AN INTEGRATED THEORY OF THE ECONOMIC LONG WAVE

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ABSTRACT

The economic crisis of the 1980s has revived interest in the economic long wave or Kondratiev cycle. Since 1975 the System Dynamics National Model has been the vehicle for the development of an endogenous, dynamic theory of the economic long wave. The model has now reached the point where an integrated theory of the long wave can be described. The theory incorporates many of the partial theories that have been proposed by others. Simulations of the model are presented to show the wide range of empirical evidence accounted for by the model.

In particular, the theory suggests the long wave arises from the interaction of two fundamental facets of modern industrial economies. First, the existence of physical lags in the economy, limited information available to decisionmakers, and bounded rationality in economic decisionmaking creates the potential for inherently oscillatory behavior. Second, a wide range of self-reinforcing processes exist which destabilize the inherent oscillatory tendencies of the economy, leading to the long wave. These processes involve many sectors of the economy including capital investment, labor markets and workforce participation, real interest rates, inflation, debt, savings and consumption, and international trade. The paper discusses the relative strengths of these mechanisms and the amplification of the long wave through their interactions. The linkages of the long wave theory to innovation, technological progress, and political value change are discussed.

AN INTEGRATED THEORY OF THE ECONOMIC LONG WAVE

1. Introduction

The economic malaise of the 1970s and 80s has revived interest in the economic long wave or Kondratiev cycle (Kondratiev 1935). Numerous theories of the long wave have emerged in the past 10 years, including theories stressing innovation, labor dynamics, resource scarcity, and class struggle.[1] Since 1975 the System Dynamics National Model (NM) has provided an increasingly rich theory of the long wave (Forrester 1981, 1979, 1977, 1976; Graham and Senge 1980; Senge 1982; Sterman 1984). Though the model focuses primarily on economic forces, the theory emerging from the NM is not monocausal: it relates capital investment; employment, wages, and workforce participation; inflation and interest rates; aggregate demand; monetary and fiscal policy; innovation and productivity; and even political values. The NM is unique among recent theories of the long wave in that it views the long wave as a syndrome consisting of interrelated symptoms and springing from the interactions of many factors. The NM integrates diverse hypotheses about the genesis of the long wave. The NM also provides an analytical framework in which alternative theories can be tested in a rigorous and reproducible manner.

This paper describes the integrated theory of the long wave that has now emerged from the NM. The behavioral underpinnings of the theory are discussed and contrasted against traditional economic theory. The major sources of the long wave are presented and analyzed through simulations. Though not intended as a definitive treatment of empirical evidence for long waves, the paper presents some of the basic corroborative evidence to show how the NM endogenously generates a wide range of economic data.

2. Behavioral Foundations

The NM is a structural, behavioral model. It is a dynamic, disequilibrium model. These features distinguish the NM from econometric and optimizing models (such as general equilibrium models) in several important respects.

2.1. Macrobehavior from Microstructure

The NM is a structural model. Structure as used here includes the physical structure of the economy (the stock and flow networks of capital, goods, people, and money), flows of information about the state of the system, and the behavioral decision rules people use to manage their affairs. The structure of the economy is represented at the microeconomic level of individuals and firms. By modeling decisionmaking and the physical structure of the system at the microlevel, the macrolevel dynamics of the economy emerge naturally out of the interactions of the system components. Because such models provide a behavioral description of the economy firmly rooted in managerial practice, they are well suited for examining the dynamic effects of policy initiatives.

2.2. Disequilibrium Dynamics

The model does not assume that the economy is always in equilibrium, or that it moves smoothly from one equilibrium to another. Though individuals may be striving for equilibrium, disequilibrium is the rule rather than the exception. To properly model adjustment dynamics, one must not presume the stability of the system. Rather one must model the pressures that may lead to equilibrium, including the way people perceive and react to imbalances, and the delays, constraints, and inadequate information that often confound them.

2.3. Bounded Rationality

The behavioral assumptions of the model rest on the theory of bounded rationality (Cyert and March 1963, Merton 1936, Nelson and Winter 1982, Simon 1947, 1957, 1978, 1979). The essence of the theory is summarized in the principle of bounded rationality, as formulated by Herbert Simon (1957, p. 198):

> The capacity of the human mind for formulating and solving complex problems is very small compared with the size of the problem whose solution is required for objectively rational behavior in the real world or even for a reasonable approximation to such objective rationality.

The theory of bounded rationality provides both theoretical underpinnings and a rich data base for the development of behavioral models in economics.[2] Bounded rationality has several important implications for behavioral modeling of economic dynamics.

2.3.1 Limited information-processing capability: Humans have a limited ability to process information. As a consequence, "perception of information is not comprehensive but selective" (Hogarth 1980, p. 4; original emphasis). Human decisions are made on the basis of a small number of cues rather than an extensive appraisal of the situation. Further, people rely on information they judge to be relatively certain, and on information they believe to be causally important. But at the same time the mental models people construct to guide their decisions are often systematically incorrect. Learning, which might gradually eliminate such biases and errors through "natural selection," is often slow and hindered by the limited information available, by the common tendency to ignore unfavorable information, and by the use of selective hindsight.[3]

2.3.2 Decentralized Decisionmaking: The impossibility of comprehending the system as a whole and of processing the masses of

information that confront us in the real world have forced people to evolve decomposition strategies to simplify decisionmaking. The chief strategy for simplification is decentralized decisionmaking. The total task of managing an organization is divided into smaller tasks assigned to subunits within the organization. The subunits ignore, or treat as constant or exogenous, those aspects of the total situation that are not directly relevent to their subgoal (Simon 1947, p. 79):

> Individual choice takes place in an environment of "givens" --premises that are accepted by the subject as bases for his choice....

2.3.3 Rules of Thumb: In addition to ignoring much of the potentially available information, people within organizational subunits use simple heuristics or rules of thumb to process information. Rules of thumb rely on relatively certain information that is locally available to the subunit. Rules of thumb are not the result of rational calculation but evolve in response to environmental pressures. They are the routines and standard operating procedures of organizations (Morecroft 1983).

2.3.4 Bounded Rationality and Traditional Economics: The theory of bounded rationality stands in stark contrast to the classical rationality of traditional economics. Unlike classical economic theory, the NM does not presume that individuals and firms have perfect information or the ability to optimize their performance. Such behavioral models are often criticized because they assume people rely on decisionmaking heuristics, "irrationally" failing to optimize their performance. Performance, it is argued, could be improved by using more information or more sophisticated decision rules. But a good model of economic dynamics must be descriptive: to simulate (in the sense of mimic) the behavior of a system accurately, decisionmaking must be portrayed as it is and not as it might be if people

were omniscient optimizers. The empirical work on decisionmaking heuristics and cognitive biases provides a firm empirical foundation for behavioral models in economics.

3. Multiple Modes of Behavior

Figures 1a-d show the behavior of important economic variables in the United states from 1800 to 1984. The data exhibit many modes of behavior. The behavior of real GNP, for example, is dominated by the long-term growth of the economy, which has averaged 3.4 percent/year for nearly two centuries. In addition, GNP fluctuates around the growth trend with the business cycle, which has an average period of four to seven years. And there is a hint of longer term fluctuations in the rate of output--output is lower than normal between 1830 and 1840, during the 1870s through 1890s, during the Great Depression, and from the 1970s to the present. These dates coincide with the timing of the long wave established by van Duijn (1983) through examination of global economic data.

The long wave is more apparent in the behavior of unemployment, aggregate prices, and interest rates. Unemployment fluctuates strongly with the business cycle, but also exhibits major peaks during the 1890s and the 1930s. Unemployment rates today are the highest since the Great Depression. Consumer prices likewise fluctuate with the business cycle but also exhibit a fairly regular long wave, with peaks roughly coincident with the peaks of the long wave in real activity. An additional mode of behavior develops after World War II, however, as inflation has carried the price level to unprecedented levels, dominating the long wave pattern in prices. (Note however that the reduction in inflation since 1980 is consistent with the deflationary forces of the long wave downturn). The

postwar inflation coincides with the expansion in the relative size of government from about 10 percent of GNP in the 1920s to about 35 percent in the 1980s, and with the increasing reliance on deficit financing and monetization of the public debt (Richmond 1984).

Interest rates show a similar pattern, rising and falling with a roughly 50 year period. Note that interest rates are approximately in phase with the price level. Indeed, interest rates and prices were among the chief data Kondratiev relied upon to argue for the existence of long waves. Like prices, interest rates have risen above historic levels in the last decade as inflation has reached double digit rates.

The available data reflect the combination and interaction of several distinct modes of behavior, including long-run population growth and technological progress, the business cycle, the relative growth of government, post-war inflation, and the long wave. The interaction of the modes makes it difficult to establish the existence of the long wave through purely empirical means, especially since reliable numerical data are not available over a long enough period.[4]

Because the National Model represents behavior at the microlevel of individuals and firms, it generates the multiple modes of economic behavior that appear in the historical data. Compare the historical data against figures 2a-c, which show a simulation of the National Model from 1800 to 1984. As shown in table 1, all the macroeconomic aggregates are generated endogenously, as are a host of variables at the sectoral level. The only exogenous variables are population (which is assumed to grow at a uniform two percent per year rate); technological progress (assumed to grow at a uniform one percent per year rate); and per capita government activity (which grows in response to a constant pressure starting in 1930). In

addition, a small amount of random noise has been added to production and ordering rates. The noise serves to trigger the business cycle and causes the point-by-point behavior to be somewhat irregular.

