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**ECONOMICS, TECHNOLOGY, AND THE ENVIRONMENT**

by

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<b>1. THE NATURE OF SOCIAL SYSTEMS</b>	<b>4</b>
<b>2. UNDERSTANDING SOCIAL SYSTEMS</b>	<b>5</b>
2.1. <i>System Dynamics</i>	5
2.2. <i>Mental Models</i>	6
2.3. <i>Combining Mental and Computer Models</i>	6
2.4. <i>Characteristics of Social Systems</i>	7
<b>3. MODES OF ECONOMIC BEHAVIOR</b>	<b>8</b>
3.1. <i>Life Cycle of Economic Development</i>	8
3.2. <i>Economic Long Wave</i>	9
<b>4. AGRICULTURE</b>	<b>12</b>
4.1. <i>Economic Long Wave Affects Agriculture</i>	12
4.2. <i>Life Cycle of Growth Affects Agriculture</i>	13

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Will recent decline of stock markets around the world cause another great depression? No, not by themselves. But unstable stock markets are a symptom of deeper forces. Unfavorable pressures have been growing for many decades. Those forces can lead into a major economic downturn.

The world is now influenced by changes from three directions. First, economic forces are causing greater unemployment, increasing trade protectionism, idling manufacturing capacity, and raising defaults on debt. Second, new technologies are demanding different worker skills, redirecting trade routes, and altering production methods. Third, environmental deterioration is threatening health, killing forests, poisoning water tables, and modifying climate.

All these forces affect the future of agriculture. Agriculture operates at the intersection of economics, technology, and the environment. Throughout history, changing economic forces of supply and price have dominated the well-being of people in agriculture. For the last hundred years, technology has offered hope of more plentiful and less expensive agricultural products. During the last several decades, pesticides and herbicides have increased agricultural yields. But now, environmental damage from those technological advances is forcing reconsideration of past agricultural practices.

Such social forces are only partially perceived. They are poorly understood. By contrast, the last century has seen great advances in understanding physical science and its application to technology. During that same time there have been no corresponding improvements in understanding society, economics, or the relationship of people to the natural world within which we live. As

has been true for centuries, we still have imbalances in trade, difficulties with exchange rates, inflation, and wars.

In reaction to unfavorable social pressures, governments change regulations, increase expenditures, and alter tax laws. In doing so, governments are running experiments on actual full-scale economies. But the complexity of social systems often obscures the relationships between policies and their consequences. Because cause and effect are not correctly perceived, social experiments fail far too often.

By contrast, methods for understanding systems in modern technology are well developed. If a corporate executive were planning a new kind of chemical plant, he would not start by building a full scale installation. He would not use the final system for experimenting with the separate processes and their interactions. Instead, he would first make limited experiments, using small pilot plants and computer simulation models until the processes were well understood.

## **1. THE NATURE OF SOCIAL SYSTEMS**

Why has our knowledge of social systems progressed so little since ancient times? The reason is not because social systems differ in kind from physical systems that can be well understood. The answer lies in the greater complexity of social systems along with the inability of the human mind to comprehend the behavior of such systems.

Although most people believe otherwise, social systems belong to the same class as physical systems. The difficulty in understanding social systems does not arise because social systems are fundamentally different from physical systems. Social systems, like physical systems, are multiple-loop, information-feedback structures. They belong to the class that is mathematically described as high-order, nonlinear, differential equations. In science and engineering, no one attempts to solve such systems by intuition and debate. In technology, computer simulation models are used to reveal the behavior that would be created by a particular system structure.

But managers, politicians, and even most people in the social sciences are not aware of the extreme difficulty presented by dynamic behavior in social systems. They do not realize that such systems lie beyond the power of the traditional processes of thought and discussion. They do not know that methods now exist for reaching a far better understanding of such systems. Leaders of our political and business institutions still try to manage social and economic behavior by using the inadequate methods inherited from the past. The traditional processes based on historical precedent are not sufficient

for understanding the interrelationships of economics, technology, society, and the environment.

