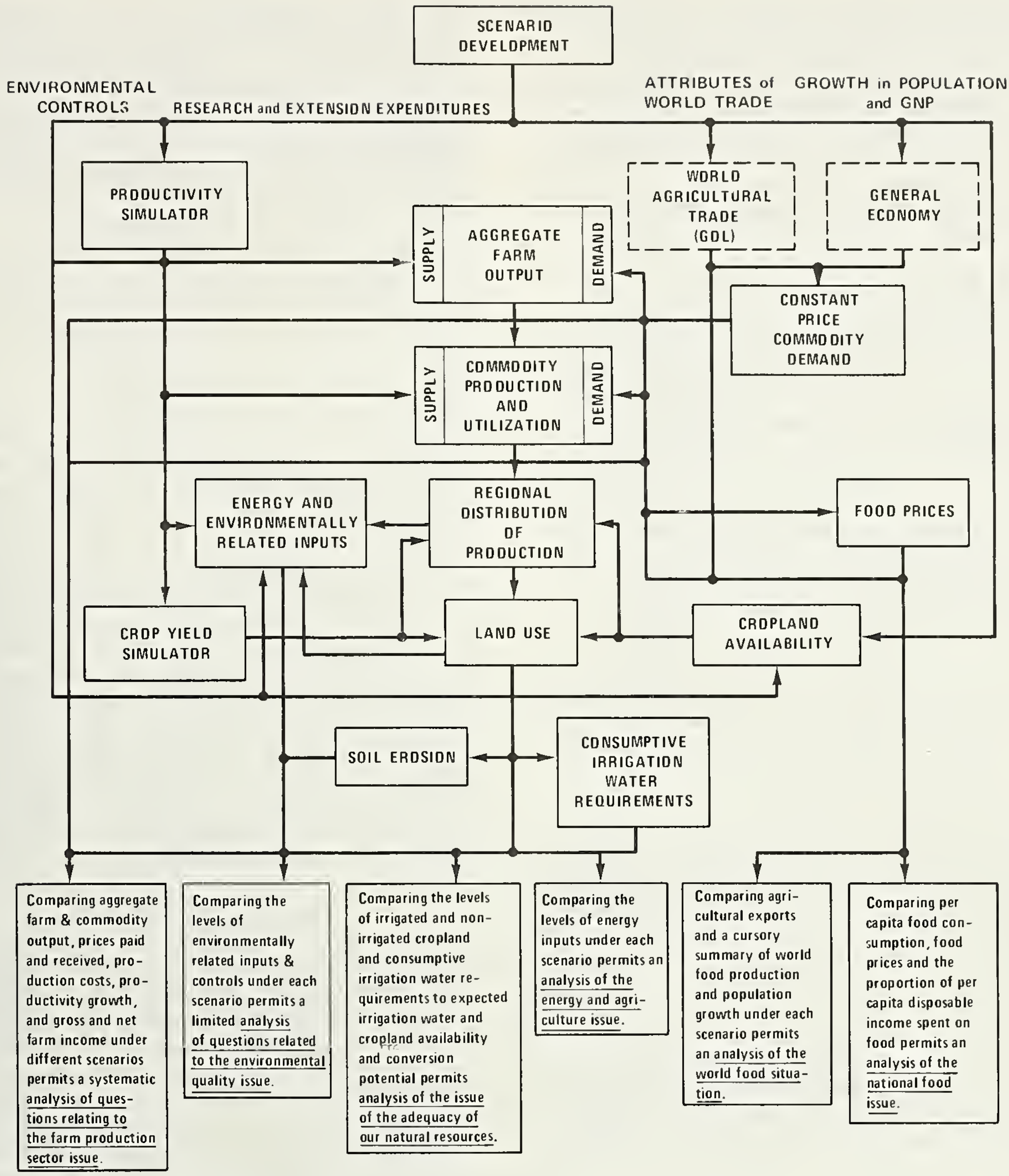
Prices received by farmers and food consumption projections from the aggregate farm output and commodity production and utilization components provide a basis for projecting food prices.

The crop yield simulator, cropland availability, and commodity production and utilization components provide inputs for the regional distribution of production and land use components. National and regional commodity production, land use, and prices paid and received by farmers are used to project energy and environmentally related farm inputs and variables such as fuel, fertilizer, consumptive irrigation water requirements, pesticides, and soil erosion.

Comparative analysis of resulting alternative futures, based on scenarios differing only with respect to attributes relating to a specified issue, constitutes our analytical capability.

Other Modeling Efforts

Since the recent surge in concern over the world food situation, there has been a virtual explosion in economic modeling of food and agriculture. Four years ago, at the annual meetings of the American Agricultural Economics Association, S. R. Johnson and Gordon Rausser summarized their survey of modeling and simulation in agricultural economics. Their work, to be published in the forthcoming AAEA review of literature in agricultural economics, is a very comprehensive survey and exposition of modeling efforts in food and agriculture. But it is undoubtedly already out of date.



NOTE: Dots on flow lines indicate lines connect.
- - - means no formal endogenous model.
——— means a formal endogenous model.

FIGURE 2: GENERALIZED FLOW DIAGRAM OF THE NATIONAL-INTERREGIONAL AGRICULTURAL PROJECTIONS (NIRAP) SYSTEM

In 1975, the Subcommittee on Fisheries and Wildlife Conservation and the Environment of the Committee on Merchant Marine and Fisheries, U.S. House of Representatives, sponsored the Congressional Research Service in inventorying 20 major computer simulation models in *Computer Simulation Methods to Aid National Growth Policy*. The food and agricultural models included in the Congressional Research Service's report didn't even exist three years earlier, when the Johnson and Rausser effort was completed.

Just as there is an apparent cycle in the world food situation and our shifting concern between feast and famine, there also is a rise and fall in the fortune of economic modeling efforts. There was a proliferation of U.S. regional adjustment studies in the 1960's with attendant linear programming models. At least two major national agricultural modeling efforts in the Economic Research Service relating to farm program policy analysis and Natural Resource Development have risen to short-lived fame and then disappeared. More recently, one of the most ambitious of the major modeling efforts reported in the above mentioned Congressional Research Service Report, the Environmental Protection Agency's Strategic Environmental Assessment System (SEAS), appears to have lost momentum.

An example of the spread of food and agricultural modeling from national and regional concerns to global proportions is the International Institute for Applied Systems Analysis (IIASA) sponsored Third Symposium on Global Modeling--Food and Agriculture Models, at Baden, Austria, in October 1975. This symposium, reviewing agricultural modeling efforts in Latin America, Asia, Europe and North America, concentrated on the Club of Rome sponsored Model of International Relations in Agriculture (MOIRA) directed by the Dutch economist Hans Linneman [5].

There are so many research groups developing and planning to develop agricultural models that keeping track is virtually impossible. A very recent but limited General Accounting Office (GAO) survey inventoried 66 models that may be applicable for evaluating food policy (see the paper by Gary Boss et. al. in this proceedings). These 66 models include 16 world, 23 national, 2 regional, 19 single crop, and 7 food reserve models. Incidentally, during the time it took to write the last two sentences, two more very significant models came to mind that are not included in the GAO report. There is virtually a modeling explosion in food and agriculture! There are so many agricultural models that newcomers to the field sometimes conclude that their resources might be better spent inventorying existing models rather than developing new ones.

We believe in not "putting all our eggs in one basket." But aren't we perhaps going too far? It is becoming difficult to see the eggs for the baskets. Perhaps it is about time we concentrated on getting more "bang for the taxpayers' buck."

We could conclude that the thing to do is to have some super model builder gather up all the existing models and build the "model to replace all models." But that would be going to the other extreme. Analysts tend to feel "proprietary rights" over their models, and rightly so, because model developers tend to be just as much a part of the model as the mathematical representations and ADP soft-and-hardware.

But what can we do? A close examination of existing agricultural models would undoubtedly reveal significant gaps in important issue coverage and considerable "overkill" in other issue areas. Such an examination, however, would be extremely difficult. Due to our individual entrepreneurial heritage, we have developed our models with inconsistent econometric notation, inconsistent systems and automated data processing (ADP) standards, and sinfully inadequate documentation.

We think we should try to bring about more systematic procedures in the development and use of food and agricultural models. A consortium of model developers and users with perhaps a sponsoring institution could possibly do the trick. The consortium could develop consistent notation, subscripts, variable names, and systems, and ADP documentation standards. The sponsoring institution could provide funding for encouraging standardization activities, developing consistent national-international scenarios, and operating models for projecting and analyzing resulting alternative futures.

Consortium members would be responsible for adopting the systems and documentation standards approved by the consortium, providing a user's manual for their model, adding scenario statements required for operating their model, running their model under the standard consortium scenarios, providing a report on their findings, and providing their own funding source for model development.

SUMMARY AND CONCLUSIONS

Systems science can be a very powerful tool when applied to food and agricultural modeling and systems development. There are very important issues and questions to be specified and researched and resulting information to be disseminated to social managers for timely and anticipatory decision making. Recent history in national and international food and agricultural systems and in economics research indicates a void in our food and agricultural information system. Many groups are scrambling to fill that void. We have the opportunity to combine man, nature, and machine in a single, highly sensitive life-sustaining food information system. The opportunities for professional reward and gratification as well as returns to society are great indeed. But there are also many pitfalls, as witnessed by old experiment station and USDA reports and bulletins, journal articles, yellowing IBM cards, and promises unfulfilled.

If we are to move toward a more ideal food information system, systems science must be used in complementary proportions with economic theory, mathematics, statistics, technical sciences, and, above all, professional judgment from all these fields. Like any powerful tool, systems science can be used constructively or destructively. Too often, model builders became preoccupied with the gadgetry of their models and failed to maintain the required balance so that their efforts collapsed. We need to find better ways to manage and integrate our modeling efforts, earn the renewed trust placed on our efforts by social decision makers, and thus better realize the potential contribution of modeling to social decision making in food and agriculture. We think a consortium of model builders could go a long way in overcoming much of what we see wrong with many past and present modeling efforts in food and agriculture.

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MODELING FOR AGRICULTURAL SECTOR DEVELOPMENT PLANNING IN KOREA

George E. Rossmiller

ABSTRACT

This paper presents a brief overview focusing on agricultural sector model development, testing, and utilization by the Michigan State University Agricultural Sector Analysis and Simulation Projects team in Korea over the six-year period, 1971-1977. First the development of the Agricultural Sector Analysis and Simulation work at MSU, the scope of the project in Korea, and the multiple objectives of model development, institutionalization, and utilization are dis-discussed. Next is a section on the general systems simulation approach as practiced by the MSU team, with respect to philosophies, techniques, sources, and kinds of data and information. The models are then presented, using block diagrams, with an explanation of the linkages and variable flows, performance variables, data requirements, and policies which can be assessed. Finally, some lessons learned from the experience, with respect to credibility with decision makers and utilization, are detailed.

BACKGROUND TO SYSTEMS SIMULATION MODELING OF THE KOREAN AGRICULTURAL SECTOR

The Agricultural Sector Analysis and Simulation team at MSU traces its lineage back to active MSU participation in the Consortium for the Study of Nigerian Rural Development (CSNRD) in the mid 1960's. At that time, a consortium of six U.S. institutions under contract with the U.S. Agency for International Development (AID) were charged with a comprehensive study of rural Nigeria, which led to recommendations for a Nigerian rural development strategy [5]. The methods used in this study were traditional paper-and-pencil analyses with quantitative projections made by hand or with the use of desk calculators.

This study was very demanding of time, professional resources, and funding. It required four years, thirty-five professional man-years of input, and $1.5 million of funding to complete. Concerned AID officials and MSU participants in the study were disturbed with this high cost and were convinced that finding less costly, faster, and more versatile methods of carrying out such sector analyses would be a worthwhile endeavor.

Once the CSNRD activities were completed, a contract was negotiated between AID and MSU for a feasibility study to determine whether the systems approach and simulation techniques from systems science could be the means for reducing the time and resource cost of sector analysis studies such as that done by the consortium in Nigeria. Since the consortium had produced and collected a wealth of data and information which was available to the feasibility study team, the Nigerian agricultural sector was chosen as the case example to be modeled.

The Nigerian agricultural sector model was completed in 1970. The study team concluded that the systems simulation approach was effective in agricultural sector analysis modeling to provide input to sector development planning and policy decisions [7]. While there was no responsibility under the contract to use this model in Nigeria, it has been used several times for planning and policy formulation activities by Nigerian decision makers [2]. The Nigerian modeling feasibility activity showed such promise that AID and MSU entered into another contract to further develop, test, and adapt system simulation models for agricultural sector analysis and to institutionalize and utilize such models within the decision-making structure of at least one developing country.

This contract, negotiated in 1971, provided for activities in four major dimensions: (1) field activities, (2) methodological and theoretical research, (3) training, and (4) preservation of models developed in a form facilitating transfer and use in other locations and contexts. This paper focuses on the modeling work in Korea carried out under the field activity dimension of the project.

In summer 1971, Korean decision makers had completed the drafting of the Third Five-Year Economic Development Plan for initiation in January 1972. The first and second five-year development plans focused on building the social infrastructure and establishing heavy and export industries. During the first two plan periods, the agricultural sector had been purposely neglected as part of the national development strategy to establish a solid and dynamic industrial and urban sector base in the national economy. This strategy contributed to a widening disparity in growth rates and incomes between agriculture and the rest of the economy. During the period 1962-1971, the average annual growth rate of the non-agricultural Korean economy was 12.4 percent, while that of agriculture was 3.9 percent. Agricultural per capita gross national product, as a percentage of nonagricultural per capita gross national product, rose from 60 percent in 1962 to a peak of 71 percent in 1964 and then declined to 49 percent by 1971, despite the relatively high rates of off-farm migration during the period. In addition, a growing, more affluent urban population was placing increasing demands on domestic food supplies, in terms of both quantity and quality. Domestic agricultural production was lagging behind this increased demand, and increasing quantities of foreign exchange were required to import food supplies, particularly grains, to satisfy the deficit. Thus, during the first and second five-year plans, pressures requiring attention mounted. These increasing pressures caused Korean economic planners to place heavier emphasis on agricultural sector development in the Third Five-Year Economic Development Plan to be carried out during the period 1972 through 1976 [6].

The third five-year development plan was published in Summer 1971 [1]. Its perspective was macro and its scope economy wide. It was primarily a budget document, useful as a departure point for sector-level planning, but not an operational planning instrument by itself. The decision makers in the Ministry of Agriculture and Fisheries recognized the strong need for a comprehensive agricultural sector analysis leading to recommendations for an agricultural sector development strategy during the third five-year development plan period.

At the same time, the Korea field mission of the U.S. Agency for International Development (USAID/K) recognized that the increasing attention being given to the agricultural sector afforded the opportunity to provide economic and technical assistance in that area to enhance further the development of the Korean economy. USAID also recognized the need for a comprehensive agricultural sector analysis to identify investment priorities for agricultural sector development which would provide potential investment opportunities for agricultural sector loans and grants by AID and other international assistance agencies.

At this point, the MSU team was searching for a country with decision makers who would be interested in collaborating to apply the systems simulation approach to problems of agricultural sector development. Additional minimal prerequisites were of a cadre of agriculturally-trained personnel at the intermediate managerial level in government and an institutional structure into which the MSU team could fit. Thus, working with indigenous colleagues, they would further develop, test, and adapt the systems approach and simulation modeling techniques and attempt to institutionalize and utilize the approach within an actual governmental decision-making structure responsible for agricultural sector development. A project was negotiated between the Korean government, AID, and MSU wherein the MSU team and Korean counterparts in the National Agricultural Economics Research Institute (NAERI), the economic research arm of the Ministry of Agriculture and Fisheries (MAF), would produce an agricultural sector analysis with recommendations for a development strategy within the first nine months of the project [8] and a study on investment priorities in the Korean agricultural sector within the first year [3].

In return, AID and the Korean government agreed to provide base-level support for the joint team to develop an analytical infrastructure and a series of model components, based on the general systems simulation approach, to provide analytical input to the planning and policy-making process in the Ministry of Agriculture and Fisheries on a continuous basis. Once this analytical capacity was established and institutionalized, the MSU team would withdraw, leaving the ongoing operation and further development of the capacity to the indigenous personnel of NAERI and MAF.

The sector analysis report and the investment priorities study were completed as scheduled. It was possible to meet those deadlines because of the crude simulation model developed to project the consequences of the three alternative policy strategies identified by the team. It was primarily an accounting model developed to speed the preparation of the sector analysis report and to free the team members from tedious hand calculations. During the limited time available to them, team members were able to concentrate on the more important work of collecting better qualitative information for broader understanding of the Korean agricultural sector. The model not only provided the means to make projections, but also became the vehicle for integrating and synthesizing the contributions from all team members into a consistent set of data and information.

Since the first computerized portion of the KASS model performed primarily accounting functions, it was viewed by the team as part of a man/machine model in which much off-line calculation was performed by committees to determine the effects of various policies and programs on yields, land base, production input requirements, livestock production, and feed grain consumption. Because of the almost infinite variety of policies and programs which could be analyzed and the stringent deadline for producing the sector analysis report, policy and program assumptions were grouped into three policy strategy sets. With three clear-cut policy strategies identified, the problem domains were specified, and model development could be directed toward contributing information related to the solution of the many problems within the three problem domains.

A major advantage of the man/machine, rather than a fully computerized model, was that it facilitated interaction, not only among the analysts themselves, but also with decision makers. This decision maker interaction was crucial to keep the decision maker informed of the process and to provide him with a user's understanding of the models. It also kept the analysts, who were developing and using the models, informed of the real and, thus, relevant problems. The Korean agricultural sector study report was a synthesis of the quantitative projections and the qualitative knowledge of how the agricultural sector operated within its environment; of the institutions established by the Korean government and within the Korean society for carrying out the functions pertinent to agricultural production and marketing and the consumption of agricultural products; and of the relevant and feasible policy choices from a political, social, technical, and economic viewpoint.