Simulated unemployment, real GNP, interest rates, and prices all exhibit the long wave and business cycle. The period of the long wave is approximately 50 years. The long wave does not die out over time. In addition, GNP exhibits the long-term growth of the economy, and prices show the postwar inflation due to the growth of government and the partial monetization of growing government deficits. Because historical data series are not used as inputs, the behavior, and in particular the long wave, is the endogenous result of the interaction of the system components and is not driven by the exogenous variables. Without attempting to reproduce the point-by-point behavior of the economy, the simulation captures the major patterns in the development of the economy over almost 200 years.[5]

4. Origin of the Long Wave

The long wave is characterized by successive waves of overexpansion and collapse of the economy, particularly the capital-producing sector. Overexpansion means an increase in the capacity to produce and in the production of plant, equipment, and goods relative to the amount needed to replace worn-out units and provide for growth over the long run. Overexpansion is undesirable because, eventually, production and employment must be cut back below normal to reduce the excess.

How does the long wave arise? In particular, how does overexpansion of the capital-producing sector of the economy arise? The explanation can be divided into two parts. First, the internal structure and policies of

individual firms tend to amplify changes in demand, creating the potential for oscillation in the adjustment of capacity to changes in the desired level. Second, a wide range of self-reinforcing processes significantly amplify the response of individual firms to changes in demand, increasing the amplitude and lengthening the period of the fluctuations generated by each firm. Through the process of entrainment, the fluctuations generated by individual firms become coherent and mutually reinforce one another (Homer 1980).

4.1 Amplification of Demand by Individual Firms

One basic cause of overexpansion is the tendency for production systems to amplify changes in demand. For example, consider a retailer of consumer goods. Imagine (for simplicity) that customer orders are constant. Now consider the effect of a sudden, unanticipated step increase in orders, say of 10 percent. In the long run, the retailer will increase orders to its suppliers by 10 percent and will probably hold 10 percent more inventory to provide the same coverage of demand. The suppliers, in turn, will increase their production by 10 percent as well. But what happens during the adjustment period?

First, the retailer will wait to see whether the unanticipated increase in demand is lasting enough to warrant a change in orders or whether it is merely a transient change. Once the persistence of the new level of demand becomes clear, the retailer will decide to order 10 percent more to meet the customer's needs. But it takes time to receive goods from suppliers because of shipping delays and because the suppliers must increase their own production. Increasing production takes time because more parts and raw materials must be ordered, more workers hired, and possibly, new capacity acquired. The delays in reacting to the new level

of orders, and in increasing output and shipping it to the retailer, mean the retailer's inventories will decline. Backlogs will rise. To correct these imbalances, the retailer must place more orders with suppliers, expanding orders above customer demand. Orders must remain above customer demand long enough to replenish inventories and work off the excess backlogs. Thus customer demand is amplified by the stock adjustments caused by the delays in receiving goods.

But the situation is worse: a higher volume of business requires a larger stock of inventory to maintain the same coverage ratio. So orders to suppliers must rise even farther above demand to build inventories up to a higher level consistent with the higher demand. Further, retailers may find themselves unable to get the units they need to meet demand and replenish inventories. As a direct result of the surge in orders, the lead time for supplies may rise, since the suppliers face delays in ordering their own parts and materials, hiring new workers, and expanding capacity. Faced with rising delivery times, retailers may hedge by ordering still more and placing orders with more than one supplier, a process described by economist Thomas W. Mitchell (1923, p. 645):

> Retailers find that there is a shortage of merchandise at their sources of supply. Manufacturers inform them that it is with regret that they are able to fill their orders only to the extent of 80 per cent; there has been an unaccountable shortage of materials that has prevented them from producing to their full capacity. They hope to be able to give full service next season, by which time, no doubt, these unexplainable conditions will have been remedied. However, retailers, having been disappointed in deliveries and lost 20 per cent or more of their possible profits thereby, are not going to be caught that way again. During the season they have tried with little success to obtain supplies from other sources. But next season, if they want 90 units of an article, they order 100, so as to be sure, each, of getting the 90 in the pro rata share delivered. Probably they are disappointed a second time. Hence they increase the margins of their orders over what they desire, in order that their pro rata shares shall be for each the full 100 per cent that he really wants. Furthermore, to make doubly sure, each merchant spreads his orders over more sources of supply.

Such hoarding behavior is quite common. A recent example is provided by the paper industry, which, faced with surging demand and operating at 97 percent of capacity instituted "an allocation system in which, for example, everyone receives just 90 percent of an order." As a result, "many customers are also 'double booking' -- placing orders with two manufacturers to make sure their needs are met, then often canceling one of them" (The New York Times, 5 April 1984, p. D-1).

Other sources of amplification include growth expectations and the spread of optimism, as described by Wesley C. Mitchell (1941, p. 5):

> Virtually all business problems involve elements that are not precisely known, but must be approximately estimated even for the present, and forecast still more roughly for the future. Probabilities take the place of certainties, both among the data upon which reasoning proceeds and among the conclusions at which it arrives. This fact gives hopeful or despondent moods a large share in shaping business decisions.... Most men find their spirits raised by being in optimistic company. Therefore, when the first beneficiaries of a trade revival develop a cheerful frame of mind about the business outlook, they become centers of infection, and start an epidemic of optimism.

Additional amplification arises because the increase in customer demand and lagged response of production will boost prices, causing further expansion of orders and output as profits rise (Mass 1980).

Thus each stage in the production-distribution network of the economy tends to amplify changes in demand. The amplification increases at each stage as demand, swollen by adjustments for inventories, supply lines, expectations, and anticipated profits, is passed back from retailers to wholesalers, manufacturers of finished goods, manufacturers of intermediate goods, and finally to capital and raw materials producers. Amplification in successive stages of the production chain explains why the volatility of an industry tends to increase as it becomes further removed from consumer demand (Hansen 1951). The capital-producing industries (construction,

machinery manufacturing, raw materials, etc.) are the farthest removed from final demand and hence experience the most instability.

The preceding analysis shows that the internal management policies of firms, coupled with the unavoidable lags in reacting to changes in demand and in increasing capacity, lead to the tendency for production and capacity to fluctuate. The amplification of demand by stock adjustments is a fundamental characteristic of firms, and is responsible for several oscillatory modes of behavior including the four- to seven-year business cycle and the Kuznets or intermediate cycle of approximately 15 to 25 years.[6] Parallel oscillatory structures exist in the household sector and govern the adjustment of consumers' stocks of durable goods and housing.

The mechanisms responsible for the business and intermediate cycles have been identified and are distinct. The business cycle is primarily the result of inventory and employment interactions. The intermediate cycle is primarily the result of attempts to balance the mix of capital and labor as factors of production. The difference in period arises from the differences in the relatively short time required to adjust inventories and change employment compared to the longer time required to acquire and discard capital and alter the mix of factors.

Simple models show that the amplification of demand by inventory and backlog adjustments leads, in isolation, to highly damped oscillations in capital investment with periods of approximately 20 years (Mass 1975, Sterman 1984). Yet the long wave is a 50 year fluctuation which does not die away. The long period, large amplitude, and persistent nature of the cycle arise from a wide range of self-reinforcing processes which operate in the economy as a whole. These positive feedback loops couple different

60 firms to one another and to the household and financial sectors of the economy. The net effect of these self-reinforcing processes is to further amplify the inherently oscillatory tendencies of individual firms, stretching out the period and increasing the amplitude of the fluctuations. Analysis of the model isolates several independent processes which contribute to the 50 year cycle of overexpansion and economic decline.

4.2 Capital Self-ordering

The National Model distinguishes producers of capital plant, equipment, and basic materials from other firms in the private sector. The capital sector differs from others due to the existence of "self-ordering." In order to expand capacity, producers of capital plant and equipment must order additional plant and equipment from each other. In the aggregate, the capital-producing sector acquires capital from itself, hence self-ordering. Though all sectors of the economy are linked to one another to some degree, self-ordering is strongest in the industries that produce capital plant and equipment, basic industries such as steel, and other heavy industry (Sterman 1982).

To illustrate the role of self-ordering in the long wave, consider the economy in equilibrium. If the demand for consumer goods and services increases, the consumer-goods industry must expand its capacity and so places orders for new factories, equipment, vehicles, etc. To supply the higher volume of orders, the capital-producing sector must also expand its capital stock and hence place orders for more buildings, machines, rolling stock, trucks, etc., causing the total demand for capital to rise still further in a self-reinforcing spiral of increasing orders, a greater need for expansion, and still more orders.

Figure 3 shows the behavior of real GNP, consumption, and investment generated by the National Model. Population growth, technical progress, and the relative growth of government have been suppressed to focus attention on the long wave. In the simulation, therefore, there are no exogenous variables whatsoever, and the behavior is entirely the endogenous result of the interaction of the assumed decision rules with the physical structure of the economy.[7] Real GNP fluctuates with the business cycle but is dominated by a long wave with an approximately 50 year period. The long wave tends to be asymmetrical, with a gradual expansion over about 20 years followed by a relatively swift decline and a depression period of 15 to 20 years. While the long wave is visible in consumption, it is by far largest in real investment. The magnitude of the fluctuation in investment is larger than that in consumption even though investment is only about a fifth as large as consumption. The large amplitude of investment relative to consumption is a reflection of the destabilizing influence of capital self-ordering: changes in the demand for capital deriving from the goods sector are amplified by self-ordering to cause a much larger swing in the total demand for capital.

