The System Dynamics National Model: Understanding Socio-Economic Behavior and Policy Alternatives

JAY W. FORRESTER, NATHANIEL J. MASS and CHARLES J. RYAN

ABSTRACT

The System Dynamics National Model is a computer simulation model of social and economic change in the United States. It is designed for public policy analysis and contains a deep policy structure ranging from governmental, fiscal, and monetary policy down to corporate accounting, pricing, and ordering of the factors of production. The Model will treat the highly interrelated issues of inflation, unemployment, recession, balance of payments, energy, and environment. With regard to each of these issues, the Model should help to explain the forces that underlie major national difficulties, clarify feasible futures, and examine policies that can lead to more desirable behavior. The National Model, which has been under development for the past three years, consists of six principal sectors—production, financial, labor, demographic, household, and government. At present, preliminary versions of most of the model sectors exist, and the sectors are being tested extensively. Over the next three years, each of the sectors of the National Model will be reformulated, refined, and documented. At the same time, the individual sectors will be assembled into an overall Model. Extensive computer simulation testing, validation, and outside review with a wide range of academic and professional groups will be part of the Model development process. The Model should provide useful insights about behavior and policy at each stage of its development. Application and interpretation of the Model should build in a cumulative fashion from testing of individual sectors to combined testing of two or more sectors, and finally, to policy studies in the complete assembled National Model.

I. Introduction

Whether viewed from Capitol Hill, Wall Street, or Middle America, the list of serious national problems is lengthening. Such problems include inflation, unemployment, recession, resource scarcity, environmental damage, instability of governments, decay in American cities, increasing food prices, and shifting balance of international power from resource-consuming to resource-producing nations. The persistence of serious national problems has engendered widespread public dissatisfaction with the nation's inability to find and apply effective solutions to major difficulties. As the nation increases in complexity beyond the capacity of conventional social management, new tools are

JAY W. FORRESTER is Germeshausen Professor, Sloan School of Management, Massachusetts Institute of Technology, Cambridge, MA, where NATHANIEL J. MASS is Assistant Professor of Management and Director, System Dynamics National Modeling Project. CHARLES J. RYAN is a public policy analyst who has been affiliated with the Atlantic Institute in Paris, and in Washington, DC, with the offices of the Secretaries of Commerce, Health, Education and Welfare, the Director's Office of the Office of Economic Opportunity, and with other Government agencies.

needed to aid in understanding socio-economic behavior and designing more enduring public policies.

For three years now, the MIT System Dynamics Group has been working, supported by a grant from the Rockefeller Brothers Fund, to develop a computer simulation model of the national socio-economic system. The National Model is intended to integrate the major sectors of national activity into an explicit dynamic simulation model for investigating how the different parts of the socio-economic system function, how they produce the behavior of the entire system, and how alternative policies might yield a more desirable future. The Model is designed to simulate a wide range of socio-economic behavior for evaluating both short-term and long-run consequences of a variety of national policy alternatives. Ultimately, the Model is intended to describe the processes of national social and economic development over approximately a 200–year period, from 1850 to 2050.

The National Model is composed of six basic sectors: production, financial, household, demographic, labor, and government. These sectors describe the major determinants of production, consumption, investment, employment, prices, government policy, and other activities and indices of economic performance. The six sectors of the Model are interconnected by flows of information, people, money, goods, services, and orders. In addition to the conventional economic variables, the Model contains real-life variables like expectations, affluence, level of technology, labor mobility, and social stress.

The National Model is far more comprehensive than the earlier system dynamics modeling efforts. Over the past two decades, the MIT System Dynamics Group has developed and analyzed computer simulation models of industrial, urban, national, and global systems. The resulting studies, primarily *Urban Dynamics, World Dynamics,* and *The Limits to Growth,* have raised public awareness of a number of critical long-term urban and global issues. By comparison, the earlier projects were exploratory, and the models were relatively simple and highly aggregated. In contrast, the National Model is highly detailed, containing a range of internal structures spanning from short-term inventory-management and price-setting policies to capital investment policies and long-term demographic and environmental forces. By encompassing a diversity of short-term and long-term forces, the National Model will deal with the long-range issues of economic growth, resources, energy, population, and capital investment, as well as with the shorter-term dynamics of the business cycle and economic stabilization policies. The detailed structure and ability to integrate long-term and short-term behavior are necessary for comprehensive policy analysis and describing alternative futures.

II. System Dynamics

A brief description of the system dynamics approach should help in better understanding the National Model [1,2,3].

System dynamics is a way of combining all available information, including written description and personal experience, with computer simulation to yield a better understanding of social systems. The field of system dynamics has been under development at MIT and elsewhere since 1956. Twenty or more books have been published on subjects ranging from corporate policy to major world interactions. The principal books from the research programs have each been adopted as texts in dozens of universities in the United States and abroad.

II.A. Background

System dynamics is perhaps best described in terms of the background threads on which it builds. In Fig. 1, three earlier developments—traditional management of social systems, feedback theory, and computer simulation—combine to become system dynamics. Traditional management is the process used to govern social systems throughout history. Feedback theory or cybernetics is a body of methods and principles developed during the last hundred years dealing with how decisions, and the way they are imbedded in information channels, cause the dynamic behavior of systems. Computer simulation allows one to determine the time-varying behavior implicit in the complex structure of a system.

People start the traditional management process by observing the world about them, noting the pressures and reactions of people and groups, and detecting the linkages and flows of information and influence. From these observations people form mental images of the structure of a social system. From the mental images they attempt to anticipate what will happen next and how a different policy might make the system behave more desirably.