## **2. UNDERSTANDING SOCIAL SYSTEMS**

Methods for achieving more desirable human systems are now available. Powerful computer simulation methods, originally developed for technological systems, have advanced to a point where they can deal with the far greater complexity of social and economic systems.

Those responsible for managing countries have not in the past been able to test policy changes in the laboratory before trying them full-scale on entire populations. Now, however, computer simulation models are becoming laboratories for evaluating economic policy alternatives quickly and at low cost before new policies are committed to broad social implementation.

Such simulation models can combine the advantages of the human mind with the advantages of modern digital computers, while avoiding the weaknesses of both. But relatively few resources are now being directed to achieving a better understanding of how to cope with deficits, trade imbalances, debts, inflation, unemployment, and environmental degradation.

### *2.1. System Dynamics*

During the last thirty years, a professional field known as "system dynamics" has been established to develop computer simulation models based on the institutional knowledge of managers and political leaders. World-wide participants in the field have formed the System Dynamics Society. The 1986 international meeting of the Society was held in Seville, Spain, and this year in Shanghai, China. Next year the conference will be in California, and the year after in Germany. A regional chapter of the System Dynamics Society is now being formed in the Latin countries including Italy, France, Spain, and Portugal.

In a system dynamics study, one builds a computer model that acts out the behavior of the real system that is being represented. Such a computer model is not based on difficult mathematics. It is a role-playing model that demonstrates how the parts of a system influence one another. The computer model is then used to understand how the components of a system interact to produce the observed behavior. When the behavior is not as desired, the model is used as a laboratory in which policies can be changed to determine how the behavior of the system could be altered.

## *2.2. Mental Models*

The use of models may at first sound unfamiliar. But everyone uses models. All decisions are made on the basis of models. A person does not have an actual family, or city, or business, or country in his head. Instead, all decisions are made on the basis of assumptions, perceptions, and recollections. Those mental images are models. We use mental models to make decisions and to anticipate the future results of our actions.

Mental models have both great strengths and severe weaknesses. The mental models are excellent sources of reliable information about the structure of social systems and the policies being followed in making decisions. But mental models often give the wrong answers about how those structures and policies interact to produce behavior.

On the other hand, a computer model can show with certainty the dynamic consequences of the structural and policy assumptions that are built into the model.

## *2.3. Combining Mental and Computer Models*

The promise for the future lies in combining the advantages of mental models with the advantages of computer models. In doing so, one uses the insights that people already possess in their heads about how decisions are made, what information is available at each decision-making point, how various kinds of crises affect decisions at each place in a social system, and the local goals that motivate decisions. From such knowledge, one then constructs a replica of the actual system in the form of a computer simulation model. The behavior of such a model is usually different from what people thought was implied by the system structure with which they are familiar.

We often see the discrepancy between actual behavior and that which is expected from the policies being followed. For example, one can go into a company that has a severe and widely known difficulty, such as falling market share, or especially low profitability, or unusual fluctuation of employment. Interviews reveal descriptions of policies followed within the company. Such policies are often justified on the basis that they are aimed at solving the difficulty. The asserted policies are then used to construct a system dynamics model. To the surprise of most people, the model manifests the serious symptoms arising within the actual company. In other words, the corporate difficulty is implicit in the policies that people know they are following. Such a situation is treacherous. People believe that their policies lead toward a solution. But, in the complexity of the situation they do not realize that their policies are causing the problem. So, as

matters get worse, increasing troubles are interpreted as reasons to take more of the very actions that are causing the difficulties.

Within a computer simulation model, one can locate the policies that are most responsible for undesirable behavior. Alternative policies can be tested to learn how to improve behavior.

#### 2.4. *Characteristics of Social Systems*

More important than finding unexpected behavior in a specific system is the discovery of general characteristics that are applicable to a broad class of systems, or even to nearly all systems. Kinds of behavior can be identified that are usually valid and give an improved basis for thinking about systems.