The strength of self-ordering depends on a number of factors, but chiefly on the capital intensity (capital/output ratio) of the capital-producing sector. A rough measure of the strength of self-ordering can be calculated by considering how much capital production expands in equilibrium in response to an increase in investment in the rest of the economy. It is easily shown that the equilibrium multiplier effect created by self-ordering is given by:[8]

$$1/(1-KCOR/KALC)$$

where

KCOR = capital output ratio of the capital sector (years)
KALC = average lifetime of capital in the capital sector (years).

Assuming an average life of capital of 20 years and an average capital/output ratio of three years (approximate values for the aggregate economy) gives an equilibrium multiplier effect of 1.18. In the long run, an increase in the demand for capital from the rest of the economy yields an additional 18 per cent increase in total investment through self-ordering.

The long wave is an inherently disequilibrium phenomenon, however, and during the transient adjustment to the long run the strength of self-ordering is greater than in equilibrium. During the adjustment to the long run, the disequilibrium effects that lead to amplification of demand all act to further augment the demand for capital, creating a number of additional positive feedback loops.

4.2.1 Amplification Caused by Inventory and Backlog Adjustments: Rising orders deplete the inventories and swell the backlogs of capital-sector firms, leading to further pressure to expand and still more orders. During the downturn, low backlogs and involuntary inventory accumulation further depress demand, leading to still more excess inventory. Figure 4 shows the effect of inventory and backlog pressures on desired production of capital by the capital sector. The "output discrepancy" measures the need to adjust production above or below the order rate in order to bring inventories and backlogs into balance with their desired levels. A positive output discrepancy indicates inadequate inventory and bloated backlogs are boosting desired production above orders. As shown, the output discrepancy of the capital sector builds up during the expansion

phase of the long wave, forcing desired production well above orders, even as orders are rising, and substantially reinforcing the demand for capital. Peaking shortly before the peak of real GNP, the output discrepancy collapses precipitously during the long wave decline as excess inventories rapidly accumulate.

4.2.2. Amplification Caused by Rising Lead Times for Capital: As shown in figure 5, the delivery delay for capital rises well above normal during the long wave expansion. Delivery delay tends to peak four to 10 years in advance of real GNP, reaches normal levels roughly at the time of the peak, and drops well below normal during the downturn of the cycle. As the demand for capital outstrips capacity during the long wave expansion, backlogs rise, causing lead times for plant and equipment to rise. Capital producers find it takes longer than anticipated to acquire new capacity, causing capacity to lag further behind desired levels, creating still more pressure to order and further swelling the demand for capital. In addition, longer lead times force capital producers to order farther ahead, further augmenting orders, as described by T. W. Mitchell.

The delivery delay for goods likewise fluctuates with the long wave. During the long wave expansion, capital is scarce, and the goods sector cannot increase capacity fast enough to meet demand, causing the delivery delay for goods to rise. But note that the amplitude of the fluctuation in the availability of goods is only about eight percent of normal while the amplitude of the delivery delay for capital averages about 25 percent, showing the powerful role of self-ordering in destabilizing the capital sector.

The lead time for capital also exhibits the 20 year Kuznets or construction cycle, which creates smaller and narrower peaks in delivery

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delay between the major surges which occur during the long wave expansion. The intermediate cycle is primarily the result of efforts to balance the mix of capital and labor as the availability and price of these inputs vary.

4.2.3. Amplification Caused by Growth Expectations: The special role of the capital sector in creating the long wave is again demonstrated by the behavior of growth expectations. During the expansion phase, rapidly growing demand, rising backlogs, and long lead times all encourage expectations of additional growth in demand for capital. Expectations of future growth lead to additional investment, further swelling demand in a self-fulfilling prophecy. As shown in figure 6, capital producers' long-term expectations of growth in the demand for capital fluctuate substantially over the long wave. Expectations of demand growth in the capital sector fluctuate between about -4 and +6 percent per year over the long wave, peaking two to eight years before the peak of real GNP. Note however that due to perception lags and institutional inertia growth expectations are highest just before real investment peaks and begins to decline. (Compare figure 6 to the timing of real investment shown in figure 3.) Thus growth expectations exacerbate the excess capacity that develops at the peak of the long wave. In contrast, expectations of growth in the demand for goods show a substantially smaller amplitude and peak slightly after the peak of real GNP.

4.2.4 The Sufficiency of Self-Ordering: The positive feedback loops created by self-ordering significantly reinforce the natural tendency of firms to amplify changes in demand. Once a capital expansion gets under way, the self-ordering loops amplify and sustain it until production catches up to orders, excess capacity is built up, and orders begin to fall.

At that point, the self-ordering loops reverse: a reduction in orders further reduces the demand for capital, leading to a contraction in the capital sector's output, followed by declining employment, wages, aggregate demand, and production of goods and services. Capital production must remain below the level required for replacement and long-run growth until the excess physical and financial capital is depreciated--a process that may take a decade or more due to the long lifetimes of plant and equipment. Once the capital stock is worn out, investment rises, triggering the next upswing.

To illustrate, consider the development of the U.S. economy after World War II. The capital stock of the economy was old and severely depleted after 15 years of depression and wartime production. Demand for all types of capital equipment--roads, houses, schools, factories, machines--surged. A massive rebuilding began. In order to both satisfy long-run demand, fill pent-up demand, and rebuild the capital and infrastructure, the capital-producing sector had to expand beyond the long-run needs of the economy. The overexpansion of the capital-producing sector was exacerbated by self-ordering: as the demand for consumer goods, services, and housing rose, manufacturers of capital plant and equipment had to expand their own capacity, further swelling the demand for structures, equipment, materials, transportation, and other infrastructure. Thus self-ordering helped trigger the boom of the 1950s and '60s. By the late 1960s, the capital stock had been largely rebuilt, and investment began to slow to levels consistent with replacement and long-run growth. Excess capacity and unemployment began to show up in basic industries. Faced with excess capacity, investment in these industries was cut back, further reducing the need for capital and reinforcing the decline in investment as the economy moved through the 1970s and into the 1980s.

Self-ordering is one of the most important and fundamental causes of the long wave. Simple models that include only the most basic self-ordering feedbacks can generate a robust long wave (Sterman 1984). Self-ordering is therefore a sufficient cause of long waves.

4.3 Employment and Wages

Self-ordering, though it may be sufficient to generate the long wave, is not the only mechanism at work. Other positive feedback loops operate through the labor markets to add additional amplification (figure 7). As illustrated by figure 8, employment growth is rapid during the early years of the long wave expansion, but slows once the available pool of unemployed is largely utilized. Growing scarcity of qualified labor then force real wages to rise. Wage growth is especially high during the late expansion period. Scarcity of qualified workers and higher labor costs during the late expansion encourage the substitution of capital for labor throughout the economy, further augmenting the demand for capital. Real wages fall after the peak in real GNP, further undercutting the incentives for capital investment during the depression phase.

If the positive loops surrounding labor and wages play a significant role in the long wave, one would expect the early phase of the long wave expansion to involve simultaneous expansion of labor and capital. As real wages rise, a period of stagnant employment but continued growth of capital and output should follow. Such patterns have been documented for both the U.S., Europe, and Japan (figures 9a and 10a). Compare these figures against figures 9b and 10b which show the shifting balance of labor and capital generated by the NM simulation shown in figure 2. Though the long-term growth of population and technology cause both labor and capital to rise, the long wave causes significant fluctuations in their relative rates

of growth. Like the historical data, simulated labor and capital rise together as the long wave expansion begins. Labor growth then slows as the pool of unemployed is exhausted (employment continues to grow slightly as high wages cause an increase in workforce participation). At the long wave peak, labor falls sharply, while capital, due to construction lags, continues to increase for a few more years. During the downturn, capital stock declines while employment remains depressed. Finally, labor rises while capital continues to decline, completing the cycle. Note also that in both the simulated and actual data the amplitude of the business cycle (as shown by the fluctuations in employment) increases as the economy moves towards the peak of the long wave. The rising amplitude is a result of the developing margin of excess capacity as the economy nears the peak.[9]

4.4 Real Interest Rates and Inflation

Another major mechanism that contributes to the long wave revolves around the dynamics of interest rates and inflation. Historically, long wave expansions have been periods of low or even negative real interest rates, especially in the later part of the expansion. Near the peaks, real interest rates have risen sharply and remained at high levels through the downturns and into the depression periods. Figure 11 shows the real interest rate from 1960 to the present.[10] Real rates declined gradually from 1960 to the mid-'70s, when they were generally negative. After 1979 real rates rose sharply and remain at the highest levels since the deflation of 1929 to 1933 caused real rates to soar.

In the current long-wave downturn, the high level of real interest rates has been blamed on restrictive monetary policies and high government deficits. Yet the National Model generates the same historical pattern (low, then sharply rising real interest rates over the long wave expansion,

peak, and downturn) without a tightening of monetary policy or large deficits. Figure 12 shows the simulated behavior of real interest rates over the long wave. Real rates fall steadily during the expansion, becoming negative just before the peak. As the economy declines, real rates rise sharply and remain high through the trough.

The role of real interest rates in the long wave is described in detail by Senge (1983), and shown in figure 13. Early in the long wave expansion, the demand for goods and especially capital is growing, putting upward pressure on prices. As prices rise, the real interest rate falls, encouraging still more investment. The resulting expansion in investment demand and the demand for assets such as land and housing puts further upward pressure on prices, and the resulting increase in inflation further reduces real interest rates. During the downturn, the process reverses. As demand for capital, land, housing, and other assets falls (due to the buildup of excess capacity), prices soften and inflation subsides. Real interest rates therefore rise, discouraging investment still further, creating still more downward pressure on prices, and reinforcing the rise in real interest rates.

