Simulating Economic Development.
330 Michigan State Univ.
H417 Simulating Economic Development. NTIS
Marvin L. Hayenga. 1971(?)
24 p.
Contract AID/csd-1557.
Proj. 931-17-190-477.

1. Models, Economic. 2. Agricultural economics. 3. Simulation methods. 4. Economic planning. I. Contract. II. Hayenga, Marvin L. III. Title.

Contr
AID/csd 1557
~~Proj. 931-17-190~~-477
PN-ABT-255
72035

62
PN-ABT

SIMULATING ECONOMIC DEVELOPMENT

By:

Marvin L. Hayenga
Thomas J. Manetsch
Albert N. Halter
Glenn L. Johnson
Michael H. Abkin
Tom W. Carroll
Derek R. Byerlee

A.I.D.
Reference Center
Room 1656 NS

SIMULATING ECONOMIC DEVELOPMENT*

The problem of designing, planning, and evaluating development policies, programs, and projects is vastly complicated. The development process is affected by the dynamic interaction of a multitude of physical, social, economic, and political variables. Sometimes, these variables are not controllable or, at the least, are insensitive to the overt efforts of governments to guide them by their plans and resource allocation decisions. At other times, some development policies and progress trigger spontaneous responses within the system which lead to a sustained accumulation of benefits for the members of the developing society. Knowledge about objectives to seek and what to avoid is often poor. Thus, the wise choice of development policies and programs is usually clouded by poor or nonexistent information as well as the inherent complexity of the process. Poor communication facilities often impede the accumulation of potentially available relevant information which might otherwise provide a reasonably well-informed basis for decision making. Since the social opportunity costs of mistaken development efforts are high in many underdeveloped countries, improved approaches for evaluating alternative projects, programs and policies are much needed.

Many different approaches have been utilized in the past to improve the policy and program evaluation process. Building up the research

---

*This paper reports on progress made on an Agricultural Sector Model Project underway at Michigan State University, funded by the U. S. Agency for International Development, Contract No. AID/csd-1557.

staff capability in many less-developed countries has greatly enhanced their ability to make well-informed decisions. Utilizing outside agencies to supplement the ongoing government staff program evaluation and research efforts has been a common practice in many countries. These internal and external policy and program evaluation efforts have typically involved pen and pencil projections of the consequences through time of a (necessarily) limited number of policy or program alternatives.

In most cases several measures of program performance have been calculated for the consideration of decision makers. Naturally, both the number of alternatives and the measurement of benefits achieved and of various costs incurred (hereafter referred to as have been limited by the time required to calculate by "hand" methods the consequences of the basic organization of the economy and of slight modifications.

Computerized techniques have recently been utilized to automate the hand calculation process and expand the range of alternatives which can be examined. Several different computerized techniques have been considered for experimentally studying development alternatives in a variety of less-developed settings. A brief description of a few distinctive attributes of these computerized approaches will help portray the background setting from which our project evolved. When several performance criteria can be transformed into a single basic objective along with necessary and appropriate constraints are resources, technology and institutions, linear and non-linear, recursive, dynamic programming models have at times been utilized to determine

the best policy, program and project package available from among the alternatives considered. [Richard H. Day, Recursive Programming and Production Response, Amsterdam, North Holland Publishing Company, 1963.] However, determining the appropriate weighting of each factor which should be incorporated into the single performance criterion to be optimized is often extremely difficult. This difficulty in determining the weights and the problem of settling conflicts on positive and normative (value) questions within the decision making group may give the optimizing results little credibility.

A group of computer models has been used which can be characterized as emphasizing economic equilibria, probabilistic estimation of parameters on the basis of historical data and simultaneous equations. These models are typically based on sets of equations reflecting equilibrating tendencies in an economy. The coefficients or parameters of these equations are probabilistically estimated from time series or cross-sectional data available for the region or economy of interest. Thus, a substantial series of data for many different variables is required with sufficient variability within each series to allow reliable estimation of the coefficients for each variable. Once these coefficients are probabilistically estimated, these models can be used to estimate values for the variables which satisfy the equilibrium conditions built into sets of two or more simultaneous equations. Some of these variables measure the performance of the systems and can be regarded as performance criteria as that term is used herein. If the equilibrium sets of equations contain sufficient lagged dependent variables, they can be

run recursively. While some of these models require prior specification of the objective function, many do not. To the extent that simultaneous equations are based on equilibrium consists of economic theory, they assume maximizing behavior on the part of micro-decision makers. As the data requirements for adequate coefficient estimation are often not met, this approach (interpreted in the narrow sense) has limited applicability. To the extent that micro-decision makers have not been maximizers, in the sense assumed in setting up the simultaneous equations, these models have been unrealistic.

Some of the pioneering work in applying systems analysis and computer simulation to modeling less developed economics was done by Edward P. Holland and his associates [Holland, 1963]. These and other studies [Manetsch, et al., 1968] attempted to provide more realistic projections of several performance criteria from a model utilizing both the most relevant formal probabilistic estimates of coefficients and less formal, less probabilistic estimates for new previously unconsidered technological, institutional and behavioral alternatives.

