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A GENERALIZED SYSTEM SIMULATION APPROACH TO AGRICULTURAL DEVELOPMENT PLANNING AND POLICY MAKING

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ABSTRACT

The problems of planning for economic development arise from the interplay of the political, social and economic subsystems of a developing country. These problems are characterized by the uncertainty necessarily inherent in any process of planning for the future--uncertainty arising both from the quantity and quality of available data and from the difficulties of forecasting how a large-scale system of complex interactive and feedback relationships will respond to policy inputs. In this paper, we discuss generalized system simulation as an approach to dealing with these problems. We view this approach as a flexible, iterative, problem-investigating process that includes problem formulation, mathematical modeling, testing and refinement of the model, and model application to problem solution--all in close consultation with decision makers. This discussion will be followed by a brief description of a policy-oriented, system simulation model of the Nigerian economy. The model consists of two detailed regional agricultural submodels, an aggregated national nonagricultural submodel, and components which model Nigeria's population and the interregional trade in food. The policy options the current model is capable of investigating include programs to modernize agricultural production and various forms of tax and commodity marketing board pricing policies. Finally, we outline how the generalized system simulation approach could be implemented within the development-planning and policy-making process, including the use of a hierarchical "library" of models.

THE PROBLEM

Colm and Geiger[1] have defined development planning as:

> . . . *deliberate, rational, continuous* efforts by governments to accelerate the *process* of development and to channel it into *desired directions* by means of the comprehensive and detailed *choice* of objectives and the *determination* and *allocation* of the resources necessary for their achievement.* (p. 272)

This definition of development planning implies a whole range of complex problems which have bedeviled planners. The key words (emphasized above) stress the notion that development planning is as much a political effort as it is a socioeconomic one. The basic problem which makes planning essential to the development process is the allocation of scarce resources in an uncertain environment of complex interactions among physical, social, economic and political forces.

Two principal types of uncertainty can be identified in this context: *state uncertainty* and *process uncertainty*. State uncertainty arises from a scarcity of reliable knowledge about present and past states of the economy and of the society in general. In this situation, it is difficult to identify and measure needs accurately and to define meaningful objectives. State uncertainty is basically a data problem.

Process uncertainty, on the other hand, is much more than a data problem; it is primarily a problem of understanding how the socioeconomic system operates as a *process*, as an evolving behavioral phenomenon. Certainly, in attempting to explain how the system behaves and responds to external stimuli, knowledge of past states is necessary; but it is not sufficient. Theoretical models of causal and structural relationships are also necessary. The process uncertainty problems encountered by development planners and policy makers make it extremely difficult to forecast even the *relative* (much less *absolute*) short- and long-run effects of alternative development strategies. In particular, the degree to which policies aimed at one set of economic and social phenomena may have unintended side effects ("good" or "bad") on other aspects of the society is often even more in doubt than the direct consequences. In short, even if meaningful development objectives could be defined, the optimum path to the attainment of those objectives--that is, the maximization of "goods" and the minimization of "bads"--would lie in darkness.

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*Emphasis added.

supplies the larger model with the decision vector X over time, while the larger model generates for the LP the time paths of the price vector C, the activity matrix A and the constraint vector b.

Conceptually, a simulation model of an economic system can be viewed in the following general mathematical form:

$$\psi(t+1) = F[\psi(t), \alpha(t), \beta(t), \gamma(t)]$$

$$\pi(t) = G[\psi(t), \alpha(t), \beta(t), \gamma(t)]$$

where:

- $\psi(t)$ = a set of variables defining the state of the simulated system at any given time. State variables may include such quantities as production capacities, prices, population by subgroups, levels of technology, etc.
- $\pi(t)$ = a set of output variables, including such performance measures as profit, income, growth rates, balance of trade, employment, etc.
- $\alpha(t)$ = a set of parameters defining the structure of the system. These usually involve rates of change of variables between levels and input-output coefficients, such as technical coefficients, behavioral response parameters, price elasticities, migration rates, birth and death rates, etc.
- $\beta(t)$ = a set of environmental variables, such as world prices, weather, etc.
- $\gamma(t)$ = a set of policy instruments, such as tax policies, production campaigns, investment alternatives, etc.

The state equation is a general representation of the difference equation formulation of the system model which describes the state of the system at discrete points in time. The output equation generates the performance criteria necessary in the model application stage to evaluate, in terms of the goals specified in the problem definition, the performance of the system over time under various policy alternatives.

This general formulation of a simulation model is realized in the hundreds or even thousands of parameters and structural relationships (depending on the size of the model) actually incorporated in the model. Specification of the model, given the problem definition, requires: (1) precise description of the model components; (2) explicit algebraic and difference equations to represent the structures and mechanisms within components and the linkages between components; and (3) programming for computer implementation.

In modeling a socioeconomic system, we note that many of the underlying processes of that system are continuous in nature. Others, considered continuous when viewed in the aggregate, are really made up of discrete events. Examples of the former include demographic processes of populations (of people, trees or cattle) aging through time.[10] An example of the latter is the social diffusion of innovations, which may be modeled in the aggregate as a continuous diffusion model[2] or on the micro level as the discrete decisions of individual entrepreneurs.[11]