The strength of the reinforcing mechanism involving inflation and real interest rates depends on a lag between a change in inflation and the response of nominal interest rates. If nominal rates rapidly and accurately adjusted to the rate of inflation, then the real rate would remain quite stable, and the process described above would be weak. The historical evidence verifies that nominal interest rates do not immediately adjust to changes in inflation, but rather lag significantly behind (Senge 1983). To see why nominal interest rates lag behind inflation, consider the situation at the beginning of the long wave expansion. Demand for

capital and goods is rising while capacity lags behind. The gap between orders and capacity begins to push up prices. At the same time, firms attempt to expand capacity, boosting credit demand and bidding up nominal interest rates. The pressure on interest rates and the pressure on prices arise from the same source--the surge in investment and consumer demand during the long wave expansion--and therefore prices and interest rates move roughly in phase. Real interest rates, however, are the level of nominal interest rates less the fractional rate of price change. Price change (inflation) reaches its peak approximately when the pressure to invest is highest, while prices and nominal interest rates continue to rise until the pressure to invest has been dissipated. Thus during the long wave expansion, nominal rates rise more slowly than inflation, leading to low real interest rates. Near the peak of the long wave, nominal rates again lag behind declining inflation, leading to a sharp increase in real interest rates. Figures 1c and 1d show that historically prices and interest rates have in fact moved in phase, with inflation leading nominal interest rates. Figures 2c and 14 show that simulated prices and interest rates exhibit the same pattern.

Simulations of the National Model show the positive feedback loops surrounding real interest rates and inflation to be powerful destabilizers of the economy. Like self-ordering, the interest rate dynamics are sufficient to create the long wave and contribute to the self-sustaining nature of the long wave by substantially amplifying the inherent oscillatory tendencies of individual firms.

4.5 Debt/Deflation Spiral

Another major process that contributes to the long wave, closely related to the behavior of real interest rates, lies in the dynamics of debt and aggregate prices.

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As shown in figure 15, debt levels and aggregate prices are relatively low at the end of a long-wave downturn, the result of liquidation and price cutting in the face of unemployment and idle capacity. As the expansion phase gets under way, firms, particularly in the capital sectors, take on more debt in order to finance the expansion. Debt relative to GNP rises and the money supply expands. Expansion of debt is justified because vigorous growth, high rates of capacity utilization, high profitability, and low real interest rates all encourage expansion of external financing.

Toward the later years of the expansion, investment in capital begins to soften as excess capacity develops. The upward momentum of prices and money growth may then trigger a continuing expansion of debt through speculation in land, stocks, precious metals, or other assets. Near the peak of the long wave, overcapacity develops and investment falls, depressing employment and aggregate demand. With declining income, the ability to service the debt falls, and bankruptcies increase. Prices soften as the growing debt burden depresses aggregate demand, further squeezing debt service ability and forcing additional liquidations.

During the long-wave downturn, debt is liquidated and prices typically fall. In such a debt/deflation spiral, as described by Irving Fisher (1933), defaults and liquidations reduce the stock of money, squeezing nominal incomes and wealth, forcing further cutbacks in aggregate demand and further price cuts. In the extreme, the debt/deflation spiral can cause the collapse of the banking system and international trade, as occurred in the 1930s. Whether the liquidation is orderly or whether it takes the form of bankruptcies and defaults, possibly leading to a panic, cannot be predicted in advance. The greater the degree of speculation during the expansion, the more likely is a panic during the downturn. The

record post-Depression rate of business failures and bank closings and the current third world debt crisis are symptoms of the pressures that may trigger the debt/deflation dynamic.

4.6 Technology and Innovation

Following in the tradition of Schumpeter (1939), much of the renaissance of interest in long waves has centered on the role of technology and innovation (see note 1; also Mansfield 1983, and Rosenberg and Frischtak 1983). Fifty year long waves in innovation have been independently identified by several investigators (Mensch 1979, Hochgraf 1983). Renewed commitment to R&D and other policies to stimulate "leading edge" high-tech sectors such as information processing and bioengineering are often recommended as prime components of an effective strategy to counter the long wave (Freeman et al. 1982, Van Duijn 1983, Dickson 1983).

In contrast to the innovation theories of the long wave, the National Model suggests a long wave theory of innovation better describes the situation. The NM shows how fundamental physical processes in the economy can create the long wave without any variation in innovation rates. The bunching of innovations can thus be explained as the result of entrainment of the innovation process by the long wave (Graham and Senge 1980, p. 283-84):

> The long wave creates a shifting historical context for the implementation of new inventions. Midway into a capital expansion, opportunities for applying new inventions that require new types of capital become poor. The nation is already committed to a particular mix of technologies, and the environment greatly favors improvement innovations over basic innovations. During a long-wave downturn, basic innovation opportunities gradually improve, as old capital embodying the technologies of the preceding buildup depreciates. Near the trough of the wave, there are great opportunities for creating new capital embodying radical new technologies. The old capital base is obsolescent, bureaucracies that thwarted basic innovation have weakened, many companies committed to producing old types of capital are bankrupt, and traditional methods are no longer sacrosanct.

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Though innovation is not necessary to explain the long wave, there is little doubt that each long wave seems to be built around a particular ensemble of basic technologies, including particular forms of energy, transport, communications, and materials. These ensembles evolve synergistically and, like species in an ecosystem, compete against other candidates for a limited number of available niches.

The impact of technology and innovation on the long wave itself, on its strength, period, and character, remains less certain. The strong influence of the self-ordering, labor, and interest rate dynamics suggests innovation is not likely to be a high leverage point for countering the long wave (Sterman 1983, Forrester et al. 1983). Much work needs to be done to examine how innovation might feed back and affect the other mechanisms that create the long wave. Can fluctuations in innovation amplify the long wave? Can policies directed at stimulating innovation shorten the depression period or reduce the amplitude of the long wave? These questions remain, so far, unanswered. The proper framework for addressing them is an endogenous theory of innovation and technological change coupled to the other mechanisms capable of generating the long wave.

4.7 Political and Social Values

Substantial evidence exists that political and social values in Western nations fluctuate with the period and phasing of the economic long wave (Namenwirth 1973, Weber 1981). Independent content analyses of political tracts in the U.S. and Great Britain revealed statistically significant 50 year value cycles in both countries which coincided with each other and with the phasing of the economic long wave. During periods of long wave expansion, material wants are satisfied, and social concerns turn to civil liberties, income distribution, and social justice. During

the later phases of the expansion, foreign-policy concerns predominate. As the expansion gives way to decline, conservatism grows, and political attention returns to material needs. Economic policy takes center stage in legislative agendas. During the downturn, the accumulation of wealth becomes the overriding concern, at the expense of civil rights, equity, and the environment. The most dramatic example of this cycle is, of course, the rise of fascism in the 1920s and 1930s. The rebellion of the 1960s and growing conservatism of the 1980s in many Western nations are also consistent with the current long-wave cycle.

The variation of political values is primarily the result of entrainment by the economic cycle. It is quite natural to emphasize material needs during depression periods. People find it easier to be charitable and to extend the rights and privileges of society during good economic times when incomes are rising than in times of economic retrenchment and depression.

As in the case of technology, the effect of social value shifts on the severity and length of the long wave remains terra incognita. The connection between political values and international conflict may be especially important here, especially in view of the theories that relate war to the long wave (Goldstein 1983). Long wave research should broaden the boundary of analysis to include the effects of the long wave on international relations, including trade, debt, foreign aid, and conflict.

5. Conclusion

The National Model has been the vehicle for the development of an integrated theory of the economic long wave. Analysis of the full NM and of simple models has shown that the long wave is a complex phenomenon which

influences a wide range of economic and social factors. In contrast to several recent theories, the National Model shows there is no single cause of the long wave. Rather, the long wave is the result of the interaction of the physical structure of the economy and the decisionmaking of individuals and firms. The long wave springs from fundamental processes and structures in industrial economies. It is generated endogenously, and does not depend on random shocks such as gold discoveries to account for its persistence or for turning points.

In essence, the long wave arises from two fundamental characteristics of economic systems:

1. Inherent oscillatory tendencies of firms. Due to the inevitable lags in acquiring factors of production and reacting to changes in demand, firms tend to amplify unanticipated changes in demand, creating the potential for oscillation in the adjustment of production capacity to demand.

2. Reinforcing processes amplify the instability. Though individual firms are likely to be stable, a wide range of positive feedback loops are created by the couplings of individual firms to one another, to the labor markets, and to the financial markets. These reinforcing mechanisms substantially amplify the fluctuations in the demand for capital created by individual firms, boosting the amplitude and lengthening the period of the inherent oscillatory tendencies of firms. The major self-reinforcing processes are capital self-ordering, labor market interactions, and real interest rate dynamics.

Because the NM represents the physical structure of the economy and the decisionmaking routines used by individuals and firms to manage their affairs, it generates the multiple modes of behavior most important in

modern economies, including the long wave, the business cycle, government growth and inflation, and the long-term growth of population and technology. The model shows that it is possible to integrate in a single analytic framework the processes responsible for each of the modes, examine their interactions, and evaluate the likely effects of policies.

More importantly, diverse hypotheses and theories on the origin of each of the modes can be integrated and tested rigorously and in a reproducible manner. The relative strengths and synergies of the various processes can be evaluated. The model thus provides a flexible framework for the development of an integrated theory of economic dynamics and a consistent understanding of the problems facing the world economy.