Such generalizing usually establishes scientific explanations for the timeless lessons brought to us through history, myths, fables, and religions. The lessons from such traditional sources contain powerful threads of truth that are being ignored in modern thinking that is dominated by short-run considerations.<sup>1</sup> Some examples will illustrate.

First, a long-term versus short-term trade off occurs in most decisions. A policy that produces favorable results in the short run will usually produce unfavorable results in the long run, and vice versa. The inherent conflict between immediate and ultimate consequences is not given proper weight in management and political decisions. On the other hand, the recognition of the inherent conflict between the present and the future goes back at least as far as the ancient Greeks. Aesop's fable of the grasshopper and the ant contrasts the short-term advantage of playing in the summer with the long-term penalty of freezing in the winter.

Another general characteristic of systems lies in the high resistance to most policy changes. Perhaps as many as 98 percent of the policies in a system have little effect on behavior. Systems are an assembly of feedback loops that can compensate for changes in most policies. Yet much of the debate in business and government is directed at those low-leverage policies. Much time and effort is expended in arguing over policies that have almost no effect. A skillful system dynamics study can distinguish between the low-leverage policies and the very few influential policies that have the potential for improving conditions.

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<sup>1</sup> Several general characteristics of systems were identified in *Urban Dynamics* (Forrester 1969, 107-114).

To help build a public understanding of social systems, we should seek those general insights that can connect current problems with themes from the traditional truths inherited from the past.

### 3. MODES OF ECONOMIC BEHAVIOR

National economies exhibit several different kinds, or modes, of economic behavior. On the shortest time scale, ordinary business cycles are fluctuations in economic activity with peaks from three to ten years apart. On an extended time scale, the economic long wave, or Kondratieff cycle, is a large rise and fall in world economies with peaks 45 to 60 years apart. On a still longer time scale, the life cycle of economic development describes growth of population and industrialization until the environment is overloaded and resists further growth. All of these forces are now combining to create the economic stresses that dominate newspaper headlines and political debate.

#### 3.1. *Life Cycle of Economic Development*

The life cycle of economic development can extend over two hundred years or more. It represents the time during which population and technology grow until they can no longer be supported by the capacity of nature to supply food, water, resources, and pollution-dissipation capacity. Social and technological changes over such a long time scale are hard to see and to understand. Computer simulation allows a time compression so that our assumptions about the future can be examined. One needs to bring space, time, technology, and social change into a common framework for examination and discussion. A common language is needed for dealing with change.

System dynamics can provide a powerful language for communication. Assumptions for a model are explicitly stated so that they can be debated and improved. Behavior of a model can be compared with real-life observed behavior. A model permits complete internal consistency between assumptions, behavior, and the consequences of recommended policy changes.

The communication process based on a system dynamics model is illustrated by the *Limits to Growth* book<sup>2</sup>. *Limits to Growth* describes a model of the life cycle of economic development. It shows how population, industrialization, resources, crowding, and pollution

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<sup>2</sup> Meadows, Donella H., et al, 1972, also the predecessor book, *World Dynamics*, Forrester, 1971.

lead to counterpressures from a stressed natural environment. The book resulted from a joint project between the Club of Rome, founded by the late Aurelio Peccei who lived here in Italy, and the System Dynamics Group at the Massachusetts Institute of Technology.

*Limits to Growth* produced widespread public debate about economic development. Although some critics claim the book has been discredited, a careful reading shows that it demonstrates forces that now appear in newspaper headlines describing social turmoil from crowding, hunger in many countries, and pollution of the environment.

The book has been translated into about 30 languages and has sold some 3 million copies. Following publication in 1972, it was discussed in conferences on university campuses, in the developed and developing countries, and at meetings of corporate executives. The book provoked spirited debate in newspaper editorials and on television programs.

Why would a book based on a computer simulation model receive such extensive public attention? There seem to be several reasons. The book addressed concerns of the public about the population explosion, crowding, and pollution. It helped meet the human desire to see the future more clearly. More than that, it put the population and industrialization picture together. It showed how economic growth related to environmental concerns. *Limits to Growth* combined descriptive text with organizational diagrams and computer simulations of behavior over past and future time. It provided a clarity that is missing from books that attempt to treat complexity using only written language.