Continuous processes may often be described by linear and nonlinear partial and ordinary differential equations. The following oversimplified model of a demographic process will illustrate this:

$$\frac{d}{dt}\bar{x}(t) = A(t)\bar{x}(t) + \bar{u}(t)$$

$$\bar{p}(t) = B(t)\bar{q}(t)$$

$$s(t) = \sum_{i=1}^{n} q_i(t)$$

where $\bar{x}(t) = [x_1(t) \;\; x_2(t) \; \ldots \; x_n(t)]'$ is the state vector of aggregate maturation rates of the individuals of the population being modeled (trees, cattle, people, capital goods, etc.) through n stages of the individuals' life span; $\bar{u}(t) = [u_1(t)/\tau_1 \;\; u_2(t)/\tau_2 \; \ldots \; u_n(t)/\tau_n]'$ is the vector of controls applied to each life stage, e.g., planting rates, investment decisions, liquidation rates, etc.;

$$A(t) = \begin{bmatrix} (\beta_1\tau_1-1)/\tau_1 & \beta_2\tau_2/\tau_1 & \cdots & \beta_n\tau_n/\tau_1 \\ \alpha_1/\tau_2 & -1/\tau_2 & \cdots & 0 \\ 0 & \alpha_2/\tau_3 & \cdots & 0 \\ \vdots & & & \\ 0 & \cdots & \alpha_{n-1}/\tau_n & -1/\tau_n \end{bmatrix}$$

is the (possibly) time-varying matrix of coefficients; $\beta_i(t)$, $i=1, \ldots, n$, are birth rates from the n life stages, where $0 \le \beta_i \le 1$; $\alpha_i(t)$, $i=1, \ldots, n-1$, are survival rates (surviving deaths, sales, etc.) to succeeding stages, where $0 \le \alpha_i \le 1$; τ_i, $i=1, \ldots, n$, are mean maturation times for each of the n life stages; $s(t)$ is the total number of individuals in the population; $\bar{q}(t) = [\tau_1 x_1 \;\; \tau_2 x_2 \; \ldots \; \tau_n x_n]'$ is the vector of the number of individuals in each life stage; $\bar{p}(t)$ is the output vector of variables which depend upon the age distribution of the population, e.g., production from trees, capital goods or livestock, or social services demanded by a human population; and $B(t)$ is the "input/output" matrix.

This model is actually a lumped approximation to a distributed parameter process--the aging of the individuals of a population--which would otherwise be modeled with partial differential equations.[12] That is, a continuous age distribution is lumped into n stages or cohorts. The number of stages n and the time constants τ_i, $i=1, \ldots, n$, are chosen to give a good fit to the probability density function that describes the random life span of individuals. This model structure realistically handles the fact that all individuals in an aggregate population (the state variables are *aggregative* variables) do not mature at the same rate.[13]

In general, development models must contain both continuous time and discrete time variables (actions of decision makers at micro and macro levels tend to be discrete in time). It has been found appropriate

This suggests another problem: it is virtually impossible to define an objective function to be optimized. The complex physical, social, economic and political interactions involved generate multiple and often conflicting development objectives which can't all be reduced to a single interpersonally valid common denominator for inclusion in an objective function. (Some objectives might not even be quantifiable.) Examples might be employment, price stability, political stability, income and income distribution, nutrition, balance of payments, growth of GDP, political participation, education, etc. In the absence of a decision rule based on mathematical optimization, human judgment and compromise must be used to arrive at a subjective (and *political*) "optimum." Therefore, planners and decision makers responsible for the allocation of scarce developmental resources need information on the many possible trade-offs among objectives under alternative policy conditions.

In this paper, we suggest the "generalized system simulation" approach as a means of dealing with these problems of development planning and policy making. Highlights of this approach, as developed and applied in Nigeria and Korea,[2,3] will be described in the next section. This will be followed, for illustrative purposes, by an overview of the simulation model developed at Michigan State University of the agricultural economy of Nigeria. Finally, we will suggest how this approach can be implemented in the development-planning and policy-making process.

THE GENERALIZED SYSTEM SIMULATION APPROACH

The formalized problem-solving process contains three distinct phases: specification of needs and definition of the problem, identification of a set of feasible solutions, and selection and implementation of a solution. Generalized system simulation contributes to all phases of this process with the construction of a mathematical model of the problem and the use of computer simulation techniques to generate numerical solutions of the model under various assumptions and policy conditions. The process--including problem definition and model building, testing, validation, and application--is iterative in nature rather than strictly unidirectional (Figure 1); that is, information gained at later stages may (probably will) indicate a need to return and repeat earlier stages before continuing.

Central to the whole approach are the interactions among decision makers, researchers, consultants, and modelers and simulators. These creative interactions are essential not only to properly define the most relevant development problems to be considered by planners and policy makers but also to specify meaningful policy simulation experiments and to interpret the results. As decisions are made through these interactions, both normative and non-normative (positive) information will be brought to bear. Where it is felt such information is deficient, new information will be sought.

Mathematical Modeling

Mathematical modeling, although in principle not absolutely necessary to the problem-solving process, in practice is almost indispensable, particularly if there is any degree of complexity to the problem. Mathematical models may be constructed and used as either analytical models or simulation models. However, as the number and the nonlinearity of differential equations increase with the complexity of the model, analytical solutions become impossible given the present state of the mathematical art. Therefore, taking advantage of the capabilities of large-scale digital computers, researchers[4,5,6,7] have turned to simulation as a means of generating numerical solutions and, hence, of providing policy makers with information about the likely consequences of alternative resource allocations, including the vector of criterion variables needed to evaluate alternative development strategies. For an economic development model, a vector of relevant performance criteria might include such elements as levels and growth rates of gross domestic product, employment, total and per capita income, nutrition, tax revenues, income distribution, trade balances, investments, etc.

The approach is generalized on two accounts. First, models may include, but are not limited to, such specialized techniques as linear and nonlinear programming, dynamic programming, program evaluation and review techniques (PERT), and (as commonly used in econometric models) sets of statistically estimated simultaneous equilibrium equations. Secondly, there is flexibility in the data sources which can be tapped. That is, although time series and cross-sectional data, where available, may be used to estimate parameters, the approach is not limited to this source and may rely heavily on estimations by technical experts, perhaps via the Delphi method, or on "guesstimates."

As regards mathematical programming techniques, effective use for public policy prescriptions is precluded at least until the problems discussed earlier have been overcome. Programming models may, however, have application in representing the private decision-making process. At the latter level, interpersonal validity is not a problem and it may be possible to specify a meaningful and realistic objective function or set of priority-ordered objective functions,[8] although aggregation problems do remain if one wishes to model a sector or region rather than an individual decision-making unit.