Thus, during the first year, project activities were highly operational and oriented toward producing data and information in report form usable by the Korean government decision makers. Because the information was useful and had been developed in close interaction with decision makers, using simple models which were easily understood, the KASS team and its analyses gained credibility within MAF in a relatively short period of time. Because of this credibility, the stage was then set for continued intensive work in Korea on the further development of the systems simulation model of the agricultural sector, as well as the building of an analytical capacity to surround the model, and the institutionalization of that capacity into the governmental decision making process.

THE MSU MODELING APPROACH

General systems simulation modeling, as practiced by the MSU team, can best be characterized as an eclectic approach. The purpose of this modeling is to provide a set of analytical tools to assess the consequences over future time of implementing alternative planning strategies and policies to solve a variety of problems in agricultural sector development. The models attempt to reflect the technical, economic, and behavioral characteristics of the processes, linkages, and interactions which take place in a developing agricultural sector, relationships with the other sectors in the national economy, and relevant interactions with the rest of the world. The system being modeled must be considered in the context of the particular economic, social, political, and isntitutional environment within which it operates. The models can be classified as having a subject matter orientation focused toward providing analytical input to the solution of a variety of specific problems making up the more general problem domain related to agricultural sector development.

Normative information pertaining to values, along with positive information pertaining to "what is," "what was," and "what will be" are combined to provide prescriptive information pertaining to "what ought to be" and how "what ought to be" should be accomplished. Intense and continuous interaction between decision makers, modelers, analysts, and affected persons is necessary under this philosophic orientation to produce models of relevance in providing analytical information to help decision makers solve agricultural sector development problems.

A building block concept is employed in which relatively self-contained economic, technical, or biological functions or processes take place within specified model components. As specific problems are identified, the appropriate building blocks or model components can be chosen and linked in the proper configuration to provide analytical input to specific problem solutions.

The models are built using a variety of analytical techniques. The specific technique used to model a specific process or behavioral characteristic is chosen simply because the team sees it as being the most appropriate for the job. Thus, techniques and knowledge are drawn from demographers, farm management researchers, public administration analysts, economists and econometricians, statisticians, engineers, systems scientists, operations researchers, and physical and biological scientists as required to model most accurately the reality of the system under consideration.

Kinds and sources of information and data used in the models vary according to availability and model requirements. They include time series and cross-sectional data, opinion and judgement of experienced professionals and practitioners, experimental and survey results, and "guesstimates."

Finally, the models are conceptualized to be multi-dimensional in that they consider processes, flows, and linkages among physical quantities; values, usually in the form of prices or priorities; and information within the system and between the system and its environment in time and space. Since the focus is on problems, the time and space dimensions are extremely important in assessing consequences of technical, institutional, and human change.

This eclectic approach provides a flexible set of models and components which can be used as tools for analysis of a wide variety of agricultural sector development problems. No model solves problems. Analysts, decision makers, and affected persons interacting together and using a wide variety of models and information solve problems. The Korean models were built to be a part of the several tools used in this continuous problem-solving process.

THE PRESENT KASS MODELS

The model which had been hurriedly built during the first year to produce the sector report was extremely crude. These crudities were of three main types, corresponding to the three main components comprising any model--structure, parameter estimates, and initial condition data. While the original computerized model through its accounting routines described much of the structure of the agricultural sector, the major portion of the behavioral characteristics and the consequences of the behavioral responses within the sector to external stimuli were in the minds of the men who composed the committees which interacted with the original computerized model. Additional model structure could be built and linked to the existing computerized model to reflect additional structural and behavioral characteristics of the sector. In short, the activities of the original committees could be made endogenous to the computerized model. Additional and more accurate parameter estimates and initial condition data were also needed for use in the models. Thus, after the first year, the KASS team turned its attention to improvement and expansion of the computerized systems simulation model of the agricultural sector in all three of the above areas.

To be of more use to decision makers below the ministerial level, subsector models with more detail and the ability to focus on short- and intermediate-term policy problems were required. Since government intervention in grain stock management and grain pricing policy was (and remains) a major concern in Korea, the team decided to develop a grain management program model to provide analytical input into government decisions in this area. The following sections present overviews of the sector model (KASM) and the grain management program model (GMP) as they stood when the MSU component of the KASS team withdrew in late 1977.

Korean Agricultural Sector Model (KASM)

KASM is a general computerized system simulation model of the Korean agricultural sector. A block diagram of this model is indicated in Figure 1. The model provides usable results on a five- to twenty-year time horizon. The time increment for model output is an annual cycle. It presently runs at the national level, although a three-region breakdown has been run with some of the components, and other regional configurations could be easily incorporated provided data were available. Table 1 details the main model characteristics.

The model was developed using a building-block concept to link several self-contained components representing various processes within the agricultural sector and their linkages to each other and to the nonagricultural sector. These components include a sixteen-sector input/output component, reflecting the interactions between the agricultural and nonagricultural sectors of the national economy; a dynamic cohort survival demographic component for projection of the farm and nonfarm populations, and migration by age and sex; a recursive linear programming component for aggregate farm level annual resource allocation and agricultural production; a production function component to reflect technological change including yield determination and input application rates; a simultaneous equations system component to reflect farm and nonfarm demand, price determination, and agricultural foreign trade levels; and an accounting component to provide output at the household, commodity, sector, and national levels. Figure 1 indicates the types of policy variables which can be analyzed with the model and the kinds of performance indicators reflected in model output.

KASM Components

Following is a description of each of the

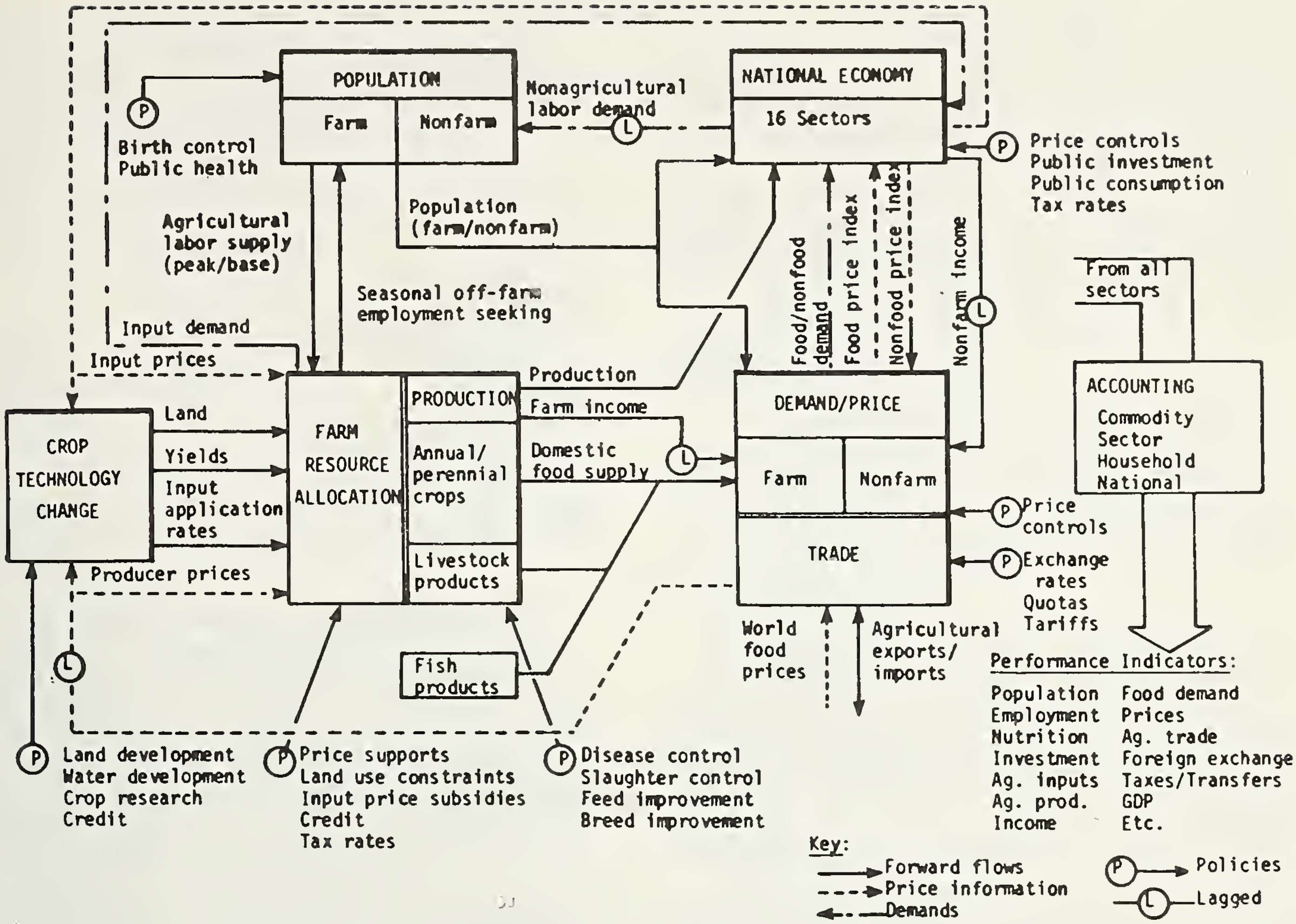


Figure 1. Korean Agricultural Sector Model: System Linkage Diagram

five major components of The Korean Agricultural Sector Model (KASM), and a discussion of the linkages and feedbacks among these components of the system.

The population and migration component (POPMIG) is a dynamic, demographic cohort survival model. It contains 89 one-year age cohorts by sex for both a farm and a nonfarm population stream. Age-specific birth rates and the sex ratio are applied to determine male and female births for each stream. Age-sex-specific mortality rates are applied to determine cohort survival for the next age group and age-sex-specific migration rates are applied to determine off-farm migration where migration rates are functions of nonfarm job opportunities. Data requirements include initial farm/nonfarm age-sex distributions, age-specific birth-rates, age-sex-specific death rates, age-sex-specific migration rate profiles, and the economically active population. Component outputs include farm and nonfarm population by age and sex, farm/nonfarm migration, and the available agricultural labor supply. Impacts of family planning programs, public health programs, changes in general economic growth rate, and changes in labor participation rates can be assessed with this component.

The farm resource allocation and production component (RAP) is a recursive linear programming model at the aggregate farm level. It consists of forty-five crop, livestock, and livestock feed activities and ten land, labor, capital, and risk activities, along with thirty-five crop and livestock production constraints and twenty-five land, labor, and capital constraints. Principal inputs to the model for each annual run include yields, product prices, input application rates, input prices, changes in the land base, and investment capital resources. Outputs include land allocation, production input requirements, livestock herd sizes, and machinery investment. In conjunction with the crop and livestock subcomponents, output also includes annual domestic crop and livestock production. Impacts of such policies as commodity price supports, input price subsidies, credit, taxes, and land use constraints can be addressed.

The demand-price-trade component (DEMAND) has three subcomponents--farm household consumption, nonfarm household demand, and consumer and producer price determination. The

Table 1

KASS Model Characteristics

Two Population Groups
1. Farm
2. Nonfarm

Sixteen Aggregated Economy Sectors
1. Agriculture
2. Forestry
3. Mining
4. Chemical fertilizers
5. Other chemicals
6. Machinery
7. Fuels
8. Other heavy manufacturing
9. Food processing
10. Textiles
11. Other light manufacturing
12. Trade
13. Transportation and storage
14. Construction
15. Utilities
16. Other services

Four Agricultural Subsectors
1. Annual crop
2. Perennial crop
3. Livestock
4. Fishery (exogenous production for use in the Demand Component)

Four Land Categories
1. Paddy
2. Summer upland
3. Winter upland (includes double crop paddy)
4. Pasture

Two Regional Options
1. National
2. Single crop, double crop, mountain

Nineteen Agricultural Commodities
1. Rice
2. Barley
3. Wheat
4. Other grains
5. Fruits
6. Pulses
7. Vegetables
8. Potatoes
9. Tobacco
10. Forage
11. Silk (mulberry)
12. Industrial crops
13. Beef
14. Milk
15. Pork
16. Chicken
17. Eggs
18. Fish
19. Residual

Twelve Factor Inputs
1. Land
2. Labor (human and animal)
3. Farm implements
4. Tillers
5. Transplanters
6. Chemical fertilizer
7. Organic fertilizer
8. Pesticides
9. Seed
10. Fuel
11. Oil
12. Other inputs

Four Agricultural Capital and Credit Constraints
1. Liquid assets
2. Investment capital
3. Long-term loans
4. Short-term loans

nonfarm household demand subcomponent is a set of simultaneous-equation Cobb-Douglas consumption functions used to estimate nonfarm household demand based on nonfarm population and nonfarm income. The total aggregate demand is constrained to meet the homogeneity principle by adjusting food/nonfood cross price elasticities. Parameters include nonfarm price and cross price elasticities and nonfarm income elasticities. The farm household consumption subcomponent has the same structure as the nonfarm household demand component. Parameters include farm price and farm income elasticities, while inputs include lagged producer prices and lagged farm household income.

The consumer price determination subcomponent simultaneously determines consumer prices or import/export quantities. Prices are determined by the "market mechanism" if imports/exports are specified and, conversely, imports/exports are determined by the "market mechanism" if bounds on prices are policy specified. It is assumed that the market clears each time period (annually) and that no carryover stocks are accumulated beyond what may be specified by policy.

Inputs to this component include domestic agricultural commodity production, farm and nonfarm population, farm and nonfarm income, the domestic nonfood price index, world commodity prices and policy-specified domestic commodity prices, and commodity import/export levels. Policies which can be assessed by this component include consumer price controls, rationing, quotas, tariffs, and exchange rate controls.

The national economy component (NECON) consists of a sixteen sector, input/output model linking agriculture and the nonagricultural sectors of the economy. The agricultural sector of this component is an aggregation of the relevant output of the agricultural sector model. The rest of this model consists of two other primary industry sectors, eight manufacturing sectors, three social overhead capital sectors, and two service sectors. Calculations for each sector include foreign trade and public demand, consumption, investment, production, labor, and price. Inputs from the rest of the KASS model include agricultural production, input demand, agricultural investment, farm/nonfarm consumption and food prices, while outputs of the model include input prices, nonfarm labor requirements, and income. Policies which can be assessed by this component include price controls, public investments, public consumption, and tax rates.

The crop technology change component (CHANGE) is a Cobb-Douglas production function model used to project yields and input application rates. Input application rates are optimized for each commodity with respect to yield responses, product price, and input prices. Yields are determined from production functions which consider input application rates, crop improvement resulting from research and extension investments, and land and water resource development resulting from public investment and credit policies. Inputs to this model include product and input prices and public investment and credit policies. Outputs include yields and input application rates. Impacts of policies directed toward land and water development activities such as irrigation, drainage, upland development, tideland reclamation, and paddy rearrangement, as well as investments in technical agricultural research and extension, can be determined.

Component Linkages

All of the components described above are linked to operate in concert in a recursive mode, passing information and data from one component to another and receiving feedback as appropriate. As Figure 1 suggests, POPMIG passes farm and nonfarm populations to DEMAND, nonfarm population and farm to nonfarm migration to NECOM, and agricultural labor supply as a residual to RAP. It receives nonagricultural labor demand from NECON for use in calculating migration rates.

NECON delivers input prices to RAP and CHANGE, the nonfood consumer price index to DEMAND, and nonagricultural labor demand to POPMIG. It receives input demands from the crop and livestock production component and food and nonfood consumption demand (expenditures) from DEMAND.

DEMAND receives world prices for agricultural commodities exogenously, quantities supplied from the crop, livestock, and fisheries production subcomponents, farm and nonfarm populations from POPMIG, and incomes and consumer prices from NECON. It delivers quantities of agricultural commodities demanded to NECON and producer prices to RAP and CHANGE.

RAP receives producer prices from the demand price component, yields and input application rates from CHANGE, input prices from NECON, agricultural labor supply from POPMIG, and internally passes land and other resources allocations and herd sizes.

Fisheries production is exogenously determined for use in DEMAND. RAP passes input demands to NECON, and quantities supplied to DEMAND.

Finally, CHANGE receives input prices from NECON and producer prices from DEMAND. In turn, it delivers yields and input application rates to RAP.

The accounting component receives and passes information from all components and provides the model output in the form of performance indicators. Policy inputs can be affected at the various points indicated in the diagram.

The Grain Management Program Model (GMP)

The grain management program model [4] is designed to be an on-line management tool for the government agency responsible for grain program management in making the short-term, recurring decisions necessary to manage grain prices, stocks, and imports. The planning horizon for the grain management program model is up to eighteen months with a time increment of one to two days. The food grain commodities presently included in the model are rice, barley, and wheat. Four subsectors--farm, government, private marketing, and urban household--comprise the model. These four subsector components are linked by a pricing and transaction mechanism. For consistency, the model is operated in conjunction with, but not directly linked to, KASM. It traces the three grains through the marketing process, from the farm to the ultimate consuming household. It keeps track of the grains in four forms--rough, hulled, polished, and flour. It also keeps track of two by-product forms--cracks and bran. Three grain processing operations are included in the model--hulling, polishing, and flour milling. Seven grain stock position points are included as farm households, production area points, consumption area terminal points, the import pipeline, seaports, retail sales points, and the urban household.

The model is capable of providing analytical input to policy decisions in such areas as high versus low price policies, dual price policy programs, controlled market price programs, alternative import schedules, average annual grains price patterns, government purchase prices, government selling prices, government-controlled industrial wheat flour prices and subsidies, government purchasing and release timing, government purchase and release quantities, import scheduling, and seasonal market pricing pattern objectives. Figure 2 is a block diagram of the grain management program model, along with a list of policy-influenceable inputs and the major performance indicators provided by the model.