NOTES

0. The contributions of my colleagues Jay Forrester, Alan Graham, David Kreutzer, and Peter Senge are gratefully acknowledged. This work was supported by the Sponsors of the System Dynamics National Model Project. I am solely responsible for any errors.

1. Van Duijn (1983) provides an excellent overview of long wave theories new and old. For innovation theories, see Schumpeter (1939) and Mensch (1979). Freeman et al. (1982) focus on unemployment and innovation. See Rostow (1975, 1978) and Mandel (1980, 1981) for theories based on resource scarcity and class struggle, respectively. See also Freeman (1983) for a survey of contemporary long wave theories.

2. Good overviews are provided by Hogarth (1980) and Kahneman et al. (1982). See Morecroft (1983) on the connection of bounded rationality and system dynamics. Nelson and Winter (1982) also apply bounded rationality to macroeconomic modeling.

3. Hogarth (1980) and Kahneman et al. (1982) discuss numerous separate sources of bias in decisionmaking. Common fallacies of causal attribution include the gambler's fallacy and the regression fallacy.

4. For discussion of the issues involved in the identification of long waves from empirical data, see Forrester et al. (1983). Anecdotal and other descriptive data (e.g. Rezneck 1968) are extremely useful and corroborate the timing of the long wave established through examination of the numerical data.

5. Though population and technological progress are exogenous, they are assumed to grow at absolutely uniform fractional rates. Historical time series for population and technology are not used. Thus the long wave and its timing in the simulation are not due to exogenous variables.

6. See Metzler (1941), Mass (1975), Low (1980), and Forrester (1982), for dynamic models of the business and Kuznets cycles that stress the role of stock adjustments. For empirical work on the Kuznets cycle, see e.g. Kuznets (1930) and Hickman (1963).

7. Exogenous random noise is still active in the simulation.

8. The multiplier effect can be derived by assuming that in equilibrium (i) capital production equals the investment of the goods sector plus the investment of the capital sector: KPR=GINV+KINV;
(ii) production is related to capital stock by the capital output ratio: KPR=KC/KCOR;
(iii) the investment of the capital sector in equilibrium equals physical depreciation. In equilibrium, discards are given by the capital stock divided by the average life of capital: KINV=KC/KALC. See Frisch (1933) and Sterman (1984).

9. Simulated employment and capital stock in the capital sector are shown. Because no historical time series are used to drive the model and because of the noise included to excite the business cycle, the point-by-point behavior of the model differs from the data. Nevertheless, the model captures the qualitative patterns of the actual data extremely well.

10. The real interest rate shown in figure 11 is given by the yield of 3-month Treasury bills less the rate of inflation as measured by the implicit price deflator.

REFERENCES

Cyert, R., and J. March (1963), A Behavioral Theory of the Firm (Englewood Cliffs: Prentice-Hall).

Dickson, D. (1983), "Technology and Cycles of Boom and Bust," Science. 219, 25 February, 933-36.

Fisher, I. (1933), "The Debt-Deflation Theory of Great Depressions," Econometrica, 1, 337-57.

Forrester, J. (1976), "Business Structure, Economic Cycles, and National Policy," Futures, 8, 195-214.

Forrester, J. (1977), "Growth Cycles," De Economist, 125(4), 525-43.

Forrester, J. (1979), "An Alternative Approach to Economic Policy: Macrobehavior from Microstructure" in Economic Issues of the Eighties, N. Kamrany and R. Day, eds. (Baltimore: Johns Hopkins University Press).

Forrester, J. (1981), "Innovation and Economic Change," Futures, 13, 323-31.

Forrester, J., A. Graham, P. Senge, J. Sterman (1983), "An Integrated Approach to the Economic Long Wave," working paper D-3447-1, System Dynamics Group, MIT, Cambridge, Massachusetts 02139.

Forrester, N. (1982), A Dynamic Synthesis of Basic Macroeconomic Theory: Implications for Stabilization Policy Analysis, Ph.D. dissertation, MIT.

Freeman, C. (1983), The Long Wave and the World Economy. (Boston: Butterworths).

Freeman, C., J. Clark, and L. Soete (1982), Unemployment and Technical Innovation: A Study of Long Waves and Economic Development. (Westport, Connecticut: Greenwood Press).

Frisch, R. (1933), "Propagation Problems and Impulse Problems in Dynamic Economics," Readings in Business Cycles, R. Gordon and L. Klein (eds.) (Homewood, Illinois: Richard D. Irwin, 1965), 155-85.

Goldstein, J. (1983), "Long Waves and War Cycles," unpublished MS thesis, MIT (political science).

Graham, A., and P. Senge (1980), "A Long-Wave Hypothesis of Innovation," Technological Forecasting and Social Change, 17, 283-311.

Hansen, A. (1951), Business Cycles and National Income. (New York: W.W. Norton).

Hickman, B. (1963), "Postwar Growth in the United States in Light of the Long-Swing Hypothesis," American Economic Review: Papers and Proceedings, 53, 490-507.

Hochgraf, N. (1983), "The Future Technological Environment," 11th World Petroleum Congress. (London: John Wiley & Sons).

Hogarth, R. (1980), Judgement and Choice (New York: Wiley).

Homer, J. (1980), "The Role of Consumer Demand in Business Cycle Entrainment," working paper D-3227-1, System Dynamics Group, MIT.

Homer, S. (1977), A History of Interest Rates. New Brunswick: Rutgers University Press, 2nd ed.).

Kahneman, D., P. Slovic, and A. Tversky (1982), Judgement Under Uncertainty: Heuristics and Biases (Cambridge: Cambridge University Press).

Kendrick, J. (1961), Productivity Trends in the United States. (Princeton: Princeton University Press).

Kondratiev, N. (1935), "The Long Waves in Economic Life," Review of Economic Statistics, 17, 105-15.

Kuznets, S. (1930), Secular Movements in Production and Prices (New York: Houghton Mifflin).

Low, G. (1980), "The Multiplier-Accelerator Model of Business Cycles Interpreted From a System Dynamics Perspective," in Elements of the System Dynamics Method, J. Randers, ed. (Cambridge: The MIT Press), 76-94.

Mandel, E. (1980), Long Waves of Capitalist Development (Cambridge: Cambridge University Press).

Mandel, E. (1981), "Explaining Long Waves of Capitalist Development," Futures, 13, 332-38.

Mansfield, E. (1983), "Long Waves and Technological Innovation," Papers and Proceedings, American Economic Association, 73(2), 141-45.

Mass, N. (1975), Economic Cycles: An Analysis of Underlying Causes (Cambridge: The MIT Press).

Mass, N. (1980), "Stock and Flow Variables and the Dynamics of Supply and Demand," in Elements of the System Dynamics Method, J. Randers (ed.) (Cambridge: The MIT Press), 95-114.

Mensch, G. (1979), Stalemate in Technology (Cambridge: Ballinger).

Merton, R. (1936), "The Unanticipated Consequences of Purposive Social Action," Sociological Review, 16, 894-904.

Metzler, L. (1941), "The Nature and Stability of Inventory Cycles," Review of Economic Statistics, 23, 113-29.

Mitchell, T. (1923), "Competitive Illusion as a Cause of Business Cycles," Quarterly Journal of Economics, 38, 631-52.

Mitchell, W. (1941), Business Cycles and Their Causes (Berkeley: University of California Press, Reprint Series edition, 1971).

Morecroft, J. (1983), "System Dynamics: Portraying Bounded Rationality," Omega, 11, 131-42.

Namenwirth, Z. (1973), "The Wheels of Time and the Interdependence of Value Change," Journal of Interdisciplinary History, III, 649-83.

Nelson, R. and S. Winter (1982), An Evolutionary Theory of Economic Change (Cambridge: Belknap Press of Harvard University Press).

Rezneck, S. (1968), Business Depression and Financial Panic, Essays in American Business and Economic History. (New York: Greenwood Publishing Co.).

Richmond, B. (1984), "The Expanding Government Sector," R. Day (ed.), The Troubled Economy. (Los Angeles: University of Southern California Press [forhcoming]).

Rosenberg, N., and C. Frischtak (1983), "Long Waves and Economic Growth: A Critical Appraisal," Papers and Proceedings, American Economic Association, 73(2), 146-51.

Rostow, W. (1975), "Kondratieff, Schumpeter, and Kuznets: Trend Periods Revisited," Journal of Economic History, 35, 719-53.

Rostow, W. (1978), The World Economy: History and Prospect (Austin: University of Texas Press).

Schumpeter, J. (1939), Business Cycles (New York: McGraw-Hill).

Senge, P. (1982), "The Economic Long Wave: A Survey of Evidence," working paper D-3262-1, System Dynamics Group, MIT, Cambridge, Massachusetts 02139.

Senge, P. (1983), "A Long Wave Theory of Real Interest Rate Behavior," working paper D-3470, System Dynamics Group, MIT, Cambridge, Massachusetts 02139.

Simon, H. (1947), Administrative Behavior (1st ed.; New York: MacMillan).

Simon, H. (1957), Models of Man (New York: Wiley).

Simon, H. (1978), "On How to Decide What to Do," Bell Journal of Economics, 9, 494-507.

Simon, H. (1979), "Rational Decisionmaking in Business Organizations," American Economic Review, 69, 493-513.

Sterman, J. (1982), "Amplification and Self-Ordering: Causes of Capital Overexpansion in the Economic Long Wave," working paper D-3366, System Dynamics Group, MIT, Cambridge, Massachusetts 02139.