Traditional management processes guide our personal lives, family affairs, cities, countries, and international relations. It is the nearly universal approach to directing human activity. Because it is the basis of civilization and because it has served well, no quick or radical break with past tradition is either possible or desirable.

Traditional management, based on observation and judgment, has great strengths, but it also has serious weaknesses. Any new contribution to better management of social systems must start from the present practices and move gradually toward improvement. Any better method of decision-making must build without discontinuity on the strengths of traditional management while compensating for the weaknesses.

The greatest strength of traditional management comes from the wealth of information available from the separate observations and experiences of people. In the mental stores of knowledge are probably a thousand or a million times more information than has been converted to written form in libraries. In turn, written descriptions cover a thousand or a million times the scope and richness of information that is available in measured and numerical form. If we are to improve on social decisions, we must be able to build on the most comprehensive information base available—the observations, knowledge, and judgment stored in people's heads. System dynamics uses that descriptive information along with any available written and numerical information.

However, traditional management has several serious weaknesses which the system dynamics approach helps to alleviate.

The first weakness in traditional management arises from the very wealth of information that is the greatest strength. In fact, we have too much information. We are flooded and overwhelmed with information. The traditional processes contain no general principles or organized philosophy for picking the relevant from the extraneous information. As indicated in Fig. 1, principles drawn from feedback theory assist in choosing from the excess of information that is relevant to the behavior modes of interest.

The second weakness of traditional management arises from lack of organizing principles for the structuring of information. Even if the first weakness is overcome and the relevant information and relationships are chosen, no guidelines exist for organizing the chosen assumptions into a structure that explains the observed system behavior. Again, feedback theory offers principles [1,2] for simplifying and organizing the structure of a system.

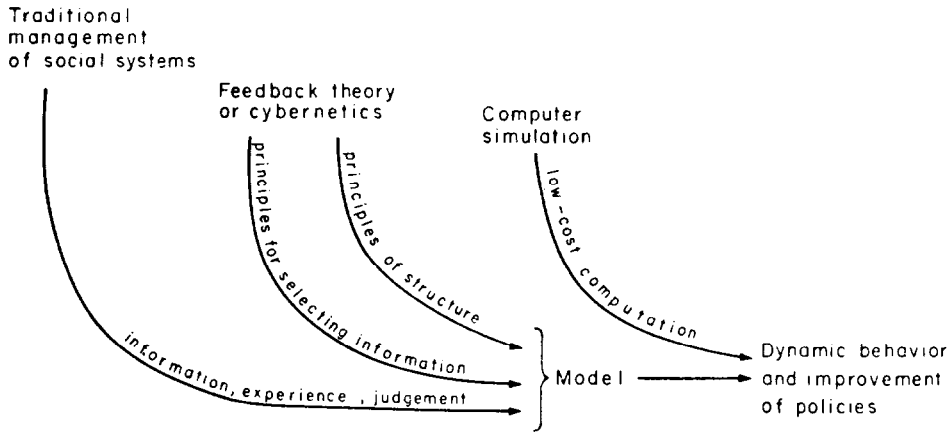

Fig. 1. Background of system dynamics.

But even if information is effectively selected and usefully organized into a relevant model, traditional management encounters a third weakness. Although assumptions may be explicitly stated, the human mind is not well adapted to determining the future time-varying consequences of those assumptions. Different people may accept the same assumptions and structure, and then draw contrary conclusions. A consensus is hard to reach, and even a majority opinion may be incorrect. As suggested in Fig. 1, computer simulation can be used to determine, without doubt, the future dynamic implications of a specific set of assumptions.

To summarize, system dynamics starts from the practical world of normal economic and political management. It does not begin with abstract theory nor is it restricted to the limited information available in numerical form. Instead it uses the descriptive knowledge of the operating arena about structure, along with available experience about decision-making. Such inputs are augmented where possible by written description, theory, and numerical data. Feedback theory is used as a guide for selecting and filtering information to yield the structure and numerical values for a computer simulation model. Because the resulting models are too complex for either intuitive or mathematical solution, a computer simulates, or plays the roles, of the many participants in the system to determine how they interact with one another to produce changing patterns of behavior.

II.B. Utility of Computer Simulation Models

Models are not new in social decision-making. System dynamics does not for the first time introduce models into the social and political process. Models have always been the basis for the traditional management methods.

Every decision we make is based on a model. One does not have a family, city, or nation in his head. He has only images, relationships, and abstractions from real life. These perceptions are models in the same sense that the word is used in system dynamics. One uses observation to form a mental image, or model. The mental model becomes the basis for decisions.

System dynamics does not impose models but is a way of improving on the models that would otherwise be used to manage human affairs. The system dynamics model is more explicit than a mental model, so it can be communicated with less ambiguity. A

system dynamics model is more carefully structured in accordance with dynamic principles, so it better relates underlying assumptions to system behavior. A system dynamics model can be simulated on a computer, so, unlike a mental model, its behavioral implications can be determined precisely.

II.C. Main Features of System Dynamics Methodology

The system dynamics methodology embodies several features and underlying viewpoints that contribute to the capability of the methodology to shed light on policies and causes of behavior. Five of the more important features are described below, and examples are drawn from the National Model to illustrate the features. Although other modeling techniques embody some of these features, system dynamics appears to be unique in combining all of these aspects into a single approach.

(1) *Broad Information Base.* The structure of the National Model is drawn primarily from descriptive information about how people act and decisions are made under different circumstances, pressures, and motivations. Such descriptive information provides a more varied information source than is generally used in other types of modeling. In addition to conventional numerical data, the Model explicitly incorporates social and psychological variables such as expectations, perceptions, and attitudes, which influence real-life decisions, and, consequently, the future course of the system. The National Model will encompass such social variables as the effect of attitudes toward public support of individuals on the evolution of welfare and social security payments, pressures for environmental control, and attitudes toward retirement age.

