The System Dynamics National Model: Macrobehavior from Microstructure[1]

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The System Dynamics National Model was undertaken to show how local policies governing decentralized decisions in an economy create observed overall economic behavior. I feel we have succeeded well beyond our original expectations. The model, endogenously, without any external driving time series, generates the major observed modes of economic behavior:

business cycles,
inflation,
stagflation,
the economic long wave
and growth.

In economics there have been two separate fields—microeconomics and macroeconomics. Few links exist between the two. Microeconomics does not provide an adequate basis for explaining behavior of the economy as a whole. Macroeconomic theory fails to explain much of the behavior seen in national economies. The National Model generates behavior as observed in an actual economy from the interactions of local structures and decision-making policies. By doing so, the model builds a bridge joining microstructure with macrobehavior.

The System Dynamics National Model is the largest system dynamics project with which I have been associated. It has cost the most money. It has taken the longest time—some 15 years.

Although the work has been interspersed with many other activities, I am at a loss to explain how it has taken so long. On the other hand, we feel that we have made progress in areas that have baffled economists for the last century. It has taken time to develop an approach and the corresponding philosophy, to understand the paths taken by others in the past, and to decide how much of prior work should be retained and how much is inconsistent with a proper dynamical approach to economic behavior. We have also invested substantial time in understanding economic behavior that was revealed by the National Model, in particular the economic long wave or Kondratieff cycle, which we

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[1] This paper is drawn from the introduction of a book now being written on the System Dynamics National Model.

first encountered in the model behavior itself before we discovered the extensive literature that already existed.

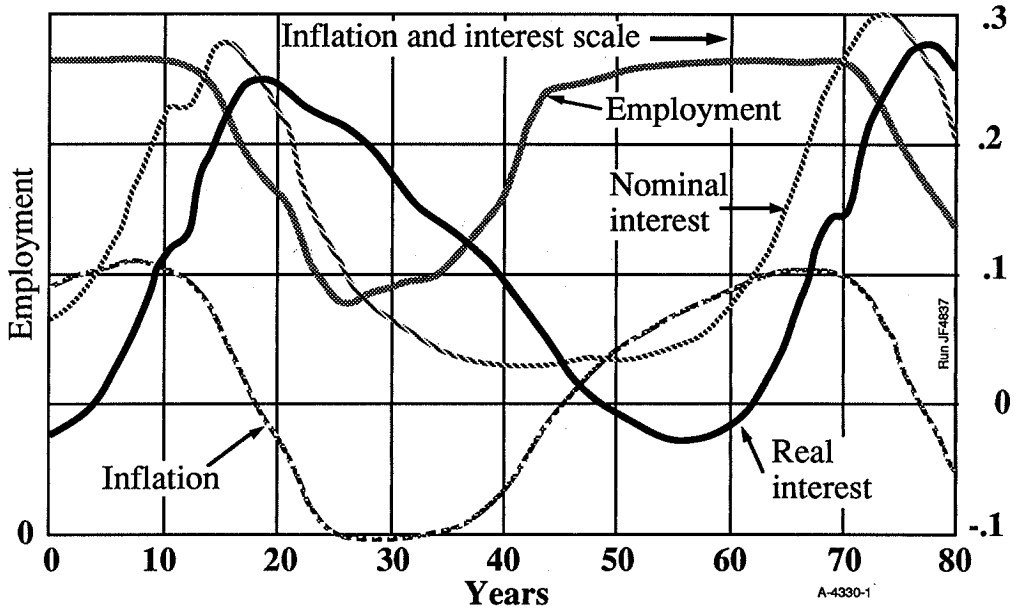

Figure 1. One cycle of simulated economic long wave.

Figure 1 shows a cycle of the long wave as generated by the National Model. For clarity, business cycles and growth have both been suppressed. Varying real interest provides one of several major driving forces for the long wave During the expansion phase when employment is high, real interest (nominal interest minus inflation) declines, even to negative values, giving strong incentives for excessive capital investment and speculation in physical assets. As economic decline sets in toward a long-wave depression, at about year 70 in the figure, real interest rises steeply, further discouraging investment and accentuating the downturn. This pattern of real interest as generated in the model has been occurring in the United States. Real interest rate was low in the 1970s and has now risen to values that were last reached in the early 1930s. The interest rate pattern is much more a consequence of system structure than it is a result of government monetary policy.