Sterman, J. (1983), "The Long Wave" (letter), Science, 219 (18 March), 1276.

Sterman, J. (1984), "A Behavioral Model of the Economic Long Wave," Journal of Economic Behavior and Organization, forthcoming.

Van Duijn, J. (1983), The Long Wave in Economic Life. (London: Allen and Unwin).

Weber, R. (1981), "Society and Economy in the Western World System," Social Forces, 59 (4), 1130-48.

Table 1
Major Variables in the National Model

Endogenous	Exogenous
GNP	Population (constant 2 per cent/yr rate)
Consumption	Technological Progress (constant 1 per cent/yr rate)
Investment	Authorized government services per capita (constant exogenous pressure for expansion starting 1930)
Saving	Random noise in order rates and production
Government Expenditure	
Tax rates	
Prices	
Wages	
Inflation rate	
Employment	
Unemployment	
Workforce participation	
Wealth	
Interest rates	
Money supply	
Private debt	
Public debt	
Banking system reserves	
Monetary policy (open market operations)	
Fiscal Policy (transfer payments, government purchases, employment, deficit)	
Sectoral variables for the goods and services sector and plant and equipment sector:	
Production	
Capacity	
Capital stock	
Employment	
Investment	
Price	
Debt	
Dividends	
Return on investment	
Taxes	
Balance sheet	
Income statement	

Figure 1a: Real GNP in the United States, 1800-1984

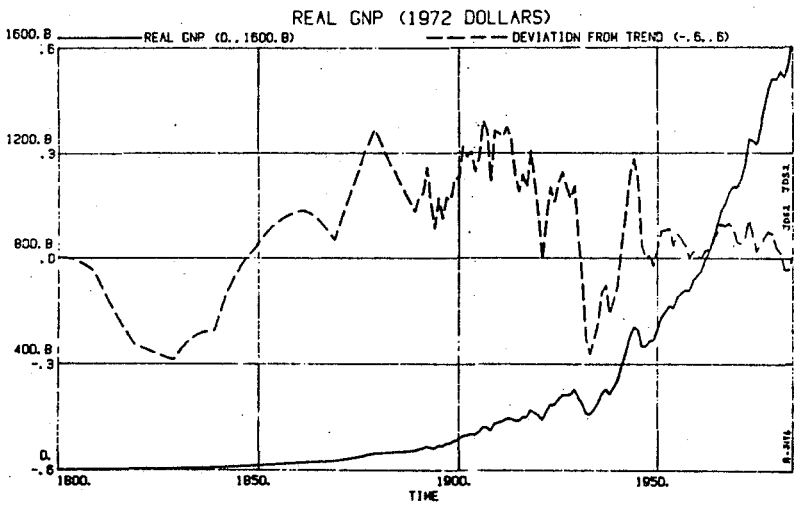

Figure 1b: Unemployment rate in the United States, 1890-1984

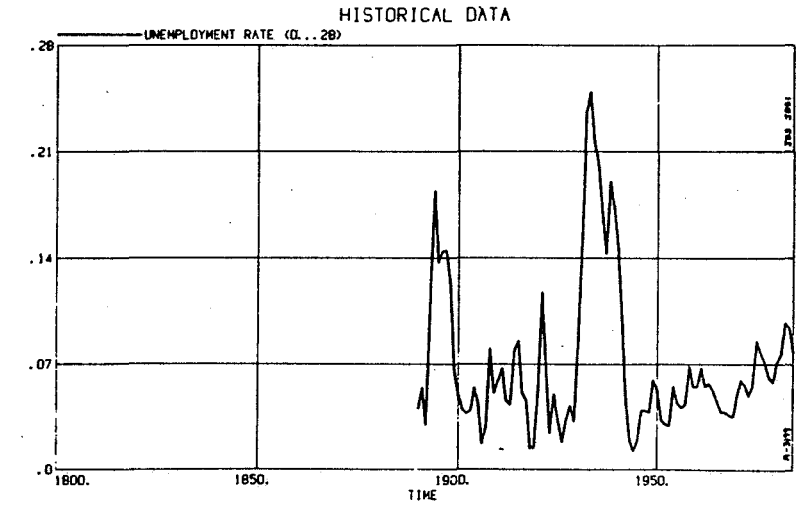

Figure 1c: Consumer Price Index in the United States, 1800-1984

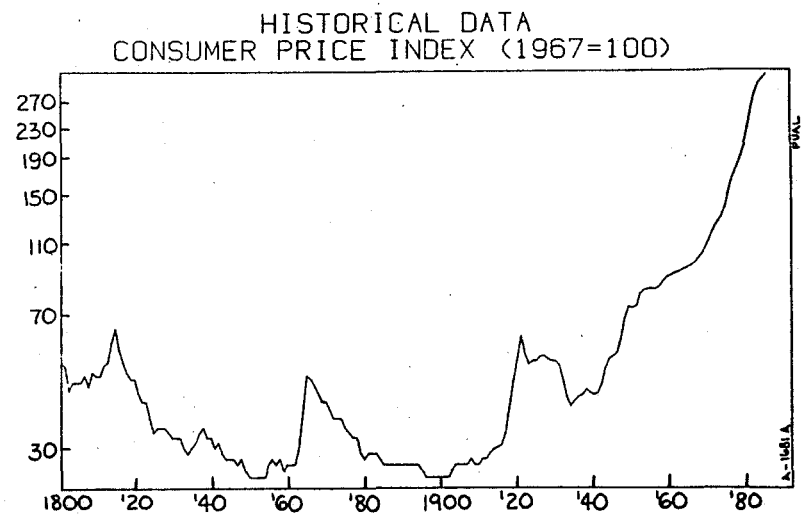

Figure 1d: Interest rates in the United States, 1860-1984
Source: Homer (1977). 1860-1899: average yield on higher grade railroad bonds. 1900-1975: prime corporate bonds. 1975-1984: Moody's AAA bonds.