In addition to social variables, the National Model also portrays the diversity of motivations, perceptions, and constraints which influence real-life decisions. For example, in representing the decisions of producers to invest in capital equipment, the Model incorporates explicitly such factors as the desired expansion or contraction of production capacity, long-term and short-term growth expectations, the available information on prices and delivery delay, and the constraints of limited money and credit—all of which impact on investment decisions in real life. By including a broad range of social, economic, and psychological variables, the model will be able to deal with the interaction of economic and social forces. Explicit representation of real-life decisions should also facilitate better communication of the Model to a broad audience in business, government, and other institutions.

(2) *Portrays a Full Range of Dynamic, Disequilibrium Behavior.* The National Model will be a fully dynamic, disequilibrium model of the national socio-economic system. No theoretical assumptions that markets always clear or that they function in an optimal manner are made in the model. Instead, the model portrays the actual processes of adjustment governing the behavior over time of markets for goods, labor, and financial assets. For example, in the Model, market clearing will involve not only price changes, but also changes in the delivery delay for various goods and services, reflecting availability, rationing, and allocation. The importance of such a portrayal is that many pressing national problems are manifestations of disequilibrium behavior—rising prices and unemployment, excess inventories, credit shortages, and rising interest rates.

One important way in which disequilibrium behavior is captured in the National Model is through the representation of level variables, or accumulations, that decouple rates of flow. For example, in the model, as in real life, the difference between production and sales of a business accumulate in a level of inventory. In the model, therefore, production

and consumption (sales) need not be equal at each point in time. If, for example, production is below sales, inventory will fall, thereby signaling a need to expand production by acquiring additional labor, capital, materials, and other factors of production. By incorporating conserved levels of inventories, money balances, and other tangible items, the National Model will contain the processes of accumulation (integration) that give real systems their dynamic behavior [4].

(3) *Generates Multiple Modes of Behavior and Shows Shifts between Modes.* The National Model will contain a range of detail and internal structures spanning from short-term inventory-management and price-setting policies at the level of the firm to capital investment policies and long-term demographic and environmental forces. By encompassing a diversity of short-term and long-term forces, the model will be able to deal with the multiple modes of behavior exhibited by the real economy, from the short-term dynamics of the business cycle (of three to seven years' length) to the observed intermediate economic cycles (of fifteen to fifty years' duration), and to the life cycle of economic development (covering two hundred years or more). (See Sec. V.) Once the model is generating these different behavior modes, it can be used to show the fundamental cuases of these modes.

Understanding how the different modes of behavior arise is critical in diagnosing symptoms of difficulty and developing appropriate policy. If, for example, the economy is in recession due to long-term forces, then policies appropriate to a normal short-term business cycle may be ineffective or even counterproductive.

The National Model will also incorporate a diversity of nonlinear relationships which are critical in generating the long-term behavior spanned by the Model. Nonlinear relationships are needed to show, for example, how resource extraction costs and resource prices rise as a result of resource depletion or how the need for pollution-control expenditures arises as environmental pressures begin to impose previously unencountered constraints. By incorporating a rich internal structure and a full range of nonlinear relationships, the Model will be able to show how shifts in the mode of the national economy can arise. For example, the Model should show how behavior can shift from a situation in which high inflation accompanies low unemployment to a condition of simultaneous high inflation and unemployment. By generating such shifts in behavior internally, the Model should help to anticipate future problems and develop appropriate policies and reactions.

(4) *Focuses on Policy-Making Rather than Decision-Making or Prediction.* The focus of the National Model is on the various modes of behavior of the socio-economic system and the policies which generate them and/or influence them to change. An important objective of the modeling process is to produce a set of policy recommendations that are internally and mutually consistent and which lead to desired behavior.

It is important to distinguish here between *policy* and *decisions.* A policy, as analyzed in a system dynamics model, is a general rule that states how decisions are made on the basis of available information. For example, a policy might state how the Federal Reserve's desired rate of expansion of the money supply depends in general on its perceptions of unemployment and inflation rate in the economy. In contrast, a *decision* is the result of application of the policy to a specific set of input information; for example, it would be a *decision* to expand the money supply at 5% per year if unemployment rate is 6% and inflation rate is 5%. The National Model will provide a device for testing the effects of various *policies* on the behavior of the overall national system. That is, the

model is used to clarify the rationale for policy and the general nature of policy; the model is not used to examine individual or isolated decisions at a point in time.

The policy focus on the National Model can also be contrasted with the objective of predicting the exact future state of the economy one or two years hence. Social systems such as the national economy are subject to numerous random influences. The presence of such random disturbances tends to preclude forecasting the state of the economy far enough ahead to allow time for effective action. On the other hand, even if the future condition of the economy cannot be forecast accurately, effective policies can still be designed to improve the overall mode of behavior of the economy. Thus, for example, the National Model will be used to design policies that would minimize the sensitivity of the economy to fluctuations in production and employment triggered by random disturbances.[1]

(5) *Generates Behavior through Internal Mechanisms.* The National Model generates behavior modes such as economic fluctuations and growth from the interactions of internal mechanisms. In other words, behavior results from the internal structure of the Model. Any real-life process that changes over time and is involved in generating important real-world behavior must therefore be included as an internal model variable; no "exogenous inputs" (external influences) except for random disturbances will be used or required to generate the major modes of the national socio-economic system.