The National Model has not been easy to understand. It contains over 200 integrations and more than 1,500 equations. This means one is dealing with a 200th order, nonlinear differential equation, to use the normal mathematical terminology. Even now, we are still discovering its counterintuitive nature. When we observe a mode of behavior in the model that clearly is without precedent in the real world, it may take several days of experiments to determine the structure behind the particular behavior. During those several

days, the "obvious" causes often turn out to be low-leverage policies of no consequence. When we try in the model those policies that are popular with governments, we see why commonly accepted policies are so often ineffective.

However, in spite of the difficulty of the task, I believe that the National Model will prove to be well worth the effort. It should become a basis for clarifying the nature of economic behavior. It casts a new light on how an economy can be studied. It points to resolutions of many controversies in economics. The National Model and future work to follow from it, should lead to improved economic policies.

STRUCTURE OF THE NATIONAL MODEL

The National Model consists of a consumer products sector, a capital-producing sector, a household sector, a government sector, a labor sector, and a financial sector. Within each sector are detailed policies that govern decisions for the control of activity.

Nomenclature and units of measure in the model closely follow their real-world counterparts. People move in the model as people. Capital equipment is represented as physical units of capital, not as the dollar equivalent. Money is handled as a conserved flow of dollars moving from one demand deposit to another. Nominal prices, wages, and interest rate are generated. The separate flow systems interact at points where they influence one another. For example, the number of employees multiplied by the wage rate and overtime premium determines the flow of wage payments from a production sector to the labor force. Market clearing is not by price alone but by the interaction of price and availability; the model can thereby deal with the effect of shortages and excesses in the economy that are ignored in equilibrium economics but that are central to the creation of dynamic change.

Coefficients and table functions are located generously throughout the model so that changes in behavior can be tested in response to different assumptions and decision-making policies.

Production Sectors

Two production sectors are included in the National Model. The consumer-goods sector provides all goods, services, and housing purchased by the household and government sectors. The capital sector produces all capital plant purchased by the consumer goods sector and the government sector. In the early days of developing the National Model, many more production sectors were projected. However, as the work progressed, there seemed to be no compelling need for going beyond the basic two that are included.

The two production sectors are sufficient for generation of the several modes of economic behavior that seem most important.

A production sector in the model is essentially a model of a corporation, which represents an aggregate of all corporations within the sector. Parameters are chosen to reflect the combined distributed characteristics of many corporations, rather than the more sharply defined characteristics of a single corporation.

A production sector produces output, determines price of its output, maintains a balance sheet and profit and loss statement, borrows money, pays for factors of production and taxes and interest and dividends, and maintains a money balance.

Household Sector

The household sector purchases from the goods sector and harbors the population that is not in the work force. Under pressures from the nonemployed pool, the household absorbs or yields people to the labor force. The household receives wages, interest, dividends, and transfer payments. It uses its money receipts for purchases, saving, and taxes.

Labor sector

The labor sector provides for the flow of people among the production sectors, the government sector, and the household sector. It also determines wages.

The labor sector contains a nonemployed pool linking the flows of people to and from other sectors. Just as the production sectors generate a delivery delay as well as price to determine market clearing, so does the labor sector provide a labor availability and wage. Falling labor availability restrains hiring.

Wages are computed by a floating level (an integration) that is driven by availability of labor, and inflation. A tight labor market pushes up wages, where they will remain if driving forces return to neutral. A fraction of perceived inflation drives wage. The sensitivity to positive and negative inflation can be set differently.

Financial Sector

The financial sector is an aggregation of all banks and financial institutions. It has a balance sheet with reserves, demand deposits, household net savings, debt of the production sectors, and government bonds.

The financial sector determines interest rate as a floating level driven by available reserves. The financial sector receives interest payments from the production sectors and

government and channels them to the household. It allocates defaults on production sector debt to money balances and household savings, taking into account federal deposit insurance.

Government Sector

The government sector hires people, buys goods and physical capital, sets tax rates, makes transfer payments, responds to desired government services, issues government debt, and controls bank reserves. Monetary policy is endogenous to the model and responds to free reserves, economic growth, inflation, unemployment, and interest rate.

As in the production sectors, labor, goods, and capital are balanced by benefit cost ratios for each.

