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(Editor)

THE LONG-WAVE DEBATE

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Preface

If there is not enough evidence of long waves in economic variables, the meeting that spawned this book brought forth some evidence to show that at least interest in these phenomena manifests a wave-like form. It is exceptional for any economist, due to the periods involved, to participate in two upswings of interest. Much of what is said at the beginning of a period is usually forgotten by the end. The participants of the International Meeting on Long-Term Fluctuations in Economic Growth: Their Causes and Consequences (held in Weimar, GDR, 10–14 June 1985), of which this volume is the *Proceedings,* were privileged to hear of one such exceptional case.

In his welcoming speech, Professor Jürgen Kuczynski recalled his research, of 51 years ago, on long waves in the prices of industrial goods in the years 1820–1933, when he said "Lange Wellen aber sind nicht zu finden" [Kuczynski, *Das Problem der langen Wellen und die Entwicklung der Industriewaren-Preise in den Jahren 1820–1933* (Philographischer Verlag, Basel)]. "Since then," the speaker confessed, "I have come to acknowledge the existence of long waves, without being able to find a satisfactory explanation for them in my own or in other studies."

Professor Kuczynski stressed the necessity to develop a satisfactory theory for long waves, and then to establish which factors are important components of the general trend and which are not. He expressed his pleasure in seeing an increased interest in structural change and innovation, and posed the question: Once the mechanisms of long waves are known will this not bring about their end? When it is so that a steady, even if slow, development sets in, will long waves be but a temporary historical fact for which no theory is necessary? Or perhaps two theories – one for their existence in the past, and one for their future nonexistence?

It can be said that most of the deliberations that followed were an attempt to respond to Professor Kuczynski's challenge.

Dr. Thomas Kuczynski (Chapter 5) examines the works of Marx and Engels in relation to the processes responsible for fluctuations in the economy. He shows that when Marx and Engels spoke about "fluctuations extending over very long periods ..." caused by changes in the general rate of profit, but also taking into account fluctuations caused by capital turnover as a "material basis for the periodic crises," they were aware of all of the basic mechanisms that cause long waves and business cycles.

Based on Marxist views, Professor Yu. Yakovets (Chapter 20) introduces a certain "taxonomy" into the cycles of science and technology and recognizes the following cases:

(1) "Sequencing" of technology (machines) generation (for example, generation of robots).
(2) Transfer to new directions of technology (partial technological revolutions).
(3) Periodical reproduction of fixed capital on a mass scale on the basis of the generation of new machines.
(4) Overall (general) technological revolutions, leading to basic changes in the level of productive forces.

Individual cycles are structured into several phases, such as start-up, contagion, maturity, obsolescence, etc. He argues that general technological revolutions can be traced back to prehistoric times.

Professor G. Bruckmann in his brief contribution (Chapter 1) poses a question that was more than just a rhetorical one, "Will there be a Fifth Kondratieff?", pointing out that the recent economic "low" seems to be qualitatively different from previous ones. Also, there are indications that we may be approaching a new socioeconomic age. Whether or not, in the new age, we will continue to observe Kondratieff remains to be seen.

The search for trustworthy mechanisms behind cycles sharpens the view of researchers. Dr. R.M. Goodwin (Chapter 4) points out that in the field of economics, models are usually in search of data. In the long-waves issue it is exactly the opposite. However, the search for a model is hampered by the fact that in economics there are no universal constants as, for example, in physics. Therefore, to explain a cycle of a longer period, the difficulty is in finding a mechanism that remains unchanged over many decades. The model Dr. Goodwin puts forward transforms the steady flow and cumulative growth of knowledge into an alternating growth of the economy. He also discussed the interrelationships of the variables involved. This model turns the economy into an evolutionary pulsator.

Another interpretation of the long wave was presented by Drs. L. Klimenko and S. Menshikov (Chapter 25), who apply catastrophe theory and simulate non-equilibrium growth. Preliminary results suggest that the economy has a tendency to move close to two different equilibrium trajectories (corresponding to either a maximum or minimum GNP over profit rate). Changes in profit realization could cause switching from one trajectory to the other. They have tested on real data for the US economy for the years 1889–1982.

A more microeconomy-based formal model of long waves is described by Professor G. Mensch *et al.* (Chapter 27), who divide the analysis of product life cycles into two parts:

(1) Intrinsic dynamics – given by a "natural" maturing of the product.
(2) Interaction dynamics – describing how the life cycle is influenced by technological and market interaction with competing products.

This interaction can enhance or hinder the maturing process. When these relations are described by coupled differential equations it is possible to show that, under certain conditions, this can lead to a swarming process (synchronization of the maturing process).

Dr. A. Kleinknecht (Chapter 16) presents a well-documented essay on rates of innovation and profits in the long wave. He uses patent statistics as a proxy for the rate of innovation and differentiates between product and process innovation. The data support the idea that patents are not emerging randomly, but in swarms. It is difficult, though, to select the secular set of innovations and distinguish between "basic" and other types of innovation. Dr. Kleinknecht's analysis gives some hint as to the mechanism behind turning points in long waves based on innovation, complementing rather than contradicting other theories. The same is valid for profit rate, the declining tendency of which can be counteracted by raising the labor productivity of growing new industries.

An application-oriented study of long waves can hardly ignore the issues of structural change. Even if these issues seldom can explain the whole cycle, they are important components of potential mechanisms behind the dynamic behavior of the economy.

Professor W. Krelle *et al.* (Chapter 26) presents the preliminary results from his multination model. He considers a long-term fluctuation in economic growth to be a fluctuation in the equilibrium growth path of an economy. In the model, the growth paths of economic variables (GDP, export, import, manufacturing) are determined by four exogenous variables (saving ratio, rate of technical progress, rate of growth of labor, and money supply) which, when fluctuated, can cause switching between the different equilibrium growth paths. The main candidate for fluctuation is, of course, technical progress and the related entrepreneurship.

Dr. J. Sterman (Chapter 11) presents the System Dynamics National Model which seems to integrate several hypotheses. The long wave is shown to arise from the interaction of locally stable firms with a variety of self-reinforcing feedback processes. These involve capital investment, employment wages, inflation, interest rates, etc. The linkages between long-wave theory and innovation, social change, and political values are also discussed. This model is based on the multicausality of long waves and explains the phenomena solely through endogenous processes.

Professor K. Val'tukh (Chapter 13) tests the relation of two basic laws of economy – the law of value and the law of reproduction – by means of dynamic input–output tables. Changes in input–output coefficients were tested on the real data of several countries. These changes could convey the general direction of shifts in the technological system.

Dr. E. Mosekilde *et al.* (Chapter 18) present a new derivative of the System Dynamics Model of long waves, trying to account for the qualitative changes in economy and society that occur with each upswing. One of the important parameters – the growth rate of upcoming new industries when it reaches 15–20% – of the model generates 50–60 year oscillations. It was pointed out that the increase in this parameter reduces the wave period, while in the MIT model the increase in the investment rate prolongs the wave period. Attempts will be made to integrate both models.

Professor S. Menshikov (Chapter 7) approaches long-term economic development from another viewpoint. He stresses that the best manifestations of a contradiction in capitalism are the structural crises characterized by changes from intensive to extensive growth, waves in the organic composition of capital and general profit rate, changes in the flow of technical progress, and the overaccumulation and relative shortages of capital. Menshikov shows that, in the course of structural crises, a radical recasting in the sectoral structure occurs, the technological and interindustry base changes, as does the level of concentration, market control, and macroeconomic intervention.

Dr N. Nakicenovic (Chapter 8) shows some examples, reconstructed from historical records, of how technological change took place in energy consumption, steel production, and the merchant marines in the USA. To capture the dynamics of these changes logistic substitution analysis was used.

How technical revolutions are influenced when changing economic efficiency is described by Dr. H-D. Haustein (Chapter 15). He contends that it is dynamic efficiency (the efficiency of a set of growth industries) that predetermines the evolution of average efficiency in the production system and, at the same time, directs the trajectory of technical revolution. Dynamic efficiency is measured by the relation of net returns to productive funds. He has tested these relations on a corresponding model with data that covered a 30-year period and obtained a cyclical pattern of dynamic efficiency.

Dr H. Maier (Chapter 6) pursues a similar concept, and shows how innovation can influence employment. Maier also shows how "revolution in value" enhances innovation and speculates on a potential new combination of basic innovation which could generate the next long wave in productivity growth.

Dr. C.W.A.M. van Paridon (Chapter 12) argues that growth and change are two inseparable companions. Many sciences have managed to merge them into a single theory. The author argues that economics is not among them because it considers change only marginally. Then he elaborates on the concept of the structure in which he includes not only shares of branches in production, but also consumption and external relations. This concept is especially useful in small open economies, where an important determinant is the outside world. The author described the multifaceted character of structural change during the long-wave period.

In the early years of long-wave research, monetary factors played a key role in explaining long waves. Later, especially after Schumpeter's groundbreaking work, innovation took the lead as a factor of interest. Nevertheless, any trustworthy theory of long waves should respond, and have an explanation for, any important events that occur in both cost and monetary fields.

Dr. P. Korpinen (Chapter 24) presents a model based on a neo-Keynesian type of growth model (á la Harrod, Kaldor, and Kalecki). After defining an equilibrium growth he tries to find a monetary explanation for disturbances in the equilibrium path, leaving money supply as an endogenous variable. The model can show cyclic behavior and delivers information on the relation of money supply, interest rates, wages, etc. Dr. Korpinen suggested the period with high interest rate be called a "monetarist" regime, and the period with low interest rate a "Keynesian" regime. The task of a researcher then would be to describe the mechanisms causing the change in regimes. When speculating in wider terms he points out that economic policy has a tendency to be late, and therefore "wrong", because reality determines consciousness, and consciousness determines the action. This process takes time and causes delays. Dr Korpinen cites past cases to prove his point.

Dr. M. Di Matteo (Chapter 23) presents a model based on W.W. Rostow's theory of long waves (relation of foodstuffs and raw material prices to prices of manufactured commodities). He discusses ways to merge the dynamics of relative price processes with technical change.

Dr. J. Delbeke (Chapter 22) presents an interim report of his research into long-term trends in the money supply of Belgium (1877–1984). He avoids complicated statistical procedures by choosing a Juglar-oriented research, and concentrates on money supply. He treats money supply as both the product of the "base money" and as a multiplier. Dr. Delbeke manages to track down a causal circle in the monetary domain where the growth of the base money stimulates the growth of the other determinants, including private banking, as a result of public optimism, and so a "virtuous circle" is created. When the possibilities are saturated the relationships change and the "virtuous circle" become a "vicious" one. In a small open economy such as that of Belgium this depends on the competitive position of the country.

Dr. B. Sipos (Chapter 10) presents the results of his empirical research on historical Hungarian and World data to explain long-term fluctuations. (Dr. E. Gidai also presented a paper on a Hungarian study of long-term development, but it is not included in this volume.)

An interesting attempt is presented by Drs. F. Foders and H.H. Glismann (Chapter 3) on long waves in Argentinian economic development. The message here is that several existing theories have to be adapted before application to a country such as Argentina. For example, a lack of endogenous technological innovation invalidates Schumpeter's hypothesis; distributional conflicts have a more explanatory power. Related to this is the impact of an oversized government sector that creates disincentives for private entrepreneurial activity.

Drs. R.M. Entov and A.V. Poletayev (Chapter 9) discuss the fluctuation in the rate of return that has a key position in Marxist theory. They also present the methodological problems in collecting data, especially for the pre-World War II period.

It seems sure that as long as long-wave research exists it will be accompanied by methodological issues, as explained by Professor Chizov (Chapter 2). His argument is that while spectral analysis of statistical time series shows the existence of long-term harmonics, nobody can estimate rigorously long-term oscillations in a macroeconomic time series generated by a macroeconomic model. The author has also tested business cycles in a macroeconomic model, but several issues remain open. This is because during the sample period many changes (structural, price changes) take place that influence a business cycle. The question is how to represent these in the model.

A sophisticated method to analyze data series was presented by Dr. R. Metz (Chapter 28) using the theory of linear filters. After a criticism of the original Kondratieff method (polynomial) he points out its main weaknesses:

(1) In trend determination.
(2) Potential "Slutzky-effect".
(3) The problem of determining upper and lower points.

After a discussion of the spectrum analysis he suggests a linear filter, designed by W. Stier, that shows many advantages.

Professor Mensch *et al.* (Chapter 29) present the results of an extended Mensch–Wold PLS (Partial Least Squares) method applied to Swedish and FRG data.

Even the most outspoken critics of long waves do not expect (or consider unlikely) a steady growth. The same holds true for territorial uniformity. Development dynamics has its regional ramifications, which may contain some determinants that are needed to comprehend the reality. Several papers touched on this topic. Dr. G. Bianchi *et al.* (Chapter 14) present a comparison of Italy and Great Britain on a regional basis and have devised several hypotheses for the regional takeoffs and tested them on real data. Professor Nijkamp (Chapter 19) presents a method that tries to identify significant parameters behind the diffusion of new technology in different regions of the Netherlands. Among the parameters were education of the labor force, R&D infrastructure, amenities, etc., that are important "social" parameters. Baaske *et al.* (Chapter 17) has a similar orientation which tried to identify growth retarding factors and paradigms of the new upswing. With data from 19 countries they show that many factors which helped economic growth became growth retarding (government spending, economies of scale, social factors).