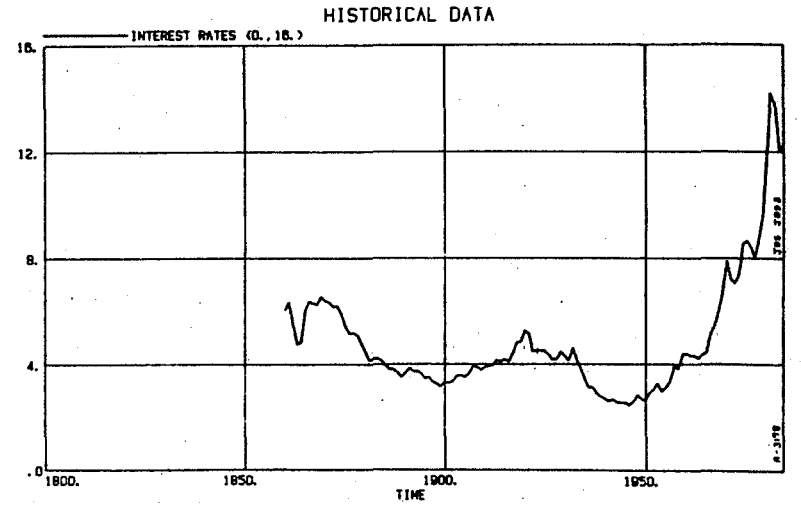

Figure 2a: Simulated real GNP, 1800-1984

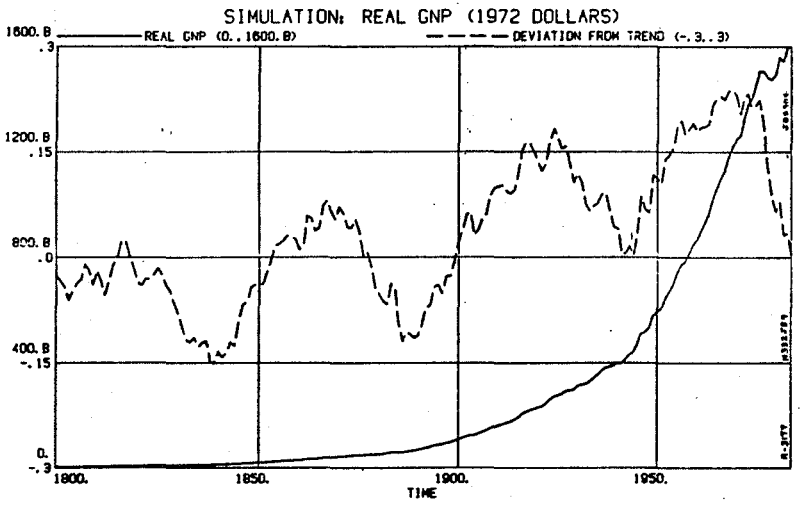

Figure 2b: Simulated unemployment rate, 1800-1984

Figure 2c: Simulated interest rate and price level, 1800-1984

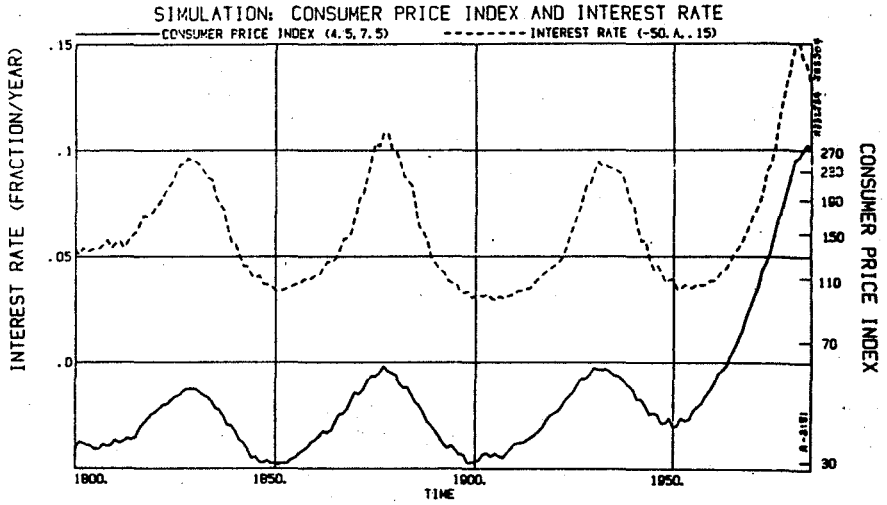

Figure 3

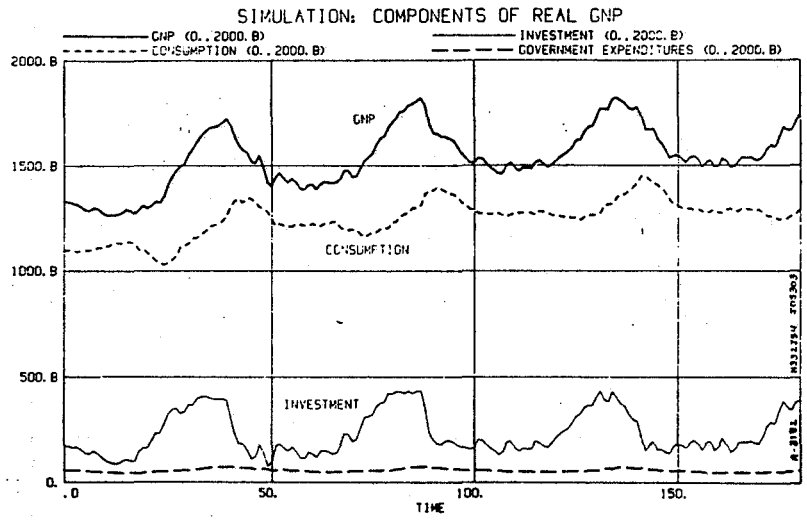

Figure 4

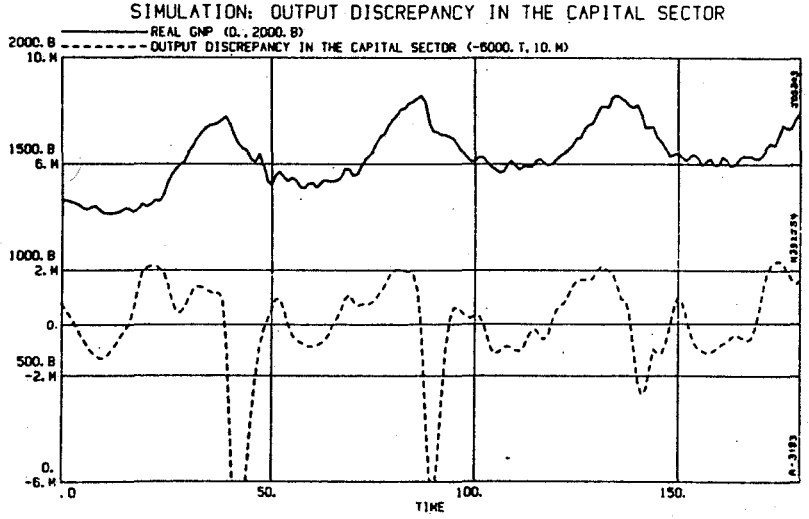

Figure 5

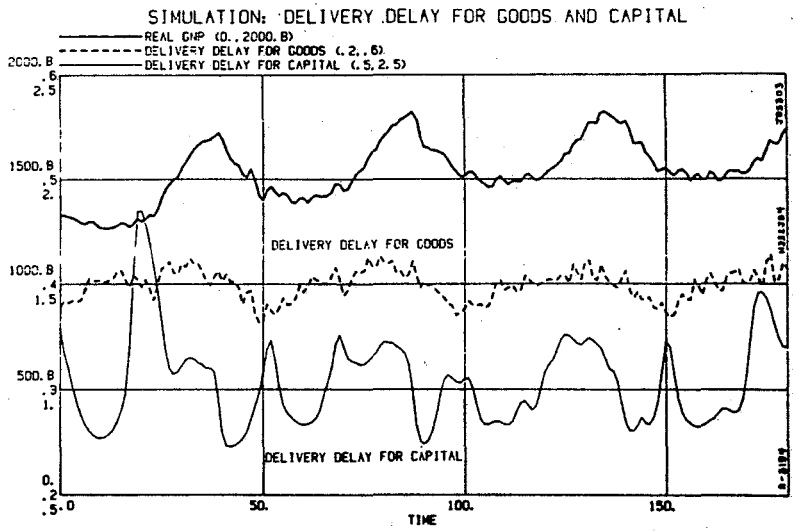

Figure 6

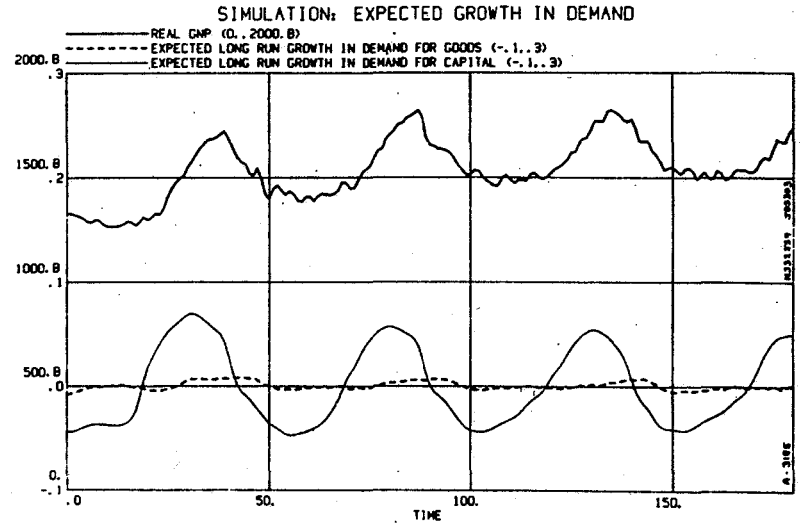

Figure 7

REINFORCING LOOPS INVOLVING CAPITAL "SELF-ORDERING" AND CAPITAL INTENSITY

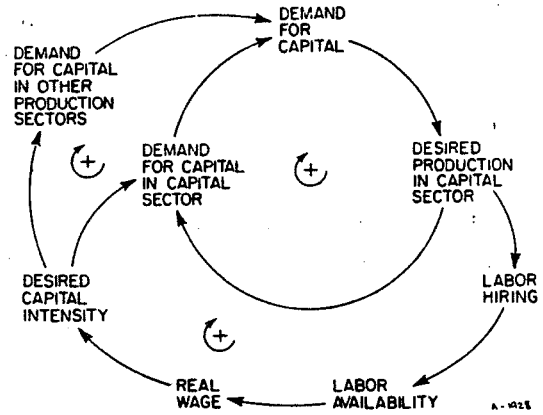

Figure 8

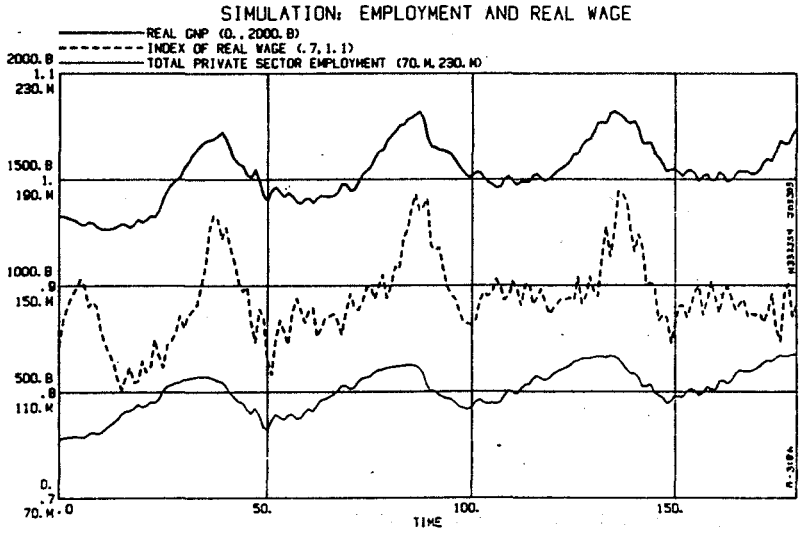

Figure 9a: Historical data: labor/capital mix in the United States, 1889-1939
Source: Kendrick (1961, p. 328).