Desired government services change in response to government size, level of taxes, the government deficit, economic growth, and unemployment.

THE MODELING PHILOSOPHY

In developing the National Model we followed a number of guidelines that we believe are important to understanding economic systems. Most of these directions already have been individually called for by earlier writers in the economics literature. We have chosen those earlier suggestions that we believe are consistent with good dynamics practice and combined them in such a way that they can reinforce one another. The uniqueness of our approach to economic behavior does not arise so much from the individual guidelines as from the combination of all and from the degree to which they are applied.

Disequilibrium

We start from the belief that the important questions about economic behavior relate to change. How did the economy get where it is? What path would be followed as a future response to a present policy change? Employment, interest rates, and prices exhibit unexpected changes. In modeling an economy, one will best start with an approach that gives full scope for disequilibrium behavior.

By taking the model-simulation approach, there is no restraint on disequilibrium behavior. The model can generate whatever behavior is implied by its structure and the decision-making policies within it.

Simulation Modeling

By using a simulation model, one is freed from many restraints that are imposed by statistical analysis and by equations that are to be solved mathematically.

Simulation modeling is a practical trial-and-error approach. It does not possess the elegance of more analytical methods, but it allows far greater scope for representing the actual structure of an economic system and for discovering the causes of behavior that are observed in the real world.

Complexity

We have chosen in the National Model to represent a rather high degree of complexity. There are good arguments for both complexity and simplicity in modeling. Simpler models are easier to explain and to understand. More complex models come closer to the structure of real systems and are less subject to questions as to whether or not important sources of behavior have been omitted.

Many aspects of real-life behavior arise directly from complexity. For example, corporations and national economies exhibit a high resistance to most policy changes. Managers and politicians are often frustrated by adopting a policy intended to correct an undesirable situation only to discover later that little or no improvement was achieved. The cause of such frustration usually lies in the way multiple feedback loops can generate counteracting forces to cancel the effect of an apparently corrective policy. Such compensating processes are likely to be absent in simple models with the result that policies and parameter values in the model seem much more sensitive than they are in real life.

In the National Model and the future work it can lead into, we try to gain the advantages of both complex and simple models. At this stage we have constructed a rather comprehensive model within which to identify the behavior modes that have been occurring in actual economic systems. Then, with confidence that the economic modes of behavior and their causes are properly identified, it will become possible to develop simple models that illustrate particular issues. Some of those simpler models have already been developed by John Sterman at M.I.T.

Endogenous Behavior

Our objective has been to include within the model the causes of the important modes of economic behavior. If the causes of behavior lie within the model, then the model by itself, without external driving inputs drawn from the actual economy, can generate the behavior of interest. The boundaries of the model have been set to include the structures

that can generate business cycles, the economic long wave, growth, inflation, and stagflation. The model is, therefore, a theory of how those behaviors are generated.

Real-life behavior is interpreted as coming from interacting forces within the real-life system. Our objective is to have the same true for the National Model. Behaviors are expected to be endogenously generated within the model. One does not look to events or accidents outside the system as the primary cause of economic behavior. On the other hand, random events can excite modes of behavior to which the system is internally inclined. For example, the business cycle emerges as an inherent oscillatory tendency in the structure of the economic system. But, business cycles are a damped mode that would die out unless kept in motion by the vast number of small random events that occur continuously. Such randomness is included in some of the decision-making policies of the model.

Feedback-Loop Structure

We adopt here the viewpoint that all dynamic behavior arises from within feedback loops. In other words, change occurs through the circular processes in which actions change the state of a system and the new state influences future actions. Growth, goal seeking, and oscillatory behavior are generated by feedback loops.

Drawing on decades of working with dynamics in feedback structures, we have been alert to search for feedback loops that have characteristics capable of generating observed economic behavior.

Integrations (or Accumulations)

An interest in disequilibrium conditions, endogenous generation of behavior, and feedback structures calls for special attention to the integrations (stocks, levels, or accumulations) in a system. Integrations uncouple inflow rates from outflow rates and make dynamic behavior possible. A system representation with no accumulators can show only static, equilibrium conditions. Bank balances, inventories, backlogs, stocks of production factors, and debt all are accumulations or integrations; they allow short-term independence of decisions in one part of a system from those in another part. They are involved in the central processes of generating dynamic behavior.