The approach we used differs somewhat from the previously discussed probabilistic, equilibrium approach in that the system structure is identified without heavy reliance or preoccupation with simultaneous equations and in that either probabilistic or synthetic estimates of the structure's parameters are developed from various types of available data or knowledgeable people. Often, physical, institutional and biological processes are more explicitly considered. Our approach incorporates

consideration of the impact of non-historical changes in technology, institutions, and people and is thus more useful than approaches tied to historical data in designing and evaluating new projects programs and policies.

By building our models in small, recursively-linked components, various sources of data and various functional relationships (linear, non-linear, etc.) can be utilized thereby reducing or avoiding some of the estimation problems encountered for blocks of simultaneous equations). Further, prior specification of a single performance criteria to be maximized is not required (although optimization procedures can be employed if a single performance, criteria or objective function can be specified). While a substantial amount of progress in the simultation approach had been made in the 1950's and 60's, a seminar at Michigan State University in February, 1966, ended with the general consensus that "simulation models are of questionable operational value for economic development research at this time ... and efforts are needed to adapt and extend existing simulation models for use in economic development."[1/]

One of the consequences of the 1966 Michigan State University simulation conference was an Agency for International Development decision to support a multi-disciplinary research project at Michigan State University directed toward developing a simulation capability, including specific model components, which would have relevance to development environments in countries being assisted by AID.

1/ Report on the "Workshop on Possible Use of Simulation Models by CSNRD for Nigerian Agriculture," based upon a conference sponsored by Michigan State University, February 11 and 12, 1966. Much credit for organizing this conference goes to Dr. Douglas Caton, AID. He was also instrumental in negotiating the subsequent contract (AID/csd-1557) under which the research presented herein was done.

In the following sections, we will consider in more detail the simulation approach which was utilized in the Michigan State University project. The overall model structure and some major sectoral components will then be briefly described, and some tentative conclusions about the uses of this kind of model (at the current stage of development) will be presented.

The Simulation Building Block Approach

Simulation is viewed as an iterative problem-investigating process that includes problem formulation, mathematical modeling, refinement and testing of the resulting model in close consultation with and, in later application stages, under the partial direction of decision makers. This process involves creative design and the simulated execution and study of the consequences through time of alternative courses of action which the policy maker might prescribe for the problem at hand. The process can be conceptualized diagramatically as shown in Figure 1. As the arrows indicate, the general procedure is from problem definition to model application, including interaction with decision makers throughout the process. The reverse arrows indicate that the process is iterative or "learning" in nature. Prior stages are often repeated on the basis of information acquired during a subsequent stage; that is, the approach explicitly recognizes the feedback nature of the problem investigation procedure and can thus accommodate the learning the knowledge accumulation which is likely to take place at any stage in the process. This flexibility allows sequential changes to be made in model structure,

parameters, and performance criteria, leading to a better model with a broader range of outputs. The "output" of a simulation is a set of data referred to as performance criteria on the attainment of various benefits and the incurrence of various damages from alternative possible actions. These estimated results (through time) can be compared by decision makers and investigators for different alternatives in selecting project, program and policy alternatives. The performance variables are normative in the sense that they measure the goodness and badness of conditions, situations and things. Interactions between decision makers and researchers may lead to more feedback and improved realism of the model structure, while stimulating the policy maker and investigators to acquire greater normative knowledge about performance variables as well as a greater positive understanding of the system.

One objective of the initial problem formulation phase is to specify clearly the structure of the system, what measure of system performance or values are appropriate, and the available means for changing the system. In a large scale system study, effective problem definition requires creative interaction among decision makers, planners, systems analysts and other specialists. The multidisciplinary 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), headquartered at Michigan State University, provided a substantial backlog 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