Generating behavior through endogenous mechanisms is important if the Model is to be used for explaining the causes of problems such as inflation, recession, and resource depletion. Internal generation of behavior is also important if the Model is to be used as an input to policy choices. For example, a model that is "driven" by external inputs is not useful for policy analysis unless the future values of the external inputs are themselves known. Such a model could not anticipate future changes in the mode of behavior of the economy (see point (3) above) or show all the important tradeoffs stemming from policy changes.

III. Structure of the National Model

III.A. Overview of Structure

The National Model treats all major aspects of the socio-economic system as internal variables to be generated by the interplay of mutual influences within the model structure. The model contains production sectors, labor and professional mobility between sectors, a demographic sector with births and deaths and with subdivision into age categories, commercial banking to make short-term loans, a monetary authority with its controls over money and credit, government services, government fiscal operations, consumption sectors, and a foreign sector for trade and international monetary flows.

A generalized production sector is being created with a structure comprehensive enough that it can be used, with selection of suitable parameters, for each of some fourteen or more producing sectors in the economy: Each sector will reach down in detail to some ten factors of production, ordering and inventories for each factor of production,

[1] Appendix K of Ref. [1] emphasizes the importance of designing improved policies for guiding decisions, rather than attempting prediction. In Appendix K the presence of random disturbances is shown to preclude accurate forecasting of the future condition of a social system. On the other hand, if two policies are compared, the policy that is less vulnerable to random disturbances is always less vulnerable regardless of the particular random sequence that impinges on the system.

marginal productivities for each factor, balance sheet and profit and loss statement, output inventories, delivery delay computation, production planning, price setting, expectations, and borrowing.

The Model is being formulated for the new DYNAMO III compiler, which handles arrays of equations and makes the replication of the production sector and its subparts especially easy. For example, an equation in the ordering function need be written only once with array subscripts to identify the ordering functions for each factor in each sector.

By reaching from national monetary and fiscal policy down to ordering and accounting details within an individual production sector, the Model will bridge between the concepts of macro- and micro-structure in the economy. Because major modes of the economy develop from deep within its structure, the Model should be able to exhibit the major behavior modes of the economy, and provide important insights and information about causes of socio-economic behavior.

III.B. Standard Production Sector

A standard production sector will be replicated to form a major part of the model. With appropriate parameter values, the standard sector can be used to represent a variety of production and distribution activities—consumer durable goods, consumer soft goods, capital equipment, building construction, agriculture, resources, energy, services, transportation, secondary manufacturing, knowledge generation, self-provided family services, military operations, and government service. Such generality focuses attention on the fundamental nature of production of goods and services and simplifies both construction and explanation of the model.

Within each production sector are inventories of some ten factors of production—capital, labor, professionals, knowledge for capital intensity, knowledge for capital productivity, buildings, land, transportation, and two kinds of materials. In addition, production is affected by length of work week for labor, length of work week for capital, and the content of each of two kinds of materials in the product.

For each factor of production, an ordering function will create an order backlog for the factor in response to desired production rate, desired factor intensity, marginal productivity of the factor, price of the product, growth expectations, product inventory and backlog, profitability, interest rate, financial pressures, and delivery delay of the factor. By comparison to other national models, the ordering function in the System Dynamics Model is more influential than the production function. Much of the depth of dynamic behavior of the Model grows out of this feature.

The structure of a standard production sector is essentially the structure of a single firm in the economy. As with a firm, the sector has an accounting subsector that pays for each factor of production, generates accounts receivable and payable, maintains balance-sheet variables, computes profitability, saves, and borrows money. The structure should generate the full range of behavior that arises from interactions between the physical variables and the money and information variables. By carrying the Model to such detail, it should communicate directly with the real system where a wealth of information is available for establishing the needed parameter values.

A production sector will generate product price in accordance with conditions within the sector and between the sector and its customers. For testing price and wage controls, coefficients can be set to inhibit price changes. The sector will distribute output among its customer sectors. Market clearing, or the balance between supply and demand, will be

struck not by price alone but also on the basis of delivery delay reflecting availability, rationing, and allocation.

III.C. Labor and Professional Mobility

People in the production sectors are divided into two categories—labor and professional. For each category a mobility network defines the channels of movement between sectors in response to differentials in wages, availability, and need. A mobility network has a star shape with each point ending at a production sector and terminated in the level representing the number of people working in the sector. At the center of the star is a general unemployment pool, which is the central communication node between sectors. Between the central pool and each sector is a "captive" unemployment level of those people who are unemployed but who still consider themselves a part of the sector. They are the people searching for better work within their sector or who are on temporary layoff but expecting to be rehired. In a period of rising demand for labor, those in the captive level can be rehired quickly, but longer time constants are associated with drawing people from other sectors by way of the general unemployment pool.

III.D. Demographic Sector

The demographic sector generates population in the Model by controlling the flows of births, deaths, immigration, and aging. Age categories divide people into their different roles in the economy from childhood through retirement. The demographic sector divides people between the labor and professional streams in response to wages, salaries, demands of the productive sectors, capacity of the educational system, and family background.

III.E. Household Sectors

The household sectors are distinguished by economic category—labor, professional, unemployed, retired, and welfare. Each household sector receives income, saves, borrows, purchases a variety of goods and services, and holds assets. Consumption demands respond to price, availability of inputs, and the marginal utilities of various goods and services at different levels of income. The household sectors also determine workforce participation—the fraction of the population actively seeking work—in response to historical tradition, demand for labor, and standard of living.

