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SYSTEM SIMULATION AND POLICY-MAKING FOR ECONOMIC DEVELOPMENT

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SYSTEM SIMULATION AND POLICY-MAKING FOR ECONOMIC DEVELOPMENT

by
Michael H. Abkin

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, generalized system simulation is offered as an approach to dealing with these problems. It is a flexible, iterative, problem-investigating process that includes problem formulation, mathematical modeling, model testing and refinement, and application of the model to solve problems — all in close consultation with decision-makers. As an illustration, an overview will be given 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. Finally, I shall outline how the generalized system simulation approach could be implemented within the development-planning and policy-making process.

THE PROBLEM

Colm and Geiger (Reference 1, p. 272) 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.*

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 socio-economic 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 socio-economic system operates as a *process*. Certainly, 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. Process-uncertainty problems make it extremely difficult to forecast even the *relative* short- and long-run effects of alternative strategies. In particular, the degree to which policies aimed at one set of economic and social phenomena may have unintended side effects 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.

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 valid common denominator for inclusion in an objective function. (Some might not even be quantifiable.) Objectives might involve employment, price stability, political stability, income and income distribution, nutrition, balance of payments, growth of gross domestic product (GDP), political participation, education, etc. In the absence of a decision rule based on mathematical optimization, human judgment 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

*Emphasis added.

many possible tradeoffs among objectives under alternative policy conditions. The generalized system simulation approach is offered as a means both of providing that information and of reducing some of the uncertainty inherent in the planning 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 (feasible from the standpoint of physical, social, economic, political, financial, and administrative realizability), 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, and application — is iterative in nature rather than strictly unidirectional; that is, information gained at later stages may (probably will) indicate a need to return and repeat earlier stages before continuing. Creative interaction among decision-makers, researchers, consultants, modelers, and simulators is 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.

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. The language of mathematics allows the deliberate and explicit representation of socioeconomic phenomena — which heretofore might only have been conceptualized in verbal or diagrammatic models, or only "felt" in intuitive models — in a form which lends itself easily to manipulation and analysis. By identifying and specifying the relevant system components and causal and structural relationships in the model, the model, once validated, may be used to experiment with — and to draw implications from — alternative policies.

Mathematical models may be either analytical or simulation models. However, at the present state of the art for large models with many nonlinear differential equations analytical solutions are impossible. Fortunately, the capabilities of large-scale digital computers have enabled researchers (e.g., References 4, 5, 6, 7) to use simulation to generate numerical solutions and so to provide policy-makers with information about the likely consequences of alternative courses. Given specific assumptions about system structure, values of system parameters, and exogenous influences, a simulation model generates time-paths of relevant endogenous variables, including the vector of criterion variables needed by decision-makers to evaluate alternative development strategies. For an economic development model, a vector of relevant performance criteria might include such elements as GDP levels and growth rates, employment, nutrition, tax revenues, income distribution, trade balances, investments, etc. Many strategies can thus be tested and their outcomes compared and evaluated.

The approach is generalized because 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. There is also flexibility in the data sources which can be tapped. Although time-series data, where available, may be used to estimate parameters, the approach may rely heavily on estimates by technical experts, perhaps via the Delphi method, or on "guesstimates." Because of this flexibility the models structural equations need not be linear in the parameters.

For a decision-maker to base policy decisions on the experimental results of a model — *any* model, verbal, 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. Three ways are considered in which a simulation model may be validated.* The first is by a sort of knowledgeable intuition. During the building of the model, much reliance for both data and structural and causal relationships will be placed on people with a great deal of experience with the problems at hand as well as on secondary sources. By studying the simulated behavior of the model, these same people and others like them may, through their expertise, have an intuitive feel for how well the model represents the real economy. More concretely, behavior predicted by the model under various policy conditions can be compared with what actually occurs as real time passes under the same conditions. Alternatively, the model can be compared with historical data from the real world *which has not been used in the model-building process.* Such tuning, updating, and validation of the model would be an ongoing process, continuing even once the model has been implemented.

Sensitivity tests play a particularly essential role in model building and validation. For example, they help to identify those parameters which can most effectively be used in tuning the model to track re-

*For further discussions of the validation problem see, for example, References 8 and 9.

corded behavior of the economy and to bring the model's behavior in line with the expectations of accepted theory and knowledgeable intuition. An analysis of sensitivity test results may also be used to check the logic and internal consistency of the model. Troublespots can be located in the course of tracing through the model to find explanations for simulated behavior exhibited as a result of a change in the value of some parameter (Reference 10, Chapter 9). Finally, sensitivity analyses are valuable in the identification of the most profitable areas for data-collection activities. The relative sensitivity of a parameter is an indication of the priority that should be given to obtaining better estimates of its value.

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 better one which may even involve basically modifying the model. The objective of such simulation experiments is to unfold a set of development strategies that are consistent and mutually reinforcing and that show how resources could be effectively used to solve the problem as defined. 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.

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 follows.[2,10,11,12]

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. 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.

Briefly, the agricultural submodels allocate land, subject to input constraints and policy specifications, to the available commodities based on profitabilities perceived by farmers. From the land allocations (given commodity yields and other technological coefficients, e.g., factor input rates, marketing losses), the total production of each commodity is determined, and marketing and processing functions are performed. 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 from grazing and from the production of forage and grain. While the component structures of the two regional agricultural submodels are quite similar, the nature of perennial commodities — trees exhibiting such characteristics of dynamic populations as growth, maturity, decline — considerably complicates the southern submodel where the population dynamics of trees is modeled as a distributed-parameter process.[10]

The nonagricultural submodel is an aggregated, ten-sector input-output model of the Nigerian economy. 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 agricultural, 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.[11] 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 by three-year age groups. 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, thus determing the market price of food in each region.

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IMPLEMENTATION

The ultimate objective of developing a simulation model such as the one described above is to implement it as an integral part of the general problem-solving process outlined earlier. Although the present case deals with problems of development-planning and policy-making, the approach is applicable to many areas such as health-care delivery, environmental quality, urban society, and transportation.

In the development context, there are primarily two ways in which to implement this type of system simulation. One incorporates the model (and the whole approach) within a national planning unit of a developing country,* while the other would charge a donor agency with building and maintaining the simulation models and applying them to the policy questions as requested. In this connection, it seems worthwhile to summarize some of the preconditions now envisioned for successful use of generalized system simulation in the developing countries.

First, a continuing capacity to develop this approach must be maintained. Further development of the approach will largely depend upon practical experience in applying simulation models to real-world problems and issues with substantial interaction between investigators and policy-makers.

Command over models and their components by persons and agencies or institutions responsible to individual groups of decision-makers is essential to the full development and application of the approach. Therefore, the development of such capacities and institutional arrangements within any country or agency of application is crucial. It is important that the host country's capacity to apply, modify, and extend these models be developed if the models are to be fully utilized.

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

In addition, it will be necessary for agencies using the approach to have access to substantial computer capacity if large, complex, multisector 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. (The Nigerian model described earlier requires almost all of the 32,000-word core of a CDC 6500 computer and uses about 50 seconds of central processor time for a run of 42 years.)

CONCLUSION

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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ABOUT THE AUTHOR

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