INTRODUCTION TO THE SYSTEM DYNAMICS NATIONAL MODEL STRUCTURE

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The System Dynamics National Model is a large computer simulation model of a typical industrialized economy, with parameters adjusted to reflect the size and character of the United States. The model's purpose is twofold: understanding the major difficulties of the aggregate economy such as inflation, business cycles, and slowing productivity growth; and to facilitate the evaluation of policies to influence those behaviors.[1] In the existing publications on results from the National Model, the structure of the model is described in a page or two, doing no more than supplying a flavor for the scope of the model.[2] This paper goes to the next stage in describing the content and structure of the model for those readers with some previous exposure to the results of the National Model research. The discussion starts with the overall architecture, then goes through the major connections among the sectors of the model, and concludes with one example of more detailed structure: the interrelations among selected decisions in the corporate sector of the model.[3]

Any document that describes a complex economic model, and is smaller than a full-sized book, must omit substantial amounts of information. What information, then, is excluded here? There will not be descriptions of any model equations. An example will describe only 10 of the 41 blocks of equations in the model. And although there will be a comprehensive treatment of the overall functions of the model's sectors and their major interconnections, the description of the interconnections will not be exhaustive. Finally, the

description will not relate structural features of the model to the corresponding economic theories. The only function of this paper is to set out, as best as can be done at moderate length, what is represented explicitly in the model.[4]

Two themes recur in the description below. The first theme is that model structure comes more from model purpose and the observed structure of real organizations than from a prior theory on what creates the economic behavior.[5]

The second theme is that the structure of delays and amplifications that one observes at the level of the individual corporation, household, or bank will suffice to create the macroeconomic difficulties at which the model is aimed. This is true of the real economy; in the physical world there are individuals acting, according to the information they have, subject to the limitations and motivations that go with their position. There is no "macrostructure," other than the aggregation of microstructures. Just as the economy's behavior results from its microstructure, so too should the behavior of a realistic model of that system come from its microstructure. The discussion below will point out some of the cause-and-effect links that create the variety of behavior modes that the National Model exhibits: inflation, three- to seven-year business cycles, 20-year Kuznets cycles, and 50-year long waves.

1. ARCHITECTURE

Figure 1 shows the organization of the model. It is divided into sectors, each sector is divided into equation blocks, and these blocks contain the equations themselves.

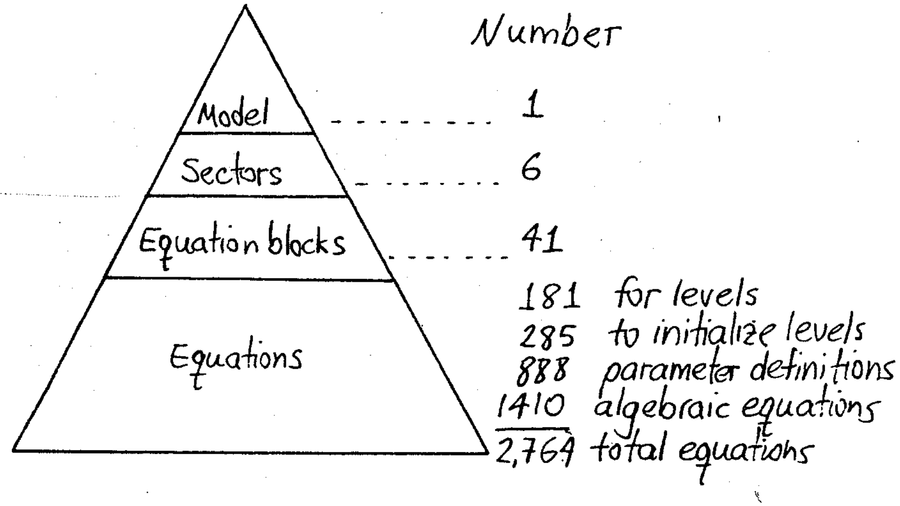

Figure 1. Hierarchical organization of the System Dynamics National Model. It is divided into sectors, with each sector containing several equation blocks, and each equation block containing several equations.[5]

2. SECTORS OF THE MODEL

The structure of a model should derive from its purpose. As discussed previously, the model is aimed at understanding inflation, monetary and fiscal policy, and economic growth, to name a few of the issues being addressed.

To examine fiscal policy, a government sector is needed to represent the activities of the local, state, and national governments that impinge upon the economy through fiscal policy: setting tax rates, collecting taxes, purchasing goods, hiring people, and making transfer

payments (social security, unemployment compensation, and so on). Likewise, to examine monetary policy, the model's government sector must represent money supply growth targets, and the open-market operations by which the federal government, through the Federal Reserve system, attempts to control the money supply.

Moreover, if the government is to intervene in financial markets (for the Treasury to borrow to finance deficits, and for the Federal Reserve to influence the money supply), then there must be a financial sector within which to represent these actions. Moreover, both supply and demand for financing should be represented, including both savings by the household and debt owed by both private borrowers and governments. The interest rate should be created endogenously.[6]

If the causes of price inflation are to be studied, and the conflicting theories about it resolved, the model must contain a representation of demand for goods and services by households; the aggregation of all the nation's households is represented by the household sector. It also determines how many people are seeking work.

If wage inflation is to be understood, there must be a labor market that mediates between the supply of people seeking work, and the demand for employees, determining wages and labor availability. In the model, this market is represented in a separate sector, the labor sector.