But accumulations occur not only in physical variables like inventories. They are also present in information flows. All memories represent accumulations. Computing a trend requires the use of integration. Perception delays, as in the delayed psychological response to changing conditions involves an integration process.

Special attention has been given to representing integrations in the National Model. Over 200 integrations are present in the model equations. Of these, only about 30 are in

physical variables such as inventory, factor stocks, and backlogs. All others are in the financial, informational, and psychological networks of the model.

Market Clearing

In academic economics, price is usually the only factor in market clearing—simple supply-demand curves determine a price that forces supply to equal demand. But in the real economic world, most exchanges depend on a more complex ensemble of conditions than price alone. In the National Model we go one important step beyond price in clearing markets—that is in balancing supply and demand. That step beyond price involves availability, or delivery delay. In the majority of markets, there are often buyers who would buy at the stated price, but the product they want is not available. Conversely, there can be sellers who would sell at the current price, but there are not enough buyers to take all their product—the balance goes into inventory.

In fact, delivery delay or availability is the principal signal that causes prices to change. The indication that price is not that which will balance supply and demand comes from the abnormal condition of backlogs and inventories. In conditions of rationing, either self-imposed by suppliers or dictated by government, availability plays a major role in balancing supply and demand. Usually a mixture of availability and price are at work in market clearing. The buyer who waits for a product because the particular item wanted is not available at the locally accessible outlets is being influenced by availability.

Availability is a central influence in many markets and is widely used in the National Model along with price to balance supply and demand.

Bounded Rationality

If a dynamic model is to replicate real-world behavior over a wide range of operating circumstances, its internal decision-making procedures must reflect the essential nature of those followed in the actual economy. We believe that local corporate and financial decision making is not an omniscient and goal-maximizing process. Instead, decision making is based on limited information, guided by goals that are in conflict between the long and short run, and compromised by many objectives other that economic profit. Our view of realistic economic decision making agrees with the "satisficing" or "bounded rationality" process described by Herbert Simon.[2]

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[2] Simon, Herbert A. (1977). "Rational Decision-Making in Business Organizations," Les Prix Nobel 1977, Almqvist & Widsell International, Stockholm In this Nobel Memorial Lecture, Herbert Simon discusses the contribution of psychology and research on actual decision making in firms as these differ from economic theory based on optimizing and an all-encompassing rationality in decisions.

We believe that the bounded rationality approach is the most plausible assumption about local decision making. For 30 years the system dynamics field has worked with corporations to study the way decisions are made in the actual business setting. Policies governing corporate decisions became the basis for modeling growth, market share, and stability of corporations. That same background regarding the actual limited processes of decision making has now been brought to bear on modeling national economic behavior. The National Model is constructed from very localized decision processes. The policy assumptions in the Model can be understood by and evaluated by those at the corresponding decision-making points in corporations, banking, and government. Macroeconomic behavior arises from interactions among the many local decision points.

Economics as a Systems Profession

We see the study of economic behavior as a systems-oriented profession rather than as a science. The study of economic dynamics is more like the professions of engineering, management , and medicine than like chemistry or physics. The systems-oriented professions rest on large bodies of underlying science, but the challenge is to apply that science to understanding complex real-world systems.

From a systems viewpoint, economics and management become parallel professions, rather than thinking of economics as a science underlying management. A national economy is a larger system than a corporation but the structures and process of the two are similar. Each rests on underlying sciences of human behavior, information processes, and feedback-loop dynamics.

POLICY ANALYSIS WITH THE NATIONAL MODEL

The System Dynamics National Model is intended for two major objectives—to help reach a better understanding of how an economy works, and to help in analyzing the effects of proposed economic policies. Figures 2 and 3 present an example of using the model for studying how a policy change affects long-wave behavior. Again, business cycles and growth have been suppressed. In Figure 3, as employment begins to decline, bank reserves are increased to make credit more available for a period of 15 years until inflation becomes excessive. The result is little change in the initial employment pattern, later, the minimum occurs at year 55 as before but is deeper. More bank credit has increased the excessive peak in physical capital, requiring the deeper employment dip later to compensate. The principal consequence of the easier credit appears as a higher peak in prices and a higher interest rate after the monetary stimulus is removed.