III.F. Financial Sector

The financial sector is divided into three parts—commercial banking, savings institutions, and the monetary authority. The financial sector determines interest rates on savings and bonds, buys and sells bonds, makes long-term and short-term loans, and creates intangible variables like confidence in the banking system.

The commercial banking system receives deposits, buys and sells bonds, extends loans to households and businesses, and generates short-term interest rates. In doing so it manages reserves in response to discount rate, expected return on investment portfolio, demand for loans and liquidity needs.

The savings institution receives savings, extends long-term loans to households and businesses, generates long-term interest rates, buys and sells bonds, and borrows short-term from the banking system. The savings institution balances money, bonds, deposits, and loans. It allocates loans between businesses and households, and it monitors the debt levels and borrowing capability of each business and household sector.

The monetary authority controls discount rate, open market bond transactions, and

required reserve ratios. In doing so it responds to such variables as owned and borrowed reserves of the bank, demand deposits, inflation rate, unemployment, and interest rates.

III.G. Government Sector

The government sector of the National Model will generate government services, tax rates, government expenditures, including transfer payments, and sales of government bonds to finance the national debt. It will also provide government service, and manage fiscal policy and the government debt. Government services will be generated through use of a standard production sector whose inputs are labor, capital, buildings, energy, and other factors of production, and whose output is government services. An additional replication of the standard production sector may be used to represent military personnel and military services.

III.H. Foreign-Trade Sector

The National Model will simulate the behavior of a single domestic economy. Once the Model is developed, either the whole Model, or parts of it, can be replicated to represent an aggregate trading partner (or multiple trading partners) of the domestic economy. For example, standard production sectors could be replicated to represent an aggregate foreign manufacturing sector and an aggregate foreign resource sector. Such foreign sectors will be connected to the domestic assets, energy and resources, and other goods and services. The foreign-trade sector will thus consist of one or more foreign producers and a set of coupling equations linking the foreign and domestic economies. The coupling equation of the foreign-trade sector will generate exchange rates, balance of payments, and flows of imports and exports.

IV. The National Model as a Tool of Public Policy

The National Model is expected to contribute to better policy formulation in three important ways:

- Establishing Long-Term National Goals
- Explaining the Causes of Socio-Economic Behavior
- Developing Policies to Deal with Interconnected National Problems

These objectives will be met through use of the model in a number of ways.

IV.A. Testing Alternative Policies

By explicitly linking proposed laws and policies, the National Model offers a means for improved choices among policy alternatives. Policies can be quickly tested in a model, and at low cost compared to the expense of real-life social experiments that take decades before they can be evaluated. Some proposed policies are so ineffective or detrimental that laboratory testing in a model will lead to their rejection from further consideration. Other policies may be so clearly desirable and effective under almost any assumptions that they could be adopted without lengthy debate. The middle ground encompasses policies whose outcome is sensitive to uncertainties in the structure and assumptions in a model. These alternatives will demand more data collection, more modeling, and more public debate to ascertain their likely impact. The National Model should clarify the issues, shorten the debate, and increase the percentage of public actions that yield desirable results.

IV.B. Identifying Feasible Futures

Many expectations for the future are not consistent with current realities. By showing how assumptions and policies bring about future consequences, the National Model should help to distinguish between unjustified hopes and possible futures. Any aspirations about the future should reflect a realistic understanding of the structure of society and a set of viable policies capable of leading to that future. When the National Model becomes a sound basis for judging the merits of future alternatives, national leaders and the general public may be able to use the Model to help set achievable national goals and choose feasible futures.

IV.C. Examining Short-Run Versus Long-Run Policy Tradeoffs

Very often, the short-term desirable consequences of a policy will in time result in long-term undesirable consequences. If the short-term effects are favorable, the long-term effects may be detrimental. Or, even when the short term promises hardship, the long term may prove more favorable. For example, spending beyond one's means by charging purchases and borrowing money can go on until such time as one must reduce personal standard of living to repay debts. Conflict between short- and long-term well-being is evident in nearly every decision at many different levels: private debt, use of nonrenewable resources, investment, use of farm land, and choice of family size. If long-term consequences are not understood, long-range goals tend to be subordinated to short-term expediences. By relating the past to the future and by relating the assumptions of structure and policy to their consequences in real life, the National Model should elucidate the tradeoffs among short-term and long-term effects of policies.

IV.D. Identifying Tradeoffs Between Sectors of Society

In addition to tradeoffs between the short- and long-term, the nation faces numerous tradeoffs between different sectors of society. The present is characterized by tight interconnections between the many aspects of society and by rapid transfers of pressures from one sector to another. Such tradeoffs and transfers of pressures become especially severe as population and industrialization grow, causing psychological, political, and physical space to become crowded. With increased crowding, every action tends to impinge quickly on other facets of the society. The price for advantage is not only paid in the future but is paid increasingly at some other point in the system. The rapidity with which pollution controls on automobiles have coupled to more gasoline consumption, to an oil shortage, and to international tensions in the Middle East is a case in point. The environment, technology, resources, and power politics have shown a tight degree of interconnectedness over time spans as short as five years.

V. Dynamics to be Represented

Dynamic behavior can be described in terms of periodicities, modes, and time horizon. These characteristics are discussed below.

V.A. Periodicities

If the different rapidities of response in a system were separated into individual models, each model would be designed to examine a particular kind of behavior. However, in a national socio-economic system the wide range of inherent periodicities may overlap and influence one another. Oscillatory models of similar duration might pull

together and entrain one another into a single dynamic behavior. Or they might remain separate but enhance one another's effect. Because so little is known about the diversity of such interactions, the present model combines a wide range of dynamic phenomena into one structure.