The portion of the economy not yet discussed is the portion that produces goods and services. For some purposes, it may be adequate to represent the entire productive sector of the economy as a single aggregated sector. For the purposes of the National Model, such as understanding the process of long-term economic growth, more subdivision is useful. As described previously, the instability in long-term capacity accumulation that creates the 50-year long wave motivates modelling the ability to produce plant and equipment explicitly. So the present model divides the producing portion of the economy into two sectors: the capital goods (plant and equipment) producing sector, and the consumer goods and services sector. Capital goods are used by producing sectors in the process of production: factory buildings, gas stations, stores, bulldozers, machine tools, and industrial hand tools would all be considered capital goods. Even a government office building is a capital good that is used to produce various government services. Consumer goods and services are things that are purchased only by consumers: food, restaurant meals, video-cassette recorders, cars, houses, and clothes, for example.

Because businesses have so much in common with each other, the model uses a single generic set of equations to represent the two production sectors of the present model, or indeed, any number of sectors. Of course, for each sector the parameters that characterize the sector will differ, so that each sector's behavior is represented appropriately. For example, capital goods often take longer to be produced than do consumer goods and services. So in the model the normal production delay would appear as a parameter that has different values for the two sectors. The generality of the equations allows both a briefer model and a more succinct description of the model. Interestingly, the equations have been general enough that they have served as the basis for applications ranging from the impact of management information systems on production planning to the issues surrounding the transition from oil-based energy sources to renewable sources over 100 years.[8]

The present model, then, is divided into six sectors: capital, consumer goods and services, government, financial, household, and labor. Figure 2 summarizes the primary functions of the sectors, with the entries for "production sectors" applying to both the capital-goods-producing sector and the consumer-goods-and-services-producing sector. For example, one government action represented explicitly in the model is hiring government employees. For each such action, the model represents the policies that govern it and the information used by those policies in considerably more detail than might be indicated by figure 2. Section 4 will give an example of such detail.

Sector	Action Represented
Government Sector	Determine level of government spending, hiring, and transfer payments Decide tax rates Buy and sell government bonds Set reserve requirements Finance deficit/surplus
Financial Sector	Determine interest rates Extend credit
Household Sector	Purchase goods and services Save Participate in work force Manage cash
Labor Sector	Negotiate wages Accept jobs Compute unemployment
Production Sectors (both consumer goods and services sector, and capital goods sector)	Produce output Create job vacancies Order capital Manage inventories Make shipments Manage cash Pay dividends Borrow Set prices Negotiate wages

Figure 2. The six sectors of the model, and principal actions represented within each sector.

3. INTERACTIONS AMONG SECTORS

3.1. Flows among Sectors

The sectors interact through multiple physical flows, financial flows, and information flows. For example, when a consumer goods manufacturer places an order for a new piece of capital equipment, that information (the order) is transmitted to the capital sector. When the equipment is shipped, material (the machine) and the information (the bill) flow back to the goods manufacturer. When the bill is paid, money flows back to the capital sector.

Figure 3 shows the principal physical flows that couple the six sectors to each other. Most of the flows shown on the figures are self-explanatory. The exceptions are issues of how something is represented: the financial sector treats its employment activities as negligible by comparison to its primary function of facilitating, borrowing, and saving, so employment, and thus flows of people, are not represented explicity in the financial sector. Also, movements of workers between sectors go through a pool of nonemployed representing individuals currently seeking employment. This pool represents the typical delay encountered when a worker transfers from one production sector to another or when a worker enters or leaves the work force. It also includes those unemployed for longer durations, even if they are too discouraged to actively seek employment.[9]

With the exceptions just described, all of the hiring and firing, and all of the buying and selling occur in exactly the places one would expect, because the structure is firmly based on the microstructure of the conduct of ordinary business.

Note that there is a flow of consumer goods and services to the government sector, to allow the government to buy both relatively short-lived goods and services and the much longer-lived capital goods. The latter include such items as aircraft carriers, office buildings, and dams. The distinction between short-lived and long-lived acquisitions is important in analyzing the flexibility of government spending in times of financial stress: how much can the government cut back in the short term?

For clarity, figure 3 does not show the information flows that correspond to the physical flows. For every physical flow, information about the price and availability goes along with the physical flow. For example, the flow of people from the nonemployed pool in the labor sector to employment in the production sectors is accompanied by

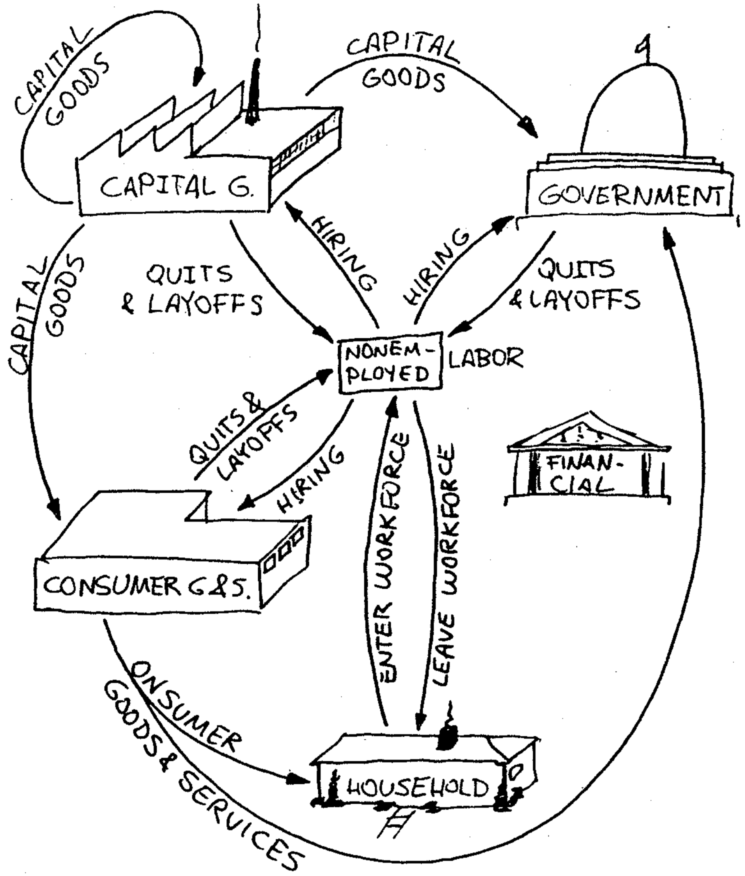

Figure 3. Principal physical flows among sectors. Consumer goods and services flow from the consumer goods and services sector to the household sector and the government sector. Capital goods move to the capital-producing sector, the consumer goods and services sector, and the government sector. People move between all sectors except the financial sector through the pool of nonemployed people.