An interesting nonlinear model is presented by Professors Craig and Watt (Chapter 30). It depicts the relation between use (depletion) of resources and economic factors. The model also accounts for other relevant factors (demography, government policy, etc.). It captures, with precision, most of the temporal variation in wages and prices over a period of 100 years for the USA. The authors suggest using the model to understand potential changes induced by the impending transition away from an oil-based global economy.

The conference that produced these proceedings had several specific features, such as its wide scope and the participation of senior scientists from socialist countries. All of the participants felt that, in spite of unresolved theoretical questions, we have to focus more on the applied side if these theories are to prove of some utility to decision makers. The recent problems of structural change and employment, and the accompanying societal problems, present an immense task and their solution, as practice shows, can not be achieved by traditional means. Many participants felt that research on long-term fluctuations could prove helpful.

Several scientists from socialist countries presented a time series for their countries. However, when testing some models and long-term hypotheses, they had to turn frequently to US data because of its consistency. Many long-term theories cannot be tested on data from socialist countries as most of them have existed for a shorter period than a full Kondratieff cycle. Even in this period the real economic forces are distorted by the excessive impact of World War II. In several socialist countries the war theater swept through twice in a five-year period.

This conference was organized and sponsored jointly by the International Institute for Applied Systems Analysis (IIASA), Laxenburg, Austria, and the Institute of Theory, History and Organization of Science of the Academy of Sciences of the German Democratic Republic, Berlin.

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Welcome Address

I am happy to say a few words of welcome to you. First, welcome from the scholars of the German Democratic Republic! Second, welcome to the important subject that you are dealing with! Welcome also from a social scientist who, more than 50 years ago, wrote the first statistical study on long waves by a Marxist, in which I denied their existence on the basis of the development of industrial wholesale prices in the major industrial countries from the middle of the nineteenth century until 1933.

Since then I have come to acknowledge the existence of long waves – without being able to find a satisfactory explanation for them in my own or in other studies. If long waves are really a law of the development of capitalism, it is necessary to develop a completely satisfactory theory to explain them.

And once such a theory has been developed for the economy as a whole, it will be necessary to investigate trends in the major factors of the economy, in order to establish which are or are not a necessary part of the general trend. We know, of course, that prices do not necessarily follow the general trend if there is strong inflation. But what are the current and future trends with regard to unemployment? Many economists (and I agree with them) fear, regardless of any waves, a steady rise of unemployment in the future, because of the steady advance of the present technological revolution combined with a low rate in the rise of production.

I am glad that structural changes and innovations are also being dealt with here. Quite a number of scholars believe that they are the cause of long waves in the economy. But the question is: Can they not also bring about the end of long waves?

And if, as I suspect – naturally, not more than suspect! – long waves will not be an aspect of capitalist development in the future, if there will only be a slow, long-term development of capitalist industrial production, are long waves really no more than an historical fact for which no theory is necessary? Or would our task be to develop two theories, one for the existence of long waves in the past and one for their future non-existence?

You see, I am as eager as I was more than half a century ago to deal with these deliberations. But I must not allow this eagerness to lengthen my welcome to you.

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CHAPTER 1

Will There Be a Fifth Kondratieff?

Gerhart Bruckmann

In recent years a substantial number of scholars have attempted to interpret a number of phenomena of our time and/or the result of analyses of various time series as the trough between the fourth and fifth Kondratieff waves. In their (implicit or explicit) view, there will be a fifth Kondratieff, i.e., an economic wave of some 50 years' duration, carried by a new bunch of innovations (e.g., microelectronics, robotics, bioengineering, etc.).

In many respects, however, the present extended economic "low" seems to exhibit characteristics different from the "lows" between earlier Kondratieff waves. Indeed, many writings, from Daniel Bell onward, seem to indicate that we find ourselves at the brink of a new socioeconomic age rather than between two Kondratieff cycles. It may well be that future historians will divide the economic history of man into three ages: the preindustrial age, which lasted until the end of the eighteenth century; the age of industrialization (the 200 years from the late eighteenth to the late twentieth century, subdivided into four Kondratieff cycles); and the postindustrial age, from the late twentieth century onward. A variety of symptoms seem to support this view.

Throughout the age of industrialization, the industrial process was characterized by concentration and by growth in average size – car producers, airline companies, hospitals, supermarkets, mass media – and by standardization of products. But in recent years, we have begun to experience trend reversals.

To quote just a few examples: Small firms make good money by adapting standard automobiles to individual tastes. Tiny airline companies have found ecological niches where they earn higher profits than large ones. Hundreds of local or specialized newspapers have sprung up. The trend toward bigger and totally comprehensive hospitals has given way to small, specialized care centers. Supermarkets are yielding ground to "superettes". Twenty years ago, the growth of city agglomerations seemed inevitable; in recent years, large cities have steadily lost population not only to suburbia, but to rural areas.

There seems to exist an intriguing common explanation for all these symptoms: Agrarian Society was decentralized, Industrial Society centralized, and in the Information Society the main tendency will be decentralization (and diversification) again. Hence, what at first glance looks like a regression to preindustrial times could rather be interpreted as a distinct advance into the new socioeconomic age. Moreover, there is – at least – one aspect in which Information Society will differ profoundly from Agrarian Society.

Agrarian Society had its system of norms and values, fitting the exigencies of agrarian life. Later, this system was replaced by a different set of norms and values, as required by industrial (mass) production. As we proceed into the Information Society, we neither return to the old values of Agrarian Society, nor is a new, generally accepted value system emerging. Rather, one of the main characteristics of the Information Society is that, contemporaneously, several norms peacefully coexist. For example: Learning, work and leisure were, in the Agrarian Society, integrated during all periods of life. Learning (mainly non-formalized "learning by doing") and work took place from early childhood to ***Ausgedinge***; evenings and holidays were enjoyed by all generations alike. The necessities of Industrial Society led to a separation: a number of years of (formalized) "learning", during which "work" became increasingly banned, led to "work life", followed by a "retirement period". Information Society, however, brings neither a return to the integrated system of Agrarian Society, nor a new, generally valid system. What we observe is a multiplicity of concurrent systems of distribution of learning, work, and leisure over the lifespan of an individual. For highly specialized professions, e.g., surgeons or opera singers, the traditional succession of learning, work, and leisure periods continues; the majority of the younger generation, however, chooses different mixes on an individual basis.

This may not be the only unique characteristics of current society. Some authors hold that this age represents the most distinct break in the development of humankind. All earlier times were characterized by (a) scarcity and (b) no visible limits to development; "more" goods was synonymous with "better off". In industrialized nations, for the first time in human history, neither feature holds true any more. We have arrived at a period characterized by (a) affluence and (b) threateningly visible limits to growth. Our generation, hence, is challenged with the most profound revolution in attitude any generation ever had to face.

The purpose of these remarks is not to discourage researchers in their attempts to dig out the fifth Kondratieff; but rather to sharpen their visions with regard to a more appropriate interpretation of the phenomena they are attempting to investigate. Maybe, in the Information Society of the centuries to come, Kondratieff cycles will reappear, in which case we are living now in the most fascinating of all times – the verge between two Kondratieff waves plus the verge between two ages of civilized man.

CHAPTER 2

Problems of Model Estimation of Long-Term Economic Oscillations

Y.A. Chizhov

This chapter is divided into two parts. The first part deals with the results of the spectral analysis of long-term statistical data from the USA, and in the second part some approaches to the use of macroeconometric models for investigating long-term economic oscillations are discussed.

Theoretically, there may be five types of long-term oscillations around a trend (see *Figure 2.1*). Type I oscillations are described by a sinusoidal curve with constant period (T) and amplitude (A). Types II and III have different T and A, respectively. Type IV is an "in-step" line, where different development types substitute one for another. Finally, Type V reflects the influence of some short-term disturbances that occur periodically in an economy . In reality, all five types of oscillations may take place and period and amplitude instability of oscillations are more probable. Traditional methods of spectral analysis enable oscillations to be effectively identified only in cases of A and T stability, and the last condition is more important.

Long-term statistical series for the US economy have been analyzed in order to identify long-term harmonics within a long sample period and for subperiods within it. Estimates of US industrial production (see *Table 2.1*) were made for 65 observations (N) between 1920 and 1984 by varying investigated frequencies (M) from 24 up to 40. Our results showed the existence of short-term (four years), medium-term or cyclical (seven years), and long-term (16 years) harmonics. Using Kondratieff's methodology, the original time series was modified with a seven-year moving average to exclude short- and medium-term harmonics. As a result only one harmonic with an 18–22-year oscillation was identified, whose spectral power (SP) was three times greater than the maximum in the original series estimation.

The same experiments were made for producer price time series for 94 observations from 1891 to 1984 (see *Table 2.2*), and in the original series three

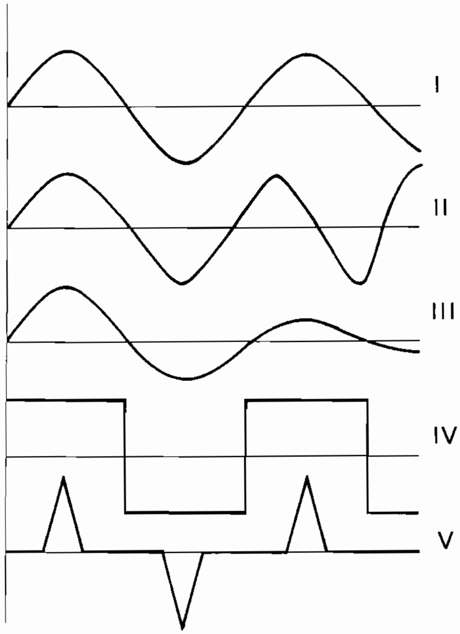

Figure 2.1. Types of long-term economic oscillations.

Table 2.1. Industrial production (IP), 1919–1984, $N = 65$.

M	*T*	*SP*
24	16	2.3
	7	3.7
	4	3.3
28	16	2.5
	7	3.8
	4	3.6
32	16	2.7
	7	4.0
	4	4.1
36	16	2.7
	7	4.0
	4	4.1
40	16	2.7
	7	4.1
	4	4.3
Moving average – seven years		
28	18–22	12.8
	4	0.3

Table 2.2. Producer prices (PP), 1891–1984, N = 94.

M	T	SP
24	32	3.7
	9	4.2
28	28	3.7
	9	4.5
	6	2.9
32	32	4.2
	9	4.8
	6	3.1
36	29	4.5
	9	5.2
	6	3.3
40	32	4.8
	9	5.5
	6	3.6
Moving average – nine years		
30	30	16.7
	6	0.8
1891–1938, N = 48		
28	16–22	2.8
	9	5.6
1939–1984, N = 46		
28	37	6.0
	5	5.1

harmonics (30, nine, and six years) were identified. Having modified the series with a nine-year moving average, we identified only one harmonic with an oscillation period of 30 years and with a fairly high spectral power. By dividing the sample period into two equal subperiods (1891–1938 and 1939–1984) we were able to identify 16–22-year oscillations with a low spectral power for the first period, and 37-year oscillations with a high power for the second.

Similar estimates were developed for the GNP deflator time series for the whole sample period as well as for two subperiods (see *Table 2.3*), and the results were close to those for the producer price time series. Finally, GNP per capita estimates (see *Table 2.4*) were close to those obtained for US industrial production, with only one exception: the absence of reliable estimates of long-term oscillations for the two subperiods. The results of these investigations can be summarized as follows:

(1) Spectral analysis has enabled us to identify long-term oscillations in the dynamics of US macroeconomic data. The use of moving averages corresponding to the length of the business cycle is a fruitful method.
(2) In US production data for the last 60–90 years the identified oscillation period was 20 years, whereas the long-term oscillation in prices was about 30 years.

Table 2.3. GNP deflator (GNPD), $M = 28$.

N	T	SP
94 (1891–1984)	28–37	6.5
	9	4.1
	6	2.3
48 (1891–1938)	22–28	5.0
	9	5.3
	6	1.9
46 (1939–1984)	36	7.6
	5	5.7
Moving average – nine years		
85	30	17.4
	6	0.5

Table 2.4. GNP per capita (GNPC), $M = 28$.

N	T	SP
94 (1891–1984)	16	3.2
	7	4.0
	3	2.3
48 (1891–1938)	10	3.2
	6	4.0
	3	2.9
46 (1939–1984)	11	6.8
	4	1.4
Moving average – seven years		
87	17–20	13.4
	4	0.4

(3) The division of the sample period into two subperiods was inefficient in the case of production dynamics, probably because of the lack of observations within the subperiods. In the case of price dynamics this division enabled us to conclude that the oscillation period increased from more than 20 years in the first subperiod up to 36–37 years in the second.