In spite of their problems (e.g., aggregation, choice of objective functions, computer execution time), such models may be the only feasible way to determine the simultaneous allocation of several resources to a large number of activities subject to a large number of resource and behavioral constraints. For example, deHaen and Lee[9] have proposed a linear programming model for Korean agriculture that allocates land, labor and capital in each of three regions to 39 activities subject to 27 resource and behavioral constraints ($AX \{\leq, =, \geq\} b$) so as to maximize farmers' expected net revenues ($Z = CX$). The model is recursive in that it interacts with a larger simulation model of the Korean agricultural sector. The LP model

to obtain particular solutions for these large, usually nonlinear, continuous/discrete time models with a FORTRAN-based digital simulation approach. The approach uses simple numerical integration techniques to solve the differential equations for continuous processes and readily handles discrete time phenomena. In most cases it has been possible to structure the entire model in terms of recursive first order difference equations.

While there are inconveniences with using a general purpose computer language such as FORTRAN, there are two overriding advantages. The relatively universal character of FORTRAN makes it possible to adapt models to a variety of computers in many countries of interest. Secondly, the subroutine structure of FORTRAN permits the use of a "building block" approach to modeling which greatly simplifies the construction of a large model with many subsystems alike in structure but differing as to input/output interconnection and parameter values (i.e., industries in an economy, firms in an industry, etc.).

The sector models developed using this approach have been efficient. A typical 42-year simulation of a sector model which requires almost all of the 32,000-word core of a CDC 6500 computer takes about 50 seconds of central processor time. This efficiency has made it economically feasible to conduct extensive sensitivity and Monte Carlo analysis with the models.

Testing, Validation and Policy Application

Model testing, refinement and validation are closely linked processes. A simulation model is tested both to check its internal consistency and to assure that it is an adequate representation of the real economic system (adequate for the purposes at hand as stated in the problem definition). Tests may include such activities as tuning the model to track recorded time series, conducting sensitivity tests on model parameters and subjecting the simulated system to exogenous shocks or disturbances and observing the consequent responses. Test results will suggest refinements and modifications to be made in system structures and parameter values and will indicate areas where better data are most needed.

For a decision maker to base policy decisions on the experimental results of a model--*any* model, verbal or mathematical, paper-and-pencil or computer--he must have some degree of confidence in the validity of that model, i.e., how well it simulates the relevant behavior of the real system or phenomenon it is supposed to represent. As long as the decision maker is aware of the model's validity, perfect validity is not necessary. Indeed, perfect validity--in the sense of perfect information on the future behavior of the real system under various assumed conditions--is not possible. Decisions must be taken and implemented with or without models; models can be used, however, to improve the information input to the decision-making process as long as cognizance is made of their validity and until they are replaced by better, more "valid" models. Further discussion of validation of simulation models, which space does not permit here, may be found in the literature (e.g., references 14 and 15).

The most important reason for developing a simulation model (in this context) is to provide a laboratory for exploring the consequences of a wide range of alternative plans or management strategies. This is an iterative process involving close interaction among decision makers and systems analysts. One simulation experiment can lead to the creative design of a new and better one which may involve reprogramming or even basic modifications of the model. The objective of such simulation experiments is to unfold a set of development strategies that are consistent, mutually reinforcing and show how resources could be effectively used to solve the basic problem (as defined).

Policy simulation results may suggest further alternatives to be tested in an iterative process of policy formulation. Eventually, a decision is made to implement a particular set of policies. The real-world consequences of that decision will influence later policy formulations and may even lead to a redefinition of the problem, thus continuing the iterative problem-solving process outlined in Figure 1.

THE NIGERIAN MODEL

Utilizing the generalized system simulation approach described in the last section, a preliminary, planning-oriented simulation model of the Nigerian agricultural economy has been developed.* A broad description of this model and its policy orientation follows. More detailed discussions of the mathematical model and its potential applications may be found elsewhere.(2,10,12,16)

The Model

The Nigerian model is composed of three major submodels: the northern regional agricultural submodel, the southern regional agricultural submodel and the nonagricultural/national accounts submodel. In addition, there are components which model the national food market and the population. Figure 2 indicates the major interactions of these submodels as well as the principal inputs and outputs of the system.

Many planners in the less-developed countries are interested in evaluating alternative policies (often involving economic incentives or government assistance of various kinds) affecting regional specialization of production and trade. To permit considerations of simple questions related to regional specialization and interregional trade, a two-region (North and South) commodity-oriented model was conceived. In addition, several ecological zones within each region were differentiated to permit more detailed consideration of intraregional problems. Although the model is based on Nigeria, its orientation toward both annual and perennial commodities with distinct ecological zones and regions makes its components adaptable to a broad range of countries.

The basic component structures of the two agricultural submodels are quite similar, as is evident in Figures 3 and 4. The nature of perennial commodities,

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however--trees exhibiting such characteristics of dynamic populations as gestation, growth, maturity and decline--considerably complicates the southern submodel, particularly in the land allocation and modernization component, where the population dynamics of trees are modeled as a distributed parameter process.(12)

Briefly, the agricultural submodels allocate land to the available commodities (indicated in Figures 3 and 4) based on profitabilities perceived by farmers and subject to input constraints. From the land allocations, and given commodity yields and other technological coefficients (e.g., factor input rates, marketing losses, etc.), the total production of each commodity is determined, and marketing and processing functions are performed. Agricultural processing in the North is modeled with input-output ratios, while in the South, because of the significance of palm and rubber processing activities to the agricultural producers themselves, processing is modeled in greater detail. Finally, economic performance criteria are generated and the agricultural sector accounts are balanced for each region.

An additional component of the northern submodel, the cattle production component, simulates the meat and milk production process in traditional and modern herd management situations, using inputs of total digestible nutrients (TDN) from grazing and from the production of forage and grain crops. The main interactions between the cattle and annual crops components in the northern submodel occur in the land allocation component where crop land competes with grazing land and in the production component where crop residues contribute to the TDN available to the cattle population.