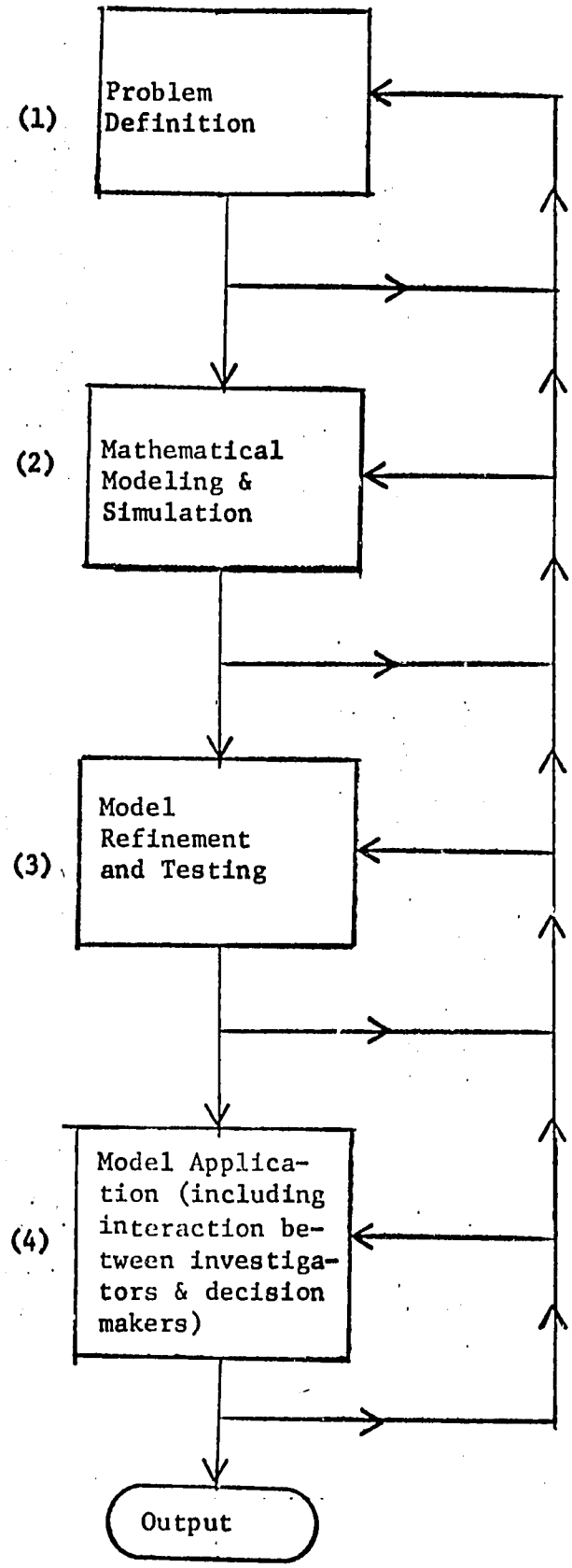


Figure 1. Computer Simulation as an Iterative Problem Investigating Process

development (Johnson, 1969). Further, the CSNRD collaborations with AID, FAO, and Nigerian planners and policy makers provided 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. Nigeria was selected as the country to model in part because of the available expertise which could be tapped. As a consequence, the major problems with respect to policies, programs and projects and the corresponding relevant sectors, interrelationships, and performance variables in the Nigerian economy were isolated more easily than they might have been. Our current contractual obligation is to develop a simulation capability, but not to go further and apply the model to solving practical development problems. We were not required to model Nigeria and, of course, are not constrained to apply the model in Nigeria. However, we hope that our efforts will prove useful at a later data to Nigerian and donor agencies concerned with Nigerian agricultural development, as well as to similar agencies in other countries with similar development problems.

The following are examples of questions which the model is designed to answer. While many other questions could be posed through further interaction between the systems researchers and the decision makers, this list illustrates the policy level at which we aimed and, thereby, helps to specify the level of aggregation toward which the simulation model is oriented.1/

1/ Our model can be differentiated from the simulation models built by Holland for the Indian and Venezuelan economies and Kresge's model of the Pakistan economy by its adaptability to questions which require either intermediate level and macro of aggregation in contrast to the more macro nature of the Holland and Kresge models.

What would be the impact on farm and non-farm income (total and per capita), per capita nutrition, export earnings and export-import balances, level of demand for farm and non-farm products, levels of employment, government tax revenues and expenditures of:

(1) increasing prices paid to export crop producers (i.e. reducing the spread between world and domestic prices)?

(2) increasing production research and extension efforts on export crops?

(3) increasing research on food crop varieties and production practices, and subsequently funding production campaigns to implement the most promising findings?

(4) stimulating private investment or making public investments in agricultural input industries, storage and processing facilities, and required supporting infrastructure improvements?

(5) stimulating private and public investments in nonagricultural sectors of the economy?

(6) instigating human population-control programs?

(7) promoting import substituion in various sectors of the economy to provide for greater backward linkages in the economy?

(8) changing the distribution of incomes between rural and non-rural people and/or from relatively higher income to lower people.

These are general questions encountered in many less developed countries. The production of models to answer such questions for Nigeria was consistent with our contractual obligation to develop the computer simulation approach for general use in development planning situations. Other countries could have been modeled and the results are adaptable for application in other countries.

A model of an economic system is based upon the analyst's theoretical, institutional, and empirical understanding of the economy. The information and assumptions incorporated into the model specify the relevant technological and behavioral interrelationships and the cultural, institutional, technological, and resource constraints.

In building a model of an economic system we have to: (1) specify the structural interrelationships, (2) determine the important instrumental (policy) variables, (3) determine the directions of causation, (4) specify functional forms of the technological or behavioral relationships that seemed to fit the current and potentail situations envisioned, (5) tentatively specify the parameters and shapes of the functional relations, and (6) indicate what "goods" we will measure this attainment of and what "bads" we will measure the incurrence of (performance variables, to use the terminology of the systems analyst). The consistency of the various structural relationships and parameter values can be checked by computer simulation. Conceptual and programming errors can often be detected during the first few runs of the model on the computer. Refinement and testing of the model follows until the model behaves fairly realistically as judged by relationships known to exist in the system, the realism of dynamic rates of change exhibited by the simulated system, the consistency of model behavior with recent historical behavior, and the accuracy of the model's projections over time. Use of the model to evaluate policy, program and project alternatives then follows. In conjunction with such applications further refinement and testing is likely to accompany the further accumulation of normative and postive knowledge about the system.

The basic building blocks of a simulation model are the physical, biological, economic, social, political and cultural relationships existing within and among the major sectors of the economy. If great complexity and accuracy are desired in the model, a substantial research investment is necessary to design and build a satisfactory simulator incorporating realistic mathematical descriptions of current and potential production, consumption, and marketing relationships within the economy. Simulation can incorporate many types of functional relationships--including dynamic interactions, curvilinearities, discontinuities, time lags, probabilities, and irreversibilities--into the model to reflect closely current or potential real systems. The chief constraint appears to be the ability of researchers and policy makers to specify accurately the functional relatinoships among the positive and performance variables of the system.