information on current wages and how difficult it is to hire people. On the basis of that information and more, information flows back from the production sector to the labor sector on current job vacancies. Analogous information flows accompany the flows of capital goods and consumer goods and services.

The sectors are also interconnected through financial flows. Each sector pays for what it acquires, whether for labor, capital, or consumer goods and services. The household sector saves its money at the financial sector, which lends to, and collects principal and interest from, the production sectors and the government. The government sector collects taxes and transfers some of its receipts directly to household members, for unemployment insurance, welfare, and other transfer payment programs.

There are also information flows that accompany the financial flows. Production sectors demand credit on the basis of the price (interest rate) and availability of credit. The household sector's decision on whether to consume or save is influenced by both the interest rate it can earn on its savings, and the value of the equity it holds by owning the production sectors. The production sectors pay taxes and make investments according to the tax rate determined in the government sector.

3.2. Markets for Products and Services

The physical flows, together with their corresponding information flows, comprise the several markets for the products of the production sectors. Figure 4 shows the interactions between a buying sector and a selling sector that create the market. (Of course, there are many influences from inside each sector that are not shown.) The buying sector places orders for the output of the selling sector. The backlog of orders, along with the inventory of product, is depleted when orders are filled and shipped. The relation of the order backlog to the inventory of product available for shipping influences changes in price; if orders are high and inventory is scarce, the price will rise, all other influences being equal. Higher prices eventually reduce the

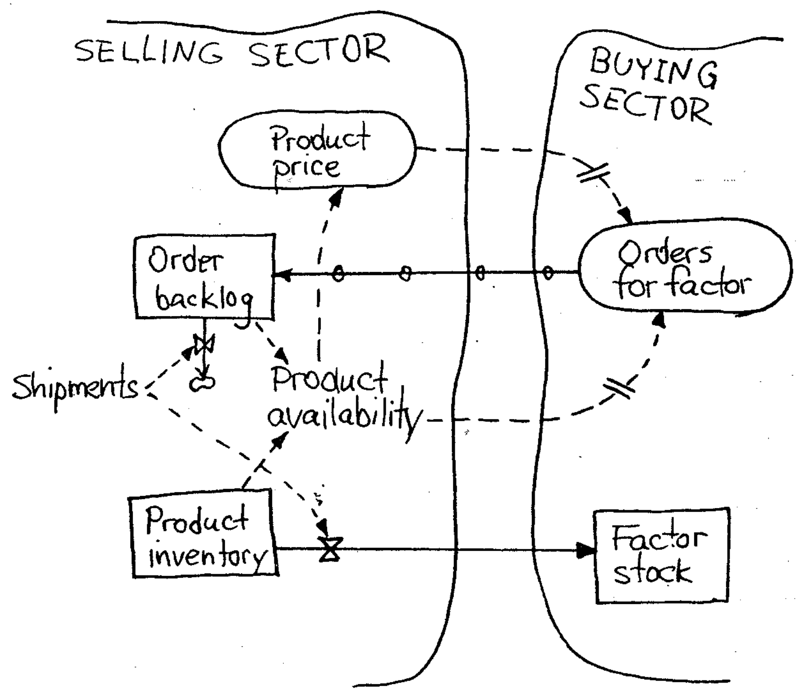

Figure 4. Interactions between a selling sector and a buying sector that create a market for the product. Demand (the stream of orders) is regulated through two channels: price and availablity. The boxes represent stock variables or levels. The ovals represent equation blocks, and the double slashes indicate the presence of delays and other structures between the source and destination of the information flows.

stream of orders coming from the buying sector. There is a parallel channel of influence, where the inventory and backlog condition determine product availability. Sales and orders for product eventually will be discouraged if the product is very difficult to obtain. This parallel structure clears markets through both price and rationing.

The parallel influence of price and availability on demand is important to the behavior of the economy. In cases like price controls, the price feedback may not be available to control demand. Even during normal economic fluctuations, prices do not instantaneously adjust to bring supply and demand into balance; the process takes time, and creates dynamic behavior.

The contrary viewpoint is often taken in more traditional economic analysis: that the economic system is almost in equilibrium almost all the time, so analysis can proceed validly by considering economic change to be merely a transition from one equilibrium to another. But as economist Alan Blinder observed,

> Many central markets don't clear. And it isn't a matter of shrugging it off by saying "they almost clear." They don't come close. For example, studies indicate that prices in auction markets move to erase arbitrage opportunities in a few seconds. Price disequilbria in non-auction-product markets last a month or so. In contractual labor markets, the half-life of a disequilibrium is half a decade.
>
> By analogy, if the speed of adjustment in auction markets is the speed of light, then that of contractual labor markets is 55 miles an hour. You wouldn't think much of a physicist who assumed that the national speed limit is the speed of light; you shouldn't think much of theories that assume markets clear at lightning speed.[10]

Moreover, there are markets where the transient response is opposite the movement of the equilibrium.[11] Due to such considerations, the construction of the National Model has provided both price and availability feedback in every market, be it for capital goods, loans, labor, or consumer goods and services. If economic conditions are such that the economy is not in equilibrium, then so should the model show the same kind of disequilbrium behavior.