The use of macroeconometric models for analyzing short-term (four years) and cyclical (7–8 years) oscillations in the post-World War II US economy, combined with spectral analysis, thus enables oscillations in economy dynamics and the sources that generate them to be identified (Chizhov, 1984).

The common algorithm for analyzing economic oscillations is based on the investigation of harmonics generated endogenously by the model and traditional methods of simulation analysis. It is clear that the model should generate the same oscillations that have been identified in the real statistical time-series data. The methodology provides answers to the following questions:

(1) If the model generates long-term oscillations endogenously, are the given interrelationships responsible for generating them?
(2) If so, within what limits of interrelationship parameter changes do these oscillations occur, and how do the changes influence common dynamic characteristics of the model?

This approach can be illustrated by a simple model:

$$C = a_1 W + a_2 P_{-1} + \cdots \tag{2.1}$$

$$I = a_3 P - a_4 K_{-1} + \cdots \tag{2.2}$$

$$Y = C + I \tag{2.3}$$

$$W = Y - P \tag{2.4}$$

$$K = K_{-1} + I \tag{2.5}$$

where C = consumption, I = investments, W = wages, P = profits, Y = national product (income), K = capital stock, and a_i = coefficients > 0. The negative feedback created by equations (2.2) and (2.5) generates endogenous oscillations in the model dynamics. If I includes a change in business inventories (CBI), the period of the main harmonics equals 4–4.5 years. If (CBI), is excluded the oscillation period increases to 8–9 years (all data for post-World War II US economy).

If I and K in equations (2.2) and (2.5) are disaggregated into equipment and structures (the latter have much longer periods of service), this will lead to the generation of an additional long-term harmonic. In that case the simulation analysis based on the variation of the negative feedback parameters in relation to investments and capital stock in construction will give an opportunity to estimate the features of the so-called "construction cycle".

Another approach is based on the use of the production function:

$$Y = f_1(L, K) \tag{2.6}$$

$$K = \sum_i b_i K_i \tag{2.7}$$

where L = labor. In function (2.7) the distribution of weights b_i with lags i enables the venture structure of fixed capital stock to be described, as well as the influence of this structure (depending on the lifetime of each venture) on long-term oscillations in an economy. Since the substitution of technology generations might be reflected through changes in the venture structure, i.e., parameters of function (2.7), this approach enables us to determine indirectly the influence of technological progress (embodied in capital goods) on long-term oscillations.

The explicit (albeit partial) representation of technological progress factors might be made through the insertion of a new variable in function (2.6), such as expenditures on research and development:

$$Y = f_2(L, K, \sum_j d_j RD_{t-j}) \tag{2.8}$$

where RD_{t-j} = expenditures on research and development with a time lag j. Estimates of coefficients for the US economy showed maximum sufficiency for $j = 5$ years and the second peak of t-statistics for $j = 1$ year (see *Figure 2.2*). The existence of a relationship with such a long time lag might also influence long-term oscillation parameters sufficiently to transform irregular dynamics of innovations into long-term oscillations in economic growth.

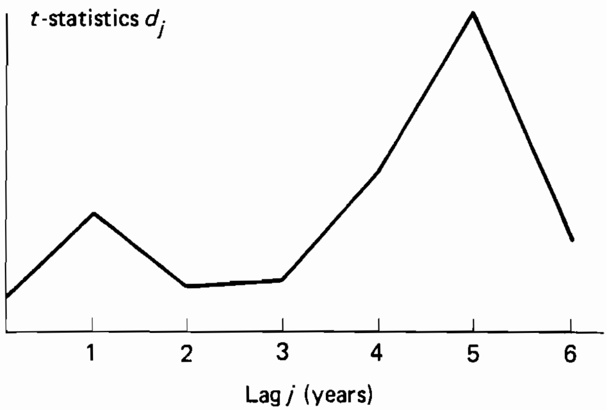

Figure 2.2. The t-statistic values for the coefficient d_j estimates. The function (2.8) was estimated by OLS for $j = 0,1,...,6$.

The main methodological problems that arise in such investigations are connected first with a shortage of long-term statistical data: for spectral analysis of long-term oscillations it is sufficient to have isolated time series twice as long as the oscillation period, but for econometric model development a complete system of national accounts over a long period is needed. The second problem is due to the absence of reliable and disaggregated data for various elements of fixed capital stock. A third problem is connected with the need to exclude disturbances in statistical series caused by World Wars I and II. It is possible that these two strong (even for the USA) disturbances either generated their own long-term harmonics or destroyed long-term "innovation cycles", "construction cycles", etc.

Finally, we consider the most important problem in long-term econometric model development to be that during the sample period there were many structural changes, price-system developments, and business cycle transformations. All of these led to important changes in medium-term econometric model parameters and structures. What model structure and parameters can represent the long-term sample period? This problem calls for additional investigations. In this context we consider that an approach based on preliminary transformation of the original time series data to exclude short-term and business cycle oscillations (e.g., using moving averages) is interesting. But here there are many more questions than answers.

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CHAPTER 3

Long Waves in Argentine Economic Development

Federico Foders and Hans H. Glismann

3.1. The Overall Picture

> ***Every physical and moral development favoring the social order can thus be grasped at one point: an increase in net product.***
>
> Mirabeau, 1976

Argentina's historical pattern of economic development differs in more than one way from that experienced by comparable countries, and particularly so in her poor growth performance during the last 50 years. In this respect Argentina is an outstanding example of a country that is economically declining relative to both other countries and its own past record (Diaz-Alejandro, 1981). Yet Argentina's slow growth can hardly be explained by low or inadequate resource availability, for she is relatively richly endowed with human and natural resources; in fact Argentina seems to match quite well the paradox of a resource-rich but poor country.

Analyses of growth cycles in less-developed countries are rare (but see Kuznets, 1973; Lewis, 1978). This is surprising because slow economic growth is generally acknowledged to be the main problem of these countries. The reason for this deficiency may be that, rather than growth itself, underemployment of factors of production, a lack of complementary factors like physical and human capital and/or basically noneconomic aspects (illiteracy, health standards, and food shortages) have been held to be the important issues (Lewis, 1984; Papanek, 1983). Also, a lack of a sufficiently reliable data basis is probably more commonly a hindrance for empirical studies regarding less developed than developed countries (Randall, 1976).

Figure 3.1 gives an overview of the Argentine economic performance since 1864. The curves represent investment shares, and three- and nine-year moving averages of the deviations of real gross domestic product and investment from their exponential trends. At first glance the pattern of Argentina's development does not show evidence of the long-wave behavior in industrial countries' aggregate production, which suggests that the current economic downswing (measured by social products, investment, and employment) began in the early (FRG) or late (France) 1960s (van Duijn, 1983; Freeman, 1983). Several particular features deserve to be mentioned:

(1) The regular pattern of economic upswings and downswings, resembling a sinusoidal curve of the Kuznets rather than the Kondratieff type. Measured peak to peak, each cycle has a length of about 17 years.
(2) Amplitudes seem to have been declining continuously, in fact they have virtually disappeared in recent years.
(3) Since the late 1930s economic development has been persistently below its long-term average.

The peaks and troughs reveal that there have been at least three full cycles since 1870: the first had its trough about 1880 and its peak in 1893; the second "began" in 1900 and reached its zenith in 1909; and, finally, the third trough can be located around 1918 with the upswing ending in 1926. From then on one may speak of a continuous trough in development, with some small indication of recovery starting around the early 1960s.

The purpose of this chapter is to present and discuss some hypotheses that explain Argentine development. Specifically, it focuses on the distributional conflicts hypothesis, the inflation hypothesis, the world market hypothesis, and the political cycle hypothesis. The Schumpeterian innovation hypothesis is not mentioned here because it does not seem to be relevant to developing countries.

3.2. Explanation of Argentine Long Waves

3.2.1. The distributional conflicts hypothesis

Hypotheses concerning distributional conflicts have been advanced since the 1970s (Glismann *et al.*, 1978) as the main cause of long-term cycles in economic development. Such hypotheses had already been put forward by Karl Marx and his followers, but today particularly by Mandel (1980) and Olson (1982). Whilst Marxists place special emphasis on the exploitation of the "working class" by "capitalists", non-Marxist authors study distributional conflicts between organized interest groups, i.e., between trades unions and employers' organizations, among entrepreneurs, between consumers and producers, between organized and non-organized labor, and between government bureaucracy and private productive factors.

In the case of Argentina, two kinds of distributional conflicts can be identified. First, that between organized labor and entrepreneurs: this hypothesis states that any change in the relative position of one party

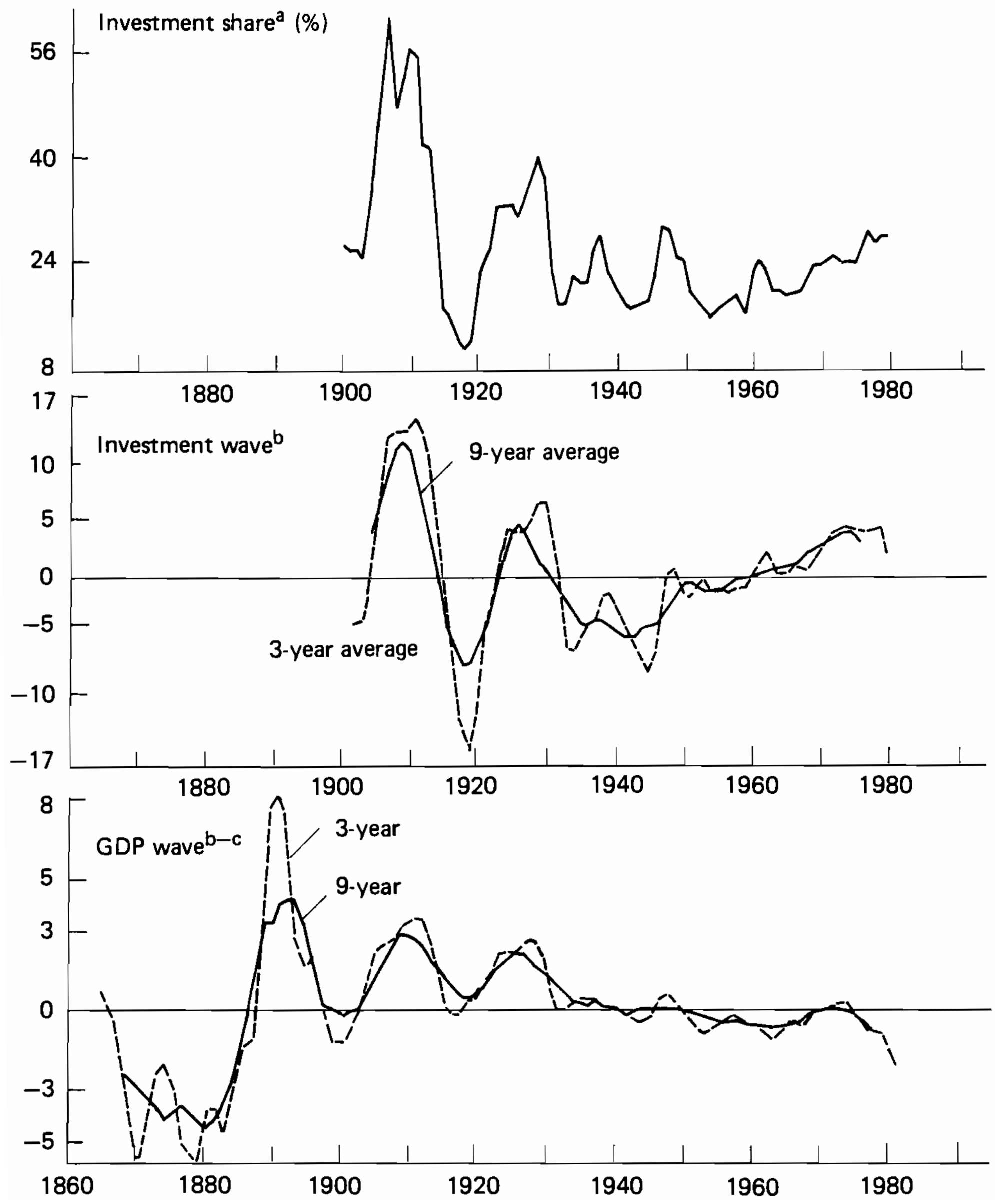

Figure 3.1. Long waves in Argentine development. [a]Gross real investment as a % of real GDP. [b]3-year and 9-year moving averages of deviations from trend, as % of trend value. All values in 1960 prices. [c]Figures for 1860–1900 based on estimates.

adversely affects the other in a zero-sum fashion. If labor demands and receives wage increases in excess of productivity growth, the profitability of capital investment is reduced. In circumstances where the marginal product of labor is equal to or even below real wages, such wage increases also lead to unemployment. In the wake of falling profit rates investment in domestic physical capital declines, and thus ultimately the social product decreases.