The nonagricultural submodel (Figure 5) is an aggregated, ten-sector input-output model of the Nigerian economy. One of the ten sectors, the agricultural sector, is modeled in detail on the micro level by the agricultural submodels, while the nine nonagricultural sectors are aggregated on the macro level. Since the primary focus of the national model is agriculture, the broad, aggregated nonagricultural submodel enables the investigation of key interactions between agriculture and nonagriculture, e.g., agriculture's demands for consumer goods and capital inputs, nonagriculture's demands for raw materials and food, and rural-urban migration.(17) This submodel also constructs the national accounts, including measures of gross domestic product, consumption, investment, government revenues and import-export balances.

Two additional components act on the national level. The population component simulates (for each region) births, deaths and the aging of a population lumped into 27 three-year age cohorts. In addition, the total labor force is determined and split between agricultural and nonagricultural occupations in each region and each ecological zone, and rural and urban food demands are computed. The market and interregional trade component models the national food market. It takes cash food supplies from the agricultural submodels and food demands from the population component, computes the price of transportation (based on investments in transport capacity) and interregional shipments of food, and thus determines the market price of food in each region.

Policy Orientation

In this work, effective problem definition required creative interaction among decision makers, planners, systems analysts, agricultural economists and other specialists. The interdisciplinary research team at Michigan State University was fortunate in having available professionals with a backlog of experience in the Nigerian agricultural economy. The Consortium for the Study of Nigerian Rural Development (CSNRD) provided a substantial fund of information about the country and served as a center for contacts with people in the U. S. and Nigeria who were knowledgeable about African agricultural and industrial development.(18)

Further, the CSNRD collaborations with AID, FAO and Nigerian planners and policy makers provided us with a fairly clear picture of the current governmental and planning institutions related to the agricultural economy and to the tools they use to influence the economy. This aided our selection of the planning clientele toward which this model should be oriented. As a consequence, the major policy questions and the corresponding relevant sectors, interrelationships, and variables in the Nigerian economy were isolated more easily than they might have been.

Policy inputs to the agricultural submodels are of three types. Others could be added, but the three included were seen to be both of interest to Nigerian policy makers at the time the model was defined and general enough to be relevant to other countries of the developing world. Indeed, the consideration of other policies *should* be added to the model as time goes on if it is to remain relevant and useful in a changing world.

Production campaigns make up the first class of policies which may be investigated. Promotion efforts aimed at modernizing agricultural production --including cattle as well as annual and perennial crops--can generate substantial returns to both the public and private sectors. Such modernization may entail the introduction of higher-yielding biological varieties and/or the encouragement of improved cultural practices such as weeding, spacing, time of planting and the application of fertilizers and insecticides. The increase in output can then result in higher incomes for the farmers and increased tax revenues and foreign exchange earnings for the public sector. The nonagricultural sector can also experience growth as a result of increased demands from the agricultural sector.

The second major policy area which can be investigated with the model is marketing board pricing policies. Most export commodities in Nigeria are handled through so-called "commodity marketing boards" which buy from the farmers at one price, perform marketing and other services, and sell in world commodity markets at a higher price. Marketing boards have the power to set producer prices as a matter of policy, whereby the boards may generate surpluses for themselves or run at a loss. While surpluses may be used for price stabilization purposes or to finance development or other projects, producer prices can have significant impacts on producer incentives and hence commodity outputs. With simulation runs incorporating different levels of marketing board surpluses for each

commodity, questions can be answered regarding the likely consequences these policies will have on production levels, foreign exchange earnings, agricultural income, and other relevant economic performance criteria.

Finally, various tax policies, particularly income and export tax rates, may be specified and their consequences projected.

IMPLEMENTATION

The ultimate objective of developing a simulation model such as described above is to implement it as an integral part of the general problem-solving process outlined earlier (Figure 1). Although in the present case we are concerned with problems of development planning and policy making, the approach is applicable to a broad range of problem areas, such as health-care delivery, environmental quality, urban society, and transportation.

In the development context, there are primarily two ways in which this type of system simulation can be institutionalized for implementation. One would incorporate the model (and the whole approach) within a national planning unit of a developing country,* while the other would charge a donor agency--such as the United States Agency for International Development, the Food and Agriculture Organization of the United Nations, the International Bank for Reconstruction and Development, and other unilateral and multilateral donor and grantor agencies--with building and maintaining simulation models and applying them to the policy questions of specific countries as requested or needed. In either case, a library of models can provide a focus for implementation efforts.

Experience with actual applications of the Nigerian model described above has shown that even in its current, preliminary form the model is quite useful for analyses of the specific policies (e.g., production campaigns and price and tax policies) and the specific problem areas (crops and cattle) for which it was designed.[19,20,21] However, there are many relevant policies and problem areas--elsewhere in agriculture and in nonagriculture--which were necessarily excluded from the scope of this model. These range all the way from the very micro (e.g., farm decision units as producer firms and consumer households) to the very macro (e.g., general inflation). Development being an evolutionary process, the concerns of planners and policy makers will range over this whole spectrum of problem areas with emphasis changing over time.

Since no single model can hope to economically cover everything of current and potential relevance to policy makers--because of limitations of human and computer resources--implementation of the system simulation approach as described in this paper would probably require the development and use of a hierarchical "library" of generalized models.[22,23] Models would be selected from the library at various levels of aggregation and used in concert as appropriate for a specific application; that is, we would choose one or more disaggregate models to consider interactions with related areas, and even more aggregate models to cover the rest of the economy.

A number of preconditions may be envisioned for successful application of the approach to problems in the developing countries. First, a continuing capacity to develop the generalized system simulation approach must be maintained. Further development of the approach will largely depend upon practical experience applying simulation models to real-world problems and issues with substantial interaction between investigators and policy makers. Secondly, it will be essential to the full development and application of the approach that persons and agencies or institutions responsible to individual groups of decision makers have command over the use of models and their components and that host country capacity to build, modify, extend and apply these models be developed. In addition, it will be necessary for agencies using the approach to have access to substantial computer capacity if large, complex sector models are contemplated. Here the required size of the computer facility will be greatly dependent upon the complexity of the system under study, the degree of detail required, and the skill of the model development team in efficiently utilizing available facilities.

CONCLUSIONS

The system simulation approach, as part of the problem-solving process (Figure 1), can provide important contributions to three broad aspects of development planning and policy making: understanding the socioeconomic system, formulating development policies, and focusing research activities. These aspects are somewhat overlapping; for example, both research and an increased understanding of the problem certainly contribute to improved policy formulations.