The model will simultaneously be able to create a wide span of time responses—from the business cycle on the short end, through intermediate interest-rate-capital-investment cycles, to the once-in-history transition from growth to equilibrium. To do so requires a structure containing the short time constants associated with inventories, backlogs, and bank balances, as well as slower, longer processes associated with accumulation of buildings and machinery, and the movement of people. At the longest end of the time spectrum, the model contains population growth, land occupancy, and resource depletion.

The business cycle of some three to seven years' duration probably arises from interaction between inventories and employment. More commonly, the business cycle has been attributed to capital investment, but the planning time and life of capital are long enough to suggest that the primary contribution of capital investment is to a longer fluctuation in the economy. By reaching down to the fine structure of employment, inventory management, and materials procurement, the model should deal realistically with the business cycle.

In the intermediate range of behavior, the Model treats the Kuznets Cycle of fifteen to twenty years' duration [5,6]. Some evidence also suggests a cycle in the economy known as the Kondratieff wave, of some fifty years' duration [7]. The existence of such a long wave is controversial. However, the structures necessary to produce such a long disturbance are to be found in labor mobility and in the processes of capital accumulation. The existence of the long wave is important to explore. If it exists, its last collapse was into the depression of the 1930's and its next could be in the near future. The long wave may have a more powerful effect than the business cycle.

At the slowest end of the time spectrum is the life cycle of economic development (See Fig. 2). The past is characterized by exponential growth, with a doubling of economic output every twenty or thirty years. Such growth is not definitely sustainable. Debates about growth are increasingly about when and how the past exponential growth will end, not about whether or not it eventually must end.

There are signs emerging that the United States is in the transition stage. The transition stage is consistent with the social, environmental, and inflationary forces that are developing. A model that is to cope with today's issues must incorporate not only the recurring processes of past business-cycles, but also the transition process triggered as an economy and its population begin to exploit fully the available energy, resources, agricultural lands, and water.

The time of greatest social and economic stress occurs during the transition stage, not during equilibrium. When equilibrium has been reached, the nature of the new mode of social and economic behavior will be understood and accepted. But in the transition stage, sufficiently great forces arise to overcome the old engines of growth. Laws, attitudes, management methods, traditions, values, expectations, and religions are put under stress to change. The transition stage is the time of turbulence as the system moves out of the growth mode.

A socio-economic model to deal with today's questions should encompass the short-term dynamics of the business cycle in concert with the structures that may produce a 50-year-lomg wave and against the background of the life cycle of economic develop-

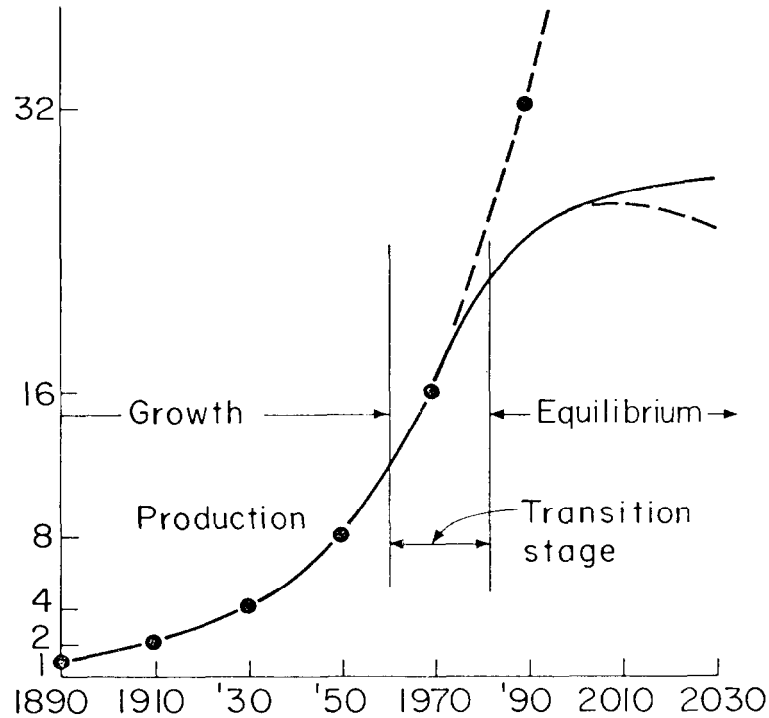

Fig. 2. Life cycle of economic growth.

ment. For the first time we may face the triple coincidence of a business downturn, a long-wave collapse, and the pressures of the transition region. The three could combine to depress economic activity and the standard of living.

V.B. Modes

System modes can be described in terms of the associated restraints. The typical economic system is probably unstable in a free mid-range region where restraints are not dominating behavior. In such a restraint-free region there will be a strong tendency for the economic system to move toward one of the possible restraints. If this is correct, shifting modes of economic behavior can be described in terms of the successive restraints that dominate behavior.

At the beginning of industrialization when there was ample land and an excess of labor, the restraint was insufficient capital equipment. The whole Philosophy of capitalism arose from the capital shortage that determined the pace of economic development. In the main, this condition of capital shortage existed until after World War II, when the United States economy moved out of the mode dominated by a shortage of capital.

In the 1950's and 1960's, the United States economy was characterized more by a shortage of manpower than by a shortage of capital, as indicated by a chronic shortage of labor and by only partial use of much of the capital plant, only 8 hours a day instead of 24. Because labor had become the principal restraint, labor demands set the style and pace of the economy.

Now the United States is moving once again into a new mode characterized by

shifting restraints. The mode of labor shortage is giving way to the mode of environmental shortage. Environmental shortage exists in terms of space, agricultural land, pollution-dissipation capacity, resources, and energy.