We are now writing two books presenting the full details of the National Model and our principal findings about economic behavior and effects of national policies. There will be important and interesting differences between our findings and the conventional wisdom about economic affairs.

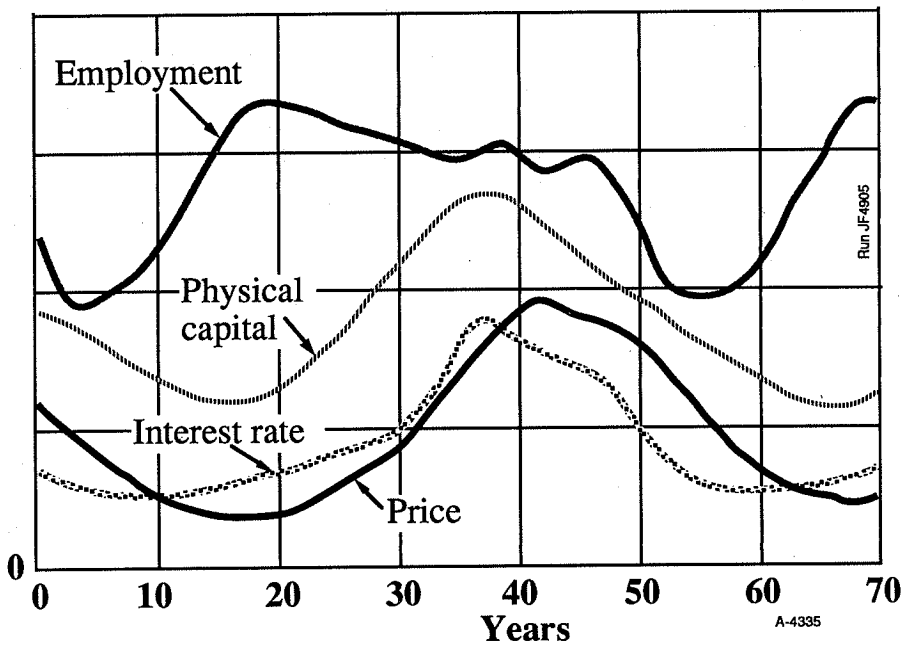

Figure 2. Base simulation without extra monetary stimulus

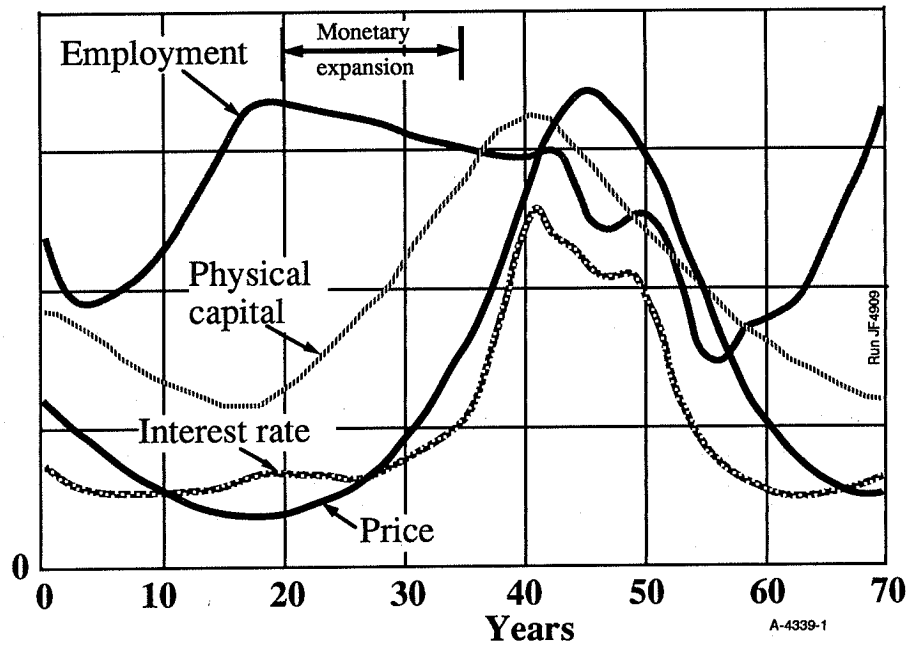

Figure 3. Like Figure 2 except for monetary stimulus between years 20 and 35.