One of the simpler mechanisms in this model has been developed separately as an annual grains price policy analyzer and used over the past three years in Korea for analytical input into the setting of rice and barley purchase and release prices by the government. These analyses have provided decision makers in the Korean agricultural ministry with new concepts of the interrelationships between prices and quantities supplied and demanded of the various grains. They now look upon grains price policy as an interrelated system, rather than as separate decisions to be made about individual commodities.

The grain management program has not yet been utilized in its fully developed form. Strong interest in its potential use as an online management aid in making grain management decisions has been expressed by Korean decision makers. Increased use of this model by Korean decision makers and analysts concerned with grain policies and management is expected.

CREDIBILITY AND UTILIZATION

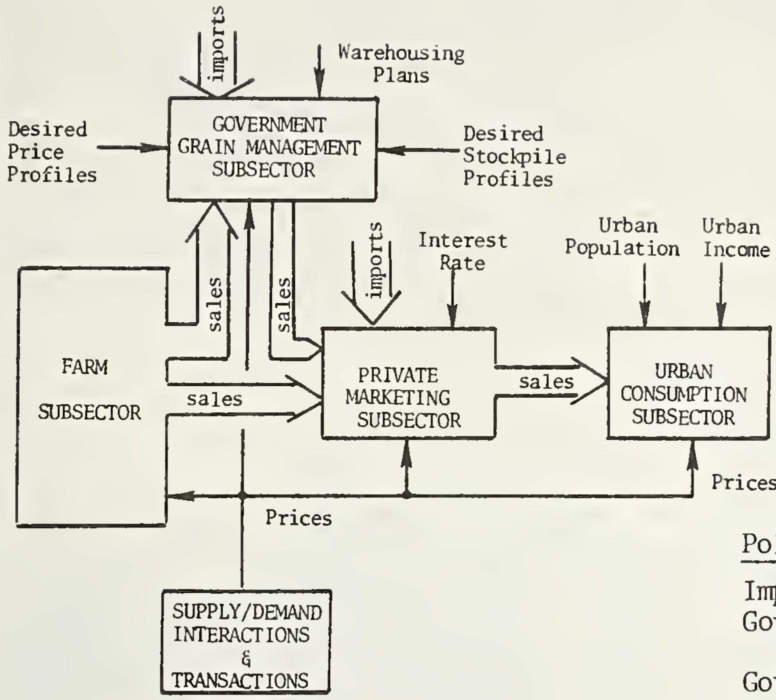
A prerequisite for use of any model for problem solving purposes is acceptance by decision makers. Model builders and disciplinarians often expect credibility and acceptance by decision makers to be achieved through model validation and verification. While validation and verification are necessary, they are not sufficient for credibility.

The concepts of validation and verification have had a wide variety of meaning among scientists. Usually validation has meant testint a concept, theory, or model for internal logical consistency and for its ability to reflect accurately the real world situation or phenomenon it is intended to represent. The term verification generally means testing a concept or model with respect to its capacity to track historical data and to project important variables of a system into the future. Validation is a test of coherence, while verification is a test of correspondence. Models, and the concepts and theories used to build them, must also pass the test of clarity in order to achieve credibility with decision makers. That is, the model's concepts and theories must be explainable and understandable to those who use them. Finally, they must pass the test of workability when used to solve problems. This simply means they must do an adequate job of what the model builders and decision makers intended.

The tests of coherence, correspondence, clarity, and workability have been applied continuously in the development, institutionalization, and utilization of the models in Korea. Intensive and continuous interaction between model builders, analysts, and decision makers have played a key role in performing these tests. Statistical tests, sensitivity tests, and tracking tests have been employed as applicable. Because of the wide variety of kinds and sources of data and information used in the model, current statistical procedures are not yet adequate to establish appropriate confidence intervals for the various kinds of data going into the models, nor confidence limits for each of the performance variables projected by the models. In the broadest sense, application of the tests of credibility involves a continuous iterative process of interaction with decision makers, and adapting and utilizing the models in a variety of problem solving applications.

In the final analysis, as the saying goes, "the proof of the pudding is in the eating." If the models are used over time by decision makers in solving problems, it can be assumed that they have passed at least the minimal standards of the four tests of credibility.

The Korean models have not yet fully passed the credibility tests. The annual grain price policy analyzer from the GMP has passed the test and over the past four years



Performance Indicators

GMSA balances
Farm income
Farm consumption
Private market profits/losses
Private market growth/decay
Urban consumption
Urban nutritional levels
Foreign exchange expenditures
Private market prices
Programmed vs. actual results
- Seasonal price patterns
- Reserve stock levels
- Annual consumption plans

Etc.

Policy Influenceable Inputs

Import regulation (quantity and timing)
Government purchase of domestic grains (quantity and timing)
Government releases of domestic grains (quantity and timing)
Government buying and selling prices for domestic grains
Government investments in storage facilities
Factor input subsidies
Wheat flour subsidies

Figure 2. Grain Management Program Model Schematic

has been used in establishing government purchase and release price levels for rice and barley. The full GMP model has not yet been institutionalized in the Korean decision-making structure concerned with grain management. KASM has been used for a wide variety of applications, though not yet utilized by decision makers to its potential.

Some of the applications of KASM include:

(1) Analysis of alternative agricultural research strategies, leading to a major AID loan to Korea for carrying out varietal research in five main crops.

(2) Input into the land and water development planning perspective to the year 2000 by the land and water development agency of the agricultural ministry.

(3) Provision of the analytical basis for drafting the Korean case study, Population and Food in Korea [6], presented at an FAO conference.

(4) Major analytical inputs to the drafting of the agricultural portion of the Fourth Five-Year Economic Development Plan for the period 1977-1981.

(5) Analysis of alternative policies designed to shift dependence away from high producer prices for grain as a major means of income transfer to farm households.

(6) Provision of the base projections for determining the demands that will be placed on the agricultural marketing system through 1985 and the investments required to develop the marketing system to satisfy these requirements.

The work under (4) above included projection of the consequences of following alternative development planning strategies during and beyond the fourth five-year plan period. While the full model and its output were used for this purpose, particularly intensive work was done in the areas of population projection, livestock policy, demand for agricultural commodities, and agricultural export potentials.

A less quantifiable, though also important, outcome of the model development and usage in Korea has been the increasing systems view taken by decision makers in the agricultural ministry and in the central planning agency of the Korean government. Through interaction with the model developers and analysts, many decision makers understand better how the Korean agricultural sector operates within its environmental setting and the linkages, interactions, and feedback which take place within the agricultural system and between it and the rest of the economy. They also realize that planning strategies and policies have many consequences--some good, and others bad. It is still uncertain whether the Korean models will become fully institutionalized as part of the decision making structure. However, the evidence is extremely promising.

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AGRIMOD: AN AGRICULTURAL POLICY MODEL WITH APPLICATION TO GRAIN MARKETS AND RESERVES*

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David G. Luenberger Donald N. Stengel

ABSTRACT

The U.S. crop market is a complex system of interacting supplies and demands that depends in part on government programs and policies. A model of the crop market that includes reserves and stockpiles has been developed as a component of AGRIMOD, a dynamic simulation model of the U.S. food production sector. First, a brief description of AGRIMOD is given. Then, the crop market submodel which is formulated as a nonlinear optimization problem with nonlinear constraints is described in detail. The concept of a support supply function is introduced to handle discontinuities caused by government policies and a scaling procedure is implemented that improves convergence. Finally, selected simulation results are presented to demonstrate the use of the submodel.

INTRODUCTION

The agricultural policy of the U.S. has significant impacts not only on the domestic, but also on the world food situation. The complexity of the interrelationships between agricultural production, food supply, prices, technological change, and the use of non-renewable resources makes the analysis of policy alternatives a formidable undertaking.

Since June 1974, a project team at Systems Control, Inc. has been developing AGRIMOD (Agricultural Model), a large scale simulation model of the U.S. food production sector. This new model is designed to provide policy makers with a quick response tool for analyzing the effects of a wide variety of policies over the 10-20 year time horizon. The specifications that explicit modeling of inputs to agricultural production (renewable and nonrenewable) be included, that the model structure be adaptive and allow for technological change, and that the annual model operate over a fifteen to twenty year time horizon governed the design of the model structure. The degree of disaggregation was established by the types of policy questions that would be analyzed using the model. Typical examples of such policies are: land regulations, government investment in land improvement (irrigation, drainage), regulations on energy conservation, environmental regulations on the use of fertilizer and pesticides, support prices and price ceilings, selective commodity taxes, stockpiling policies, export regulations, raw material import policies, as well as such questions as world food reserve policies and food for peace commitments.

These requirements contained two essentially conflicting objectives: on the one hand

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accuracy was essential, if the results were to be of use in decision making; on the other hand, an adaptive structure was necessary, if the model were to allow for structural changes in the economy as well as the agricultural sector. Much of the modeling of socio-economic systems emphasizes one of these two objectives; their integration into a balanced methodological approach was the essential challenge in the model development.

The resulting model consists of seventeen submodels that are fully integrated through information and material flows into four major sectors and three markets [1, 2]; all goods move between sectors through the markets in which prices are determined. The simplified flow diagram (Figure 1) shows clearly the multistage sequence of events within one year and the interrelationships between sectors and markets. A brief description follows.

The *Pre-Production Sector* consists of three submodels (#1, #2, and #3) whose purpose is the allocation of investments, the management of land resources, and the generation of supply curves for the three primary nutrients: nitrogen, phosphate, and potash. Land in AGRIMOD is characterized by location, type, and use. First, the land of the U.S. is divided into seven geographical regions, as shown in Figure 2. Within each region, land is classified according to use, which is related to type, and according to the crops that can be grown on it. The crops included in AGRIMOD are *wheat, rice, corn, feedgrains, hay, soybeans, potatoes, sugar, cotton, and fruit, vegetables, and tree nuts*. Government investment, which is affected by policy variables, and private investment are allocated mainly to land improvement and the development of new irrigated cropland. Investment in the fertilizer industry is used to increase plant capacity for each of the three

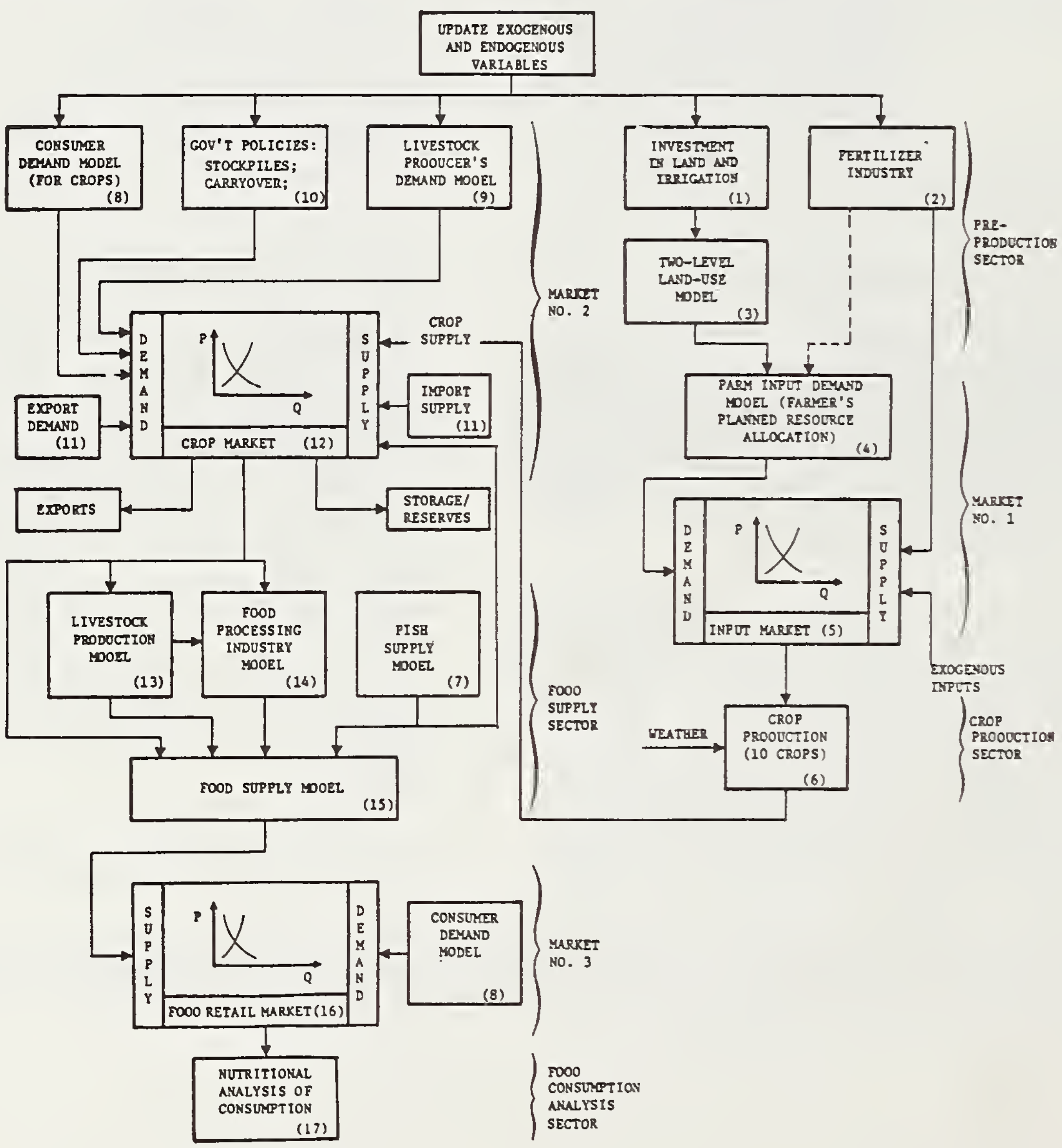


Fig. 1 Simplified Diagram of AGRIMOD

Fig. 2 The Seven AGRIMOD Regions

nutrients. The choice of feedstocks and technologies depends on the relative costs of the primary inputs and on policy variables. Implementation of new processes is constrained by the non-convertibility of existing plants and equipment.

The *Farm Input Market* contains one of the main submodels in AGRIMOD - the Farm Input Demand Model (#4) - and also the market for non-agricultural inputs to crop production (#5). The former is fundamentally a resource allocation model. The optimum allocation of cropland, fertilizers, and machinery for each crop in each region is determined on the basis of endogenously computed expected prices for the inputs to and the outputs of production. The solution to the optimization problem is used to construct demand functions for the variable inputs to production. These demand curves are the ones used in the supply-demand interaction where the actual allocation is determined. This coupling of a normative model - an optimization - used to determine demand functions with a market equilibrium model in a two-step procedure constitutes the basic building blocks for constructing the economic models in AGRIMOD.

The *Crop Production Sector* contains the crop production functions (#6) that are used to determine annual production on the basis of inputs cleared through the market. Crop and location specific indices are used to model the effect of weather on production.

The *Crop Market* is by far the most complex part of AGRIMOD; it is essentially the wholesale farm commodities market. To the annual crop production are added carryovers from previous years and imports (#11), while losses incurred during transportation and storage are subtracted. Many of the government policies (e.g., support and resale prices, CCC loan rates, price and quantity triggers) are introduced as constraints that modify the crop supply functions (#10). Demand curves for each crop are generated from the livestock sector (#9) and the retail food consumption model (#8). To these demands are added foreign demand (#11) and government commitments (#10). A generalized reduced gradient algorithm (GRG), modified to handle problems with kinks in the objective function, is used to determine the supply-demand equilibrium. A detailed description of this submodel is presented in the next section.

The *Food Supply Sector* consists of four submodels. The five types of livestock considered - beef cattle, dairy cattle, hogs, broilers, and layers - are modeled separately in the Livestock Production submodel (#13). The food processing industry is modeled simply in terms of the costs (margins) associated with the different operations undertaken to convert crops and livestock to retail commodities (#14). A rudimentary model of the U.S. fishing industry (#17) is also included (because of the substitution effects on food consumption and the use of fishmeal in the high protein component of commercial feed for livestock).

The *Retail Food Market* includes the consumer demand model (#8), which consists of sixteen coupled demand functions for food commodities, and the supply-demand interaction (#16) that establishes retail prices. Cotton fiber is handled separately at the mill level.

Finally, in the *Consumption Analysis Sector* the results are analyzed in terms of calories and protein consumption per capita (#17). Furthermore, the data are disaggregated by income level; this information is particularly helpful in observing shifts in diets and nutrition and in inferring some socio-economic impacts of alternative policies.

The detailed description of AGRIMOD and its use in policy analysis can be found in [1], [2], [3], and [4]. In the next section, the mathematical model of the crop market is presented.

THE CROP MARKET MODEL

The crop market is particularly complicated compared to markets within other sectors of the economy due to the direct influence of government support programs and stockpiling policies.

The Agricultural Act of 1949 established the mechanism for government acquisition and sales of supported crops, which has been in effect from 1949 to the present. Under the Act, the government guarantees to purchase crops at a pre-determined support price. It may then release stocks at a certain fixed percentage above the support price plus reasonable carrying charges. The two prices, the support price and the resale price, trigger government purchases and sales.† The mechanism for acquiring government stocks is the non-recourse loan to farmers, who may repay either with cash or with a quantity of the supported crop at a price equal to the loan rate. The loan rate (support price) thus becomes a floor under the market in that crop.

Only nine crops are cleared in the wholesale crop market; the tenth one, cotton, is cleared in a separate fiber market. First, the demand functions for each crop are constructed. Then the annual supply for each crop is determined. The market is modeled as a partial equilibrium one in which prices and the distribution of the crops to the various components of demand are determined.