The second distributional conflict pertains to the bureaucracy exploiting the productive sector. The model assumes that there is such a thing as a growth-optimal degree of public goods production by the government. Taking internal security as an example, inadequate law enforcement would prevent economic growth reaching its maximum, whereas too much law enforcement would present obstacles to economic development. This implies that government can be very effective in constraining economic activity by engaging in public goods production. Bureaucratic exploitation also takes place when government supplies protection of any kind, i.e., does not guarantee the openness of markets. The ensuing establishment of a market for protection takes resources away from productive use (in a macroeconomic sense) and allocates them toward unproductive activities. Artificial bureaucratization of the private sector should be closely related to the size of the official bureaucracy.

Trades unions have existed in Argentina since the late nineteenth century and can be closely associated with immigration flows because European immigrants brought with them the idea as well as the know-how of labor organization. The importance of trades unions grew with industrialization, particularly since 1930, when import substitution policies were first implemented. Concentration of workers in urban areas helped to create favorable conditions for labor organization, and since the mid-1940s trades unions have become a central element in social life. Under Perón (1943–1955) a centralized union was empowered to raise and allocate membership fees which, due to the quasi-closed-shop system in the manufacturing sector, virtually made trades unions a part of public administration.

As regards distributional conflicts arising from government intervention, two issues in Argentine economic history are worth mentioning: the nationalization of manufacturing and service companies, particularly of foreign companies, and bureaucratic redistribution. Foreigners had been the main source of entrepreneurial impulses since the country's independence in 1810. Especially since the 1940s, nationalization of "key industries" – directed first against British "imperialism" and later against US domination – brought with it the emergence of a large number of state-owned companies. In the banking sector, in public utilities and in industry, government became more and more the dominating entity (Randall, 1978).

Also begun in the 1940s was a policy aiming at distributional justice rather than at economic efficiency. Perón believed that social justice would ultimately lead to economic progress; but this turned out to be an invitation to a permanent struggle for higher shares of the national income. Productivity as a criterion for distribution has virtually not mattered since then. In Argentina the bulk of transfer payments consisted of direct firm or sectoral subsidies; interpersonal transfers, very common in more-developed countries, have been of only marginal importance.

Figure 3.1 highlights the relationship between the long-term cycles of GDP and investment activity; *Figure 3.2* shows the relationship between gross domestic activity and indicators of income distribution. As regards GDP and gross investment, their respective cyclical patterns match quite well. The first impression is that the peak years 1909 and 1926 are identical for both indicators and that the same holds true for the trough of investment development at the end of Wold War I (1918), as well as for the one in World War II (1941). From 1941 onward mainly shorter cycles of the Juglar type seem to have dominated. It is noteworthy that the ratio of investment to GNP also reveals a long-term decline since 1907–1910 up to the present. Investment activity helps to explain the weak performance of the Argentine economy after the peak of 1926: this ratio did not again achieve that of the years 1904–1914 and 1923–1929. In other words, since 1929 consumption seems to have been much more rewarding than savings and domestic investment.

Such developments can basically have two explanations:

(1) Income has been redistributed from the rich to the poor; this would result in higher consumption.
(2) Investment profitability declined and thus either consumption or capital exports increased.

In *Figure 3.2* the wage–productivity ratio has been taken as an indicator of both redistributional incomes policies and of labor costs. From 1919 to 1947 real wages increased faster than productivity, but after 1947 the "gap" between real-wage growth and productivity declined again, though very slowly at first. In fact, the time span between 1946 and 1956 resembles a high-wage plateau.

Since 1956 the ratio of wages to productivity has been falling; indeed, after 1974 this decline is extraordinary, due to the tremendous fall in real wages (Paldam, 1985). The domestic dip in real wages of about 70% between 1974 and 1978 has no precedent in recorded economic history; one of the factors "explaining" it is the freezing of nominal wages by a new administration in 1976 while inflation continued. The question to be answered is why overall economic activity did not respond to this decline in labor costs. Possibly, the distributional conflicts hypothesis – at least as far as the conflict between labor and entrepreneurs is concerned – may not be symmetrical, i.e., high wages and low profit rates always dampen investment activity, whereas the converse – low or declining real wages – does not necessarily encourage investment; other conditions may be important, too. Second, expectations matter: if entrepreneurs do not believe that the wage decline will last they will tend to wait rather than to precipitate investment; investment data (*Figure 3.1*) support this notion. Severe and sudden changes in economic variables, in whatever direction, inhibit investors; they prefer graduality to shocks.

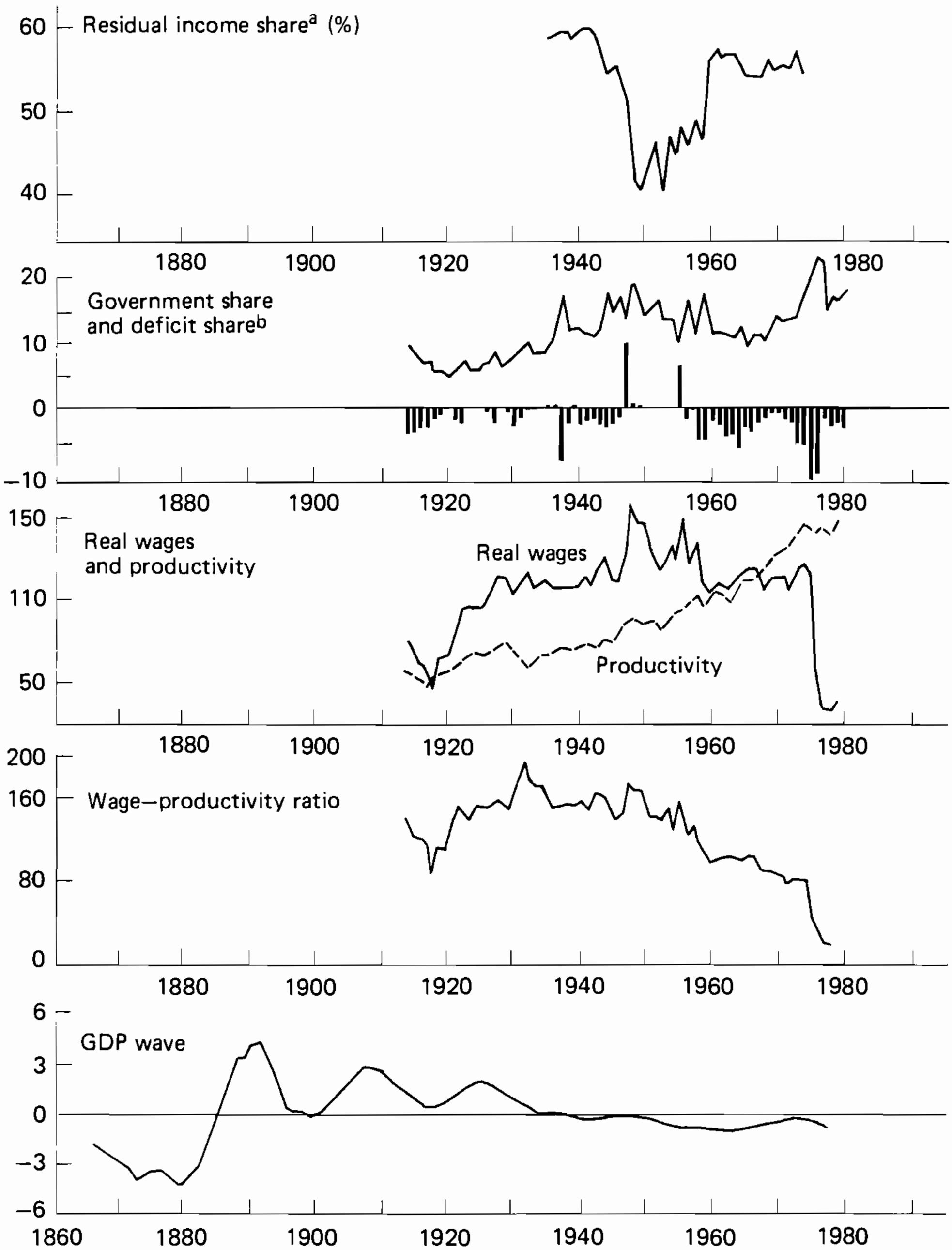

Figure 3.2. Indicators of distribution. [a]Non-wage incomes, as % of GDP. [b] Government expenditure and deficit, as % of GDP.

The mirror image of the labor income–labor costs pattern is given by the development of the residual incomes share in GDP. Again, there is striking evidence for a low residual incomes share between the mid-1940s and the late 1950s, which alone may account for the persistently low level of investment activity in this period. Since unions in Argentina have had the power to strongly influence the wage level most of the time, the share of wages in total national income can be assumed to have risen above the share that would have been determined by labor productivity alone. Thus industrialization appears to have been obstructed by the distributional effects of unionization, which may therefore have neutralized any incentives for investment created by import substitution policies.

The government's influence, as measured by total government expenditure (*Figure 3.2*), increased drastically in 1937, but this may well have been a singular event when compared with the expenditure levels achieved in adjacent years. In 1944, however, government activity expanded again and remained at high levels until 1958. This does not mean, of course, that government refrained from crowding out productive factors after 1958: Argentina's current severe debt problems seem to be related to the deficit spending policies implemented since the late 1950s. All in all, empirical evidence suggests that the economic problems of Argentina did not start only in the 1930s and 1940s, as is commonly believed. Rather, incomes and investment indicators exhibit much earlier distortions.

3.2.2. The inflation hypothesis

Inflation generally reduces economic efficiency for two reasons: one is concerned with the rate of inflation; the other with the variability of the rate of inflation. The first argument says that inflation *per se* alters resource allocation and produces losers and winners. Losers are those with fixed or lagging incomes, such as savers and asset holders, employees, and pensioners; winners are those whose incomes overadjust to inflation, such as real estate holders, speculators, and other "shrewd" people. This reduces allocational efficiency by reducing overall savings in favor of unproductive speculative investment. In addition, inflationary monetary policy does not leave relative prices unchanged because newly created money is injected into certain sectors of the economy and spent only on certain kinds of goods and services, the prices of which rise before other prices feel the pull (Hayek, 1966). In this way relative prices are constantly moving, not according to real scarcities but to monetary phenomena; in fact the link between real scarcities and prices becomes very weak under hyperinflationary conditions.

The second argument says that the predictability of inflation rates matters, too. Whilst in the case of comparatively steady inflation rates entrepreneurs and consumers already have difficulties in extracting information on relative prices from the markets, this information becomes totally blurred in cases of volatile inflation rates: "the broadcast about relative prices is as if it were being jammed by the noise coming from the inflation broadcast" (Friedman, 1977, p. 27). The overall allocational efficiency consequently declines further with an increasing unexpected variation in inflation rates.

Argentine monetary history can be divided into three important periods on the basis of the standard by which the peso was defined. The gold exchange standard prevailed until the late 1930s; following textbook wisdom, money creation was strictly limited to the gold supply during this period [1]. According to Mises (1953) such a standard is the best insurance against spendthrift governments. After a transitional period based on a Sterling standard, the US dollar became the new currency standard after World War II. Thus, Argentina became free to pursue monetary policies that were not subject to the automatic discipline of the gold standard.

One of the causes of inflationary growth of money was the nationalization of bank deposits between 1946 and 1957, and later again between 1973 and 1976. Only up to 1949 did credit expansion of the central bank have an upper limit (credits could be extended up to 25% of existing gold and foreign currency reserves). In 1949 this limit was dropped, and credit creation has been virtually uncontrollable since. Only in 1957 was a fractional reserve system introduced, but the legal opportunity to control inflation was not used. The central bank, still in the hands of the government, continued to pursue expansionary monetary policies, maybe due to the political weakness of governments *vis-à-vis* unions and other organized interests (Del Canto, 1982); the same applies to the period after 1976.

Figure 3.3 presents the highlights of Argentine monetary history. Inflation (measured by the consumer price index) and money supply turn out to be highly correlated during the periods studied. It becomes quite clear that

(1) Inflation posed no great problem before 1944. After that the money supply virtually exploded, leading to an average level of inflation of roughly 20%/year between 1940 and the late 1950s. The rates of inflation then even increased and were followed by hyperinflation from 1970 on.
(2) With a grain of salt, trend deviations of money supply – as measured by M2 (i.e., cash + demand deposits + time deposits) – support the hypothesis that monetary discipline loosened significantly in the late 1930s and early 1940s and again during the 1960s and 1970s.

These observations fit extremely well with the history of Argentine monetary institutions. What is more, trend deviations exhibit that the monetary policy of the 1960s and 1970s was by no means unprecedented. The "monetary revolution" took place in the 1940s, whereas today's inflationary money supply seems to be a follow up.