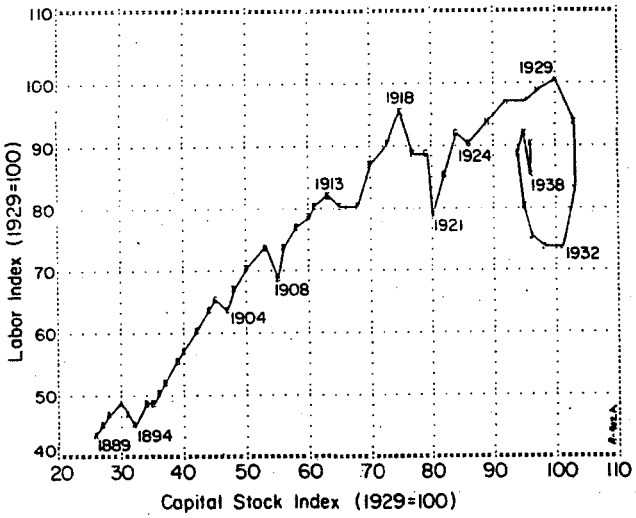

Figure 9b: Simulation: labor/capital mix in the capital sector, 1890-1945

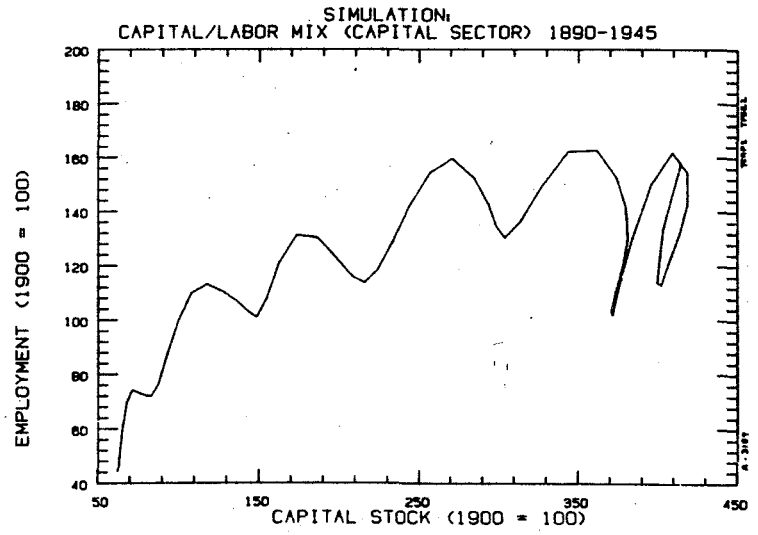

Figure 10a: Historical data: labor/capital mix in the United States, 1947-1983
Source: US Dept. of Labor (employment); US Dept. of Commerce, Bureau of Economic Analysis (investment expenditures)

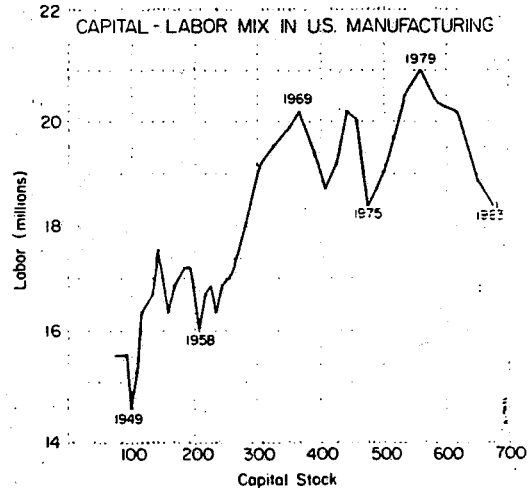

Figure 10b: Simulation: labor/capital mix in the capital sector, 1946-1983

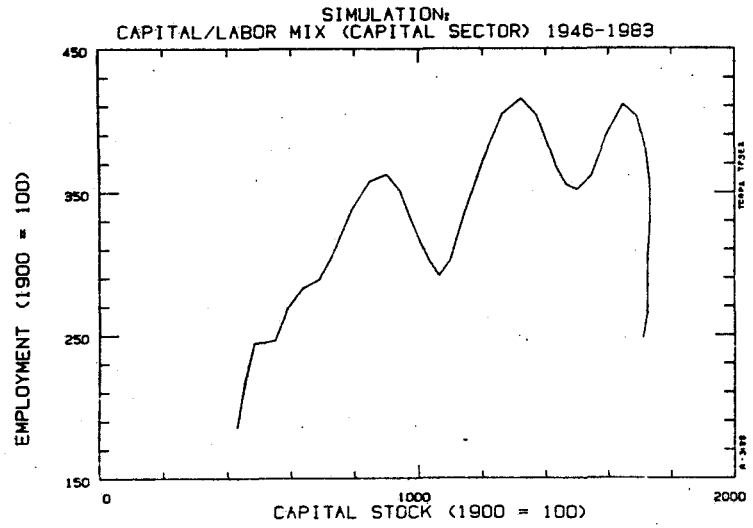

Figure 11: Real interest rate in the United States, 1960-1983

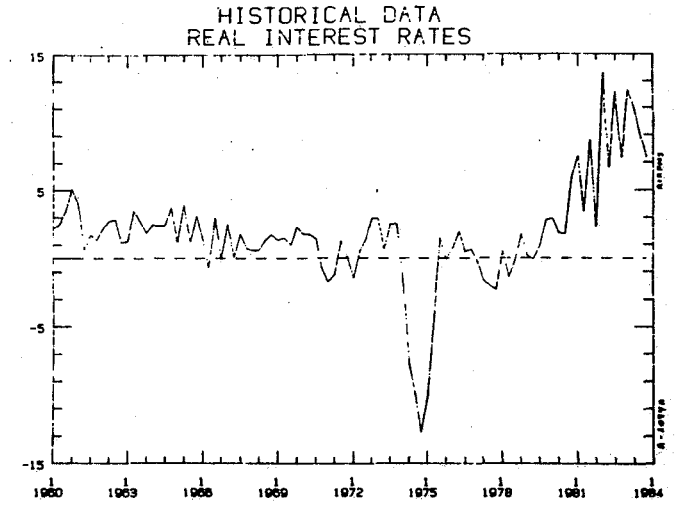

Figure 12

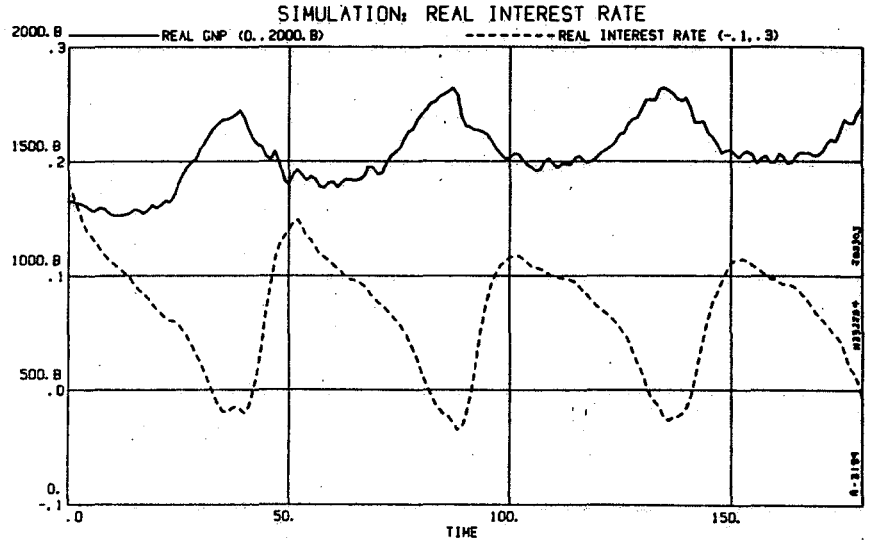

Figure 13

REINFORCING LOOPS INVOLVING CAPITAL DEMAND AND INFLATION

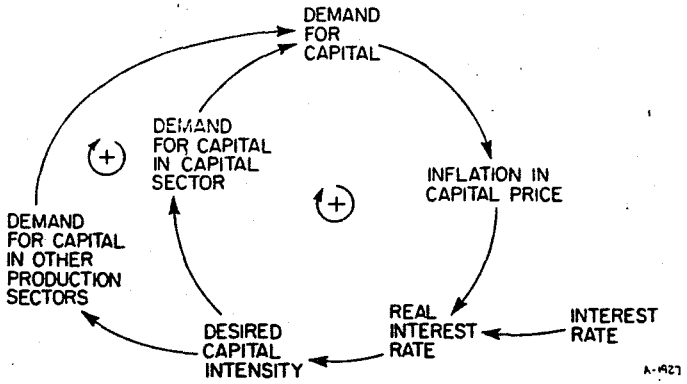

Figure 14

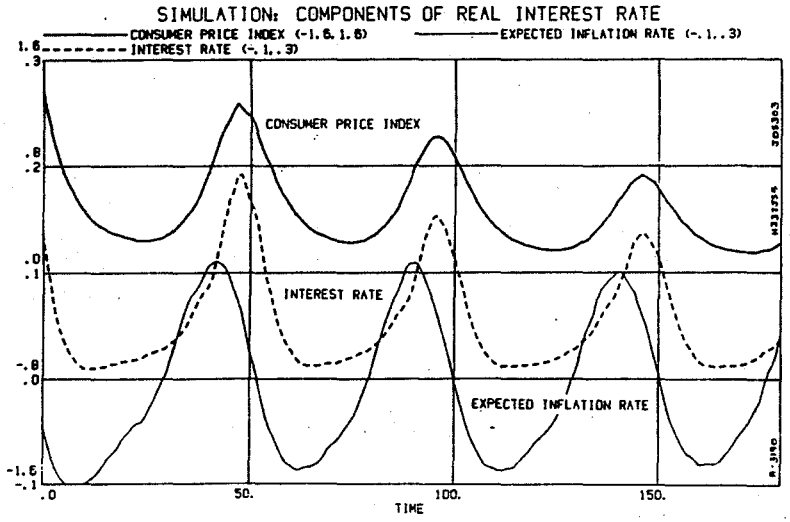

Figure 15