Demand Functions

The *Consumer Demand* for each of the nine food commodity groups given on the right side of Table 1 is expressed in terms of the corresponding quantity of crop that could be demanded, of the retail price expressed as the price at the farm level to which the retail farm spread, or margin, is added, the prices of other commodities for which the cross-elasticity of substitution is non-zero, and the income level. For example, the consumer demand for rice is given by

$$D_{c_2} = b_{13}(p_1 + \delta_{12})^{e_{13,12}} (p_2 + \delta_{13})^{e_{13,13}} I^{\tilde{e}_{13}} \qquad (1)$$

where

p	: vector of farm level prices
p_1	: farm level price of wheat
p_2	: farm level price of rice (rough rice)
δ_{12}	: retail farm spread for "other wheat" commodity
δ_{13}	: retail farm spread for rice
$e_{13,13}$	: price elasticity for rice
$e_{13,12}$	: price cross-elasticity for rice and "other wheat"
I	: GNP per capita
$\tilde{e}_{13}$	: income elasticity for rice

TABLE 1. FOOD COMMODITY GROUPS DERIVED DIRECTLY FROM CROPS

No.	CROP/LIVESTOCK	FOOD COMMODITY GROUP	No.
1	WHEAT	BREAD - bread, flour OTHER WHEAT - cereals, mixes, macaroni	6 12
2	RICE - rough	RICE	13
3	CORN	CORN PRODUCTS - syrup, dextrose, flour and meal, cereal, starch, hominy and grits	11
5	SOYBEANS	SOYBEAN OIL	9
7	POTATOES	POTATOES - fresh and processed	14
8	SUGAR - unrefined	SUGAR - refined	10
9	FRUIT & VEGETABLES	FRUIT & VEGETABLES - fresh FRUIT & VEGETABLES - processed	15 16

†These so-called trigger prices introduce discontinuities in the supply function that can be eliminated by introducing the concept of the support supply function.

POP : population

b_{13} : time varying parameter

where the subscripts for farm level quantities are the numbers found in the extreme left column of Table 1 and the subscripts for the retail level quantities in the extreme right column of the same table.

Similar expressions have been established for all commodity groups that are derived directly from crops.

Certain crops are used as livestock feed - namely, wheat, corn, feedgrains, soybeans, and hay. *Demand functions for crops used as livestock feed*, based on a set of new production functions for livestock which incorporate the concept of rations and the substitutability between grains and between meals, have been derived. For example, the demand for corn for beef cattle takes the form:

$$D_\ell = nH_1\left(\frac{p_3}{H_3\alpha_1}\right)^{\alpha_1 - 1}\left(\frac{p_m}{\alpha_2}\right)^{\alpha_2}\left(\frac{p_5}{\alpha_3}\right)^{\alpha_3}$$

$$\left[\ell n\, H_2\, \hat{p}_b - \ell n\left(\frac{p_3}{H_3\alpha_1}\right)^{\alpha_1}\left(\frac{p_6'}{\alpha_2}\right)^{\alpha_2}\left(\frac{p_5}{\alpha_3}\right)^{\alpha_3}\right] \quad (2)$$

where

n : number of cattle to be fed with corn

p_3 : price of corn at the farm level

p_m : price of soybean meal

p_5 : price of hay

$\hat{p}_b$: expected price for beef

α_i : parameters related to rations

H_i : parameters

The demand for exports and for commercial carryover for crop j is expressed directly in terms of the price at the farm level. The *export demand* model is of the form

$$D_{e_j} = F_{e_j} + G_{e_j}\, p_j \quad (3)$$

where F_{e_j} and G_{e_j} are calculated endogenously [2].

For the crops for which there is substantial carryover or for which reserves are kept by the private sector, a *demand for carryover* has been postulated of the form

$$D_{s_j} = \frac{a_j}{b_j + G_j}\left(\frac{p_j'}{p_j}\right)^{\alpha_j} \quad (4)$$

where G is the current level of Government reserves and p_j' is the support price.

The *total demand* for crop j is obtained by adding (a) the quantities required for this crop to meet the demand by consumers for each commodity that is derived from it, (b) the quantities required for feeding each livestock type, (c) the export demand, and (d) the demand for stockpiles or reserves.

$$D_j = \sum D_{c_j} + \sum D_{\ell_j} + D_{e_j} + D_{s_j} \quad (5)$$

This demand is a function of the price of commodity j as well as the prices of all the other crops that can substitute for it (or complement it) in the various final uses. The demand for crop j is a decreasing function of its own price, p_j, but may be increasing or decreasing with respect to other prices.

Soybean Constraints

The soybean crop represents a unique problem in that a large portion of it is crushed, yielding oil and meal in fixed proportions. The demands for these two products cannot be directly added; rather, in equilibrium, certain relationships must exist among the prices for soybeans and the two products.

First, assuming all of the oil and meal is sold, the prices must be at levels such that the ratio of demands for the products is equal to the fixed proportions produced from beans. If a pound of beans produces μ_o pounds of oil and μ_m pounds of meal, then

$$\frac{D_o(p)}{D_m(p)} = \frac{\mu_o}{\mu_m}$$

or

$$\mu_m D_o(p) - \mu_o D_m(p) = 0 \quad (6)$$

The second relationship arises from an equilibrium in the soybean processing industry. It is assumed that this industry is perfectly competitive, and that the processing cost plus normal profit is the constant δ_c per pound of beans. The profit per pound of beans can then be calculated as income from the two products minus the processing cost minus the price of beans paid to farmers. Thus profit is

$$\pi = \mu_o p_o + \mu_m p_m - \delta_c - p_6$$

where p_6 is the price of beans. In perfect competition, (excess) profit is zero, which leads to the equation

$$\mu_o p_o + \mu_m p_m - \delta_c - p_6 = 0 \quad (7)$$

The two equations, (6) and (7), serve as constraints among the three prices p_o, p_m, and p_6.

Note that the demand for beans to be crushed can be written either

$$D_c(p) = \frac{1}{\mu_o} D_o(p) \qquad (8)$$

or

$$D_c(p) = \frac{1}{\mu_m} D_m(p) \qquad (9)$$

The total demand for soybeans is the sum of direct demand for beans, $D_b(p)$, and the demand for beans to be crushed. Thus

$$D_6(p) = D_c(p) + D_b(p) \qquad (10)$$

Supply Functions

The other functions of interest in constructing the market are the crop supplies. Let Y_j' denote the fixed supply arising from the current year's production of crop j, and I_j the imports expressed in crop equivalent units. Let G_j denote the supply of crop j in government stockpiles. Commercial stockpiles, C_j, held by farmers and grain dealers, are also important determinants in the crop market.

The total crop supply functions are derived from current production supplies, Y_j', government stocks, G_j, commercial carryover, C_j, imports, I_j, and the operating rules for government stocks. The supply curve for crop j is modeled as the discontinuous function

$$S_j(p) = \begin{cases} \text{undefined for } p_j < p_j' \\ Y_j' + C_j + I_j & \text{if } p_j' \leq p_j \leq p_j'' \\ Y_j' + G_j + C_j + I_j & \text{if } p_j'' < p_j \end{cases} \qquad (11)$$

where p_j' and p_j'' are the government support and resale prices for crop j, respectively.

Market Equilibrium

The supply curve and four possible demand curves are shown in Figure 3. Curve 1 represents the case where the quantity demanded at the support price is insufficient to use the current supply. The government, therefore, purchases the (positive) quantity

$$\Delta G_j = Y_j' + C_j + I_j - D_j(p_1, p_2, \ldots p_j', \ldots p_n) \qquad (12)$$

and the equilibrium price of crop j is p_j'. In Case 2, the equilibrium price lies between p_j' and p_j'' and the government neither buys nor sells stocks, so $\Delta G_j = 0$.

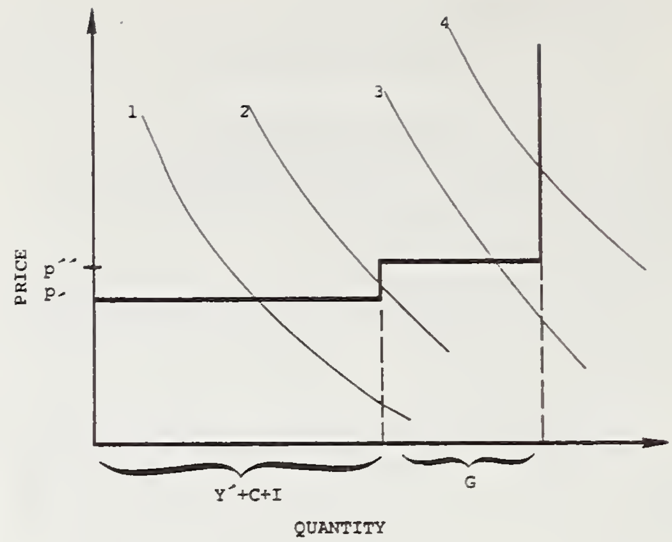


Fig. 3 The Crop Market Model: Supply and Demand Functions

In Case 3, the quantity demanded, even at the higher resale price, p_j'', exceeds current production, but there are sufficient government stocks to satisfy the demand at this price. The release of stocks equals

$$\Delta G_j = Y_j' + C_j + I_j - D_j(p_1, p_2, \ldots p_j'', \ldots p_n) \qquad (13)$$

where ΔG_j is negative, indicating releases. Finally, in Case 4, the total supply, $G_j + Q_j + C_j + I_j$, is insufficient to meet the quantity demanded at p'', therefore the price p_j must increase until an equilibrium is reached. In this case, the government releases the entire amount in its stocks; therefore $\Delta G_j = -G_j$.

In actual practice, the government might not sell its entire stock at p_j''. Other, higher trigger prices could be established to apply when stocks reach designated critical levels [5]. These additional triggers can be modeled easily by introducing multiple levels (price and quantity triggers).

From the above arguments, it follows that the supply-demand interaction must satisfy

(1) $p_j = p_j'$ if $D_j(p_1, p_2, \ldots p_j', \ldots p_n) < Y_j + C_j$ (14)

(2) $D_j(p) = Y_j' + C_j + I_j$

if $D_j(p_1, \ldots p_j', \ldots p_n) \geq Y_j' + C_j + I_j \geq D_j(p_1, \ldots, p_j'', \ldots p_n)$ (15)

$$(3) \quad p_j = p_j'' \quad \text{if } Y_j' + G_j + C_j + I_j > D_j(p_1,\ldots p_j'',\ldots,p_n) > Y_j' + C_i + I_j \quad (16)$$

$$(4) \quad D_j(p) = Y_j' + G_j + C_j + I_j \quad \text{if } D_j(p_1,\ldots p_j'',\ldots p_n) \geq Y_j' + G_j + C_j + I_j \quad (17)$$

for $j = 1,2,\ldots,n$

For all four cases, the net change in government stockpiles is given by

$$\Delta G_j = Y_j + C_j + I_j - D_j(p) \quad (18)$$

where ΔG_j is positive (representing purchases) in Case 1, zero in Case 2, and negative (representing sales) in Cases 3 and 4. The dynamic equation for stock updating is simply

$$G_j(k+1) = G_j(k) + \Delta G_j(k) - E_{g_j}(k) \quad (19)$$

where ΔG_j is determined according to the above discussion, and E_{g_j} represents government exports.

The conditions describing the supply-demand interaction result, essentially, in a system of simultaneous equations, subject to constraints, Eqs. (6) and (7). Because of the constraints, the equations cannot be solved easily by a direct method; an alternate, but equivalent, formulation as a minimization problem is used:

$$\text{Minimize } J = \frac{1}{2}\sum_{j=1}^{n}\left[D_j(p)-S_j\right]^2 \quad (20)$$

subject to

$$\mu_m D_o(p) - \mu_o D_m(p) = 0 \quad (21)$$

$$\mu_o p_o + \mu_m p_m - \delta_c - p_6 = 0 \quad (22)$$

$$p \geq 0 \quad (23)$$

where p is now the complete price vector

$$p = (p_1 p_2,\ldots p_6, p_o, p_m,\ldots p_n) \quad (24)$$

This approach cannot, however, be implemented directly because the supply functions S_j are discontinuous. The corresponding quadratic objective function would therefore also be discontinuous. In order to apply minimization techniques, it is necessary to find an equivalent formulation with an objective function which is continuous and which has continuous first derivatives. Such a formulation, relying only on the fact that the quantity of each commodity demanded decreases as its own price increases, is presented in this section.

The key device in the introduction of a *support supply function,* defined by

$$\hat{S}_j(p_1,\ldots p_{j-1},p_{j+1},\ldots p_n) = \quad (25)$$

$$\begin{cases} D_j'(p) & \text{if } Y_j' + C_j + I_j > D_j'(p) \quad \text{(Case 1)} \\ Y_j' + C_j + I_j & \text{if } D_j'(p) \geq Y_j' + C_j + I_j \geq D_j''(p) \quad \text{(Case 2)} \\ D_j''(p) & \text{if } Y_j' + G_j + C_j + I_j > D_j''(p) > Y_j' + C_j + I_j \quad \text{(Case 3)} \\ Y_j' + G_j + C_j + I_j & \text{if } D_j'' \geq Y_j' + G_j + C_j + I_j \quad \text{(Case 4)} \end{cases}$$

where

$$D_j'(p) = D_j(p_1,\ldots p_j',\ldots p_n) \quad (26)$$

$$D_j''(p) = D_j(p_1,\ldots p_j'',\ldots p_n) \quad (27)$$

The function $\hat{S}_j$ can be thought of as an effective or artificial supply which is constant with respect to its own corresponding price p_j. The equivalent problem is

Minimize $J =$

$$\frac{1}{2}\sum_{j=1}^{n}\left[D_j(p) - \hat{S}_j(p_1\ldots p_{j-1},p_{j+1}\ldots)\right]^2 \quad (28)$$

It is shown easily that this problem satisfies continuity conditions. The function $\hat{S}_j$ is continuous, although not differentiable, at points where $\hat{S}_j$ is equal to D_j' or D_j''.

The j-th component of the gradient of the objective function (28) is given by

$$\nabla J_j = \sum_{j=1}^{n} \left[D_j - \hat{S}_j \right] \left[\frac{\partial D_j}{\partial p_j} - \frac{\partial \hat{S}_j}{\partial p_j} \right] \qquad (29)$$

All terms in (29) are continuous except $\partial\hat{S}_j/\partial p_j$ at $\hat{S}_j = D_j'$ or D_j''. However, when this condition occurs, then the product in (29) is zero, and thus the whole expression is continuous, i.e., the gradient is continuous. Therefore, although J is composed of nondifferentiable functions, the objective function itself is both continuous and has continuous derivatives.

In order to establish that problems (20) and (28) are equivalent, first note that $J \geq 0$. Thus, if a point is found where $J = 0$, it qualifies as a minimum. Therefore, suppose such a point is found, then

$$\hat{S}_j(p_1,\ldots p_{j-1},p_{j+1},\ldots p_n) = D_j(p_1,\ldots p_n)$$

for all j. There are four cases to consider, the same four as given in both problem (20) and (28).

(1) In this case

$$\hat{S}_j = D_j(p_1,\ldots,p_j',\ldots,p_n)$$

Since D_j is monotonically decreasing in p_j, the equation

$$D_j(p_1,\ldots p_j',\ldots p_n) = D_j(p_1,\ldots,p_n)$$

implies that $p_j = p_j'$.

(2) In this case,

$$D_j(p) = \hat{Y}_j' + C_j + I_j$$

and the two problem statements are identical.

(3) In this case,

$$\hat{S}_j = D_j(p_1,\ldots,p_j'',\ldots,p_n),$$

which implies $p_j = p_j''$ as in Case 1.

(4) The two problem statements are identical.

Combining these four cases leads to the conclusion that $J = 0$ implies the minimization problem (20). The converse is even easier to show. In each case, $D_j - \hat{S}_j$ is zero, which implies $J = 0$. Therefore, the original problem (20) is equivalent to the smooth minimization problem (28).

A problem that can arise in the solution of (28) is that a nonnegative price vector satisfying the constraints (21) and (22) may not exist. Conditions guaranteeing a feasible solution are: (i) the demand for oil and meal go to zero as their own prices go to infinity and (ii) these demands go to infinity as their own prices go to zero.

In the AGRIMOD implementation, the demand for oil was bounded at $p_o=0$. In this situation, if the demand for meal were high enough, the price of oil could be driven to zero and excess oil would have no value. This (unlikely) possibility was prevented from occurring by introducing an additional demand for oil of the form

$$D_T(p_o) = a \cdot p_o^{-2} \qquad (30)$$

which goes to infinity as $p_o \to 0$. However, the coefficient a was chosen so that this demand was negligible for reasonable values of p_o, and any oil allocated to this source of demand is considered excess and is not sent to market.

Scaling

When the crop market model was first implemented in AGRIMOD, the algorithm converged extremely slowly, resulting in excessive computer costs. In order to improve convergence, the variables were scaled to make a certain Hessian matrix be approximately equal to the identity. This scaling proved to be extremely effective. Convergence to three places in the price variables is achieved within 5 to 10 iterations.

The solution algorithm employed is a version of the generalized reduced gradient (GRG) with a variable metric method of updating the direction of descent [8]. Convergence of the GRG depends on the partitioning of the problem variables $x = (y,z)$ such that y is of dimension m, the number of constraints, and z is of dimension $n-m$ [7]. The variables y and z are referred to as dependent and independent, respectively. In this formulation, y is regarded as an implicit function of z through the constraint equation

$$h(y(z),z) = 0 \qquad (31)$$

The objective function then becomes a function of the independent variables z, and the Hessian which determines the convergence rate of the problem is simply the Hessian of this reduced objective denoted Q. This matrix is given by

$$Q = T' L T \qquad (32)$$

where L is the Hessian of the Lagrangian of the problem and T is

$$T = \begin{bmatrix} Y(z) \\ I \end{bmatrix} \qquad (33)$$

where $Y(z) \triangleq \nabla_y y(z)$ is the matrix of first derivatives of the implicit function $y(z)$.