3.3. Markets for Financial Instruments

In parallel with the product markets, the interaction of the financial flows and their corresponding information flows creates the market for financing. Unlike the product markets, which treat all of

the buyers uniformly, the financial sector interacts slightly differently with the government sector, the household sector, and the production sectors. Figure 5 shows the interaction of the financial sector with a production sector.

The financial sector represents the aggregation of all financial institutions--banks, insurance companies, savings and loans, and so on--into a single mega-institution. It accepts savings from the household, creates money as the Federal Reserve permits, and makes loans to the production sectors and the government. The financial sector, then, is an intermediary for the financial transactions of the other sectors.

The balance sheet of the aggregate financial intermediary occupies the center of figure 5. The liabilities of the financial sector equal the total money stock (it owes to its depositors) plus bank bonds, which are the aggregated financial instruments that the household buys with its savings. The assets of the financial sector are government bonds, loans (the liabilities of the production sectors are assets for the financial sector), and reserves. Reserves are literally the reserve, in the form of vault cash or deposits with the Federal Reserve system, that banks are required to hold to insure that they can honor withdrawals. The amount of deposits determines the required reserves.[12]

When a company within a production sector borrows money from a bank, the bank can create the money, by creating a deposit for the company. When the deposit is created, the total money supply has gone up, and so have the total loans. Reserves stay unchanged, but required reserves, proportional to the money supply, have risen, so reserves are less available for further loans. Lowered reserve availability increases the interest rate (really an aggregation of the spectrum of interest rates). Higher interest rates make some investments unprofitable, so there is less borrowing demand. If reserves are very scarce, there will be a direct effect of reserve availability on borrowing, representing credit rationing. Parallel to the market for

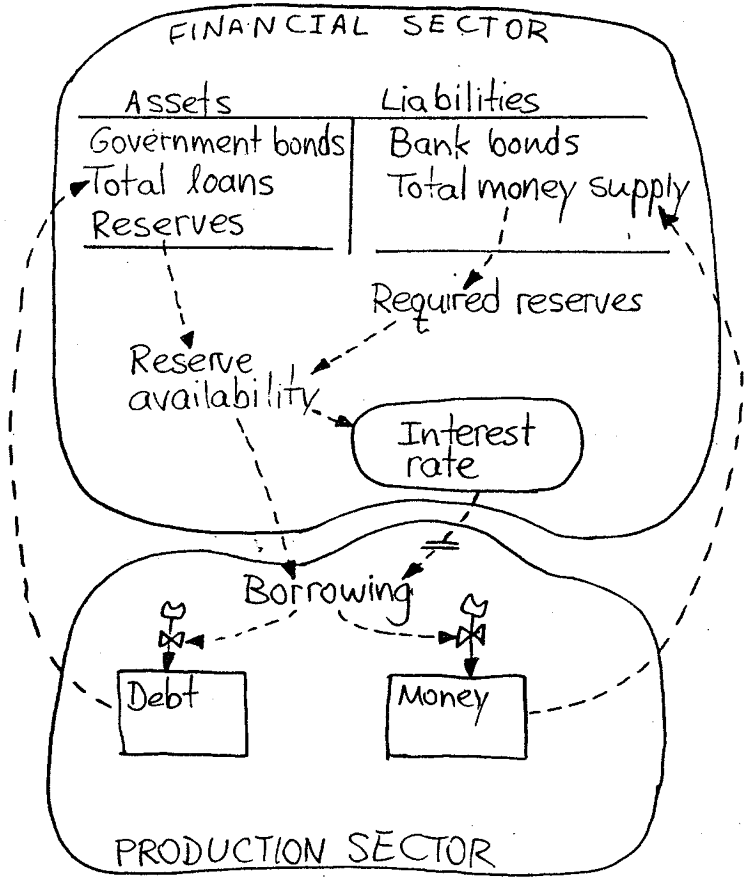

Figure 5. Interaction of the financial sector with a production sector. Similarly to the markets for products and services, the market for credit controls borrowing through two channels: price (interest rate) and availability. Borrowing can increase both the total loans outstanding and the total money in the economy. Reserves stay unchanged, but required reserves increase. The resulting reserve shortage not only directly retards borrowing, but it also increases interest rates and retards investment. Both of these effects limit further borrowing.

products, the financial market can be cleared through price (interest rate) or availability.

Note that the above description of the financial market assumes that everything not on the diagram remains constant. But in real life, other things do not remain constant. Borrowing creates money, which can circulate through the economy and produce inflation. Inflation can lower the real (i.e. inflation-adjusted) interest rate, which makes investments more, not less attractive. More investment can then cause more borrowing, money creation, inflation, and investment. This "side effect" of borrowing is an important amplifier of the 50-year long wave oscillations.[13]

There is also a process of lending where money is not created, but just transferred: the household saves, and the financial sector lends the money to the production sector. The balance sheet of the financial sector has higher liabilities (increased bank bonds, the obligation to the savers) and higher assets (the loans to the production sectors). Reserves and the money supply remain unchanged. How much money-creating lending versus non-money-creating lending goes on is a function of the willingness to lend of each source of funds (the Federal Reserve in the government sector, and the household sector).

The mechanics of the United States Treasury borrowing money from the financial markets work exactly the same way as for the production sector's borrowing just described. Similar but not identical changes in the balance sheet items can represent the Federal Reserve buying the Treasury debt, and thereby creating the reserves that can be used to expand the money supply and finance inflation. This will allow the Federal Reserve policy in the model to create inflation (or not), not because of a prior theory that says that it will (or will not), but because the model contains a reasonably faithful rendering of the actual mechanics of the process.