The Model will move through these various modes; not in response to exogenous driving assumptions, but under a progression of its own internally generated social and economic forces. In effect, the Model embodies a theory of economic development that can be tested by seeing if it will generate the modes of behavior that have been observed historically.

If the Model is successful in making the transitions between social and economic modes, it should help reveal the nature of the transitions, their causes, the forces to be expected during any specific change, and the policies that would establish and sustain a desired mode.

V.C. Time Horizon

To generate the wide range of periodicities and modes, the Model must be conceived in terms of a long time horizon. The Model should create appropriate growth and fluctuation from the year 1850 to 2050. The Model should generate behavior typical of the past as a base from which to anticipate the future. Generally speaking, forces and structures visible at any point in time dominate a very long way into the future. If the fundamental nature of the present system is carefully examined, most essential dynamic mechanisms for the next several decades should be detectable.

VI. Issues To Be Addressed by the National Model

VI.A. Inflation

A major focus of the National Model is the forces underlying inflation. Today's inflation is a much deeper issue than revealed by the public press or by explanations generally suggested in the economics literature. It is much more than a question of inflation versus unemployment.

Present inflation arises from major imbalances in the economy. Some two-thirds of employment is outside of agriculture and direct production. This constitutes a very high overhead in government, education, and the service industry. Two-thirds of the working population in overhead is probably too great for the economy as it moves from a growth period into a time in which production is progressively more limited by environmental restraint while, at the same time, population continues to rise. Much of the inflationary pressure comes from governmental efforts to sustain a rising standard of living when real output per capita is running into inherent barriers.

The efforts to hide, by monetary and fiscal means, the fundamental changes now occurring in the industrialized economies are driving inflation. Changing social attitudes, greater complexity arising from crowding, and increasing capital investment required as space and resources become over-committed are all interlocked in the inflation syndrome.

VI.B. Nature of Economic Growth

By linking population, resources, environment, the production of knowledge, and the contribution of technology to productivity, the National Model should provide insights into the nature and future pattern of economic growth. The nations of the world have been pursuing economic growth with success in some countries and lack of success in

others. The Model can be used to identify the reasons for past growth and to help decide whether or not the gains of the past can be sustained and/or replicated.

Population produces population; technology produces more technology. Technology raises the standard of living even in countries with growing populations as long as industrialization expands faster than the population. However, if new agricultural space is no longer available, if resources become harder to acquire, if pollution-dissipation capacity becomes overloaded and energy availability begins to falter behind accelerating demands, technology can no longer be developed at an ever increasing pace ahead of rising population. Both during periods of accelerated economic growth and when economic growth slows, the nature of the socio-economic system changes. The economic mode of future society may be substantially different from the past. The National Model should help anticipate the actions necessary to make a tolerable adjustment to new economic and social forces.

VI.C. Economic Fluctuations

Economic and political debate have centered on policies for stabilizing the economy, enhancing economic growth, and reducing unemployment. How effective have these policies been? The reduced amplitude of business cycles in the post-war years is often cited as evidence of their effectiveness. But the suppressed business cycle may instead reflect other trends such as governmental transfer payments, the labor-shortage mode of the economy, or having been in the upswing phase of a Kondratieff long wave. The National Model, depicting internal monetary and fiscal sectors, taxation, debt management, and governmental expenditures, will offer a basis for examining the effect of past policies. The Model also will elucidate the controversy over Keynesian versus monetarist proposals for government intervention. For example, with the Model, the investigator can evaluate the monetarist argument that economic stability would be enhanced if the money supply were expanded continually at a fixed annual rate.

Computer simulations already performed on subassemblies of the National Model tend to indicate that the short-term business cycle arises from the interaction of employment and inventory-management policies within production sectors of the economy. The business cycle has traditionally been thought to occur as a consequence of fluctuations in credit avilability, fixed capital investment policies, and variations in consumption. However, preliminary results of testing the production sector of the National Model suggest that short-term business cycles can occur even when interest rates and credit availability are constant, and consumption does not vary. Moreover, the preliminary tests show that fixed capital investment policies are not essential to generating the business cycle and, instead, principally underlie longer-term cycles in the economy such as the Kuznets and Kondratieff cycles [4]. These results call for reassessment of existing theories of the business cycle and many current stabilization policies. They suggest, for example, that monetary policies designed to influence the short-term business cycle may have their principal influence not on the short cycle, but on longer-term economic modes. Such issues merit further examination, analysis, and debate.

Even if encouragement of capital investment to offset recessionary pressures were appropriate to a normal business-cycle recession, current economic fluctuations may indicate far more than a short-term business-cycle recession. The economy may be at the peak and entering the decline of a long capital-investment cycle brought about by over-investment in automobiles, office buildings, and manufacturing facilities. If so,

national policy favoring sustained investment may simply delay a needed realignment within the economy.

Major economic dislocations of the past are even today not fully understood. For example, few critics agree on the causes of the Great Depression of the 1930's. Was the Depression merely the result of governmental mismanagement of the financial system, or random bad luck, or an aftermath of World War I, or the collapse phase of a long wave economic cycle, or the consequence of migration from farm to factory? Can such an economic collapse recur?

To the extent that the slowing of long-term economic growth may be behind current economic stresses, the fundamental issues are more demographic and environmental in nature than economic. Consequently, the nation's focus of attention must be redirected from a purely economic focus. The extreme complexity of the social, financial, technological, and demographic forces suggest that the National Model's comprehensive approach to examining social-economic behavior should be helpful in analyzing economic fluctuations.