These building blocks are composed of interrelated functional relationships which can be broken apart into more manageable components because of their recursive nature (i.e., one function necessarily follows another in time, and is dependent upon the output of the previous function) or their seeming independence (geographic, behavioral) at any one point in time. By specifying the linkages between components (an output from one either being an input to another, or a performance variable), the research team members can specify in some detail the functional relationships within each component and proceed to estimate the relevant coefficients. In this way, research efforts can be effectively decentralized within the coordinated and centralized but tentative format initially determined. Later, as model changes and experimentation require, any individual component of

the model structure can be more easily isolated and changed than in many other approaches.

In our work, initial specification of relevant policy-making clientele and their most important problems determined which sectors and/or interrelationships needed particular attention within the model and the level of aggregation at which to work. The major sectors and flows as presently conceptualized within the simulation model of the Nigerian economy are shown in Figure 2. As can be seen from the diagram, our emphasis is on the agricultural sector. Since agriculture contains most of the productive resources in Nigeria (contributing 65 percent of the gross domestic product and 66 percent of Nigerian exports in 1962-63) and in most less developed countries, its role in future growth will be very important.

Many planners in the less developed countries are interested in evaluating alternative projects, programs and policies affecting regional specialization of production and trade. These typically involve farmer responses to various economic incentives or government assistance projects, etc. Consequently, our model has a commodity orientation, emphasizing export crops. To permit considerations of simple questions related to regional specialization and interregional trade, a two region (North and South) model was conceived. However, several ecological zones within each region were also differentiated to introduce enough detail to permit consideration of problems encountered in the two regions. Although the model is based on the Nigerian environment, its orientation toward annual and perennial commodities, by ecological zones and regions, makes it and its components adaptable and applicable to a broad range of countries in accordance

with the objectives of the AID contract under which the work was done.

The North, South and nonagricultural sub-models are each shown as two interacting parts in Figure 2, (1) demography, and (2) production, marketing, and consumption. These parts are linked together by the flow of income, labor migration and the demands and supplies of subsistence foods or, in the case of the nonagricultural sub-model, consumer goods and factors of farm production. The Northern and Southern sub-models are linked directly with the nonagricultural sub-model through the flow of consumer goods, raw materials for manufacturing and agricultural producers' inputs supplied by the nonagricultural sub-model. Labor migration can also take place between the agricultural and non-agricultural sub-models. The major interaction between the three sub-models takes place through interregional trade in food which is simulated by a market and interregional trade component.

Northern Sub-Model

The Northern sub-model consists of six interacting components (see Figure 3). The cattle production component simulates the meat and milk production process in traditional and modern herd management situations, using inputs of total digestible nutrients from the production of various forage and grain crops. The main interaction between the cattle and annual crop components in the Northern sub-model is the land allocation component where the quantities of land in various crops partially determines the quantities of TDN available in the cattle component. Population and income growth which affect the demand for beef are generated in the population sub-components of each major sub-model--North, South, and nonagricultural.