The rate of convergence of the GRG is governed by the ratio of the largest to smallest eigenvalue of the reduced Hessian matrix Q. If the eigenvalues are approximately unity, the ratio is approximately unity, which is most favorable. When applied to the crop market model, the matrix Q can be approximated quite easily. The approximation hinges on the characteristics of the supply and demand curves and the quadratic form of the objective function. The demand curves $D_j(p)$ in AGRIMOD were found to have two important properties: (a) $\nabla D_j(p)$ is dominated by the j^{th} component, i.e., most of the variability in demand for crop j is due to its own price, p_j, (b) the second derivatives of $D_j(p)$ are small compared to the square of the first derivative, $(\partial D_j/\partial p_j)^2$. The support supply functions $\hat{S}_j(p)$, are also well-behaved. Recall that $\hat{S}_j$ is either constant or equal to $D_j(p)$ evaluated at either p_j' or p_j''. Therefore, $\hat{S}_j$ is always constant with respect to p_j, and its first and second derivatives with respect to other prices are small.

To calculate Q, first consider the Hessian of the Langrangian of the problem. This matrix is given by

$$L = F + \lambda_1 H_1 + \lambda_2 H_2 \qquad (34)$$

where F is the Hessian of the objective function, H_1 and H_2 are Hessians of the two constraints, and λ_1 and λ_2 are Lagrange multipliers. The components of F can be calculated by differentiating the first derivatives of J given by (29). Thus

$$F_{jk} = \sum_{i=1}^{n} \left(\frac{\partial D_i}{\partial p_k} - \frac{\partial \hat{S}_i}{\partial p_k} \right) \left(\frac{\partial D_i}{\partial p_j} - \frac{\partial \hat{S}_i}{\partial p_j} \right) + (D_i - \hat{S}_i) \left(\frac{\partial^2 D_i}{\partial p_j \partial p_k} - \frac{\partial^2 \hat{S}_i}{\partial p_j \partial p_k} \right) \qquad (35)$$

This is a complicated expression; however, in view of the properties of the demand and supply functions, it can be approximated quite simply. In all cases except soybeans, the diagonal terms F_{jj} are dominated by the term $(\partial D_j/\partial p_j)^2$; other terms can be neglected. This approximation is particularly good near the solution since $(D-\hat{S})$ goes to zero, making the entire second term go to zero. The off-diagonal terms F_{jk}, $j \neq k$ are also neglected, since they contain only terms on the order of $(\partial D_j/\partial p_k) \cdot (\partial D_i/\partial p_j)$ $j \neq k$ which are dominated by the diagonal elements. Thus, except for soybeans, F is approximately diagonal.

In the case of soybeans the partial derivatives $\partial D_6/\partial p_k$ may have large values for k = 6,o, or m, all others being small. Therefore, F contains a 3x3 block of derivatives corresponding to the soybean prices.

The Hessians of the constraints are also easy to approximate. H_2 is zero, since the second constraint (22) is linear. The first constraint is non-linear, but its Hessian is composed only of terms on the order of $(\partial^2 D_o/\partial p_o^2)$ and $(\partial^2 D_m/\partial p_m^2)$ or smaller. These terms are dominated by the term in F. Therefore, assuming that λ_1 is not excessively large, $\lambda_1 H_1$ contributes nothing to L. Thus, L can be approximated by F.

The final step in the approximation of Q is the calculation of the matrix T. Since there are two constraints, two variables must be selected as basis, or dependent variables. Computational experience indicates that the GRG always selects two of the three soybean-related variables, because these variables dominate the behavior of the constraints. Whichever of these variables are chosen, the matrix Y(z) is dominated by the derivatives of the two basic variables with respect to the independent soybean variable. Carrying out the detailed construction of F and T, the Hessian matrix Q can be calculated by (32)

$$Q \simeq \text{diag}\,[d_j^2] \quad j = 1,\ldots,n \qquad (36)$$

where
$$d_j = \frac{\partial D_j}{\partial p_j} \qquad j = 1,\ldots,n-1$$

and
$$d_6 = \frac{dD_6}{dp_j} \qquad j = \text{index of non-basic soybean variable}$$

The term dD_6/dp_j is the total derivative of D_6 with respect to the soybean-related price which is not in the basis. For example, if the oil price is the non-basic variable then

$$d_6 = \frac{\partial D_6}{\partial p_o} + \frac{\partial D_6}{\partial p_6}\frac{\partial p_6}{\partial p_o} + \frac{\partial D_6}{\partial p_m}\frac{\partial p_m}{\partial p_o} \qquad (37)$$

where $\partial p_6/\partial p_o$ and $\partial p_m/\partial p_o$ are partial derivatives of the implicit functions defined by the constraints. Denote d_6^6, d_6^o as the values of d_6 calculated with respect to p_6, p_o, p_m, respectively.

The scaling method is derived from the above representation of Q. The scaled prices $\bar{p}_j$ are defined as follows:

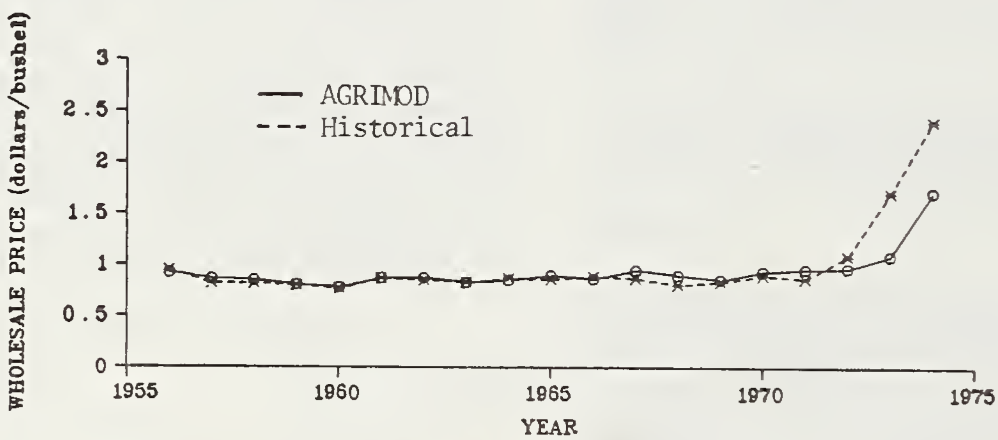
$$
\begin{aligned}
\bar{p}_j &= d_j p_j && j = 1,\ldots,n, j\neq 6 \\
\bar{p}_6 &= d_6^6 p_6 && \text{for soybeans, } j=6 \\
\bar{p}_o &= d_6^o p_o && \text{for soybean oil} \\
\bar{p}_m &= d_6^m p_m && \text{for soybean meal}
\end{aligned}
\qquad (38)
$$

Then with respect to the scaled variables, the reduced Hessian matrix, Q, is approximately the identity. This holds regardless of which of the soybean-related variables are chosen for the basis. Therefore, the desired rapid convergence can always be expected.

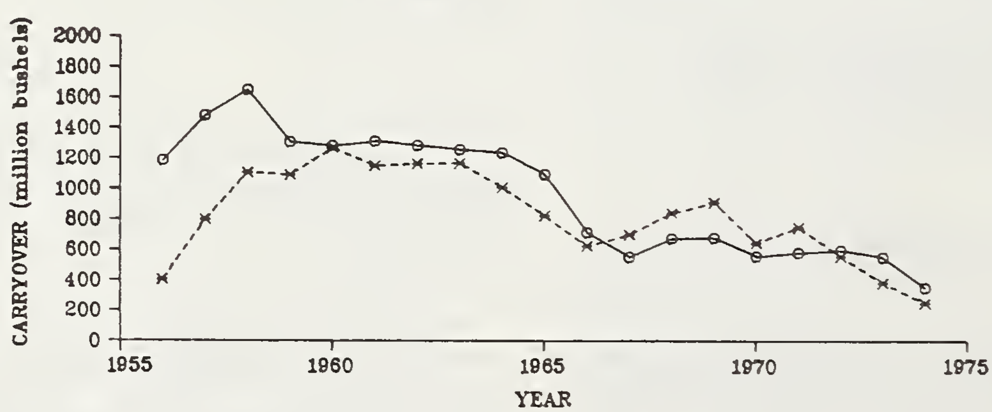
APPLICATION

This model of the crop market has been implemented in AGRIMOD and has been used in three studies [4], [3], and [8]. The accuracy of the overall simulation depends to a large extent on the accuracy with which farm level prices and the allocation of crops are determined because information about market prices, prices received by farmers, relative profitability, and level of reserves is used to trigger changes in the pattern of crop production.

The one variable that shows more clearly than any other AGRIMOD's structural adaptivity and its accuracy is the level of government and commercial stockpiles. Essentially, this variable shows accumulated errors in the simulation. If for a certain sequence of years production in a grain crop exceeded by several percentage points actual production and the price was at the support level, the increase (error) will be accumulated and displayed as government held stocks. If stocks and reserves exceed the actual values, then the price increases that occur when actual stocks are depleted will not appear in AGRIMOD. Two examples showing the model's ability to track total stocks and reserves (the sum of government held and commercially held stocks) are shown in Figures 4 and 5. To demonstrate the close relationship between reserves and prices at the farm level, the corresponding price series are also shown. When stocks are very low,

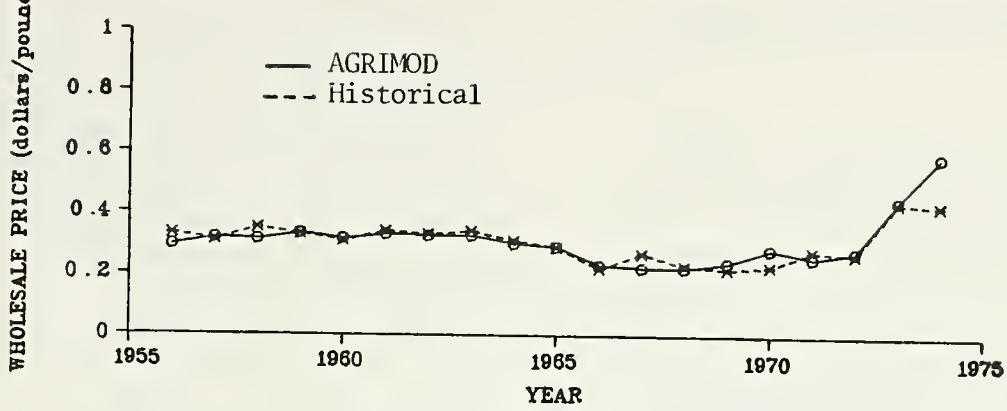


(a) Wholesale Price of Feedgrains

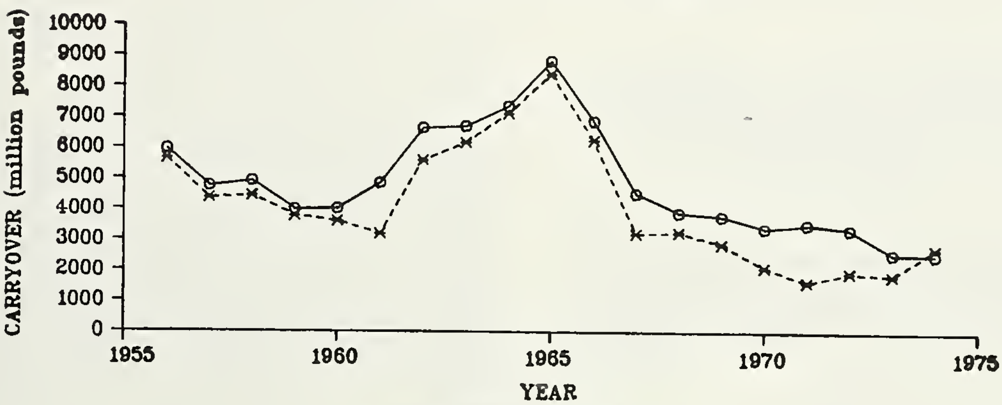


(b) End of Season Carryover

Fig. 4 Feedgrains: Wholesale Price and End of Season Carryover (Government Stocks and Commercial Carryover)



(a) Wholesale Price of Cotton



(b) End of Season Carryover

Fig. 5 Cotton: Wholesale Price and End of Season Carryover (Government Stocks and Commercial Carryover)

prices tend to be volatile. This is clearly demonstrated in the case of feedgrains, Fig. 4a, where actual stocks were lower than those computed by AGRIMOD and thus the prices were higher. The sharp increase in prices in 1974 for both crops is due to the costs of fuel and fertilizers. In reality, the actual price increases were experienced at different times in the period 1973-1974 by the various producers because of differences in contracts and the timing of the actual purchases. The use of annual time increments in AGRIMOD have on occasion caused the effect to be advanced or delayed by one year in the results.

The detailed results for all crops and all other variables in AGRIMOD as well as the full description of the exogenous variables and the conditions under which the simulations were carried out have been presented in [3]. In general, the results for 1956-1970 exceed the requirements set at the beginning of the project. Furthermore, because the historical period 1956-1970 was reasonably uneventful, it was later believed that the real test of AGRIMOD's credibility as a policy aid would be its ability to simulate the critical period 1971-1974. Although the results are not as accurate as for the earlier period, they do track published data quite well.

CONCLUSION

The wholesale crop market is a complex supply-demand interaction, complicated by government policies and the economics of the soybean crop. A model of this market has been successfully implemented as a component of a larger model, AGRIMOD. The market model was formulated as a non-linear optimization problem with nonlinear constraints. The concept of a *support supply function* was introduced to eliminate discontinuities in the supply function caused by government stockpiling and resale policies and a scaling method was derived to achieve rapid convergence. The entire AGRIMOD model is presently operational and the results of several policy analyses carried out using the model have been published.

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GRAIN1: A COMPUTER METHOD FOR EVALUATING AMERICAN FARM POLICY

Leonard J. Brzozowski

ABSTRACT

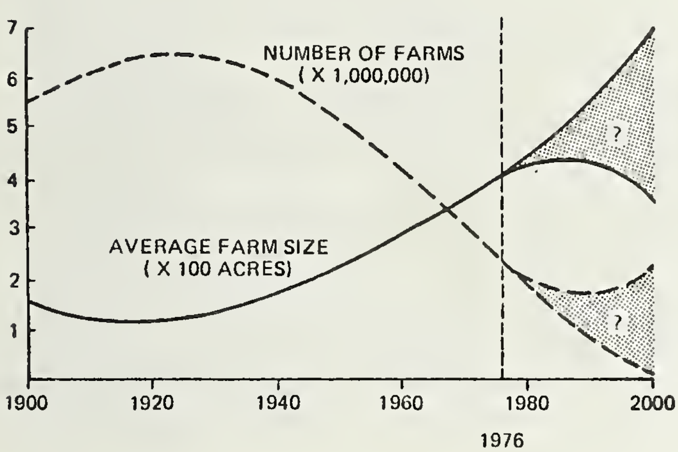
Two analytic approaches used in studying the decline in farm numbers are compared. Conventional empirical analysis is extended by the addition of a causal structure to describe the behavior of the United States wheat production system. Such a model, which incorporates the concepts of information feedback control theory, is a powerful tool that can aid in the development of future farm programs.

INTRODUCTION

For the last 40 years, the number of farms in the United States has decreased. At the same time, the average size of farms has increased substantially (see Illustration 1). This movement has occurred in many farm sectors, including wheat, dairy, cattle, and cotton. Most people explain it by assuming that increased efficiencies are available with increased farm size.

ILLUSTRATION 1

TRENDS IN FARM STRUCTURE (1900 - 2000)



SINCE 1920, FORCES WITHIN THE AGRICULTURAL SYSTEM HAVE CONTRIBUTED TO CAUSE A DECLINE IN TOTAL FARM NUMBERS AND A FOUR-FOLD INCREASE IN AVERAGE FARM SIZE IN THE UNITED STATES.

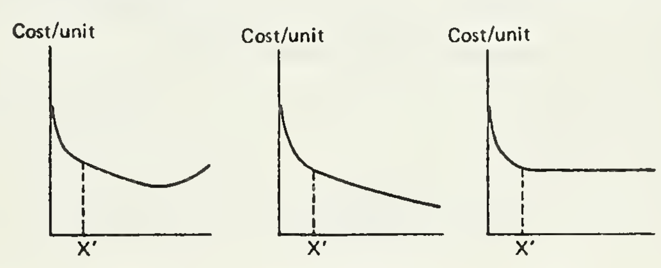
The implications of these trends have been the source of much debate and concern [1]. Some argue that farms are undergoing their natural evolution toward an optimal and efficient size. Others disagree, saying that their greater size is due to external pressures to increase productivity and efficiency. If the latter is true, and if the government is to formulate, on behalf of the American farmer, policies to ease such pressures, then an intuitive understanding of the dynamic processes underlying structural shifts in agriculture is necessary.

CURRENT ANALYSES

Much of the current debate [2] tends to focus on the theoretical nature of the so-called long-run average cost curve in the agricultural sector. The long-run cost curve shows the lowest obtainable production cost per unit of output, assuming an optimal mix of resources (e.g., land, machinery, agricultural chemicals, labor) at any given level of farm size. Illustration 2 shows three such possible curves.

ILLUSTRATION 2

THREE POSSIBLE LONG-RUN AVERAGE COST CURVES



The first curve is a traditional U-shaped curve that shows a clear optimum farm size, above and below which production costs per unit of output increase. Clearly, such a curve is not consistent with the trend in the United States, unless the agricultural sector is still proceeding toward the optimum size, or unless the curve itself has been shifting continually because of technological changes. The second curve represents increasing returns to scale over a broad range. With such a downward sloping cost curve, small farms could not compete with large farms. Eventually, given limited demand, farms would increase in size until there were at most a few farms remaining. The last curve suggests that it may be possible to have an L-shaped curve. In such a case, efficiency would be constant over a broad range of output. Small farms, or at least middle-sized ones, could compete effectively with larger farms; consequently, there would not be a concentration of farms at any particular output level.