3.5. Interaction among Prices and Wage

One last interaction between sectors should be sketched out: the interactions that underlie the "inflationary spiral." Figure 6 shows one interaction between the labor and production sectors, where wages (determined in the labor sector) become part of the basis of computing the unit cost (cost of goods sold) in the production sector. By one pricing rule available within the model, the selling price of the sector's products is computed by a (variable) markup over unit cost, so that wage increases are passed through to prices.[14] Of course, other influences cause price to change as well, most notably the supply versus demand for the product, as measured by sales rates, order backlogs, and inventories.

When a price increases steadily enough that people expect the trend to continue, this inflation becomes an input to the wage negotiation. As in the pricing decision, the wage negotiation is influenced not only by inflation, but also by availability of labor and, in extreme conditions, the financial strength of the sector. This realistic set of assumptions about how wages and prices are set allow a variety of experiments on the causes of inflation, to begin answering such questions as:

* "Can indexation of wages to prices cause inflation?"
* "How do the effects of a product shortage propagate through the system; can a single oil shortage really cause ongoing inflation?"
* "What is the role of Federal Reserve policy? Could it restrict real economic activity in the short term? in the long term?"
* "Why has the Phillips-curve trade-off between inflation and unemployment shifted unfavorably? What are the policy implications?"

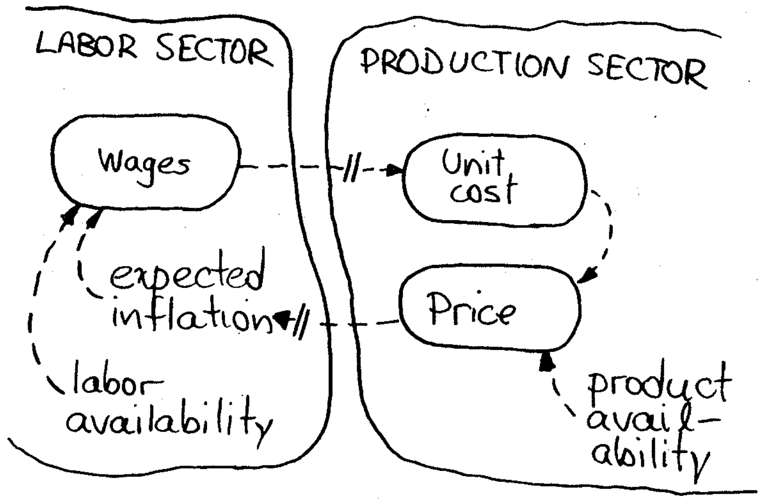

Figure 6. Interactions between prices and wage. The "inflationary spiral" is a structural, rather than behavioral, feature of the model: expected inflation is one input to wage negotiations; wages, through the unit cost of production, are an input to the pricing decision.

4. AN EXAMPLE OF STRUCTURAL DETAIL

It is obviously beyond the scope of this writing to describe each of the sectors in detail; a whole volume is required for that task.[15] But a sample of structural detail will help give an accurate image of the National Model.

The two production sectors (capital and consumer goods and services) are both represented by a generic set of equations, structured to resemble the decisionmaking within a typical corporation. With each sector representing the aggregation of corporations within that sector, the organizing principle for the structure becomes imitating the information flows and decisionmaking processes of the corporation. Accordingly, the equations are divided into three portions: first, there is the physical portion, which represents actual physical production, the accumulation of the factors of production (labor and capital) necessary to produce, the inventorying and shipment of product, and the set of nonfinancial goals that regulate these activities.

Second, there is the accounting portion, which keeps track of the sector's balance sheet, profit and loss, payments, cash, and taxes. Third, there is the financial portion of the generic production sector equations, which represents financial decisions made in the sectors: pricing, borrowing, loan repayments, and dividend payments. Together these three portions of the production sectors contain 23 blocks of equations, with the physical portion containing 10 of them. Only the organization of the physical portion will be described in more detail. To understand the critical role organization plays, consider figure 7, which shows the inputs to one policy, that which determines capital purchasing decisions.

The 16 inputs to the capital ordering policy span the physical, accounting, and financial portions of the production sector, and there are a few from entirely outside the sector as well. Not all of the inputs are equally important; their relative importance varies with the economic circumstances. When liquidity is more or less adequate, it is much less important than, say, the product order rate. But when liquidity is very low, and the corporation or sector is in serious financial difficulty, liquidity and other financial measures become an important issue. So in the model equations (which will not be detailed here), considerable effort has been made to represent realistic interactions among the inputs. And of course, each item on the list in figure 7 has its own inputs.

There is a considerable amount of structure just for the capital ordering policy. Figure 2 shows 25 actions in all of the sectors, of which "capital ordering" is just one. One could infer--correctly--that there are hundreds of cause-and-effect relationships even just within a

1. From the physical portion:

   Physical depreciation
   Capital goods on order
   Product order rate
   Trend in product order rate
   Current production rate
   Backlog of product orders
   Inventory of product
   Productivity of capital

2. From the accounting portion:

   Liquidity
   Profitability
   Debt/equity ratio

3. From the financial portion:

   Price of product

4. From outside of the production sector:

   Price of capital goods
   Availability of capital goods
   Interest rate
   Availability of financing

Figure 7. Inputs to the capital goods acquisition decision. For other ordering streams, as for employees or consumer goods, there are analogous sets of influences.

production sector. There are a great number of cause-and-effect relationships of which to keep track; this is why organizing principles based on real microstructure are so important.