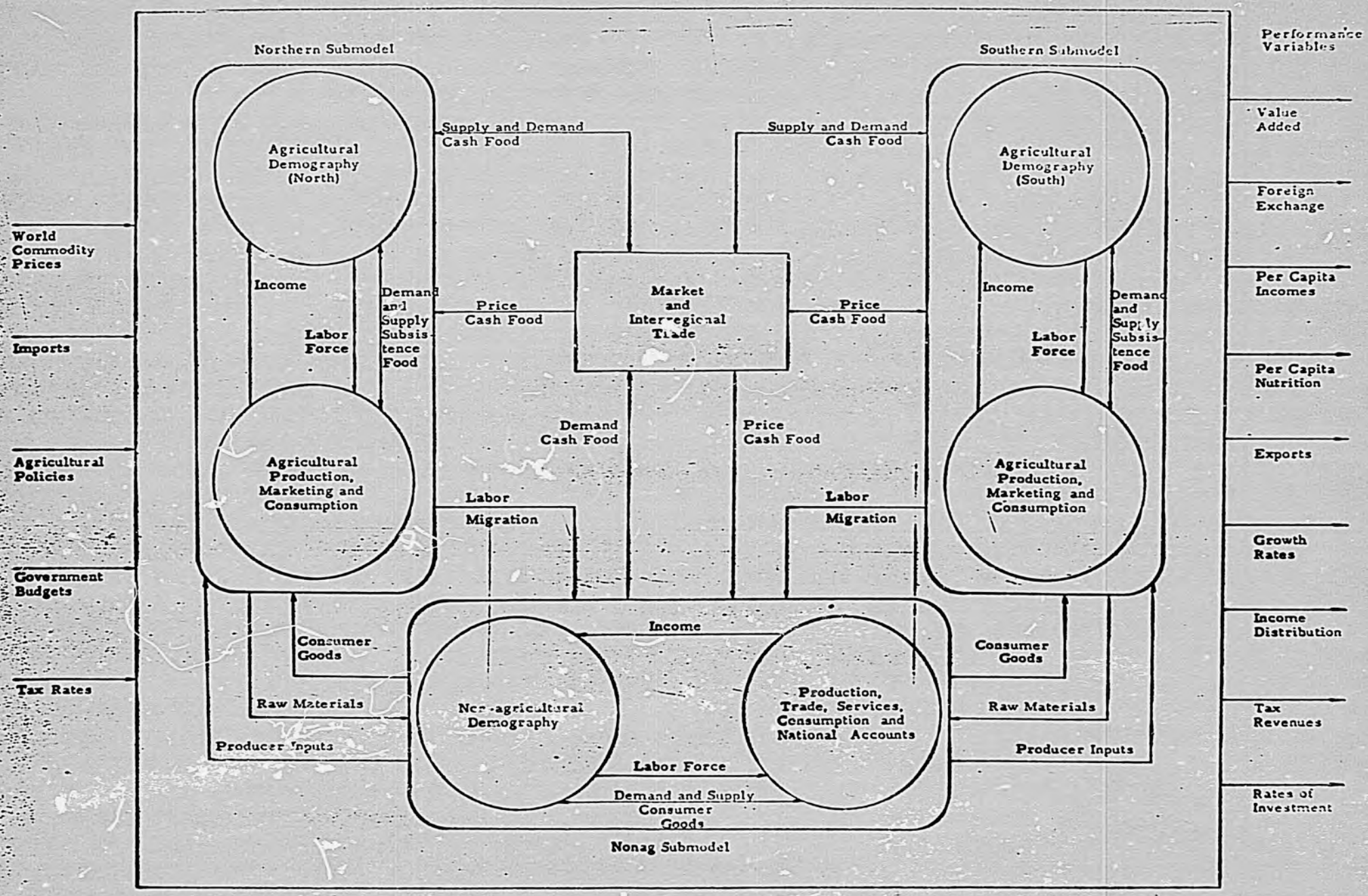


Figure (2) National model of interacting submodels.

The agricultural production and marketing component simulates the production and marketing activities for groundnuts, cotton and food. Allocated land comes from the land allocation component, prices for food from the market component, and yields from the modernization component. In turn, this component computes average returns to land and labor, which affects farmer's land allocation decisions. The value added at each stage of production and distribution is computed in the production and marketing component, and utilized in calculating the national accounts in the nonagricultural component.

In addition, the market component of the Northern model simulates the price mechanism of the cash food market in each of the regional models. This component traces the shifts in the demand for food, and utilizes the calculated food supply to determine the price of food.

The consumption and budget component computes a number of agricultural sector variables needed by the nonagricultural model. There are expenditures on chemical inputs, capital goods, and consumer goods derived from the calculated income and population levels in the North. The component also computes disposable incomes from production and marketing for use in the nonagricultural model.

Southern Sub-Model

The Southern sub-model is composed of five interacting components (see Figure 4). The agricultural production, marketing and processing component computes the production from acreages of traditional cocoa, modern cocoa, traditional palm, modern palm, traditional rubber, modern rubber, food and tobacco by simulating commodity yields and food sub-