VI.D. Taxes

The consequences of collecting taxes from different points in the economy should be examined. Congress, state legislatures, and the federal executive widely debate the merits and equity of who to tax and how. What are the relative advantages of the property tax, personal income tax, corporate income tax, sales tax, or value-added tax? Such issues can have only a short-term significance if prices, wages, and money flows readjust to compensate for tax changes. Taxation, if it triggers powerful compensatory forces, may actually have little leverage for inducing social change. The National Model will have policy control points for evaluating tax policies.

VI.E. Energy Shortage

Energy shortages appear when demands by population and industry exceed supply. If the imbalance is severe, the shortages begin to transfer internal economic pressures into international stress as the nation becomes increasingly dependent on foreign sources. Traditional alliances are strained and new animosities may grow up overnight. Energy shortages also tend to encourage environemntal degradation as the pressure for fewer environmental controls gets stronger. Such activities as more strip mining and weaker air and water standards also gain support. Energy shortage is also linked to balance of payments and the cost of producing energy, and to the quality of life through environmental effects such as the hazards of long-time storage of atomic wastes. By connecting energy with other parts of the national system, the National Model will spotlight the trade-offs between energy and other social or economic variables.

VI.F. Agriculture

As an economy moves through its life cycle, the role of agriculture changes. At the beginning of the life cycle, an economy is predominantly rural. If energy is ample, as capital accumulates and labor becomes scarce, farming becomes capital-intensive. The productivity per worker in the field increases, but the output per unit of energy input may decrease. American agriculture today is actually a low-efficiency converter of petroleum calories into food calories. Such conversion of energy into food is a useful process when energy is plentiful, but less effective when energy shortages develop. Toward the end of economic growth, if labor becomes excessive and energy and land

become scarce, a transfer of labor back to agriculture probably becomes necessary. The potential reversal of labor migration would have a profound impact on housing, transportation, welfare, and unemployment-compensation policies.

VI.G. Education

Education, a form of capital investment, increases skill, production output, and human satisfaction. In the United States, education has served primarily to fill the inventory of corporate, governmental, and academic skills; however, when the inventory is full, only replacements are needed. The educational system, along with many other capital-producing parts of the economy, can shift from being inadequate to having excess capacity as the economy passes the steepest part of its growth. Evidence of excess capacity in higher education is already appearing. Federal intervention to sustain the historical trend may only necessitate more drastic readjustments later. By interrelating consumption demands, productivity, technology, and the inventory of required skills, the National Model should generate the sequence of rising and falling trends in education. The Model structure should contain the forces responsible for overcapacity in education; then the insights from analysis of structure and behavior should help to plan better for actual future educational needs.

VII. Development of the Model Over the Next Three Years

The past three years have witnessed the creation of the basic structure of the National Model. Another three years (1975–1978) should bring the Model to the point where it can play a role in public policy. The specific objectives for the next three years are:

- To improve and assemble sectors of the Model from smaller components, most of which already exist in preliminary form,
- To expose the preliminary model formulations to public and academic review,
- To test and validate the Model by comparing components and the entire Model with information about the real socio-economic system,
- To initially employ the Model for identifying the causes of socio-economic behavior, for analyzing issues, and for understanding the mutual evaluation of policy alternatives,
- To disseminate the insights into modeling, policy development, and the causes of the national problems examined in the period of investigation.

Over the three-year period, the National Model will be assembled and tested in stages. Each of the six basic sectors will be tested thoroughly on an individual basis. In some cases, several versions of a sector may be tested. For example, tests of the production sector will be applied to both a single production sector and to multiple interacting production sectors. Aside from individual tests of the six basic sectors, tests will be conducted on several mutually interacting sectors—for example, the production and labor sectors. As the behavior of interacting sectors becomes understood, progressively more sectors will be linked together until the full National Model is assembled and working.

Simultaneously with assembly, testing, and revision, interpretive studies of a preliminary nature will be published. The Model should provide insights, at each stage of its development, about important questions of socio-economic behavior, theory, and policy. These insights will accumulate from testing of individual Model sectors, testing of submodels consisting of two or more sectors, and finally, from simulations of the complete assembled National Model. The three-year program will therefore inaugurate a

pattern of Model usage for shedding light on major national issues that can continue well beyond the model-development period.

References

1. Forrester, Jay W., *Industrial Dynamics,* Cambridge: MIT Press, 1961.
2. Forrester, Jay W., *Principles of Systems,* Cambridge: Wright-Allen Press, 1968.
3. Goodman, Michael R., *Study Notes in System Dynamics,* Cambridge: Wright-Allen Press, 1974.
4. Mass, Nathaniel J., *Economic Cycles: An Analysis of Underlying Causes,* Cambridge: Wright-Allen Press, 1975.
5. Hickman, Bert G., The Postwar Retardation: Another Long Swing in the Rate of Growth?, *American Economic Review* **53,** 490–507 (May, 1963).
6. Abramovitz, Moses, The Nature and Significance of Kuznets Cycles, *Economic Development and Cultural Change* **9** (April 1961).
7. Kondratieff, N. D., The Long Waves in Economic Life, *Review of Economic Statistics* **17,** 105–115 (Nov. 1935).
8. Forrester, Jay W., *Urban Dynamics,* Cambridge: MIT Press, 1969.
9. Forrester, Jay W., *World Dynamics,* Cambridge: Wright-Allen Press, second ed., 1973.
10. Meadows, Dennis L., Donella H. Meadows, Jorgen Randers, and William W. Behrens III, *The Limits to Growth,* New York: Universe Books, 1972.

Received 10 October 1975; revised 14 November 1975