Detailed analyses of the behavior of a simulation model of the system under a range of data and structural assumptions and policy conditions provide a comprehensive view of the complex and dynamic socioeconomic system under study. This, combined with the model-building process itself--particularly the identification of causal and structural relationships--can contribute substantially to an improved understanding of, and sharpened intuitions regarding, the development process in general as well as the particular socioeconomic system of concern. For example, sensitivity tests will pinpoint sensitive parameters, and the analyses carried out to explain the simulated consequences of parameter changes will highlight complex interactions of the simulated system.[24] Insofar as the simulated system faithfully represents relevant behavioral patterns of the real system, the heightened understanding can be a valuable asset in reducing some of the uncertainty policy makers necessarily face.

A more direct input to the policy-making process is the capability of a generalized system simulation model to explore the consequences and implications of a wide range of development policy options by projecting time paths of relevant output variables under alternative combinations of policies. Using the same

*Such an implementation is currently under way in South Korea under USAID contract AID/csd-2975.

data as is available for other approaches and techniques, the model takes account of many more complex policies and interactions than can be done by hand or with models necessarily simplified by the constraints of the specialized techniques used. In this way, a good deal of the uncertainty concerning the system's direct and indirect responses to various policies can be reduced. Another important application of such a model to policy formulation is in dealing with the uncertainty inherent in the quality of the available data. Sensitivity tests, where key parameters are varied in each of a number of alternative policy situations, can be used to evaluate the sensitivity of policies to data uncertainty. Alternatively, the model can be run in a Monte Carlo mode where uncertain parameters are assigned probability distributions, a number of runs are made with observations from these distributions, and output statistics are generated. This is information essential in the search for stable policies, that is, policies which will have the intended results even though projections were based on poor data.

A third contribution the system simulation approach can make to development planning is as a focus for research activities. There are primarily three ways in which use of a simulation model can provide a central theme to coordinate and guide research. First, sensitivity analyses will suggest data collection priorities to improve the available estimates of the most sensitive parameters and coefficients of the model. Secondly, the model's application will motivate investigations into structural relationships among, and the behavior of, component elements of the socioeconomic system. These efforts will be necessary to provide theoretical models for the continual improvement and updating of the simulation model's (or models', in the case of a library) assumptions and representations of the real system and to keep it (them) relevant to the needs and concerns of policy makers in a changing world. Finally, technological research may be suggested by policy runs speculating on the likely consequences of the introduction of an innovation which may not actually be developed at the moment. Of course, the projected consequences would have to indicate that the expense of undertaking such research and development was warranted.

As regards the construction and use of libraries of models, the Nigerian model indicates how generalized models can be built and then assembled as needed for application to a particular problem situation in a particular country. Components of the Nigerian model as presented here can be taken apart and reused to simulate and analyze other entire agricultural sectors. The nonagricultural component itself can be generally useful in relating the agricultural economies of various countries to their nonagricultural economies. Some of the Nigerian components have already found application in Korea.(3)

In addition to being useful in constructing models of the entire agricultural economy of different countries, the components are potentially useful in designing, analyzing and evaluating programs and more detailed projects at the agricultural subsector level. Thus, the perennial crops components developed to model the Nigerian cocoa, rubber and palm subsectors have widespread applicability in modeling corresponding subsectors of other countries. These perennial crop components also have potential applications in the developed world--possibly in modeling the vineyards of California, France and Chile, and the cherry orchards of Michigan. The demographic components used for modeling the Nigerian cattle herd are already being extended and applied in Venezuela and Colombia. In short, the components developed for Nigeria are generally applicable in many countries and in many subsectors of the agricultural sector of those countries. Such applications will inevitably involve much field work and a great deal of interaction with decision makers.

In conclusion, the generalized system simulation approach can be a useful and valuable tool in the battle against uncertainty in the development-planning process, providing a comprehensive view of a complex, dynamic system while at the same time facilitating policy experimentation and motivating research. The approach is characterized by high initial costs (reflecting the costs of data acquisition and modeling) but relatively low recurrent costs as models are used to explore a myriad of policy options. It must be remembered, however, that simulation models, while potentially an integral and important part of the decision-making process, will not replace the decision maker. They will, however, give him more information, help to identify new and economically feasible policy options, and sharpen his intuition--thus making for better decisions.