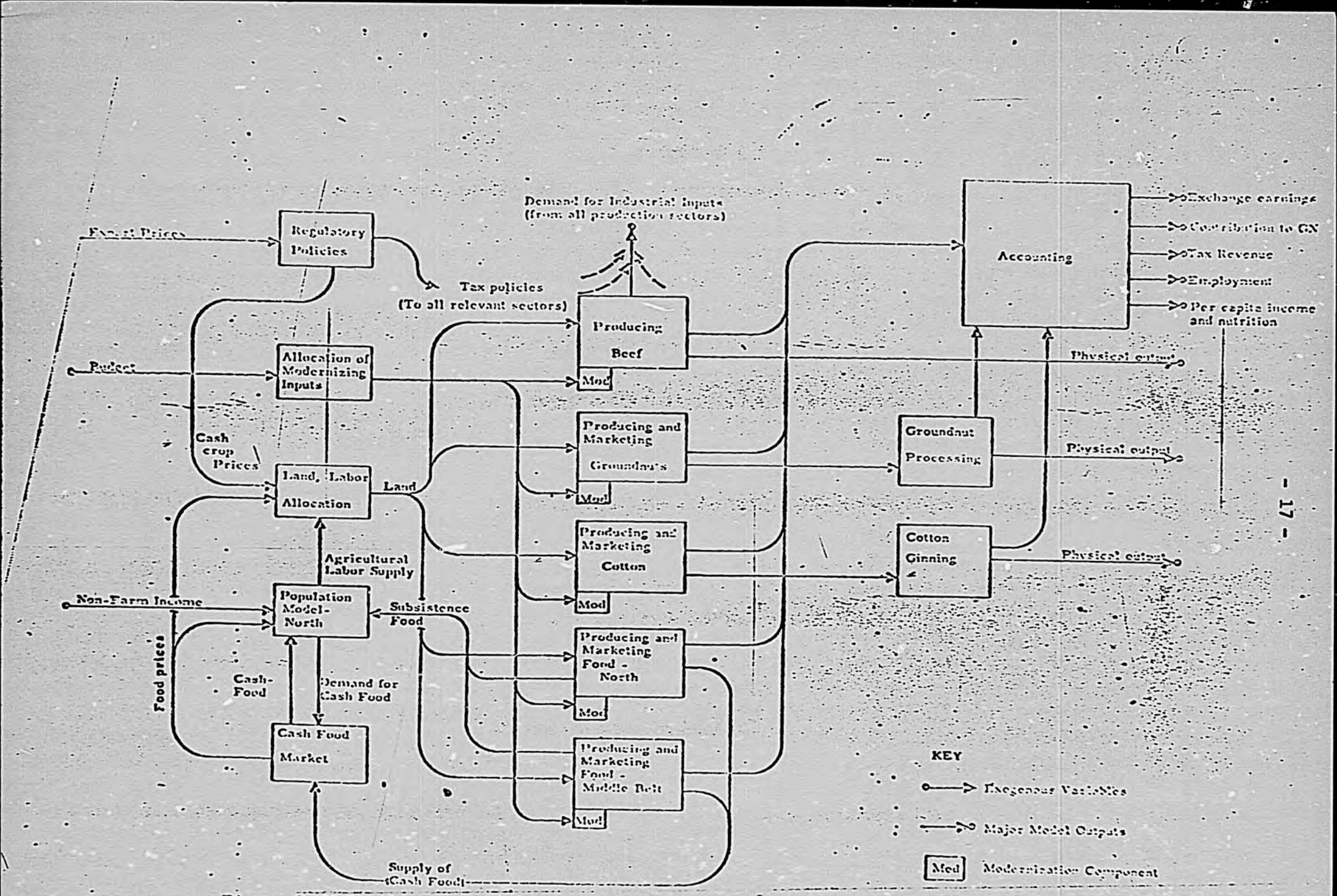


Figure 3 Major Sectors and Interactions of the Northern Nigerian Agricultural Model

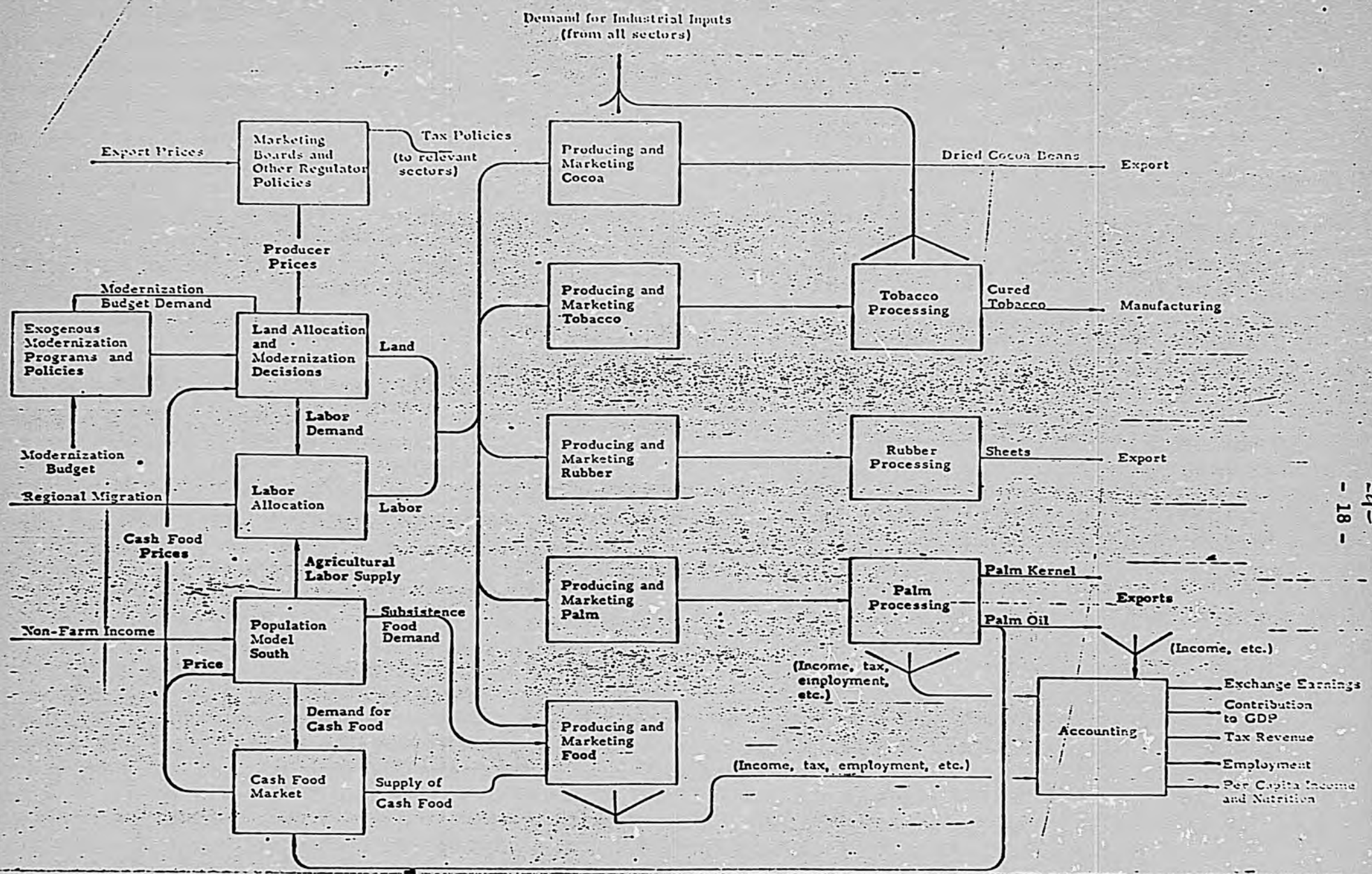


Figure 4 Major sectors and interactions of the Southern Nigerian agricultural model

sistence levels of the agricultural population. Marketing and processing are modeled using accounting equations based upon fixed relationships related to the product. Input demands--labor, capital, chemical and biological materials--are calculated for the functions of production, processing and marketing. These variables provide the main interaction with the nonagricultural component of the National model.