Liquidity coefficients of the Argentine economy – as measured by the ratios of M1 (cash + demand deposits) and M2 to GDP – show the effects of inflation on money holdings (Bernholz, 1985). The gap between M1 and M2 coefficients partly reflects the effects of inflation on savings. This gap has been decreasing since 1940, with a small and relatively stable gap between, say, 1959 and 1975. The relative level of savings, however, also decreased in

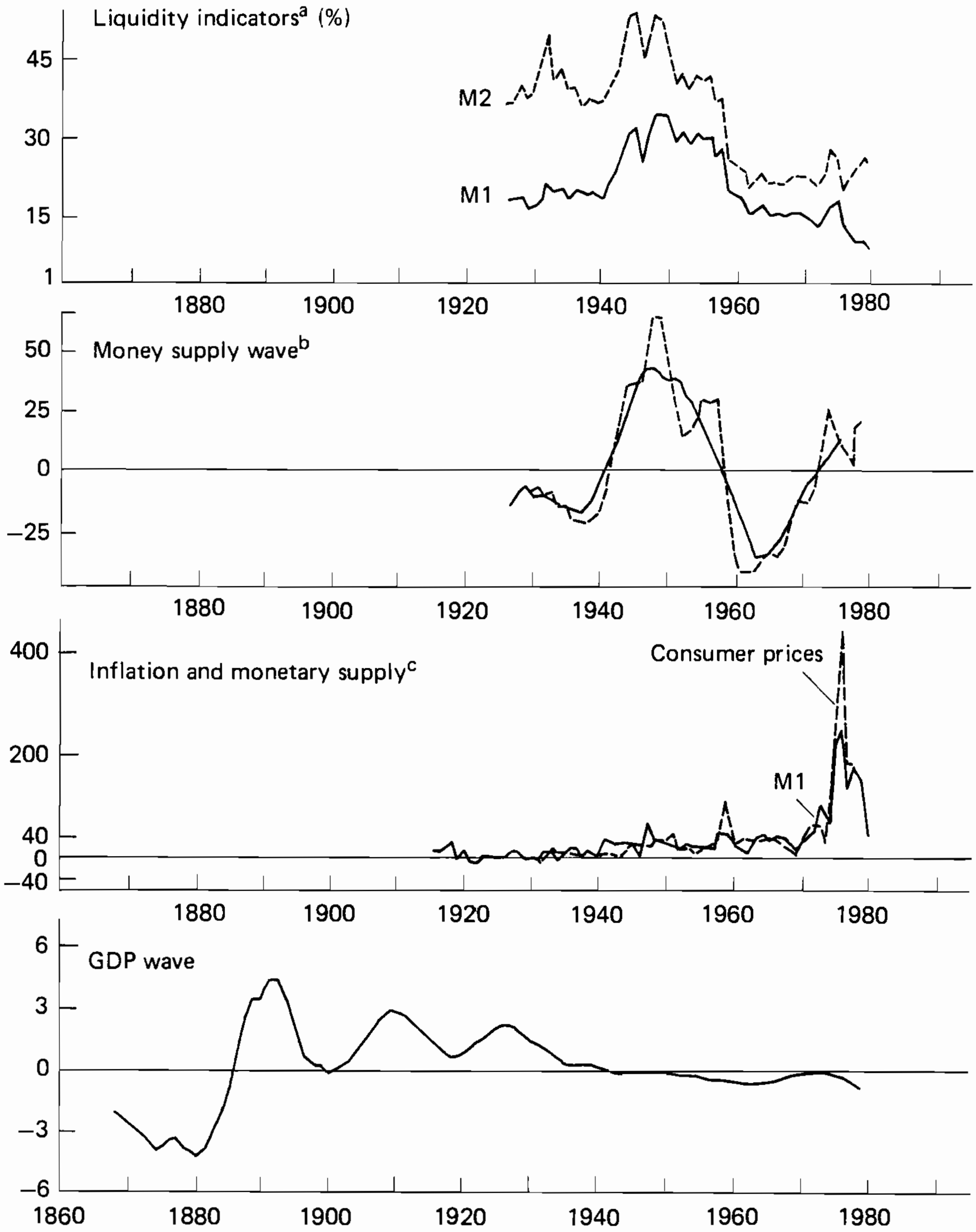

Figure 3.3. **Indicators of inflation. [a]M2 and M1 as % of GDP. [b]M2, see note b in *Figure 3.1.* [c]Annual changes in consumer prices and M1.**

the "stable" phase. After 1975, the gap increased again, possibly due to positive real interest rates since 1976.

All in all, the pattern of inflation does not contradict the long-term development of GDP. Indeed, in view of the regularity of the long wave of GDP before the 1930s one could have expected a new upswing starting in the mid-1930s. But this did not happen; in fact, under inflationary conditions GDP never recovered again.

3.2.3. Two other hypotheses

The explanatory powers of the distributional conflicts hypothesis and the inflation hypothesis do seem to be quite strong. Nonetheless, other hypotheses may also be important, given that our analysis covers a fairly long period of Argentine history, involving substantial institutional and policy changes. Of the many other approaches that also seem to fit the Argentine case the most promising appear to be:

(1) Changes in the world market conditions that had an impact on domestic economic activity.
(2) Uncertainties introduced into the Argentine economy through frequent changes in political power that presented obstacles to investment and production.

Argentina's international economic relations, both with respect to trade and capital flows, have been characterized by concentration (Kawata, 1972). Export trade was not only highly concentrated regarding commodity composition, but also regarding regional distribution. The main customer for Argentine agricultural goods was the UK, from independence until, say, the end of World War II. Since World War I the USA also gained importance as a market for Argentine products. In the past 40 years the USA has gradually become the dominant trade partner, followed by Western Europe (until 1973, when trade relations with EC countries was brusquely reduced due to the EC's agricultural protection), notably Italy. Commodity imports followed similar regional (though not product-specific) patterns, with the USA being the most important source of Argentine imports. Capital inflows into Argentina, as well as capital outflows, exhibit a similar geographical distribution.

Thus, it can be hypothesized that major changes in world markets are very likely to have had severe income effects. Examples of such exogenous events can be seen in World Wars I and II and the Great Depression. Also, *ad hoc* discrimination of Argentine exports on political grounds falls under this heading, such as the EC's boycott in the wake of the 1982 Falkland/Malvinas conflict, or as the one imposed on Argentina during World War II. Non-tariff barriers on imports from Argentina, particularly beef imports, have been applied by the USA (since the 1950s; the official reason given was the danger of transmitting foot-and-mouth disease) as well as by the EC (since 1973 within the framework of the Common Agricultural Policy). The hypothesis following from these experiences would be that the Argentine economy had strong incentives to insure against such export risks – either by diversifying exports, or through a reduction of imports and consequently through import substitution. Indeed, import substitution has been the *Leitmotiv* of Argentine economic policies since the 1930s (Foders, 1983).

The political cycle hypothesis rests on the observation that investment as well as capital imports react sensibly to political risk. Such risk can be seen in unexpected and frequent changes in government, particularly if this is associated with fundamental changes in policy.

Figure 3.4 shows the long-term development of the index for the international integration of the Argentine economy, measured as the share of exports plus imports in GDP and as the deviation of this indicator from its long-term trend. The degree of international integration of Argentina has been constantly declining over the period 1865–1980; since 1950, the average share of foreign trade in GDP was about 20%. One may distinguish three phases of international integration: the first and highest lasted until the turn of the century; the second, on a considerably lower level, can be observed between 1900 and 1920; then came a strong decline over 25 years until, in 1950, the current relatively low level was reached.

The deviations from the long-term trend are further evidence of the importance of these three phases. It turns out that the largest and longest deviation from the trend of integration lies between the mid-1920s and the 1960s. According to the world market developments discussed above, this may be labeled the "import substitution belly". Thus, neither World War I nor the Great Depression and World War II were the origin of the stepwise decline – unless, of course, there are hidden time lags.

Export performance can contribute to an explanation of the pattern of international integration. One can interpret the data as follows: exports relatively increased from 1860 until 1917. From then on came a steady decline until the early 1950s; exports never fully recovered in the sense of exceeding the long-term trend. These developments can serve to reconsider the above refutation of the hypothesis concerning the impact of the wars. It seems that, at first, World War I contributed to the expansion of Argentine exports, but that in the longer term exports have been severely hampered – either by a misguided domestic policy (import substitution), or by some sort of discrimination by its main trading partners. At this time (the 1930s) the British Commonwealth was consolidated. Argentina was not invited to participate, even though Britain was the main market for Argentine goods, and this meant an important loss of foreign markets to Argentina [2]. Neither the Great Depression nor World War II had any direct or discernible effect on exports or on the integration of the Argentine economy into the international division of labor.

The political development of Argentina can be divided into four periods. First, a long and stable period prevailed until 1930 (see *Figure 3.4*). In the "transition period" from 1930 to 1943 government instability increased for the first time this century. After 1943 stability resumed, but this came to an end in 1955, and since then a fairly long period of high instability has

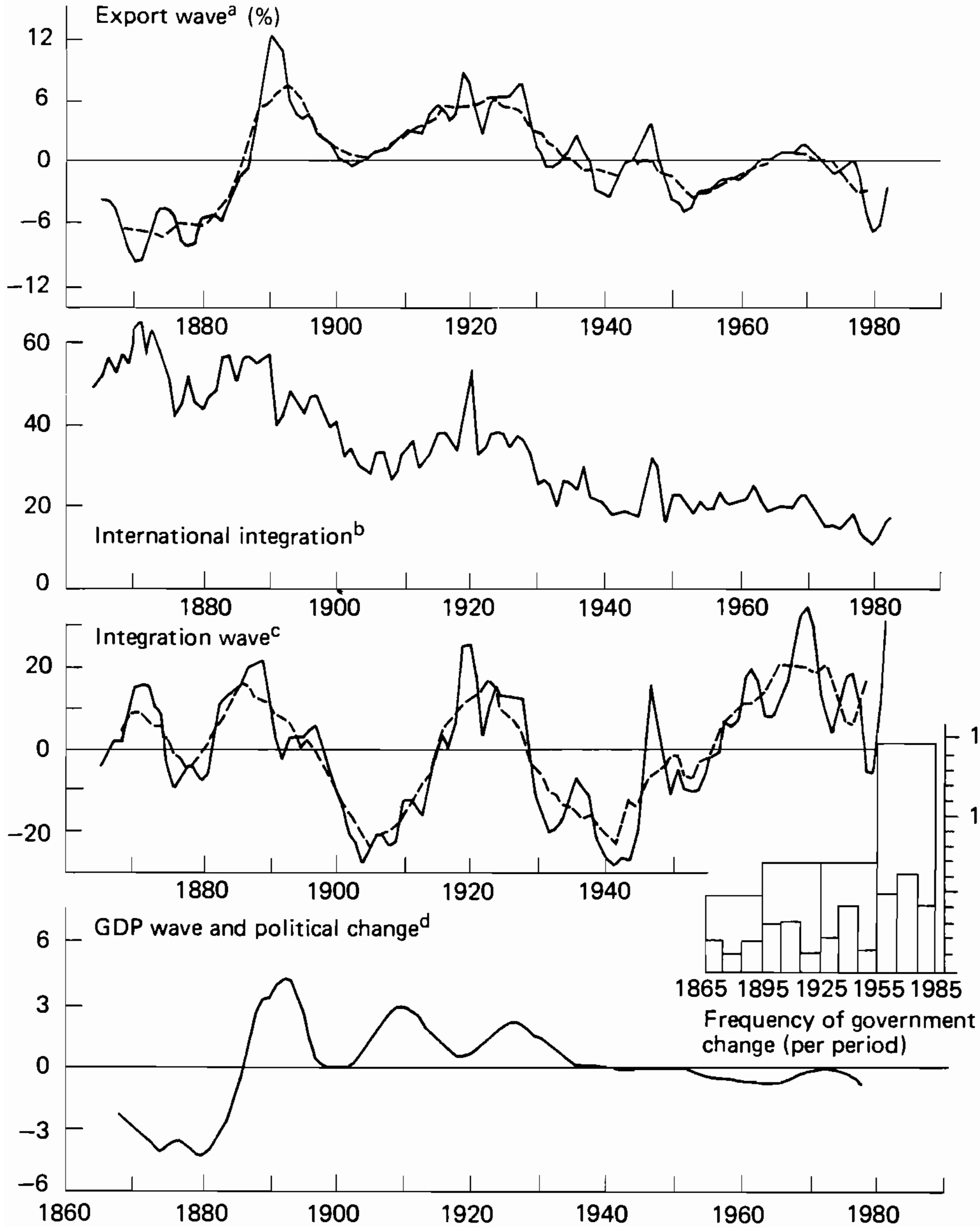

Figure 3.4. Indicators of international integration and of institutional change. [a]Real exports; see note b in *Figure 3.1*. [b]Exports plus imports, as % of GDP. [c]Exports plus imports, as % of GDP; see note b in *Figure 3.1* (expressed as % of exports plus imports). [d]Bars indicate times of changes in government.

prevailed. This pattern by and large fits into the picture of economic development – with the apparent exception of the period 1943–1955, during which income redistribution, government expansion, and high rates of inflation prevailed.