There has been little agreement among researchers as to the shape of the long-run average curve. It appears that the shape of the curve depends on the specific empirical technique used to determine it. One such method, called "the direct analysis approach," attempts to construct the long-run average cost curve by examining actual farm records. In general, average cost declines rather sharply as capacity utilization increases. Therefore, to perform such a study properly, one must sample farms not only of different size, but with the same capacity utilization as well. Often, direct analysis studies show declining average costs as farm size increases, but because of the previously mentioned difficulties, the results obtained by this technique have been conflicting [3].

Economic engineering studies, on the other hand, attempt to determine the average cost per unit of output that farms of various size could achieve, using the most modern technologies and farming practices. Budgets are developed for several hypothetical farms of different size, with all resources considered variable. The resource mix is then varied (often using linear programming) until the least cost solution is found at each farm size. In contrast to the direct analysis method, most engineering studies conclude that no significant economies of scale exist over a wide range of farm size [4], [5], [6].

To complicate matters further, many factors unrelated to efficiency can affect farm economics. For example, large farmers may receive quantity discounts on purchased inputs if their order quantity is sufficiently large. Moreover, farmers producing large quantities of a product may receive a premium price unrelated to the quality of the crop, simply because it is easier for the buyer to handle one large shipment than several small shipments. Some farmers argue that banks as well tend to give preferential treatment to large operators. In some cases large operations find that financing is easier for them to arrange than it is for small operations, and loans are sometimes made to large operations at a lower interest rate. These factors tend to provide economic benefits to large farmers and yet are totally unrelated to the competence of the operator or the quality of the farming practices employed. In other words, these economic benefits are not due to economies of scale in the truest sense: they accompany the advantages that large and influential farmers enjoy.

CONTROL THEORY OFFERS AN ALTERNATIVE

Since it does not seem possible to explain the decline in farm numbers and the rise in farm size as unambiguous results of increasing returns to scale, an alternate approach may be helpful. This paper describes a computer simulation of the agricultural economy represented as a nonlinear integration feedback system in which the specific decision rules and information links used by farmers as they make production decisions are explicitly included. The computer simulation model GRAIN1 was developed specifically for the United States wheat production system. (For a complete description of the system dynamics method used to formulate the model, see [7].)

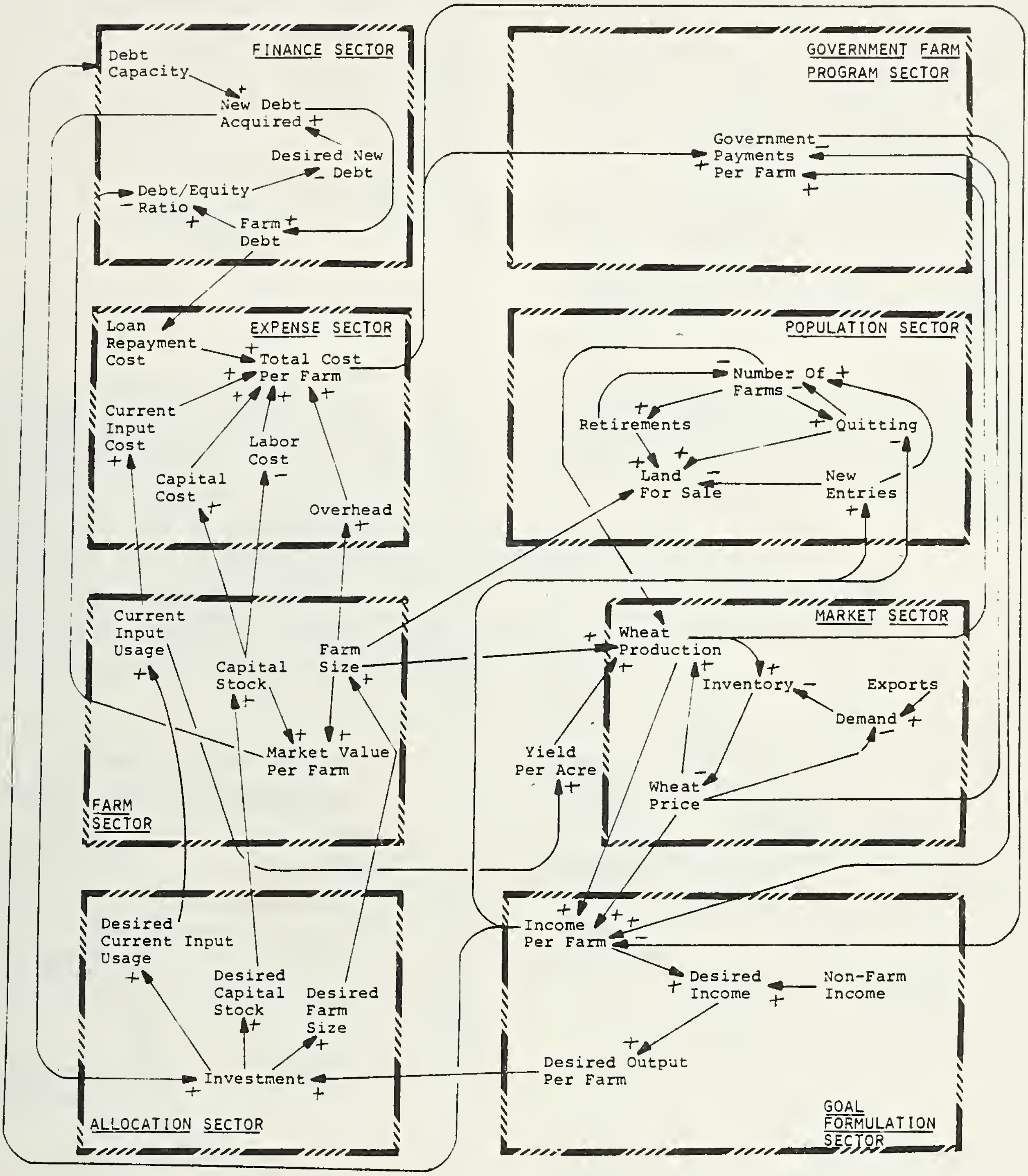
In such a model, two variable types are needed to define the system structure. Rate variables define flows of money, grain, and farmers, for example, over succeeding time periods. Level (or state) variables accumulate these past flows (e.g., the number of bushels of grain in inventories, the number of farmers in business). Levels are changed only through increases or decreases in pertinent rates. The rate variables are modified by specific information feedback relationships. These relationships are postulated by examining how actual farmers perceive and react to existing environmental conditions (economic or social). Finally, these feedback relationships are often comprised of complex, nonlinear decision rules.

THE GRAIN1 MODEL

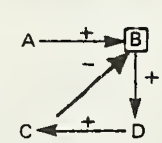
The structure of the GRAIN1 model was derived by focusing on the direct cause-effect relationships within the agricultural sector. In general, this was done by conducting interviews with various wheat farmers, bankers, equipment dealers, and farmer co-op managers in an effort to understand their respective thought and decision making processes. These processes were then combined with accepted economic theory to produce the resulting equation structure of GRAIN1.

ILLUSTRATION 3

MAJOR CAUSAL RELATIONSHIPS IN THE UNITED STATES WHEAT PRODUCTION SYSTEM



KEY:



AS A INCREASES, B WILL ALSO INCREASE. AS C INCREASES, B WILL DECLINE (ALL ELSE HELD CONSTANT).

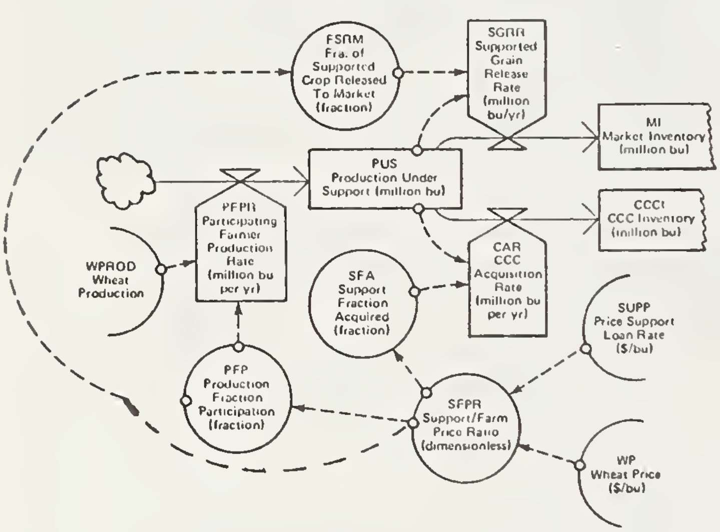
[B] IS A STATE VARIABLE. A IS EXOGENOUS. B, C, D ARE ENDOGENOUS.

Illustration 3 highlights a few of the major feedback links that govern the inherent behavior of the wheat production system. Because capital and current input costs have been rising faster than market prices for agricultural commodities, farmers have been experiencing a profit margin squeeze. In an attempt to maintain or raise income per farm, operators may either increase the size of their operation or farm their existing acreage more intensively. In both cases, additional investment is required. The necessary investment occurs subject to two major constraints. First, the farmers' cash flow must be capable of supporting the required new debt. Second, there must be a sufficient amount of farmland for sale. Since total farmland has remained relatively constant, new land becomes available through farmer retirements and farmers' quitting for economic reasons.

All of the processes described in the preceding paragraph can be translated into the computer simulation language DYNAMO. For example, the formulation of a link in the Commodity Credit Corporation's (CCC) buffer stock system will be described (see Illustration 4).

ILLUSTRATION 4

DYNAMO FLOW DIAGRAM FOR THE CCC INVENTORY SEGMENT OF THE FARM PROGRAM SECTOR



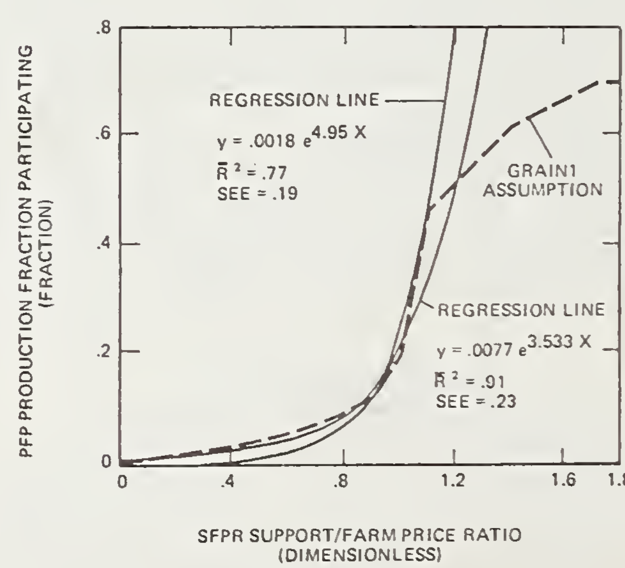
To help maintain farm incomes, the federal government establishes a level of price support against which farmers can borrow money to meet current production expenses, using their crop as collateral. If, at time of harvest, the farm price is below the support price, farmers can simply allow CCC to acquire their crop in full payment of the loan. Farmers must first decide whether they wish to participate in the commodity program for a given crop year. (To qualify for government payments, farmers have to submit to various provisions, such as acreage set-asides established by the Department of Agriculture.) In Illustration 4, the level Production Under Support represents the number of bushels of planned production that are pledged as collateral to CCC. The Participating Farmer Production Rate represents the farmer's decision to take part in any given year's commodity program. The CCC Acquisition Rate represents the decision to accept the loan rate and allow CCC to acquire the crop in full payment of loan commitments. The Supported Grain Release Rate determines the action of farm operators who decide to pay off their loan and retain their crop for sale on the open market at the prevailing market price. The behavior of the level Production Under Support (PUS) can thus be explained as follows:

$$PUS = PUS_0 + \int_0^t (PFPR - SGRR - CAR)\,dt$$

As one example of a nonlinear decision function in one of the feedback loops, Illustration 5 shows the theorized relationship that determines the fraction of production that farmers place under support in any given year. Conversations with farmers suggested that operators make that choice by comparing the existing farm price of the commodity with the established government support price or loan rate. Therefore the Support/Farm Price Ratio (SFPR) was assumed to be the independent variable in a regression performed to explain the fraction of farmers who participate and place their crops under support (PFP).

ILLUSTRATION 5

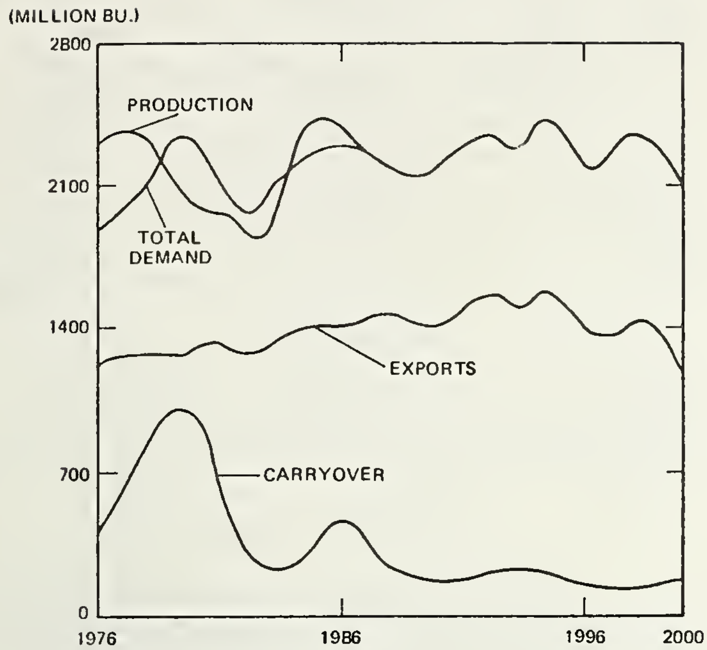
PRODUCTION FRACTION PARTICIPATING

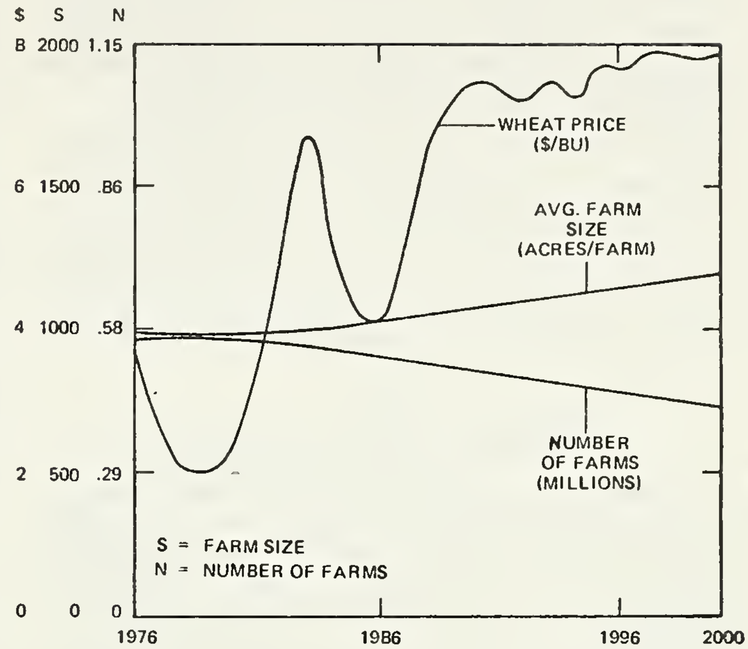


Because farm prices have been abnormally high since 1972, the last data points are found at very low values of the Support/Farm Price Ratio. As a result, the linear regression performed on 1949-74 data has a high correlation coefficient, but the theorized function does

ILLUSTRATION 6

THE STANDARD RUN

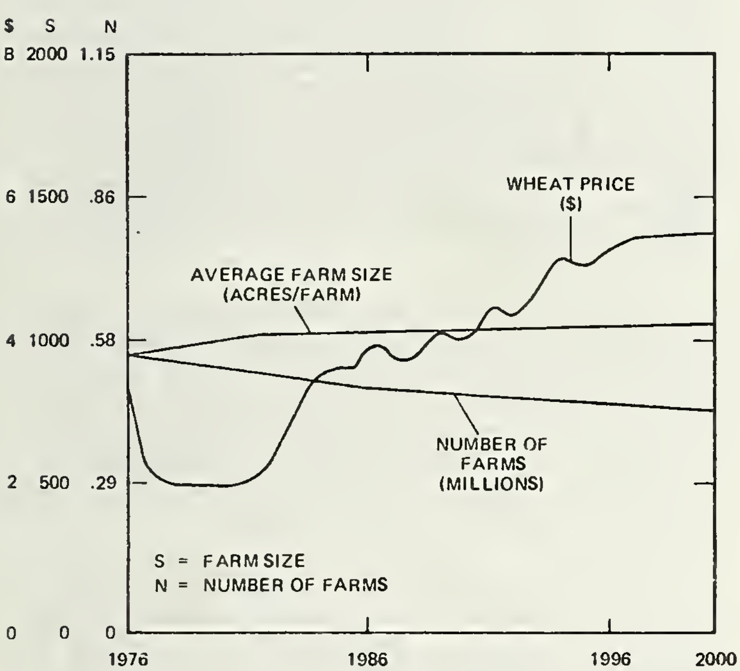


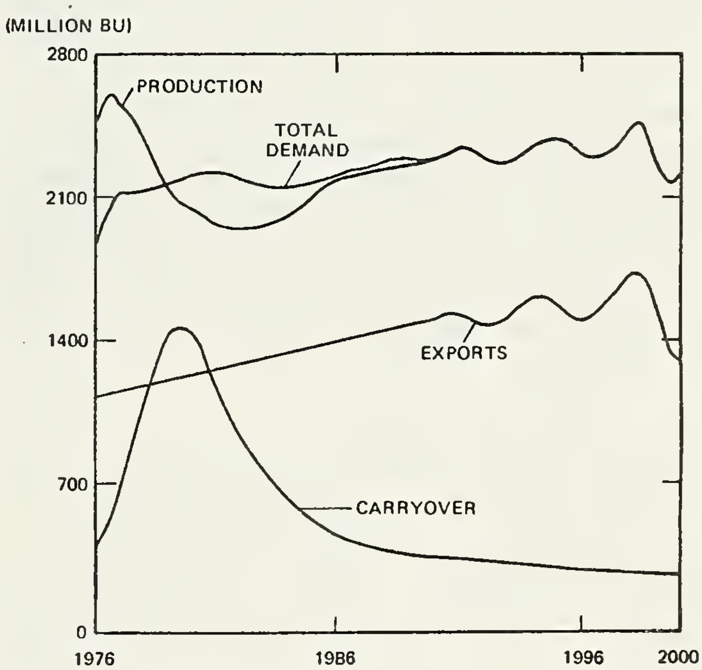


THE STANDARD RUN EXHIBITS THE BEHAVIOR OF THE WHEAT PRODUCTION SYSTEM UNDER "BUSINESS AS USUAL" CONDITIONS, THAT IS, WITH NO NEW POLICY CHANGES FROM CURRENT LEGISLATION.