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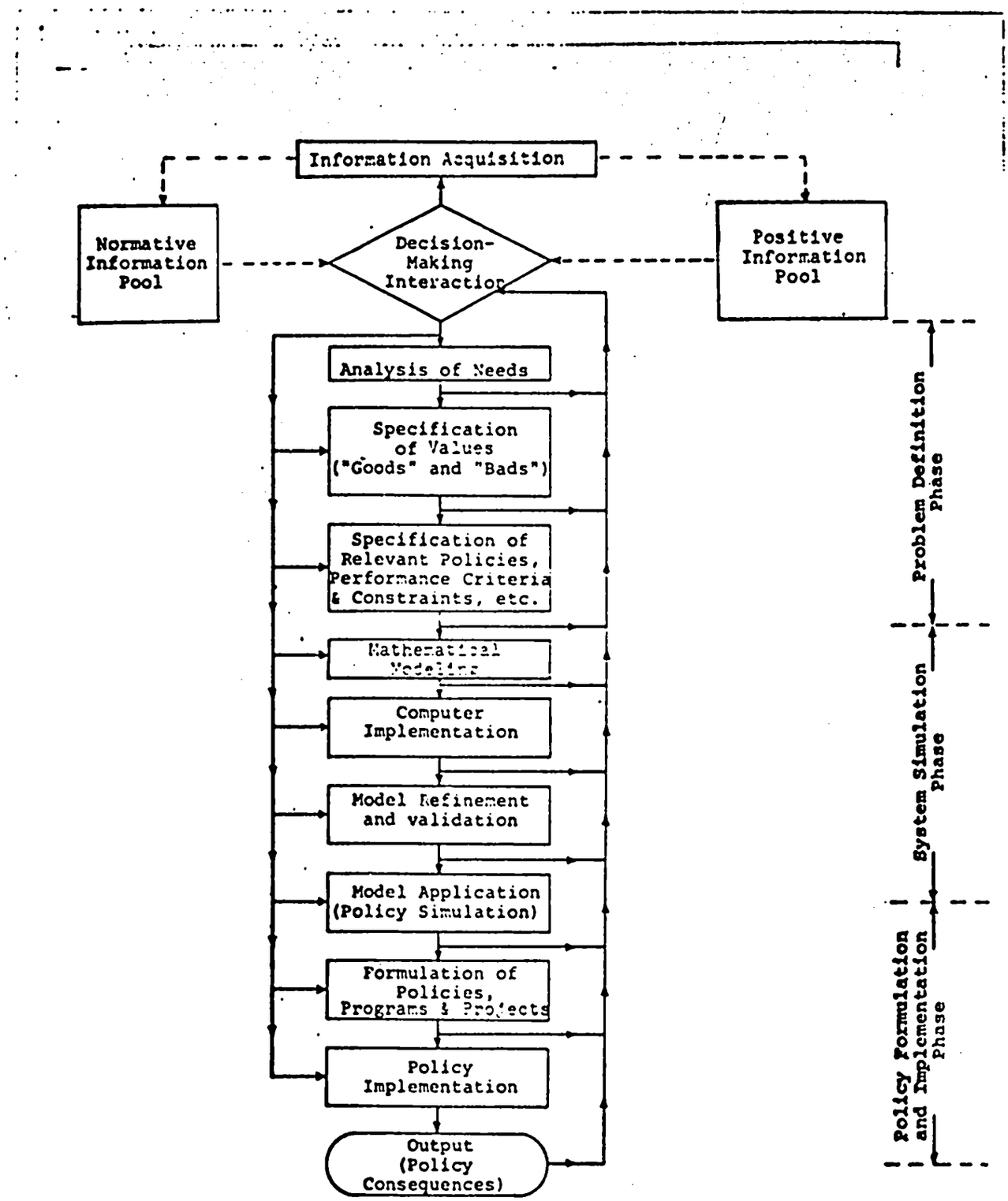


Figure 1
System Simulation and the Policy-Making Process

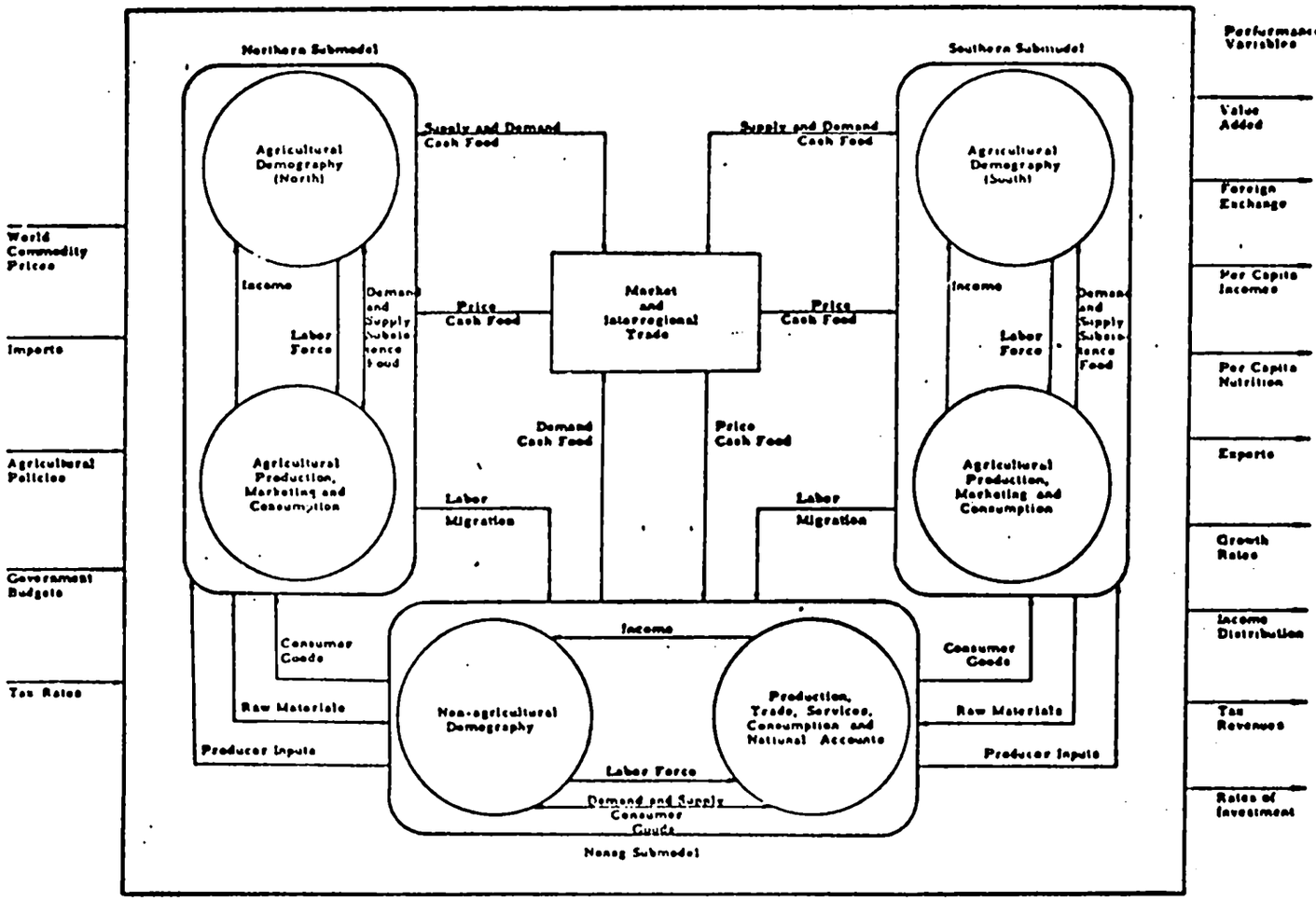


Figure 2. National model of interacting submodels.