The land allocation and modernization component of the Southern model simulates farmers' allocation of land to the traditional or modern production of cocoa, palm, rubber, tobacco and food based upon economic and cultural factors.

A third component of the Southern model generates world, market, processor and producer prices for the five commodities considered in the previous two components. Two additional components provide further interaction with other components of the national model. The allocation of agricultural modernization budget (from the national budget) is made by the modernization program and policies component. The accounting component of the Southern model computes values for the performance variables for the Southern model as a whole, as well as provides inputs to the national account section of the nonagricultural model.

Nonagricultural Sub-Model

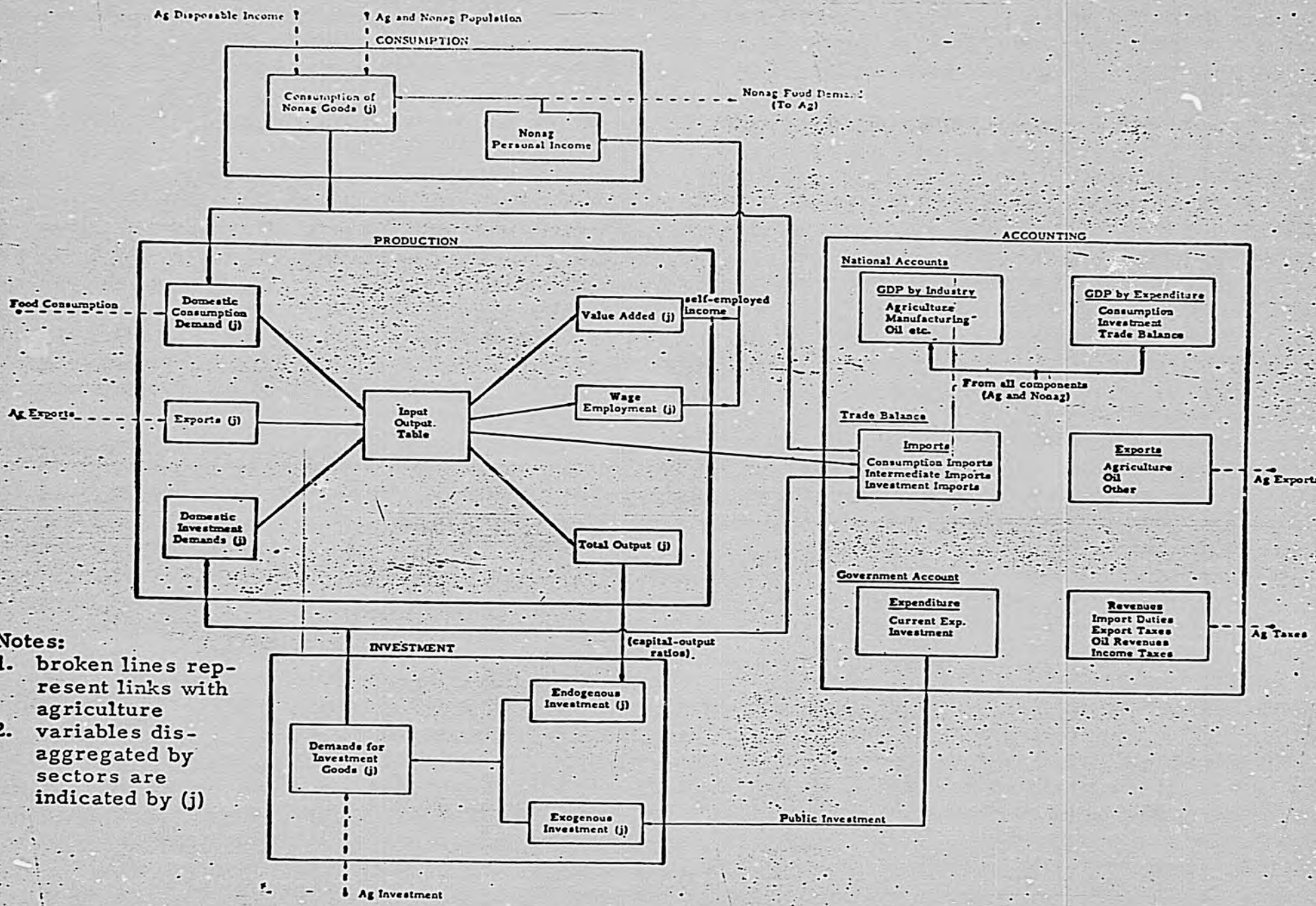
The nonagricultural model has a dual purpose within the National model. Firstly, it models, in a broad rudimentary way, the nonagricultural components of the economy to enable key interactions between agriculture and non-agriculture to be studied (see Figure 5). The nonagricultural

model simulates the demand for food by the nonagricultural population and manufacturing demand for agricultural raw materials. Likewise the model simulates the supply of agricultural inputs, such as chemical materials and fertilizer, and the supply of consumer goods and services to the agricultural population.