3.3. Summary and Conclusions

Argentine economic development from 1864 to 1985 can be roughly divided into a period of economic progress featuring significant Kuznets-type waves (1864–1934), and a period of economic decline with virtually no long-term fluctuations in GDP (1934–1983). Of the many issues that could potentially explain such an unprecedented development of a basically resource-rich country, this chapter has dealt with distributional conflicts, inflation, exogenous shocks, and political instability. The analysis shows that redistributive incomes policies in favor of labor and government, accommodated by a very loose monetary policy, seem to lie at the heart of an institutionalized distributional conflict over a relatively stagnant national income.

The explanatory power of each of these hypotheses, however, has varied over time. Argentine economic history may be described thus: the first incisive event in Argentine economic development in the period under observation was World War I. This was an exogenous shock for a country heavily dependent on foreign trade. The subsequent degree of integration of Argentina into the world economy has fallen, and consequently GDP expansion has slowed down. Starting in the 1930s, this trend triggered inappropriate domestic policies aimed at income distribution rather than at economic growth. The rise of trade unions, of populism (Péronism), and the implementation of import substitution policies gradually made government the main actor, besides trade unions and entrepreneurs, in economic matters. In order to try to satisfy the demands of the conflicting interest groups the government resorted to an easy monetary policy, with the result that in periods when one would have expected economic recovery in the wake of improved profits, high price inflation and political instability obstructed economic activity.

Exogenous shocks on world markets that occurred after World War I do not seem to have been of major importance for the Argentine economic decline. Nevertheless, such shocks as the Great Depression, World War II, the embargoes on Argentine exports by the USA and the UK, and also the EC's agricultural policies, have served to reinforced the negative effects of incomes and monetary policies.

Notes

[1] It should be noted that there has been one exception to this rule, namely the Baring crisis of 1890–1891, when inflationary paper-money creation to cope with public deficits disrupted the Argentine financial sector following the suspension of gold convertibility in 1885.

[2] Argentina tried to overcome this discrimination by signing a treaty with Great Britain, known as the Roca–Runciman treaty, but this did not improve the situation much.

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CHAPTER 4

The Economy as an Evolutionary Pulsator

Richard M. Goodwin

In economics we commonly have models in search of facts – by contrast, long waves appear to be facts in search of a model. I would like to offer a prospective model. Generally, the shorter the period, the easier it is to explain why a cycle may exist: the best theory is that of the pig cycles, with a period of two lags. Then there is the stocks cycle, the best understood of all generalized economic oscillators. The longer waves of 5–15 years are less evident and have a less agreed-on explanation. Cycles of 40–50 years are difficult to establish and more difficult to explain. To begin with, the 200 or so years of industrial capitalism are too short a time to establish the existence of a cycle from highly disturbed statistical series, so that we do not even know whether there is anything to explain. Second, if a cycle does exist, it is difficult to find a mechanism that remains unchanged for that long a time to produce a cycle. The pronounced turbulence of modern capitalism makes it more or less impossible to determine any constant system parameters.

The hypothesis proposed in this chapter is that technological knowledge accrues exogenously, in a noncyclical fashion: the rate at which it is incorporated into the production structure is conditioned by the endemic tendency of private capitalism to exhibit cycles in growth rates, i.e., first it grows too quickly and then too slowly.

Our era is characterized by an unparalleled accumulation of knowledge, which is cumulative and hence tends to be exponential. Since economies do not grow in a steady-state manner, our basic problem is to formulate an economic model that is a frequency convertor, from steady flow to alternating. This can be exemplified by what is known as a Roman fountain. A cistern is fed by a stream of water; in it is a siphon leading to a vent at a lower level. When the flow of water fills the cistern, it primes the siphon, which then empties the cistern, and remains inactive until the vessel is refilled. Thus, a steady flow is converted into a maintained oscillation of constant amplitude.

The cycle has a constant periodicity if the flow of water is constant, but for variable flow will exhibit no regular periodicity.

Whilst one does not expect any exact analogy with economics, there is a certain similarity. The knowledge of new processes and products comes in a steady flow until, once activated, there ensues a complex process of absorption into the economy, which, after a time, again relapses into quiescence. The essential point is that the rate of activation of innovations is not independent of the state of the economy and, conversely, the adaptation of new ideas depends on the buoyancy of the economy. What we wish to model is the dynamical coupling between the flow of ideas and the alternating response of the economy.

The key to this irregular morphological evolution of capitalism was provided uniquely by Schumpeter, basing himself on the profound insights of Marx, who saw that one could not understand the essence of capitalism without seeing its "law of motion". Whilst rejecting Marx's Ricardian methodology, Schumpeter translated the "vision" into the language and structure of orthodox economics. My own variant of the "vision" goes like this: capitalism is a system controlled by the search for profit rather than any static maximization of output or utility; when producers see ways of lowering costs or increasing sales, they invest; investing, they generate demand which favors further investment, accelerating the expansion; this happy progression, if uninterrupted, is ultimately arrested by the constraint of available labor supply, both skilled and unskilled. There are dual effects: first, real wages rise faster than productivity, squeezing profits and inhibiting investment; second, since unemployment goes down in the expansion, output grows at a rate that cannot be maintained, so that the consequent deceleration destroys the prospects necessary for investment in durable plant and equipment. The economy then collapses to a level that is determined by income and expenditure, and is not dependent on the current level of production. Excess capacity and wages bring a disastrous fall in profits and profitability.

Consequently, there begins an urgent search for labor-saving processes or new goods, which may, or may not, be waiting for implementation. If found and activated, investment recommences in spite of excess capacity and low profits, because the new capacity restores profitability.

My suggestion is that such a reformulation of the essential Marx–Schumpeter "vision" provides the conceptualization necessary to explain both the so-called business cycle and long waves. It means accepting the idea that the exogenous (to economics, narrowly formulated) events of social history play an essential role in this Darwinian view of economic evolution, as envisioned by both Marx and Schumpeter. But it is not a one-way causation: the impact of technology on the economy is transformed by the internal dynamics of the system into an expansion, an overexpansion, collapse, and subsequent recovery. Therefore, the wider historical processes, which do not necessarily have a cyclical character, are reshaped into a rhythmical pattern, both in the shorter, decade period and in the longer, half-century period. This is an example of what is called self-organization. The structure contains two aspects: there is the relatively fast expansion and contraction of either levels or rates of output growth, and there is the relatively slow accumulation of capacity to produce both new, innovative types and the expansion of preexisting types. The modern world has been transformed by the substitution of natural energy for human and animal energy. Hence Schumpeter rightly pointed to the long gestation periods of energy sources, e.g., steam, electricity, oil. Therefore, the shorter cycle outlined above will only be a hiccup in a longer continuing rise in investment and productivity. The collapse is brief because the investment is soon renewed, with the vital result of saving labor and recreating the industrial reserve army of labor, which is the necessary but not sufficient condition for the expansion of output. This view implies that there should be long waves in both output and prices, since one can scarcely conceive of them as independent of one another.

To model this, it is convenient to use the concept of an economic potential to illuminate such a complex problem. Prices and costs provide the information necessary to make decisions about changes in economic structure. Current, variable costs provide a stable short-term reaction, but the system is repeatedly disturbed by exogenous technological changes, so that it is kept in varying degrees of turbulence. Although it is quite wrong to formulate the problem in aggregative terms, I shall first do so to make the central issues clear.

To pursue the Roman fountain analogy, imagine that new ideas form a flow adding to the existing stock (as a lake) of unexploited ones, both useful and useless. The economic potential is simply a general representation of how the economy will move, given the level of the lake and its own position; it is not a given, unchanging thing, like gravity, but will alter shape according to technological–economic evolution. Take a cross-section of the lake as measured in aggregate output; the economy moves forward or backward along the bottom, under the influence of investment, but it cannot surface. The level of the lake may either rise or fall: it will rise with the availability of unexploited innovations; it falls as they are exploited. If a constellation of innovations is substantially incorporated into the structure of the economy in roughly half a century, we may think of three characteristic phases: initially it has limited success and the lake rises little; in the middle period, it may either rise or fall, as new uses accrue but adoption of them is also at a high level; in the final period routine adoption is facilitated along with few new applications to other sectors, so that the levels tend to fall. Therefore, with a succession of hills and valleys of variable shape, there will ensue a succession of varying growth rates, including negative ones.

The economic potential, $V(q)$, a function of national output, q, may roughly look like *Figure 4.1*, along with the phase portrait rate of growth as a function of output $\dot{q}(q)$. A succession of variable levels of the lake are indicated by V_t. My hypothesis is that a long wave begins and ends with substantially unchanging oscillations. First, there is a succession of weak rises in V; then comes a higher average level of V, possibly occasioning one or more reversals. Then follows a decline in the level of V, ending in a stable oscillation.

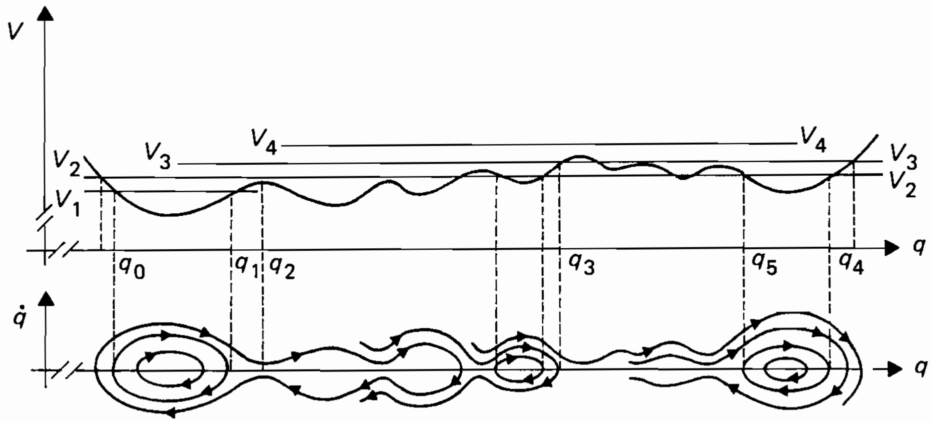

Figure 4.1.

Figure 4.1 is an imaginary simulation of an historically conditioned interaction of technological change with the resulting evolution of output. It begins with a stationary oscillation between q_0 and q_1. Then, as a result of the initiation of a major cluster of innovations, V rises from V_1 to V_2, thus bypassing the bifurcation point at q_2 and shifting the system to a lengthy variable growth, accompanied by a further rise to V_3 with changing positive growth rates, up to the point q_3 where it reverses. In the ensuing downswing V declines to V_2, and in the recovery rises again to V_3 and then to V_4. In the terminal phase, V declines slowly to V_3 and finally to V_2, initiating a stagnating cycle of constant average level, between q_4 and q_5. There the economy remains trapped, only edging slightly forward, with minor innovations completed within the cycle. Then the system awaits the rebirth of a group of major innovations.

This model has been pushed as far as possible, indeed too far. The reality is different and, alas, more complex. It is unsound to deal with technological progress in aggregative terms, because it consists precisely of shifts in the relative size of old and new sectors, thus destroying any homogeneity in the aggregates and hence any constancy in the parameters. The same is true of prices. It is not a case of parametric change inducing an alteration of motion, but rather that, after 40 or 50 years, we are dealing with quite a different mechanism. What happens is that one or more industries introduce either new products or new processes with lower costs or they provide better services. This then offers lower unit costs to a number of, but not all, other sectors. This in turn offers further similarly advantageous changes to yet other sectors, and so on until, with continuing adaptations and improvements, all the possible changes have been made. The result is a significantly different production structure from the one with which the process began.

Prices provide the information upon which the vast number of production decisions are made. It appears valid to assume, with Schumpeter (following

Walras), that with an innovation, prices gradually sink to their newer, lower costs. Hence one can define a fairly stable potential as a function of all prices. With each change of relative prices, the equilibrium point is shifted, so that the system, if previously at or near equilibrium, is then out of equilibrium. Each succeeding change in prices brings further changes in cost structures, which induce further changes, so that, in effect, the motion of the system itself shifts the equilibrium of prices. That is why such a long lapse of time is necessary to exhaust all the effects of a major innovation. There is, however, no reason to doubt that this sequential process, taken in isolation from exogenous disturbances, does come to an end, i.e., is convergent.

The output behavior is somewhat different, since in order to implement the successive changes, investment is necessary: investment stimulates demand and so, through a Keynesian-type multiplier mechanism, the result is favorable to the incorporation of the innovation, producing Schumpeter's "swarms". This explanation of the bunching of innovations was explicitly rejected by Keynes, but, nevertheless, I find it a better, more powerful formulation than his own. Furthermore, it explicitly brings in variations in the degree of employment, which he, in the neoclassical tradition, tended to ignore. The consequent swarm of investment initiates a cycle in output growth, the business cycle. The subsequent collapse temporarily inhibits innovational investment. How great is the inhibition depends on the cost effectiveness of the innovations: thus, electricity generating capacity tended to increase right through the Great Depression of the 1930s. In any case, after a time, the innovational investment will be renewed, until the new technology is fully integrated into the whole production structure. Then the system remains in a relatively quiescent state until a different major innovational cluster initiates a further long-wave expansion.