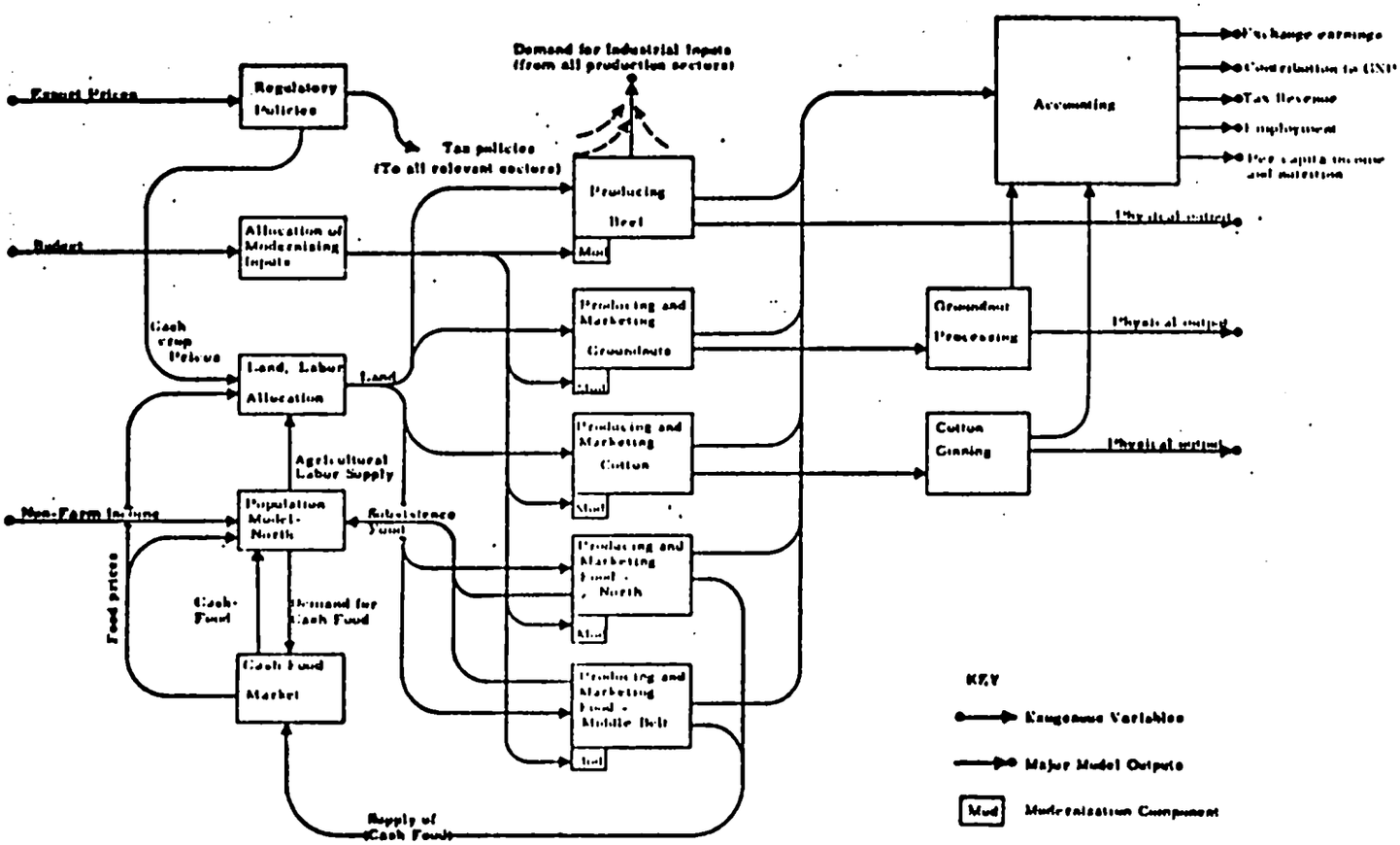


Figure 3

Major Sectors and Interactions of the Northern Nigerian Agricultural Model

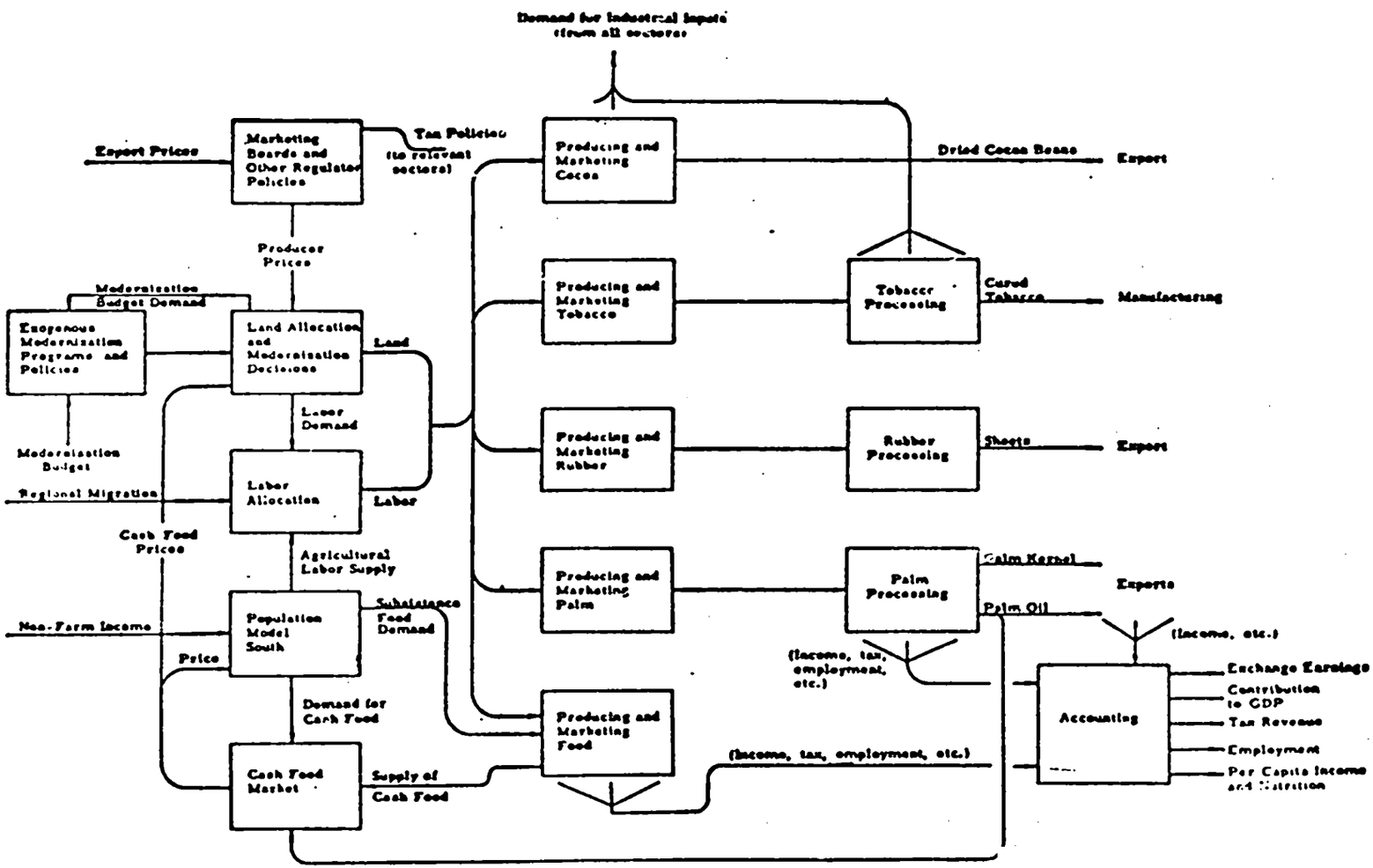
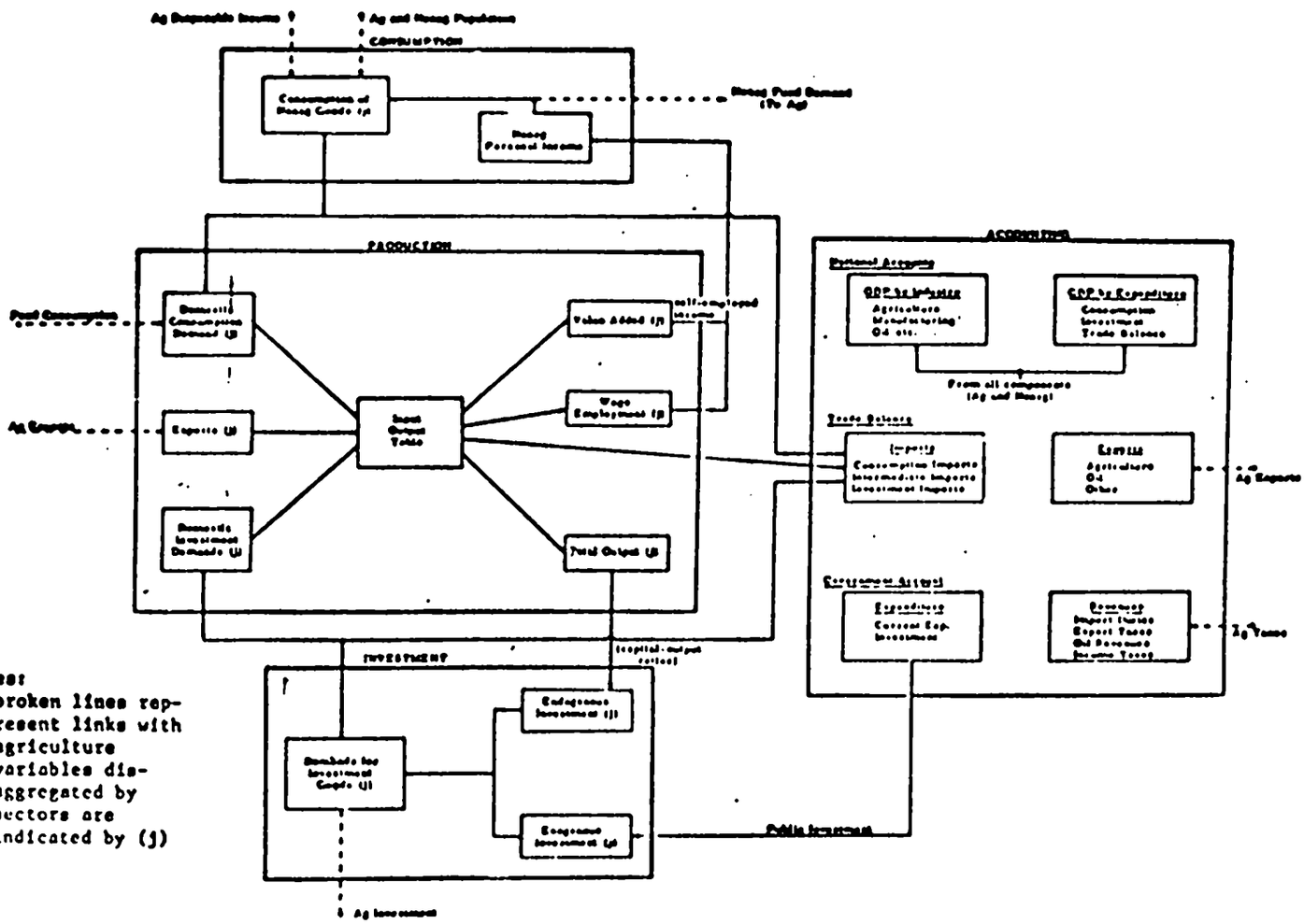


Figure 4

Major Sectors and Interactions of the Southern Nigerian Agricultural Model



Notes:
1. broken lines represent links with agriculture
2. variables disaggregated by sectors are indicated by (j)

Figure 5. Model of the nonagricultural economy and the national accounts.