ILLUSTRATION 7

ALTERNATE SCENARIO





THE ALTERNATE SCENARIO ASSUMES THAT THE TARGET PRICE IS SET TO BE 75 PERCENT OF THE AVERAGE COST OF PRODUCTION FROM THE PREVIOUS YEAR. THIS POLICY REDUCES THE RATE OF DECLINE IN FARM NUMBERS, STABILIZES AND LOWERS THE MARKET PRICE, AND SUPPORTS A HIGHER LEVEL OF EXPORTS. GOVERNMENT PROGRAM COSTS FOR DEFICIENCY PAYMENTS AND GRAIN STORAGE COSTS ARE MORE THAN DOUBLE THOSE OF THE STANDARD RUN.

not predict data points satisfactorily at values of the Support/Farm Price Ratio in excess of 1.0. A second regression was performed for 1949-74 time series data. The equation this regression yielded is a better predictor in that upper range. The shape of the actual table function used in the GRAIN1 model, then, is a hybrid of these two equations. Since, regardless of the current price, some farmers will refuse to participate (because, for example, they desire to be self-sufficient or they mistrust government programs), the function for Production Fraction Participating was assumed to level off below a value of 1.0. Similar procedures were followed for each remaining table function relationship in each of the eight model sectors.

THE MODEL: OUTPUT AND USE

The actual model output is shown in Illustration 6. Note that the heavy lines represent the model-generated values for production demand, exports, carryover, price, average farm size, and the number of farms from 1976 to 2000.

In contrast to the empirical studies mentioned earlier, the GRAIN1 model, with its incorporation of feedback and control theory concepts, extends and strengthens the power of statistical analysis by explicitly setting forth a set of causal assumptions that, in turn, can be intelligently debated. To help resolve the debate, a computer model can then be used to test alternate causal assumptions. Also, once the system structure is agreed on, the model becomes a powerful policy tool capable of testing the impact of numerous alternate policy options, like tax relief, increased exports, and modifications to the existing farm programs. This testing capability is a great strength over conventional empirical techniques. In addition, given any set of user-defined assumptions, such as technological advances or changing capital costs, the model can generate conditional forecasts of the system behavior.

One theory suggests that the trend toward fewer and larger farms is not a natural occurrence, but is caused by external pressures. Profit margins are squeezed by rising costs and the fact that the price of wheat has not risen accordingly. Because farmers can raise their incomes only by increasing total production, farm size has increased out of necessity.

It was recently proposed that, to protect farmers from declining profit margins, the Department of Agriculture's target price be fixed to rise at the same rate as the cost of production. To test this policy, an alternate computer run was made, using the GRAIN1 model. In it, the target price was set to be equal to 75 per cent of the average cost of production from the previous year. This would provide an income supplement to farmers in times when the market price falls below the announced target price. The results of this policy are shown in Illustration 7. Compared with the standard run, this policy is effective in reducing both the rate at which farmers go out of business and the rate of farm size increases. Moreover, the added income supplement makes the wheat production system more stable, and by the year 2000 price rises to only \$5.50 (versus about \$7.50) in the standard run per bushel. Because more farmers are kept in business, production is higher, and carryover is nearly twice as high as in the first example. Finally, the added production supports a slightly higher level of export trade than in the business-as-usual case.

CONCLUDING REMARKS

Although it has been suggested that setting the target price according to the cost of production is effective in retarding the decline in American farm numbers and in stabilizing price, it does not follow that the policy is desirable. More farmers did remain in business, but the cost of government farm programs for deficiency payments and grain storage nearly doubled from that of the standard run. One way to rationalize the different outcomes is to recognize that farmers need a certain amount of revenue to survive. In the standard run, it was received largely from the sale of commodities on the open market. In the alternate scenario, the revenues lost as a result of the lower market price were offset by increased government payments. In the first case, consumers paid more for their bread, whereas, in the second, bread was less expensive but the Department of Agriculture's budget was higher.

At this point, the GRAIN1 model's policy testing function can be instructive and useful in developing new programs that will have a "desirable" impact on the wheat sector. The number of various policy runs is limited only by the policymakers' interest in alternate scenarios. The time and cost involved in generating such scenarios are minimal.

The simulation model presented in this paper does not supplant human judgment in public policy making. Rather, it is a method for enhancing judgment and for testing one's intuition. It does this by providing an internally consistent framework for evaluating alternate assumptions about the presumed nature of the real world. Further, such a model can aid policy makers in recognizing the long-term consequences of any set of short-term actions. This is a goal that has historically been unattainable and, therefore, a neglected aspect of public policy formulation.

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FOOD AND AGRICULTURE MODELS FOR POLICY ANALYSIS*

Gary Boss Heber D. Bouland Patrick Doerning

William E. Gahr Patrick L. Valentine

ABSTRACT

In recent years, a large number of computer-based models have been developed to help the agriculture community analyze trends, identify problems, and evaluate policy alternatives. Over 50 models with potential for aiding decision makers in analyzing many policy related matters in food and agriculture are described. These models vary by scope, size, methodology, and issues covered. They can be viewed as a hierarchical set of analytical tools which can be used to address several levels of problems, such as local issues regarding a specific crop, regional issues involving several farm inputs, national issues integrating nutrition with production policies, or global problems addressing population, wealth, and food. However, they are only partial representations of reality based on certain assumptions of their designers.

INTRODUCTION

The international agricultural environment has undergone dramatic changes in recent years. Weather-induced crop failures in several key areas of the world in 1972-73 led to widespread famine, virtual elimination of world food stocks, massive purchases on the world food market, and higher prices. At home, farmers' incomes rose to new heights as unprecedented foreign demand all but depleted existing grain reserves despite full production efforts. Existing acreage controls, price supports, and government controlled grain reserves were not being used as they were during the surplus era of the 1960's, when food was abundant and cheap.

The 1973 Farm Act emerged during this time as a free market policy: minimum government interference, low levels of price supports, and no costly grain reserves. However, it was not long before government reentered the market place. Relatively tight food supplies, rising domestic food prices, and the Russian grain deal led the government to halt some foreign sales and to negotiate a long-term supply contract with the Soviets. As Congress began its debate on a new farm bill, U.S. and world food supplies were becoming more plentiful, causing a growing concern about the adequacy of existing policies to cope with supply/demand fluctuations and with the uncertainties of the future.

As the world food system grows more interdependent, policy actions made at home have ramifications abroad. Decisions regarding supply agreements, price supports, reserves, and food aid influence foreign demand, prices, and hunger, which in turn affect the price consumers pay for food and the amount farmers earn. Much concern stems from the fact that it is difficult to foresee future events and to evaluate how a policy, or series of policies, influences and interacts with other policies and events.

This concern about future events and potential consequences of policies has increased the need to understand better how agricultural systems operate. A major outgrowth of this need has been a proliferation of quantitative

*This paper was abstracted from the U.S. General Accounting Office Staff Study, *Food and Agriculture Models for Policy Analysis*, July 13, 1977, CED-77-87. Research for this paper was completed in January 1977. The list of models was revised in December 1977.

techniques designed to improve information processing, data analysis, forecasting, and policy evaluation. Many believe not enough analytic tools are available to evaluate and test potential policies for their probable effects.

Modeling is frequently suggested as a means for linking data with potential problems for use in evaluating policies. This suggestion is based on the belief that intelligent planning requires strong efforts to assess future developments as far as current techniques permit. Anything that could be done to structure, quantify, and focus expectations about the future could help decision makers.

MODEL DEFINITION AND SURVEY

A model is a representation of a system. It is constructed to show how a system can be expected to react under different conditions during a given period of time. Constructed properly, it illuminates and clarifies the interrelationships of component parts and of cause and effect, action and reaction. It allows people to assimilate and systematically analyze large numbers of variables which they otherwise could not do.

Models come in different shapes and sizes and are designed for different purposes. They can be classified according to a number of ways, as shown in Table 1.

The food and agriculture models discussed in this paper represent many of the characteristics listed above. In general, these models are a collection of equations which attempt to describe the many interrelationships between supply and demand. Such factors as land, yields, investment, population, climate, and other key factors may be represented by variables in the model.

Models have gained widespread use in business and government, and influenced decision making in some billion-dollar federal programs. For example, the military has used a model that simulates strategic missile launchings, determining the probability of a successful launch under varying conditions. Models have been used to simulate the effect of population and employment on land use planning. Models are used in the securities and commodities market to predict behavior, and in the auto industry for improving automobile design systems. In all of these instances, the model has been used to assess likely impacts throughout a system by altering variables and data.

The National Science Foundation recently sponsored a study on federally supported mathematical models. The study identified over 650 models and found that an increasingly large number are being used by government and the private sector to represent and analyze complex socio-economic structures.

Congress is also showing more interest in models: the budget committees, the Congressional Budget Office (CBO), the Congressional Research Service (CRS), and the U.S. General Accounting Office (GAO) have access to major econometric models. Other committees and staff are exploring other types of models for potential use. The House Agricultural Committee and Congressional Budget Office have used agricultural models to estimate the cost to the government of changes in commodity support prices. Both the Senate and House Agricultural Committees have used a large-scale national agricultural model to study the effects of different energy and environmental restrictions on the prices of agricultural products.

This survey was initiated for the purpose of identifying the major models currently in operation that have potential for food and agri-

TABLE 1. MODEL CLASSIFICATION

Methodology	Econometric, systems dynamic, input-output, linear programming
Size	Many equations, few equations
Time horizon	Short run (up to 1 year), medium term (1 to 5 years), long run (over 5 years)
Function	Economic projections, forecasting, scenario building
Geographical area	Regional, national, global with regional interaction
Levels of aggregation	Single crop, multicrop, sectoral, multisectoral
Issues covered	Agriculture only, multi-issue

cultural policy analysis, without regard to their size, mathematical foundation, structure, or location.

The first list of models was identified by talking with model builders, model users, and economists and researchers from government, industry, and academia. Discussions were held with individuals from the Economic Research Service (ERS) of the U.S. Department of Agriculture, National Science Foundation, University of Illinois, Iowa State University, Office of Technology Assessment, Congressional Research Service, World Bank, and the American Marketing Association. Searches were made of computerized data banks using key words like agriculture, food, models, simulation, econometrics, and forecasting. The systems searched were:

National Agricultural Library (NAL)
National Technical Information Service (NTIS)
Dissertation Abstracts
Science Citation Index (SCI)
Enviroline
Biosis
Current Research Information Service (CRIS), U.S. Department of Agriculture

Search abstract data--together with written materials on some of the models, comments made by model developers, notes from seminars attended in which models were discussed, and information from published literature--provided the basis for identification and description of the models.

The initial list included any model (mathematical, computerized, or econometric) used to analyze, evaluate, or forecast food production, supply, demand, stocks, and pricing. Included were major economic or trade models (such as global models and macroeconomic commercial models) that are not necessarily limited to analyzing food and agricultural policy, but contain an agricultural sector or submodel. Not included were models relating only to agricultural products not used for food, such as tobacco and cotton, and models that concentrated on physical or biological science, such as a specialized model simulating the growth of plant life.

Although, as stated earlier, models can be classified according to a number of criteria, here they are grouped by their scope: as global, national, single commodity, or food reserve oriented.

Many of the models were developed by university agriculture departments or by the U.S. Department of Agriculture, which has sponsored several university efforts. Over 60 percent of the models identified, the majority of which deal with one or more specific crops, are strictly limited in scope to analyzing conditions in the United States. Another 20 percent, frequently single or multicrop specific, confine their scope to *regions* within the United States. Still other models are designed to analyze the impact of specific government policies, such as grain reserve questions.

A number of models, including several that are global or national in scope, are very large, incorporating agricultural and nonagricultural issues. They try to model the total food system, either on a national or international scale, and have built in key influencing factors, such as demography, environment, energy, and pollution. These models are actually a series of interacting submodels, and may or may not be designed specifically for global food policy analysis.

Private research firms have also developed a number of large national models, designed to make short run forecasts at the disaggregated single crop level of activity.

MODEL EVALUATION

The proliferation of models over the past four years has caused doubts as to which model or models would be most useful. The developers were asked to list those models they felt were best for food policy analysis. Over half of them did not answer the questions. Several stated that no one model could be described as best, since the types of questions asked affect the outcome. In all, 25 developers listed 20 different models, with the majority getting 1 or 2 mentions.

A number of leading agricultural economists and modelers were also asked to express their views on models and policy analysis. Among other things, these experts felt that knowledge of existing models is inadequate, many models are poorly documented, and policy makers need to be educated on the value of models. They suggested that some type of institutional mechanism is needed to help alleviate some of these problems. However, the experts agreed that several current models could be used for meaningful policy analysis.

Response to questions about the future of models for food policy analysis varied from no comments to very lengthy ones. A majority of those responding felt that modeling would play an important role in future food policy analysis. Several stated that no one model could answer all questions on policy analysis, and that a combination of models would have to be used. Respondents also felt that models would become more specialized, and that a comparison of model outputs should, and in fact would, become more commonplace.

Some of the more general comments made were: (1) there has been a proliferation of new models in recent years, (2) models are needed due to the complexity of food policy issues, (3) there is a steep learning curve associated with model building and an understanding of the complex interrelationships that accompany food policy issues, (4) models are very expensive, and (5) models can be very useful, if carefully designed and used with care and understanding of their limitations, i.e., model use should be tempered with judgment. Reactions concerning how sophisticated the underlying economic theory in models should be were mixed: some felt more sophistication is needed, while others thought models should be simpler.

OBSERVATIONS

The survey uncovered more than 200 separate models that can perform some type of analysis of food and agriculture policies and issues. Without actually testing each model, it is often difficult to judge what model or models would be best for any one series of policy questions.

Models are used for a variety of purposes by a variety of organizations. For example, several models are used primarily for forecasting a single crop, a series of crops, or an entire agricultural sector over a period of time. Used to assess probabilities of future outcomes, such models can provide the policy makers with systematic speculations about the future. Many large commercial econometric and smaller special purpose models provide this technique.

The larger, highly aggregated national and global models appear to be designed for broader policy questions that require consideration of international ramifications and multiple issues, such as population and energy. These models typically have a longer time horizon capability (although some of the more specific purpose models also allow for long term analysis). They are designed to answer "what if" questions, allowing users to specify a series of assumptions and then learn the range of outcomes which may result from their actions or inactions.

The smaller, single or multiple crop models and the food reserve models are typically used for shorter time frame analysis and can handle more specific policy questions.

Probably no one model will be able to provide analyses for all types of policy questions. The capabilities of each model differ in terms of level of aggregation, assumptions, and range of issues covered. This fragmentation of models has led many experts to suggest the establishing of some kind of institutional mechanism to serve as a focal point for developing a consistent language, documentation standards, and a means for classifying and describing various types of models. Underlying this need for a centralized mechanism is the belief that modelers need to educate policy makers about models' potential usefulness in decision making.

Those supporting the use of models for policy analysis have argued that models can accomplish the following:

- Identify new policy options that normally are overlooked
- Detect important variables in a situation that might otherwise be neglected
- Serve as an early warning device and spot new opportunities for problem solving
- Recall specific facts and trends on critical issues
- Provide alternative scenarios of the future according to a specific set of assumptions
- Provide a series of expected outcomes of particular policy options under consideration by policy makers.

Limitations of using models include the following:

- As partial representations of reality, they cannot always identify or quantify all factors which affect system behavior
- To a certain extent, they reflect the biases of their developers
- Data base inadequacies can make their results unreliable
- Validation can be extremely difficult, if not impossible in some circumstances, because of complexity.

LIST OF MODELS

The models described here represent the more significant modeling efforts determined from search of data sources and from discussions with model builders and users. About 20 of these models are actively used in government and industry. However, because some models are constantly being developed and others modified or abandoned, a precise inventory of all models in existence is all but impossible to develop. Also, many models in existence are quite limited in scope, are not operational, or are not being used for one reason or another; such models were not included in the survey.

A total of fifty-six models are included in the main list. Among these fourteen are world models, twenty-one are models of the United States, three are concerned with countries other than the U.S., ten are single-commodity models, and eight are food reserve oriented. It must be stressed that no attempt was made by the authors to verify or evaluate any of the models described.