To model at least some aspects of this complicated sequential process, one may use a value potential in bilinear form:

$$V(p, q) = \langle p \rangle [I - a] \{q\}$$

where p and q are measured deviations from equilibrium values as determined by capital costs and labor costs. Both are treated separately: unit capital costs are estimated and applied as mark-ups on variable costs; unit labor costs as combined result of falling labor inputs and real wages, variable with the scarcity of labor. At equilibrium V is minimal and null, as are p and q. Then,

$$\text{Gradient } V_p = [I - a]\{q\} \quad \text{(supply less demand)}$$

and

$$\text{Gradient } V_q = \langle p \rangle [I - a] \quad \text{(price less cost)}$$

Assuming simply the traditional price–market dynamic that output less demand determines price change, and that profitability determines output variation, the result is an automatic control system that can be formulated as a Hamiltonian:

$$\frac{\mathrm{d}}{\mathrm{d}t}p = -\frac{\partial V}{\partial p} \quad \frac{\mathrm{d}}{\mathrm{d}t}q = +\frac{\partial V}{\partial q}$$

or, in a single, partitioned, block matrix

$$\begin{Bmatrix} \dot{p} \\ \dot{q} \end{Bmatrix} = \begin{bmatrix} [O] & -[I-\alpha] \\ +[I-\alpha]' & [O] \end{bmatrix} \begin{Bmatrix} p \\ q \end{Bmatrix}$$

where adjustment-speed coefficients are omitted for simplicity. Hence,

$$\ddot{p} = -[I-\alpha][I-\alpha]'p \quad \text{and} \quad \ddot{q} = -[I-\alpha]'[I-\alpha]q$$

From the fact that, although $[I-\alpha]$ is not symmetrical, both of these matrices are, we know that the dual systems have only real eigenvalues, thus producing two sets of n simple harmonic, constituent motions. This result applies to a given, unchanging structure of production, and therefore is valid for short periods only.

The implementation of a major innovation with relevance to many industries must be preceded by investment, which then shifts the equilibrium point of the potential basin. Then there ensues a fall in one price and sequentially in many others, thus gradually altering the $[\alpha]$ matrix, and increasing the real value of a given wage bill and consumption demand, which further shifts the output basin. Using wage rate as numèraire, we obtain oscillating prices about a falling level and oscillating outputs about a rising level. Consequently, one sees that the representation in *Figure 4.1* of a continuous output potential is too simple: the reality is a shifting potential being continually deformed as between different industries and as between net output and consumption. At any one time there is a given structure, with an oscillatory character. For short periods it may be taken as substantially constant: the shifting equilibrium and the deformations occur only very slowly. The effective demand resulting from total real wages varies in a complicated way, rising with productivity, especially in the region of full employment. This region shifts upward with productivity, introducing a nonlinearity that forces a deceleration of growth.

There seems no reason to expect any approximate long-term periodicity: there is simply no recognizable mechanism of long enough duration to produce it. There is only the basic pressure to search for new profitable ventures in the context of a continuing flow of new technologies. Viewed in this light the economy acts more as a pulsator than an oscillator: given an historically conditioned push, it rises in a wavering motion and then relaxes. The duration of the pulse depends on the time required to complete the absorption of the new technology. Then it awaits a further burst of investment, independent of its depressed state. In this conceptualization there is no identifiable mechanism of a deterministic character that is generating a cycle. Consequently, there is no theoretical or statistical basis for forecasting the length of the "low" stretch, nor the time or shape of the "recovery". The "accidents" of a wider social history enter as essential determinants of economic history, not as merely disturbances of a given, predictable course.

Thus, we end up with no explanation of the observed, rough periodicity. There seems no reason to expect major innovations to follow one another in a neat sequence, nor for their duration to approximate half a century. To achieve complete integration into the production structure, steam took about a century, as has electricity and the internal combustion engine. Nor is their incidence necessarily separated in time. I suggest that the most promising line of investigation is that of the mutual dynamical coupling of constellations of innovations with the perversely wave-like response of the economy to investment. Investment makes the economy buoyant and a buoyant economy is highly favorable to investment; hence innovations bunch into swarms. And when the bulk of investment in a group of innovations has been completed in this favorable atmosphere, the economy then relaxes into varying degrees of stagnation.

To explain the continuing recurrence of the expansive phases, it may prove fruitful to explore anew the phenomenon of replacement cycles, well observed in the case of ocean-going ships. Traditional business-cycle theory can explain the upper turning point, but not the lower one, because of the fundamental dynamical asymmetry of durable goods: they can be produced in quantity within a short period, but they cannot be reduced at anything like the same pace. The depression is characterized by persistent excess capacity as well as excess labor. A major cluster of innovations may begin tentatively and then, through its self-reinforcing tendency by virtue of the buoyant effects of investment on output, grow to a maximum followed by a slow decline. The continuing growth of new technology can act as a catalyst in launching a new wave of replacement of prematurely obsolescent equipment by the newer, superior techniques. In this fashion a Schumpeterian innovation may perform the same function for the longer as for the shorter wave, i.e., it may explain the resumption of investment in spite of the existing excess capacity. Thus, it may be possible to explain the bunching of replacement in spite of the large variance in physical lifetimes of equipment. Consequently the dynamical coupling of investment with growth can provide a link that explains the self-organization necessary for the existence of both short and long waves.

The concept of a dynamical coupling of a shorter business cycle with a longer cycle of innovations introduces some complications in the analysis. Assuming the existence of a short cycle given a constant level of innovational investment, and a longer one given a constant level of output, the behavior of both will be altered by their mutual interaction. Both systems will exhibit both cycles, but each of the periodicities will be altered, the longer one being lengthened and the shorter one shortened. Thus, an innovational wave of 30 years could, by interaction with trade cycles, be extended to 45 or 50 years. Not only this, but because the two constituent periodicities are almost certain not to be integral multiples of one another, the resultant behavior is no longer periodic: it will never repeat itself, even in the absence of exogenous disturbances (Goodwin, 1946, 1947).

To state the problem in its simplest possible form, assume that both aggregate output, q, and innovational investment, z, exhibit simple harmonic motion for constant values of each other, i.e., in deviations from equilibrium,

$$\ddot{q} + \alpha q = 0 \qquad z = \text{constant}$$

$$\ddot{z} + \beta z = 0 \qquad q = \text{constant}$$

Then, taking account of linear dynamical coupling,

$$\ddot{q} + \alpha q + \gamma z = 0$$

$$\ddot{z} + \beta z + \delta q = 0$$

The separate periodicities will be altered, and both variables will exhibit *both* of the scrambled periodicities. Thus, if by itself output would have a period of 12 years and innovations one of 25 years, then, depending on the degree of coupling, *both* will exhibit periods of 11 years and 48 years. Naturally, the shorter period will be more prominent in output and the longer one in innovations. The fact that the longer period may be lengthened strikingly by the coupling much eases the problem of explaining the long wave. Presumably, the bunching of numerous independent technical changes into successive long waves of investment may be explained by more complex models of this general character.

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CHAPTER 5

Marx and Engels on Long Waves

Thomas Kuczynski

An investigation of the publications on long waves indicates that the subject has itself cropped up in long waves. We can thus state that a downswing in the real economy creates an upswing in the discussion on the subject, whereas during an upswing the discussions take a downswing. Because of the length of this cycle, few economists have taken part in two successive upswings of such discussions, so that much of the knowledge gained in former investigations is lost.

Most economists do not remember the long-term forecasts made about 20 years ago. For example, Pareto (1917) predicted that after World War I there would be a long-lasting depression, but this was apparently forgotten during the crash and the depression of the 1930s. In 1926 the Hungaro–Soviet economist Varga said that only after a new war could there be a new upswing in European capitalism, but no one seems to have remembered his words in the 1950s. In 1944 Colin Clark not only predicted a new upswing for the period immediately after World War II, but also a downswing that would develop in the late 1960s. Yet to most of us the present downturn has come as a surprise. Long-term forecasting, both in economic policy and theory, is no rewarding job; in the long term such predictions tend to be forgotten, whether they were right or wrong. As long as 2000 years ago Horace said that time devalues the world. Although history has corroborated Horace's point of view – was he really right?

A large part of the research work done in this field during the last decade has produced interesting results, albeit results already known 50, 70, or even 90 years ago. Very often we have been reinventing the wheel for the second, third, or fourth time. For example, although articles by Kondratieff were translated into German, his theoretical approach (1928) was published only in Russian. There are fascinating similarities between Lewis's (1978) approach and that of Sirol (1942), but apparently Lewis was not aware of the earlier work. Similarly, in the introductory essay to the Italian edition of

Kondratieff's articles (1981), no reference is made to the Italian discussion that took place between World Wars I and II. Fortunately, Kleinknecht (1984) provides a fairly exhaustive survey of the Dutch debate between van Gelderen and De Wolff, etc. This debate, and the essential ideas developed within it, was conducted at a high level, and little progress has been made since then (apart from modern mathematical and statistical techniques). But we should, of course, also investigate the debate between the "monetarists" and the "agrarians" in France, the results of Dupriez's school in the 1930s, the Soviet debates in the 1920s, and the ideas of the German social democrats before World War I. (The new "stagnation theorists" are quite obviously in an even worse situation: in present-day discussions references to the stagnation debates of the 1870s and the 1880s, and even those of the 1930s and 1940s, are, so to speak, *rarissima*. Are the authors at least aware of the wave-like nature of their own contributions?)

That a thorough historiographical investigation of our subject has become an absolute necessity was made clear to me when I discovered that the main points of my own theoretical approach had been formulated as long as 120 years ago – by Marx. Of course, it is not a bad thing when an economist comes to the same theoretical viewpoint as Marx did 120 years ago. But what would we think of a physicist who presented Maxwell's equations as a new theoretical approach?

Before compiling and commenting on the thoughts of Marx and Engels, I give a brief summary of their major points in the theory of long waves:

(1) The starting point is the law of the tendency of the general rate of profit to fall.
(2) The main instrument for avoiding a fall in the profit rate is technical progress.
(3) Every technical and/or technological system can be improved only within its own limits, and the more it is improved the smaller become both the further possibilities and the economic effects of the improvements.
(4) When improvements cannot halt the fall in profit rate, capital has to look elsewhere, such as to basic innovations.
(5) Basic innovations are very risky, and are usually undertaken only in adverse circumstances since their prospective profitability, market behavior, technical requirements, etc., are uncertain.
(6) A successful basic innovation may be very profitable for the original entrepreneurs, and certainly will be so for the first followers, whose profit rates will be higher than the general rate.
(7) The higher profit rate secured by the first followers further reduces the profit rate of other entrepreneurs, so they too will be compelled to introduce the new techniques.
(8) The diffusion of the new basic techniques takes time, because it requires the restructuring of large areas of capital.
(9) The result of this diffusion process is that surplus profit dwindles away

in the areas concerned, and the general profit rate is reestablished at a new level.

(10) The cycle starts again.

These ten points summarize a purely endogenous theory of long waves, so we have to conclude that if nothing happens on the political scene, i.e., if there are no revolutions, wars, etc., a new upswing will occur. But even in a down-swing phase, when the system is old and no longer capable of coping with exogenous disturbances, such disturbances will occur more often than in the upswing phase – a point to be treated elsewhere.

In preparing this chapter an aphorism by Lichtenberg came to mind: "Very many people and perhaps most of them must, in order to find something, first know that it's there." Indeed, when Heinz-Dieter Haustein asked me whether I was aware that Marx had written about long waves, I of course answered "no". But Marx had in fact done just that – until now overlooked by all – in the third volume of *Capital:*

> In spite of the great changes occurring continually ... in the actual rates of profit within the individual spheres of production, any real change in the general rate of profit, unless brought about by way of an exception by extraordinary economic events, is the belated effect of a series of fluctuations extending over very long periods, fluctuations which require much time before consolidating and equalizing one another to bring about a change in the general rate of profit. In all shorter periods (quite aside from fluctuations of market prices), a change in the prices of production is, therefore, always traceable *prima facie* to actual changes in the value of commodities ... (Marx, 1977, 3: 166; MEW 1956, 25: 175–176).

The "fluctuations extending over very long periods" must surely be our long waves. By contrasting them to "extraordinary economic events" he sees them as neither the result of chance (in the sense of the Slutzky effect, 1937) nor of erratic shocks (in the sense of Frisch's 1933 approach). Moreover, by comparing them with "all shorter periods" their periodicity is assumed.

Marx wrote Volume 3 of *Capital* in 1864–1865, long before the so-called Great Depression, and it would not surprise me if a thorough study of nineteenth century political economy were to reveal much earlier thoughts on the problem of long waves. In Volume 2 of *Capital*, Marx quotes Potter's revised (1841) edition of Scrope's *Principles of Political Economy*, which dates back to 1833:

> The capital which is embarked in buildings, as mills, shops, warehouses, barns, in road, irrigation, etc., may appear scarcely to circulate at all. But, in truth, these things are ... consumed. ... [T]he capital invested in them may be turned perhaps every twenty or fifty years (Marx, 1977, 2: 190; MEW 1956, 24: 187).