### 3.2. *Economic Long Wave*

The world economy is unbalanced. Economic instability is increasing. Huge Latin American debts are not likely to be repaid. Speculation in physical assets has led to large discrepancies among many prices and wages. Trade imbalances are threatening economic stability. Many government deficits are out of control. Currency fluctuations are disrupting trade. Inflation has been interfering with commercial activity.

Are such forces only coincidences? Or, are they connected below the surface in a powerful process of economic change? I believe the current economic imbalances are connected by a mode of behavior called the economic long wave, which is popularly known as the Kondratieff cycle.

The economic long wave has been controversial, both as to its cause and even to its existence. Those who believe that the economic long wave exists see it as a great rise and fall of economic activity with peaks and valleys some 45 to 60 years apart. It is considered the cause of the great depressions of the 1830s, 1890s, and 1930s. For a century, the nature of the economic long wave remained unclear because in the past there has been no theory for how the long wave could be generated. Instead, major depressions have often been attributed to accidents or to governmental mismanagement. For example, in the United States, the Great Depression of the 1930s has often been blamed on nothing more than mistaken policies of the monetary authority.

Traditional theory has been unable to explain large changes in economic behavior. Most economic theory has been based on equilibrium, or steady-state, concepts that leave little room for even imagining an economy that can persist in major long-term fluctuations between booms and depressions.

However, within the last few years, a comprehensive theory of the economic long wave has come into existence. It is in the form of the System Dynamics National Model developed in the System Dynamics Group of the Sloan School of Management at the Massachusetts Institute of Technology. The National Model is a computer simulation model based on the policies followed in banks, industries, markets, and government. The model is self-contained. Unlike the more common econometric models, the National Model operates without external driving inputs for controlling its behavior.

In the National Model we find that ordinary and well-known policies of business, banking, and government can interact to produce all the important kinds of behavior observed in an economy. The National Model generates the well-known short-term business cycle with peaks some 3 to 10 years apart. It exhibits stagflation (simultaneously rising unemployment and inflation), as occurred in the 1970s, but which had previously been considered by many to be impossible. The National Model also creates an economic long wave with a major rise and fall of economic activity having peaks some 50 years apart.

The System Dynamics National Model provides a theory of how the economic long wave occurs. A computer simulation model is a theory of the behavior that it creates. The structure of a model and the decision-making policies within it cause the resulting behavior. One can examine a model to see why the behavior happens. The System Dynamics National Model shows how production, investment, saving, construction, and credit can interact to produce great waves of excessive economic expansion and contraction that extend over several decades.

The National Model provides a new perspective from which to interpret economic behavior. In the early part of a long-wave expansion, as in the 1950s and 1960s, money is borrowed to build factories. After a peak, as at the present time, depreciation cash flows and new borrowing are used for speculation in land, for corporate acquisitions, and for bidding up prices in the equities markets beyond the underlying business realities.

Conditions during the 1980s have closely paralleled those of the 1920s. There were many corporate mergers in the late 1920s as there have been recently. The price of agricultural land in the United States reached a peak in 1920 and again in 1980. The variation of land prices before and after the peaks are surprisingly similar. Land prices in American agriculture had fallen to half their 1920 peak by the late 1920s and are now down to about half their 1980 peak. Land prices will probably fall further in the 1990s just as they did in the 1930s.

The central driving force of the long wave is the over-building and under-building of physical capital investment, such as factories, machinery, offices, apartments, and homes. With this fluctuation of physical investment go other reinforcing changes in an economy. During some three decades of expansion, construction of physical facilities increases employment and personal income. The growing income supports more purchasing and creates the need for still more production facilities. As an economy moves toward a peak, the need for more physical investment diminishes. But governments make credit more freely available and change taxes to sustain the boom in construction. Such actions by governments result in still more excess physical investment and contribute to a more severe decline later.