WORLD MODELS

	TITLE	DEVELOPER	DESCRIPTION
1.	World Integrated Model	M. Mesarovic and E. Pestel Case Western Reserve University Cleveland, Ohio	Designed to assess the consequence of alternative policy scenarios on the world food situation. Disaggregates world into 10 regions and projects to year 2025.
2.	WORLD 2	J. Forrester Massachusetts Institute of Technology Cambridge, Mass.	Interrelates five world subsectors--population, capital, investment, natural resources, food production, and pollution. Effects of alternative policies on world food supplies are analyzed to the year 2100.
3.	WORLD 3	D. Meadows Dartmouth College Hanover, N.H.	Uses same world systems dynamics and subsectors as World 2. However, disaggregates to a greater degree and provides greater interrelationship among sectors.
4.	MOIRA	H. Linnemann Free University Amsterdam, Netherlands	Global in scope, distinguishing 106 geographic units. Agriculture sector is explicitly modeled; growth of nonagricultural sector is exogenous. Examines the influence of factors such as economic growth, population increases, world food prices, and aid on the incidence of malnutrition.
5.	Latin American World Model	Bariloche Foundation Argentina	Constructed from the developing countries' viewpoint to examine the feasibility of poorer countries achieving an adequate living standard in terms of food, housing, health care, and education. Disaggregated into one developed and three under-developed regions.
6.	Explore-Multitrade 85	Battelle Memorial Institute Richland, Wash.	Worldwide model dealing with agricultural supply, demand, and trade flows. Provides medium to long term forecasts for up to 70 commodities within 10 nations and trade flows for commodities. Projections on production, prices, costs, profits, imports, and exports are given.
7.	Globe 6	Battelle Memorial Institute Richland, Wash.	Divides world into two regions--developed and developing. Major elements include resources, agriculture, population, food, industry, and pollution. Designed for scenario analysis to the year 2050.

TITLE	DEVELOPER	DESCRIPTION
8. World Grain, Oilseed, Livestock (GOL)	A. Rojko ESCS, USDA Washington, D.C.	Worldwide 28-region model of the major grain-oilseed-livestock complex is analyzed physically and a world price profile calculated. Feed demand of certain commodities as inputs into production of other (livestock) commodities is specifically analyzed.
9. Social and Technological Alternatives for the Future	C. Freeman University of Sussex United Kingdom	Dynamic and simple structural models are being developed, where appropriate, to examine selected aspects of the world food situation, in particular the choice of agricultural technology and the potential interactions between changing climate and food production.
10. World Price Equilibrium Model	United Nations Food and Agriculture Organization (FAO) Rome, Italy	Short-term projections of world demand and supply of commodities.
11. On the Future: Japan and the World - A Model Approach	Y. Kaya Japan	A number of interrelated projects, mainly concerned with the effect of world trends on Japan, and the reduction of global demand-supply gaps between developed and developing nations.
12. World Rice Trade Model	W. Gregory ESCS, USDA Washington, D.C.	Total world rice economy is divided into 38 countries or regions. A set of equations denotes production, consumption, price linkages, and policy or physical constraints. The model has been used to increase understanding about how technology, weather, and domestic and international policies affect prices and trade.
13. World Food Projection and Planning Model	T. Takayama University of Illinois Urbana, Illinois	Spatial and temporal equilibrium models that incorporate population and income growth rates to generate equilibrium prices, consumption, supply, trade, and carryover quantities for 10 commodities, 20 regions, and the 1976-85 period. Also, price stabilization and world grain reserve policies are examined.
14. Japan Ministry of Agriculture Projection Model (JAM)	Ministry of Agriculture Japan	Forecasts equilibrium prices, consumption, supply quantities and carryover quantities of 11 major food products every year from 1975 to 1985 for 25 world regions.

NATIONAL MODELS

A. MODELS OF THE U.S.

	TITLE	DEVELOPER	DESCRIPTION
1.	AGRIMOD	A. H. Levis Systems Control, Inc. Palo Alto, Calif.	Dynamic simulation model for analyzing the impact of agricultural and energy policy as well as weather on U.S. food production and consumption over a 10-20 year period. It includes 10 crops and 5 livestock types.
2.	National Inter-regional Agricultural Projections Modeling System (NIRAP)	L. Quance ESCS, USDA Washington, D.C.	A computerized simulation of U.S. agriculture, used to project and analyze alternative futures based on differing scenarios and policy decisions through a 50-year planning horizon with emphasis on a 10-year projected benchmark.
3.	Model of Agriculture Policy, Land and Water Use	E. O. Heady Iowa State University Ames, Iowa	National-interregional programming and simulation model of agricultural productive capacity, policy, land and water use, and environmental impacts.
4.	POLYSIM	D. Ray Oklahoma State University and M. Ericksen ESCS, USDA Washington, D.C.	Comprehensive computerized model of the agricultural sector of U.S. economy used in policy analysis to determine the effect of policy provisions. Can be used on an annual basis up to 5 years. An exogenous baseline of the agricultural sector's situation must be provided as a starting point for POLYSIM analysis.
5.	National Systems Dynamics Model	J. Forrester Massachusetts Institute of Technology Cambridge, Mass.	Designed to help solve pressing national problems and issues, including economic growth, agriculture, inflation, taxes, energy, education, etc. Ultimately will project to the year 2050.
6.	Econometric Model of U.S. Livestock-Feedgrains Economy	E. Womack ESCS, USDA Washington, D.C.	Econometric model used for forecasting and impact analysis. Commodities covered include beef, pork, chicken, turkey, eggs, dairy products, corn, wheat, sorghum, soybeans, soybean meal and oil. Retail farm prices, slaughter numbers, production, acreage, and yield are determined.
7.	Cross Commodity Forecasting System	W. Boutwell ESCS, USDA Washington, D.C.	Consists of annual econometric models for 13 individual commodities or commodity groups. Individual models can be used to forecast for their own commodity or as part of whole system. Used for forecasting and various impact analyses.
8.	Agriculture - General Economy Linkage Model	G. Schluter ESCS, USDA Washington, D.C.	Model of U.S. agricultural sector designed to expand agricultural economic intelligence available in larger national models, such as Wharton's.

TITLE	DEVELOPER	DESCRIPTION
9. Energy Policy and Economic Growth	E. Hudson Data Resource Inc. D. Jorgenson Harvard University Cambridge, Mass.	Model of U.S. economy with nine intermediate sectors, including agriculture. A detailed projection of demand and supply, price and cost, and imports and exports is made for each sector for the years 1979-2000.
10. National Model of Energy Use in Agricultural Production	D. Dvoskin Iowa State University Ames, Iowa	A large-scale interregional linear programming model of U.S. agriculture constructed to evaluate the economic and environmental impacts of various energy situations in agricultural production.
11. Research and Development Priorities for Food Research	P. Kruzic SRI Palo Alto, Calif.	Dynamic simulation model designed to analyze "what if" type questions in several areas of interest--not specifically agriculture.
12. Two-Sector Model of Agricultural Resource Adjustment and Structural Change With Farm Commodity Program Policy Variables	F. J. Nelson ESCS, USDA Washington, D.C.	A two-sector (crops and livestock) aggregate simulation model of U.S. agriculture which uses a resource adjustment approach to supply response. Includes aggregate resource productivity, farm numbers and sizes, and price variability measures (risk proxies) as endogenous variables.
13. Wharton Agricultural Model	D. T. Chen Econometric Forecasting Associates Philadelphia, PA	A complete U.S. agricultural sector model. Contains 4 blocks, over 260 equations, and 500 variables which describe 17 commodities and farm income and expenditure flows. Integrated with the Wharton Macro models for forecasting and policy analysis.
14. A Quadratic Programming Model of the U.S. Food and Fiber System	T. Miller ESCS, USDA Colorado State Univ. Fort Collins, Colorado	Estimates the competitive equilibrium situation resulting from U.S. domestic and export food and fiber requirements. Gives consistent estimates of prices and quantities for farm inputs and outputs.
15. Aggregate Income and Wealth Simulator Model	J. Penson D. Lins C. Baker ESCS, USDA Washington, D.C.	Short-term model that forecasts components of the income accounts, balance sheet, and sources and uses of funds statement for the farm sector.
16. Consumer Price Model	Research Triangle Institute Research Triangle Park North Carolina	Uses cost-push assumption to provide projections of the impact of an increase in the cost of production on the price of 477 consumer products.
17. National Agricultural Sector Study (NASS)	V. Sorenson and S. Thompson Michigan State University East Lansing, Mich.	National agriculture model containing a large international component. Can be used for forecasting and policy analysis.
18. Chase Econometric Agricultural Forecasting Model	Chase Manhattan Bank New York, N.Y.	National 2-year quarterly and 10-year annual agricultural model for major crop and livestock products, farm income, and wholesale retail food price indexes.

TITLE	DEVELOPER	DESCRIPTION
19. DRI Agriculture Model	Data Resources, Inc. Lexington, Mass.	National agriculture model with supply and demand information for 20 commodities, farm income, and balance sheet. Incorporates weather data. Can be used for forecasting and policy analysis.
20. Feed and Livestock Evaluating System	P. Velde ESCS, USDA Washington, D.C.	A mathematical programming system of models to quantitatively measure the impact of changes in supplies, demands, and ending stocks of specific nutrients, such as a certain type of protein or specific amino acids, on the world or U.S. feedstuff commodities.
21. A Regional Crop and Livestock Model of U.S. Agriculture	T. Reynolds North Carolina State Univ. Raleigh, N.C.	An econometric model of U.S. crop and livestock production and income for 10 farm production areas with market submodels. Crops include wheat, feed grains, soybeans, and cotton. Purpose is to examine policy and export alternatives.

B. OTHER COUNTRIES

TITLE	DEVELOPER	DESCRIPTION
1. KASM--Korean Agriculture Simulation Model	G. E. Rossmiller and G. L. Johnson Michigan State University East Lansing, Michigan	General computerized system simulation model of the Korean agricultural sector. Provides usable results on a 5-20 year time horizon; the time increment for model output is an annual cycle. Includes 2 population groups, 16 aggregated economy subsectors, 4 land categories, 2 regional options, 19 agricultural commodities, 12 factor inputs, and 4 agricultural capital and credit constraints.
2. CHAC	R. Norton International Bank for Reconstruction Washington, D.C.	Programming model of Mexican agriculture with consumer demand behavior and endogenous prices. Contains 20 producing locations and over 2000 production technologies. Used by Mexican government to simulate many policy alternatives, including pricing policies.
3. Short-term Forecasting Models for the Following Countries - France, West Germany, Italy, The Netherlands, and Belgium-Luxembourg	W. Kost ESCS, USDA Washington, D.C.	Focus on the grain-oilseed-livestock sectors. Each country model contains three submodels; production, feed consumption, and food consumption.

DISAGGREGATED SINGLE COMMODITY MODELS

TITLE	DEVELOPER	DESCRIPTION
1. Dairy Policy Model	R. Fallert and M. Hallberg ESCS, USDA Washington, D.C.	Model structured to simulate industry as currently organized. It includes equations to represent (1) government pricing strategies, (2) producer behavior, (3) consumer behavior, and (4) government support activity. Designed to simulate the impact of alternative policies for the dairy industry.
2. Resource Use of Alternate Beef Production System	G. Ward and P. Knox Colorado State University Fort Collins, Colorado	Model of beef production systems in Colorado and neighboring states.
3. COPLAN	Regional Systems Program Colorado State University Fort Collins, Colorado	Resource allocation on small ranches.
4. Reactive Programming Model of the Fluid Milk Industry	J. Riley and L. Blakley Oklahoma State University Stillwater, Oklahoma	Designed to determine equilibrium market prices, equilibrium consumption, and minimum cost flows between surplus and deficit markets under alternative price or structural conditions in the fluid milk industry.
5. Egg Price Prediction Model	W. Henson Pennsylvania State Univ. University Park, PA	Econometric model designed for forecasting egg prices.
6. A Systems Model of the U.S. Tomato Processing Industry	E. Jesse ESCS, USDA University of California Davis, California	Uses econometric techniques to evaluate potential structural adjustments in the U.S. tomato subsector. Can be used to analyze specific types of structural change.
7. Market Organization, Policies and Programs in the Dairy Industry	R. King North Carolina State Univ. Raleigh, North Carolina	Model in process of development consists of spatially oriented structure with demand, supply, and transfer costs for fluid and manufacturing milk subject to administrative decisions with respect to Class I prices and Government purchases of manufacturer products.
8. Economic Analysis of Daily Hog Price-Quality Fluctuations	R. Leuthold University of Illinois Urbana, Illinois	Two-equation model explains short-run hog price and quantity fluctuations at major U.S. terminal hog markets.
9. An Economic Appraisal of the Beef Production Industry in the Cornbelt and Lake States	N. Martin University of Georgia Athens, Georgia	Model for Midwest agriculture to evaluate the impact on future beef production of changes in prices of beef and substitutes for beef, changes in input prices, and level of technology.

	TITLE	DEVELOPER	DESCRIPTION
10.	GRAIN1	L. Brzozowski Dartmouth College Hanover, New Hampshire	Computer simulation model of the U.S. wheat production which includes the decision rules and information links used by farmers as they formulate production decisions. Can be used for policy analysis and conditional forecasts of system behavior.

FOOD RESERVES MODELS

	TITLE	DEVELOPER	DESCRIPTION
1.	Simulation of Grain Buffer Stocks	S. Reutlinger International Bank for Reconstruction and Development Washington, D.C.	A stochastic simulation model designed to calculate the efficiency, equity, trade, and stabilization impacts on a less developed country of an investment in grain reserves. Can also be used to evaluate international grain reserve policies.
2.	CDTY 10	L. Brzozowski Dartmouth College Hanover, New Hampshire	A stochastic simulation model capable of assessing the impact of large export sales of wheat which are made at different points in the production cycle. Prices, production, carryover, and government costs are measured.
3.	An Optimization Approach to Grain Reserves for Developing Countries	D. Johnson and D. Sumner University of Chicago Chicago, Illinois	Model is designed to calculate optimal grain reserves for developing countries and regions. The basic unit of analysis is a single country or region over a time horizon greater than 1 year.
4.	Reserve Stock Grain Models for the World and the United States, 1975-85.	W. Cochrane University of Minnesota Minneapolis, Minn.	A world grain model and a U.S. wheat model are used to estimate what size reserves stocks are required to achieve some price stabilization goal with some degree of probability. The models are based on supply-demand equilibrium theory. Prices are determined in (1) free market situation and (2) with application of different reserve stock decision rules.
5.	GRAINSIM	R. Walker, J. Sharples, and F. Holland ESCS, USDA Purdue University West Lafayette, Indiana	Designed to analyze government buffer stock management rules. Contains short run supply-demand functions for 1976-82. Predicts how buffer stock management rules affect grain supply and demand, livestock, income of farmers, prices, and government costs.
6.	WHEATSIM	R. Walker, J. Sharples, and F. Holland ESCS, USDA Purdue University West Lafayette, Indiana	Designed to analyze government buffer stock management rules. Contains short-run wheat supply-demand functions for 1976-82. Predicts how buffer stock management rules affect wheat supply and demand, income of farmers, prices, and government costs.

TITLE	DEVELOPER	DESCRIPTION
7. Grain Reserve Sizing Model #1	D. Eaton University of Texas Austin, Texas	Model develops a procedure to calculate a lower limit on the size of a world grain reserve to reliably stabilize supplies of grain over the period 1975-2000.
8. Grain Reserve Sizing Model #2	D. Eaton University of Texas Austin, Texas	Model develops procedures to size a world grain reserve to achieve multiple public objectives. These include supply stabilization, price stabilization, consumer interests, farmer interests, and economic efficiency.

The following is a listing, by title and developer, of models identified by questionnaire respondents which were not included in the original list. No attempt was made to document them, nor to determine their present status.

TITLE	DEVELOPER
1. Food 1 - A Model for Prediction of World Food Production and Allocation	B. Dewitt Institute for Environmental Studies University of Wisconsin Madison, Wisconsin
2. Interactive Cross Impact World Food	S. Enzer Center for Futures Research University of Southern California Los Angeles, California
3. A Stochastic Model for Estimating Future Disaster	T. Miller ESCS/USDA Washington, D.C.
4. National-Interregional Model of U.S. Agriculture	E. Arnold EPA Computer Center Washington, D.C.
5. Food Impacts by Major World Regions	D. Mitchell Michigan State University East Lansing, Michigan
6. TRIM	Harold Beebout Washington Policy Studies Group Mathematics Incorporated Washington, D.C.
7. FAO Commodity Projections FAO Dietary Projections	U.N. Food and Agriculture Organization (FAO) Rome, Italy
8. Agriculture Planning Model of Iran	Bruce W. Cone Battelle Memorial Insitute Richland, Washington
9. Simulation Model of the Rapeseed Economy of Alberta and Saskatchewan, Canada	Bruce W. Cone Battelle Memorial Institute Richland, Washington

TITLE	DEVELOPER
10. REFLOW	D. A. Jameson College of Forestry and Natural Resources Colorado State University Ft. Collins, Colorado
11. Revision of Reactive Programming	Verner Hunt Mississippi State University Starkville, Mississippi
12. Model Including Economics of Scale in Milk Processing	M. C. Conner and W. T. Boehm Virginia Polytechnic Institute and State University Blacksburg, VA
13. Net Trade Model	William E. Kost ESCS, USDA Washington, D.C.
14. Net Trade Model - Coarse Grain	William E. Kost ESCS, USDA Washington, D.C.
15. A Hybrid Probabilistic System Dynamics Model of the United State Agriculture	Christian J. Donahue The Futures Group Glastonburg, Conn.
16. BACHUE	G. Rogens World Employment Planning I.L.O. Geneva, Switzerland
17. SARUM	P. Roberts Systems Analysis Research Unit Department of Environment London, United Kingdom
18. Dynamic Hog Cycle	Dennis Meadows Dartmouth College Hanover, N.H.
19. Dairy Farm	Philip Budzik, Donella Meadows Dartmouth College Hanover, N.H.

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