Beyond sectors and portions of sectors, the next-finest subdivision of the model is equation blocks. Equation blocks represent single policies or closely related sets of policies. Figure 8 shows the equation blocks that make up the physical portion of the generic production sector. Each equation block contains from 10 to 30 lines of equations, and the label of each describes the most important variable that it calculates. So for instance, the "labor in sector" equation block indeed computes the stock of labor, but it also computes

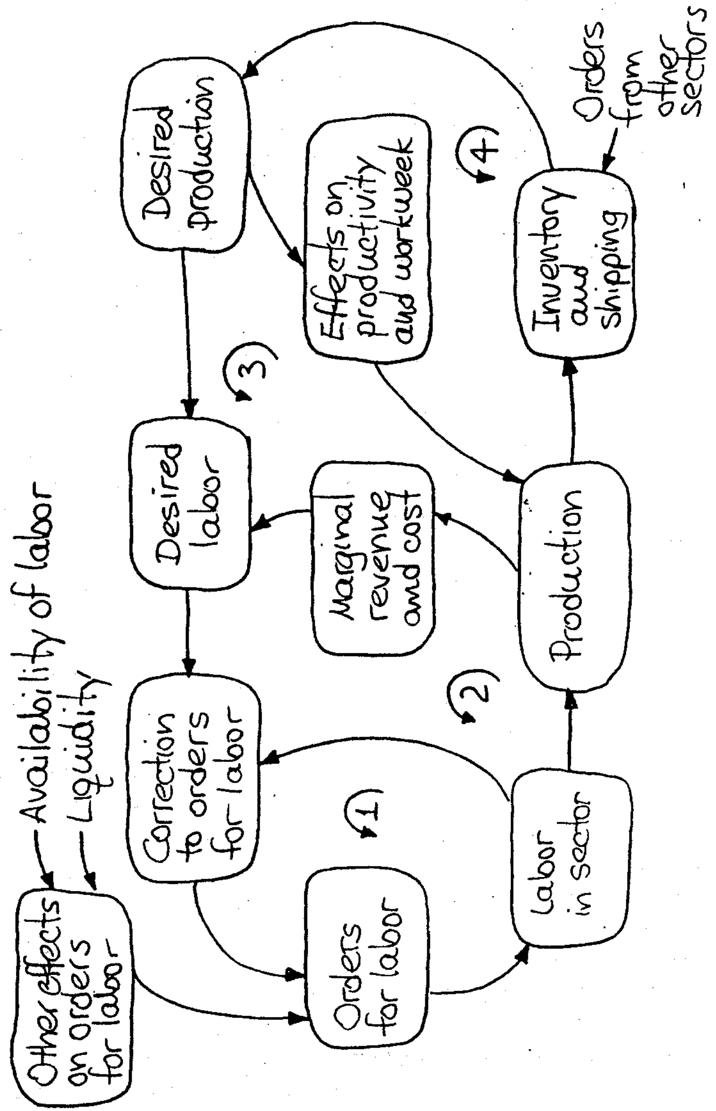

Figure 8: The ten equation blocks in the physical portion of the production sectors, showing the four major control loops. The other portions of the production sector (not shown) are the accounting and financial portions.

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an initial value for labor, a labor-to-capital ratio, and the labor quit and layoff rates.[15]

To round out the presentation of structure, figure 8 departs from the capital-ordering example of figure 7 and diagrams the equation blocks for the other factor of production, labor. Although the terminology applies to the control of the stock of labor, analogous calculations control the stock of capital.[16]

Figure 8 also shows the major interconnections that form the dominant control loops within the physical portion of the equations. Of course, there are many interactions that are not shown: minor interactions among the equation blocks of the physical portion, and interactions with the other portions of the generic production sector. For example, the "inventory and shipping" block provides important inputs to the accounting portion, and the financial portion calculates liquidity, which in the extreme can impact upon creation of job vacancies through the "effects on creation of vacancies" equation block.

This is not to imply that other loops that travel outside the physical portion of the production sector are not important; they just lie outside the structure that has been chosen as an example. Section 3 on interactions between sectors spells out many of the normal supply-demand feedback loops that control the sectors relative to each other. And even within the production sector, decisions such as product price are intimately involved with the capital-ordering decision: what is profitable at one price is a waste of money at another, and the decision structure of the model deals with such issues.

The first sample loop, Loop 1 on figure 8, guides the actual stock of labor toward the amount of desired labor: desired labor is compared with the actual labor in the "correction to orders for labor" equation block. (For the labor factor of production, to "order" is to create a job vancancy; for the capital factor of production, to "order" is literally an order.) For example, if desired labor is greater than actual labor, the correction to orders for labor (a model variable) is positive, and in the "orders for labor" equation block, more orders for labor are made. Interacting with the labor sector (not shown on figure 8), the sector hires more labor in the "labor in sector" equation block. The increased labor reduces the discrepancy between actual and desired labor.

Loop 2 regulates the amount of labor in the sector relative to labor productivity; loop 2 contains the mechanisms that determine over time how much labor (versus how much capital) should be used to produce the sector's output. Of course, the "production" equation block of course computes a production rate, but it also computes the normal marginal productivity of labor: how much additional production results from adding an employee when a normal amount of work is available. That information is combined with information about how much labor costs and how much cash the sector derives from additional production in the "marginal revenue and cost" equation block, which compares marginal revenue to marginal cost and influences the desired labor. This in turn influences ordering of labor, labor itself, and thus marginal productivity of labor (adding people reduces the productivity of adding yet another person).