The excesses from the long-wave expansion are now evident as over-capacity in many industries and as falling agricultural prices. But many imbalances remain. The larger economic corrections still lie ahead.

After examining a broad range of evidence, one can conclude that the peak of the recent long-wave expansion occurred at about 1980 and that the best estimate for the low point in the downturn is the mid-1990s. This means another decade of economic difficulty as the great imbalances in world economies are readjusted.

The economic long wave is a world-wide phenomenon. Trade and money flows lock the world into about the same timing of long-wave rise and fall. Excess production exists on an international basis. Every country is trying to solve its domestic economic weakness by exporting more than it imports, but that is not possible. The solution

to economic difficulties must come from inside each country. Individual internal economic balances must be reestablished.

Long-wave peaks and downturns are times of great international danger. Wars have tended to occur at the peaks and valleys. World War I occurred at a peak of the long wave and World War II during a valley. In a downturn, as internal economic difficulties become more acute, there is a tendency for governments to divert attention of citizens away from domestic economic troubles by focusing public attention on an exaggerated external threat. However, the greatest threat to future well-being of most countries now comes not from the outside but from the inside in worsening domestic social and economic conditions.

#### **4. AGRICULTURE**

The economic long wave and the life cycle of economic development both affect agriculture. We are entering a downturn in the long wave, and are moving into the end of the life cycle of growth.

##### *4.1. Economic Long Wave Affects Agriculture*

At the peak of a long wave, production in most industries has risen above market demand. In the downturn, falling demand puts downward pressure on prices. In the production of factory goods, declining demand is closely matched by reduced production. But agriculture responds differently, at least over a short period of a few years. The fixed costs in agriculture are high. People on the land are less likely to leave than are factory workers to be dismissed. As a result, agriculture tries to maintain income by increasing production at a time of falling prices.

For the individual farmer, greater production at a lower price seems a way to maintain income. However, when production rises at a time of falling demand, downward pressures on prices increase. During a long wave downturn, such as we are now entering, prices of agricultural crops will tend to fall further than the prices of manufactured goods. In other words, the prices of what farmers sell will fall relative to the prices of what farmers buy. This can throw a greater economic hardship on the agricultural sector than on other business sectors. I see the next ten years as a particularly unfavorable economic time for agriculture.

#### 4.2. *Life Cycle of Growth Affects Agriculture*

The life cycle of growth changes the traditional relationships of agriculture to other parts of an economy. Population growth and increasing industry encroach on agriculture. Housing and industries occupy more and more of the best land that should have been preserved for food production. Demands for water by people and industry restrict the irrigation water available for farming. Acid rain from burning coal and oil is detrimental to vegetation. Sickness caused by agricultural chemicals will lead to restrictions on chemical usage. As a result of these pressures, agriculture will become less efficient. More inputs of labor and energy will be required for growing food.

I believe a time will come when movement of people from agriculture to industry will begin to reverse. This may happen as soon as during the next 30 years. As population grows and requires more food, and as food-growing capacity declines, a sharp reversal can occur from having excess food to having a shortage of food. This has already occurred in some African countries and elsewhere. The industrial countries are not immune to a similar rather sudden reduction in adequacy of food.

Behind the long sweep of the life cycle of economic growth lies the pressure of rising population. It is population growth, with the accompanying pollution and demands for resources and space, that create the clash between man and nature. The standard of living is maximum half way up the growth curve. Beyond that half-way point, and we are about there, environmental resistance increases rapidly. More and more effort must be expended to cope with the unfavorable consequences of an overloaded environment.

Economic and social forces surrounding agriculture will increase. Short-term political responses to those forces can be detrimental. Recent developments in computer modeling can help to anticipate and understand changes. By testing policies in simulation models, it is possible to test the consequences of various laws and regulations. The agricultural community should exert leadership in examining what present laws and practices imply for the future of agriculture as agriculture interacts with economics, technology and the environment.

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