Secondly, the nonagricultural model summarizes the accounting variables of both the agricultural models and the nonagricultural sector to construct a national accounts table and a balance of trade table. These include measures of gross national (domestic) product by branch of activity and category of expenditure, government revenues, and import-export balances.

Summary

While our approach, the model itself, and its underlying assumptions cannot be fully explained in this brief space, we hope to have given an introduction to the approach and the model which we have nearly completed. Since our objective was to further develop the capability of simulation as a tool in development decision making, let us present some thoughts about simulation's potential usefulness in its current stage of development. Our model consists of over 2,000 behavioral and accounting, linear and non-linear equations which take up approximately 32,000 words in the memory of Control Data Corporation 6500 computer. To give an idea of the calculation efficiency, a 20-year simulation run of the entire model requires less than 45 seconds (at a cost of $6.00 for computer time, paper, etc.). Thus, its computational efficiency in simulating changes in the basic



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.

model is quite satisfactory.

An important question to consider is: are the components of the models we have developed thus far sufficiently well-developed and generally adaptable to be used effectively in modeling project, program and policy alternatives for industries, regions, or entire economies in other less developed situations or even in Nigeria, our initial choice for modeling.

Certainly, our simulation approach has improved our understanding of the agricultural economy of Nigeria as we have designed and developed this model. Similar results can be expected of others undertaking to use or carefully studying our results. While the current models are potentially capable of answering some planning questions at the industry, regional and national levels, the model and its components developed to data would generally require additional, careful, detailed evaluation of its structural assumptions and coefficients by experts and decision makers well acquainted with the economy where it would be applied. It would be particularly important to examine the performance criteria variables for this logical consistency, consistency with experience, meaning and workability when used to reach presumptive conclusions. This would necessarily involve creative interaction with decision makers to acquire more positive and normative information about the environment and decision situation, to determine the specific development problems to which the model should ultimately be addressed, and to generally make the model more appropriate to the decision situation. Such interaction with decision makers and further primary data collection would

lead to some revisions of the model including its components and coefficients as part of the process of using it. Still more detailed revision would be required when more detailed project, programs or policy problems and alternatives are posed to the simulation team or where different commodities, regions and industries need to be incorporated in the model.

Two final points should be discussed which were not mentioned in the body of the paper. Simulation models such as ours can be useful in identifying key information gaps and priorities for further data collection. These insights are gained by means of what is termed "sensitivity analysis." Sensitivity analysis is carried out by computer runs testing the impact of changes in model assumptions and coefficient values upon the behavior of key model variables. Such tests can identify the more important assumptions and data requirements and lead to economies in data acquisition and model implementation.

A second point has to do with the use of simulation models such as ours to compute statistics (means standard deviations, etc.) for the relevant model variables of interest to decision makers. In cases where uncertainty exists as to the values of certain model parameters (due to poor or missing information or to inherent randomness in certain parameter values) probability distributions can be assigned to such parameters. Models are then run repetitively in a "Monte Carlo" mode with each run incorporating a set of random parameter values drawn from the appropriate probability distributions. Statistics are then computed for model variables from the values obtained from individual runs. Such

statistics permit the evaluations of ranges and distributions of outcomes possible for different policy options.

Bibliography

Adelman, Irma (editor), Practical Approaches to Development Planning: Korea's Second Five-Year Plan, Baltimore, Johns Hopkins Press, 1969.

Day, Richard H. et al. "Recursive Programming Models of Industrial Development and Technological Change", in A. P. Carter, and A. Brady, North Holland Publishing Co., Amsterdam, 1970. Application of Input-Output Analysis, edited by

Fox, Karl, J. K. Sangupta, and Erik Thorbecke, The Theory of Quantitative Economic Policy, Chicago, Rand McNally, 1966.

Halton, A. N., M. L. Hayenga, and T. J. Manetsch, "Simulating a Developing Agricultural Economy: Methodology and Planning Capability". American Journal of Agricultural Economics, May, 1970, pp. 272-284.

Holland, E. P. and Robert W. Gellespie, Experiments on a Simulated Underdeveloped Economy: Development Plans and Balance-of-Payments Policies, Cambridge, MIT Press, 1963.

Johnson, Glenn L., et al., Strategies and Recommendations for Nigerian Rural Development, 1969-1985, CSNRD 33, Michigan State University, 1969.

Kresge, David T. A Simulation Model for Economic Planning: A Pakistan Example, Economic Development Report 81, Development Advisory Service, Harvard University, 1967, mimeo.

Manetsch, T. J., F. A. Ramos, and S. C. Lenchner. Simulation of a Program for Modernizing Cotton Production in Northeast Brazil. Working Paper Number Three, Division of Engineering Research, Michigan State University, August, 1968.

Naylor, Thomas H., "Policy Simulation Experiments with Macroeconometric Models: The State of the Art", American Journal of Agricultural Economics, May, 1970, pp. 263-271.

Singh, I. J., A Recursive Programming Model of Traditional Agriculture in Transition: A Case Study of Punjab, India, Ph. D. Dissertation, University of Wisconsin, 1970.