It is important to emphasize that the process of seeing how productivity and costs should influence the amount of labor does not happen overnight. In the National Model, just as in real life, it takes time to perceive such issues, convince others, and finally act. The delays and the constraints in the process are important to the dynamics. In fact, the delays and sources of amplification in loop 2 often create a tendency to show 20-year fluctuations resembling the so-called "Kuznets cycle" which has been observed in real economic data.[18]

Loop 3 regulates the amount of labor, and thus production, relative to the demand for the sector's output by other sectors. For example, if the sector's combination of labor and capital creates too much production, an excess of inventory and a shortage of backlogged orders would result within the "inventory and shipping" equation block. The state of inventories and backlogs would reduce the desired production

rate. Lower desired production would in time diminish desired labor, actual labor, and production.

Loop 3 has several delays within its equation blocks. It takes time for increased production to work down an excess of inventory, during which time there is continuing pressure to increase production. Likewise, it takes time for enough people to be hired to bring labor up to desired labor. In model simulations, the delays along loop 3 cause the system to show simulated three- to seven-year business cycles, whose properties match real business cycles very well, in terms of period, amplitude, and phase relationships among variables such as inventories, production, employment, and order backlogs.[18]

Loop 4 represents the shorter-term, more limited ways that inventory and backlog conditions influence production. The "effects on productivity and workweek" equation block represents effects on the average hours per week worked in the sector, and the productivity per man-hour, from the added efficiency of having enough work to keep busy and efficient, plus moderate supervisory pressure to work effectively, both of which are absent when desired production is low. Both ways of influencing production operate more quickly than the labor acquisition controlled by loop 1, but they are much more limited in the degree to which they can change production; supervisory pressure and working hours cannot be changed by very much before they become counterproductive.

One of the common tests for the National Model structure has been to isolate structures like that diagrammed in figure 8 and look at the resulting behavior: Does it make sense as a representation of an individual firm? What are its stability characteristics? Are its responses plausible? With such tests, the experimenter can evaluate the structure by its behavioral implications, from the level of an individual goal-seeking loop (such as any of those in figure 8), to the physical portion of a sector, to an entire sector (with accounting and finance active), to an entire macroeconomy. This is one of several procedures aimed at ensuring that macrobehavior arises from a sensible and realistic microstructure.

4. CONCLUDING REMARKS

This is the appropriate point in the exposition to point out the lack of constraint imposed by the model organization and structure. The model's organization has been rather fluid, changing from month to month as the implications of model behavior (and misbehavior) became clearer, and structure was added or changed. The resulting organization has functioned as a framework into which specific cause-and-effect relationships can be inserted (as necessitated by the model's purpose).

One difficulty for a description of a system dynamics model is the sense of ordinariness and plainness that normally surrounds the description. That sense comes from the way the model is constructed. Models are often judged by how well the structure is explainable in terms of familiar cause-and-effect relationships that people can observe in everyday life. This is the first of the two themes in this paper: that the model structure arises primarily from observable causes and effects at the level of the individual, as viewed through the lens of the model's purpose.

The only real surprises in this paper should have come in conjunction with other reports on the behavior of the National Model: that significant, troublesome macroeconomic behavior can be explained by such straightforward cause-and-effect relationships. This paper points out these relationships in the context of structure; in fact, the structures at the core of the three- to seven-year business cycle and the 20-year Kuznets cycle occur within the confines of the physical portion of a single production sector. This is the second theme of the paper: that straightforward microstructure can explain most of the observed macroeconomic behavioral problems.

5. NOTES

[1] For a description of the purpose, philosophy, and some of the results of the National Model, see [J. Forrester 1984] or [Forrester, Mass, and Ryan, 1976].

[2] A sampling of papers from the National Model Project: an application to inflation in [J. Forrester 1982]; to business cycles in [N. Forrester 1982]; problems of economic growth and stagflation as explained by long-period (fifty-year) fluctuations in capital accumulation [Senge 1984], [Graham 1982], [Graham and Senge 1980], [J. Forrester 1979]. Also, a list of publications from the National Model Project is available from the System Dynamics Group, MIT, E40-294, Cambridge, Massachusetts 02139.

[3] The outline and contents of this paper have drawn in part from a draft model description by Peter Senge. I am also grateful to Jay Forrester for his comments on an earlier draft of this paper. Naturally, any errors of comission or omission in this manuscript remain, alas, my own.

[4] Setting out what the model represents <u>implicitly</u>, and what the model does <u>not</u> represent, is a more treacherous undertaking than saying what is explicit within the model; this paper will not attempt the former tasks. There are a host of implicit assumptions in any model, which may be quite adequate for economic purposes, but which also may be considered vital to someone working on a different set of problems. Two examples: implicitly, the model assumes that air is available to employees to breathe. This assumption is perfectly adequate for an economic model, but completely inadequate for someone dealing with issues of pollution control and its economic effects (the breathability of the air is an important variable in computing the cost of pollution control). As another example, the present version of the National Model has no foreign sector. (See [Sterman 1981] for a version that has a foreign sector.) Implicitly, the model is assuming that there is at least an approximate balance of trade. This assumption is probably adequate for analyzing many issues surrounding the 50-year economic long wave (because most industrialized countries are synchronized in their long-wave growth and depression periods). But the assumption is less adequate for policy analysis for a nation with a higher dependence on exports than the U.S. And the assumption is quite inadequate for analyzing currency stabilization schemes, or the impact of monetary policy on international capital flows.

[5] At issue is not whether one approaches a problem with "priors" already in place (one always does), but the nature and appropriateness of those prior beliefs. Rather than approaching the economic problem with Keynesian or monetarist priors on the important influences on economic behavior, the National Model Project has

approached the analysis of macroeconomic behavior with prior beliefs of an entirely different nature. The prior beliefs are methodological ones, and relatively mild ones at that. System dynamicists believe that system behavior can be replicated and analyzed with simulation models of ordinary differential equations. (Most of the physical science and engineering profession shares the same belief.) [J. Forrester 1961] is the classic description of system dynamics; [Andersen 1977] and [Richardson 1983] discuss system dynamics methodological priors in comparison to other disciplines.

However, existing economic theories do have an important role in evaluating the adequacy of an economic model's structure: the structure must contain all of the important causal mechanisms that the major macroeconomic theories presume to be critical. In other words, if a given macroeconomic theory is true, the model must be able to replicate its operation, and if a theory is false, the model should contain sufficient structure to demonstrate why the given set of cause-and-effect relationships do not dominate the behavior of the economy. Also, the discipline of economics has evolved a vocabulary and a body of results about cause-and-effect relationships that are tapped for structuring several areas of the model.

[6] Technically the number of equations shown in figure 1 is the number of equation evaluations. The model's structure is expressed in the DYNAMO III version of the DYNAMO simulation language which allows a single equation to represent several quantities that are computed in the same way; the equations are written with subscripts. One subscript allows one equation to be evaluated once for each production sector. Naturally, the inputs and parameters for each equation evaluation are likewise subscripted so that they will be appropriate for each sector in turn. An additional subscript allows an equation to be evaluated for different factors of production (labor or capital) within each sector, again with inputs and parameters subscripted. For instance, accounts payable for capital goods and accounts payable for consumer goods are calculated separately, but by using the same equation. That equation appears in the model only once, but is evaluated several times, each time using different input values. The counting of equations in figure 1 would count such a case as several equations, not just one. This method of counting gives a clearer indication of the size and complexity of the model.

The equations for stocks count evaluations of L equations in the DYNAMO notation. Equations to intialize stocks are N equations. Parameter definitions are the number of parameters and whole table specifications (as opposed to counting as several values the numbers in a single table function). Parameter definitions include C, T, and I equations. The algebraic equations are A, R, and K equations.

[7] Surprisingly, many models compute interest rates in terms of a markup above the Federal Reserve's discount rate, which is given

exogenously as a fixed time series. This despite the frequent reporting in the business press (and descriptions by the Federal Reserve itself) of the discount rate changing in response to economic conditions. [Hines 1984] gives a theoretical and statistical discussion of the endogenous interest rate computation used in the National Model.

[8] [Morecroft 1983] describes the application in which the National Model's production sector was the basis for an investigation of management information systems, and [Sterman 1982, 1981] describes the use of the National Model structure in an application to energy-economy interactions.

[9] Technically, the people in the pool of nonemployed are those without jobs who are actively seeking work (which is the official definition of "unemployed"), and those who are not actively seeking work but who would accept a job if offered one. Obviously, statistics for the latter category are difficult to obtain than for the former. But the broader definition is more appropriate for this model for technical reasons.

[10] Alan Blinder is a Professor at Princeton University. He is quoted from pg. 420, "Discussion on the Current State of Macroeconomic Theory," American Economic Review, vol. 74, no. 2, May, 1984.

[11] For example, in agricultural markets, a higher product price motivates farmers to produce more wheat or hogs, for example. To produce more, they must retain more seed wheat and sows. This means they will send less to market. So the immediate effect of higher wheat or pork prices is to create more shortage and still higher prices. The long-term equilibrium production is of course more sales and production of each, which is opposite from the short-term response.

[12] The discussion of the operation of the financial sector that follows in the text is simplified, being simpler than either the model or real life. It is true that there are different reserve requirements imposed by various banking authorities for different financial instruments at different institutions. But such details do not seem to lie at the heart of the major economic difficulties at which the model is aimed. The discussion also neglects the arithmetic of fractional reserve expansion and the added complication of deposits in multiple banks. Also, to simplify the discussion, a single interest rate is spoken of, when in fact the model contains several related interest rates: a risk-free rate for government debt, a corporate bond rate for each sector, and a return on household nonequity investments. Finally, the discussion of the effect of interest rate on investment neglects all of the other influences on investment shown later in figure 7, and their implicit use in a net present value calculation.

[13] [Senge 1984] contains a detailed discussion of the role of inflation and real interest rate in the model's creation of long waves, as well as empirical results on fluctuations in real

interest rate and related quantities. [Sterman 1984a and 1984b] also provide discussion.

[14] The pricing formulation in the model is still evolving. The formulation is intended to represent, through parameter changes, a number of different pricing behaviors. The pricing behavior described in the text applies in industries that have "administered prices," such as the automobile industry, where prices respond to competitive pressures relatively slowly and there exist strong pressures to set price at a profitable level. By contrast, an auction-type pricing behavior has price responding to supply and demand very quickly, with no particular restraint on how far down or up prices will go, at least in the short term. Most agricultural commodities have auction-type markets.

[15] The diagram of equation blocks in figure 8 is similar in spirit, but not identical to, Morecroft's policy-structure diagrams [Morecroft 1982], in which an oval represents all of the structure surrounding a given policy. Here, in a substantially more complex system, the ovals may encompass more than one distinct policy; they are within one equation block because they are closely related. In such cases, creating another equation block would increase, rather than diminish, the complexity of presentation.

[16] The terminology on figure 8 differs from the terminology for the physical sector equation blocks in the actual model. There, the labels for the equation blocks, like the equations themselves, are generic, and apply to both capital and labor. This convention creates a bit of abstractness that can be difficult to penetrate at first. Rather than forcing the reader to confront issues of how factors of production or production sectors are to be represented by a generic set of equations, the nomenclature has been altered so that it describes a specific factor of production, labor, and leaves implicit the notion that the description applies to both the capital sector and the consumer goods- and services-producing sector.

[17] See [Abramowitz 1961] for an authoritative treatment of Kuznets cycles.

[18] Two studies that have come out of the National Model Project focussing especially on the short-term business cycle are [Mass 1975] and [N. Forrester 1982].

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