If one takes the turnover of capital as "a material basis for the periodic crises" (Marx, 1977, 2: 189; MEW, 1956, 25: 378), then it is but one step from

Scrope and Potter to the first attempts in the 1920s to explain the phenomenon of long waves using the theory of reproduction and investment (e.g., Spektator, 1926; De Wolff, 1929). Whether Marx actually agreed with Potter and Scrope can at best be decided by means of *argumentum ex silentio*: since he criticizes their opinions on the turnover of circulating capital, but not on fixed capital, it is likely that he was in agreement with the latter, a line of argument that cannot be refuted, of course, but which is nonetheless rather weak.

Marx also raised the subject of "fluctuations extending over very long periods" in quite a different context, but he did not do so at the point quoted first where the existence of long waves is only postulated and is not examined closely. But knowing of the existence of this quote prompted me to search for other supporting evidence elsewhere in his works and those of Engels.

Engels' considerations on this question resulted from his endeavors to understand the so-called Great Depression. In his opinion, since 1815–1825, three periods of economic crises could be distinguished, the turning points of which he established as being nearly identical with the inflection points of economic growth nowadays fixed in the theory of long waves. Thus, in 1886, in the Appendix to the US edition of *The Condition of the Working Class in England,* Engels wrote

> The recurring period of the great industrial crisis is stated in the text as five years. This was the period apparently indicated by the course of events from 1825 to 1842. But industrial history from 1842 to 1868 has shown that the real period is one of ten years; that the intermediate revulsions were secondary, and tended more and more to disappear. Since 1868 the state of things has changed again, of which more anon (Engels, 1971: 364; MEW, 1956, 22: 270).

"Anon", in which he provided the text of his essay *England in 1845 and 1885,* he described the "state of things" as follows:

> But then a change came. The crash of 1866 was, indeed, followed by a slight and short revival about 1873; but that did not last. We did not, indeed, pass through the full crisis at the time it was due, in 1877 or 1878; but we have had, ever since 1876, a chronic state of stagnation in all dominant branches of industry. Neither has the full crash come; nor will the period of longed-for prosperity to which we used to be entitled before and after it. A dull depression, a chronic glut of all markets for all trades, that is what we have been living in for nearly ten years (Engels, 1971: 368–369; MEW, 1956, 22: 275).

In a similar manner Engels describes the situation in his preface to the (1886) English edition of *Capital* (Vol. 1, p. 17; MEW, 1956, 23: 40). The turning point of 1842 quoted above was moved somewhat in the preface to the English edition of *The Condition of the Working Class in England* and a much more basic significance was attached to it: "The revival of trade, after the crisis of 1847, was the dawn of a new industrial epoch" (Engels, 1971: 360–361; MEW, 1956, 22: 266).

The question as to when the new upswing phase set in is still being debated: was it as early as 1842, as Spiethoff (1925) and Schumpeter (1939) thought, or only after the crisis of 1847–1848, as was suspected by De Wolff (1929), Clark (1944), and Rostow (1978)? This problem has already been reflected in Engels' work. But it would be mistaken to turn the observer into a theoretician of long waves. Thus, Engels states in a footnote to *Capital*, Vol. 3:

> As I have already stated elsewhere (cf. Marx, 1977, 1: 17; MEW, 1956, 23: 40), a change has taken place [in the industrial cycle] since the last major general crisis. The acute form of the periodic process with its former ten-year cycle, appears to have given way to a more chronic, long drawn out alternation between a relatively short and slight business improvement and a relatively long, indecisive depression – taking place in the various industrial countries at different times. But perhaps it is only a matter of prolongation of the duration of the cycle. In the early years of world commerce, 1815–1847, it can be shown that these cycles lasted about five years; from 1847 to 1867 the cycle is clearly ten years; is it possible that we are now in the preparatory stage of a new world crash of unparalleled vehemence? Many things seem to point in this direction. Since the last general crisis of 1867 many profound changes have taken place ... By means of all this, most of the old breeding grounds of crises and opportunities for their development have been eliminated or strongly reduced ... [But] every factor, which works against a repetition of the old crises, carries within itself the germ of a far more powerful future crisis (Marx, 1977, 3: 489; MEW, 1956, 25: 506).

Engels did not predict a new upswing but a "world crash of unparalleled vehemence." Thus, he had no intention of developing a theory of long waves; on the contrary, ten years earlier, in a letter to Bebel in May 1883, he had analyzed the then economic crisis in this manner:

> It is an intermediate crisis as that of 1841–42 but on a far more colossal scale. The ten-year recurring period has evolved distinctly only since 1847 (because of Californian and Australian gold production and, from this, the complete development of the world market). At present, when America, France, and Germany are beginning to break England's monopoly on the world market so that overproduction is beginning again – as before [18]47 – but more swiftly being brought to bear, now the five year intermediate crises are also rising again. Proof of the total exhaustion of the capitalist mode of production [*sic*]. The period of prosperity has not yet developed in full, and already after five years overproduction is setting in, and even within these five years all proceeds in a paltry way, which is by no means a proof that we will not go through a rather brisk business time in 1884–87 as we did in 1844–47. But then the universal crash will quite definitely occur (MEW, 1956, 36: 27, author's translation).

But the "universal crash" did not happen as was the case in 1847, when he and Marx were of the opinion that Germany "is on the eve of a bourgeois revolution ..." and that this would be "but the prelude to an immediately following proletarian revolution" (MEGA, 1975, 6: 519; MEW, 1956, 4: 493). Engels criticized this overoptimistic prognosis in his introduction to Marx's *Class Struggles in France* (1895, p. 16): "History has proved us, and all who thought like us, wrong. It has made clear that the state of economic development on the Continent at that time was not, by a long way, ripe for the removal of capitalist production ... " (MEW, 1956, 22: 515).

In certain respects this 1895 critique also applies to the unfulfilled predictions of 1883 and 1894, which were made under historically similar circumstances, in the downswing phase of the long wave. The "total exhaustion of the capitalist mode of production" suspected by Engels from hindsight turned out to be "only" the outmodedness of *laissez-faire* capitalism, i.e., the necessity of a transition to monopoly capitalism. Complete exhaustion of *laissez-faire* capitalism! And how could a revolutionary fireball such as Engels in such a situation not imagine that a collapse of capitalism was imminent as a result of a socialist revolution? To the reproach that he should have mentioned the other possibility – that capitalism would adapt to changing conditions – I call the reader's attention to the Bible (Revelations 3:16): it is always the lukewarm whom the Lord spued out.

Having acknowledged these thoughts of Engels, most of which were published before 1896, we should not be surprised that in 1896 Parvus, after the start of the new upswing, had already developed a hypothesis that mechanisms within the capitalist mode of production alternately produce periods of upswing and depression. What is surprising, however, is the fact that neither Engels nor any other Marxist economist ever made use of Marx's theoretical considerations, even though they had no relation to the actual history of the capitalist mode of production. We must add, however, that Marx too, in his presentation on the law of the tendency for the rate of profit to fall, does not refer to the "fluctuations extending over very long periods" he mentioned earlier. Rather, we find the following "aside" in the *Theories of Surplus Value* (1861–1863), in the midst of a polemic on vulgar economic views on "Revenue and Its Sources":

> ... the fluctuations in the *rate of profit* in every sphere depend on the existing level of market prices and their fluctuations around cost-prices. The difference in the *rates of profit* in the *various* spheres can only be discerned by comparison of the market prices of the *different* commodities, with the cost-prices of these commodities. A decline in the rate of profit below the ideal average in a particular sphere, if prolonged, suffices to bring about a withdrawal of capital from this sphere, or to prevent the entry of the average amount of new capital into it. For it is the inflow of new, additional capital, even more than the redistribution of capital already invested, that equalizes the distribution of capital in the different spheres. The *surplus profit* in the different spheres, on the other hand, is discernible only by comparison of the market prices with the cost-prices. As soon as any difference becomes apparent in one way or another, then an outflow or inflow of capital from or to particular spheres [begins]. Apart from the fact that this act of equalization requires time, the average profit in each sphere becomes evident only in the average profit rates obtained, for example, over a cycle of

> seven years, etc., according to the nature of capital. Mere fluctuations – ***below*** and ***above*** [the general rate of profit] – if they do not exceed the average extent and do not assume extraordinary forms, are therefore not sufficient to bring about a transfer of capital, and in addition the transfer of fixed capital presents certain difficulties. Momentary booms can only have a limited effect, and are more likely to attract or repel additional capital invested in the different spheres [Marx, 1972, 3: 463–464; MEW, 1956, 26(3): 455–456].

Both before and after this paragraph Marx gives other reasons "why the ***general rate of profit*** appears as a hazy mirage in contrast to the ***fixed rate of interest*** [Marx, 1972, 3: 465; MEW, 1956, 26(3): 457]. In other words, at this point, he did not intend to demonstrate extensively the real mechanism of redistribution of already invested and additional capital, i.e., of replacement and net investments. But his statements on this question are clear: the mere fluctuations around the cyclical average of the general rate of profit – including booms and slumps – set in motion a reorientation of net investment flows, but these are not sufficient to bring about a reorientation of replacement investment flows. The necessary preconditions for this are the ***long-term*** existence of surplus profit and extra surplus value, respectively. How, then, are surplus profits of this kind created? Marx maintained that

> No capitalist ever voluntarily introduces a new method of production ... so long as it reduces the rate of profit. Yet every such new method of production cheapens the commodities. Hence, the capitalist sells them originally above their prices of production, or, perhaps, above their value. He pockets the difference between their costs of production and the market-prices of the same commodities produced at higher costs of production. He can do this, because the average labor-time required socially for the production of these latter commodities is higher than the labor-time required for the new methods of production. His method of production stands above the social average. But competition makes it general and subject to the general law ... As soon as the new production method begins to spread, and thereby to furnish tangible proof that these commodities can actually be produced more cheaply, the capitalists working with the old methods of production must sell their product below its full price of production, because the value of this commodity has fallen, and because the labor-time required by them to produce it is greater than the social average. In a word – and this appears as an effect of competition – these capitalists must also introduce the new method of production ... (Marx, 1977, 3: 264–265; MEW, 1956, 25: 275).

But, looked at in this general fashion, this happens each and every day in capitalist industry and surely does not produce in its wake a long-term reorientation of replacement investments. Long-term fluctuations in the rate of profit that are thus brought about can in good conscience be diagnosed as Slutzky effects and would therefore not be a suitable theory of long waves. But there are significant differences between the "new methods of production" (innovations). Their different effects are described by Marx, in another context, as follows:

> ... uniformity or similarity of reproduction – the repetition of production under the same conditions – does not exist. Productivity itself changes and changes to conditions [of production]. The conditions, on their part, change productivity. But the divergences are reflected partly in superficial oscillations which even themselves out in a short time, partly in a gradual accumulation of divergences which either lead to a crisis, [to a] violent, seeming restoration of the old relationships, or very gradually assert themselves and are recognized as a change in the conditions [Marx, 1972, 3: 518; MEW, 1956, 26(3): 507].

At this point Marx had already approached a distinction between improvement and basic innovations (for the reinvention, see Mensch, 1975). The minor improvement innovations merely bring about oscillations. On the contrary, basic innovations (as well as some radical improvements) frequently succeed, and are recognized only very gradually as bringing a change of conditions.

That basic innovations require much time before they spread throughout the national economy is a historical fact that has been proved many times and is essentially due to two factors. First, before their diffusion, they must prove their profitability, and second, their diffusion generally requires not only a reorientation of net investments, but also of replacement investments. To some extent, old plants have to be replaced by entirely new equipment; even though the old may not have physically depreciated, they have become unprofitable and are therefore morally depreciated. But this replacement only takes place either if definite losses have been recorded or if profit is assured, which takes time. This applies with even greater force to the flow of capital into other spheres of investment caused by basic innovations and their diffusion. In this context I would like to draw attention to two observations made by Marx:

> (1) The great difference in the cost of the first model of a new machine and that of its reproduction ... (2) The far greater cost of operating an establishment based on a new invention as compared to later establishments arising *ex suis ossibus*. This is so very true that the trailblazers generally go bankrupt, and only those who later buy the buildings, machinery, etc., at a cheaper price, make money out of it [*sic*] (Marx, 1977, 2: 104; MEW, 1956, 25: 114).

However, the concentration and centralization of capital has now reached a stage at which the "trailblazers" do not go bankrupt (provided these are larger firms) even if the innovations do not create the desired results. Basic innovations are risks that are taken much more rarely if profits are secure and business is good, but which are taken precisely in extended periods of depression when the profit rate is falling:

> If the rate of profit falls, there follows, on the one hand, an exertion of capital in order that the individual capitalists, through improved methods, etc., may depress the value of their individual commodity below the social average value and thereby realize an extra profit at the prevailing market-price. On the other hand, there appears swindling and a

> general promotion of swindling by recourse to frenzied ventures with new methods of production, new investments of capital, new adventures, all for the sake of securing a shred of extra profit ... (Marx, 1977, 3: 259; MEW, 1956, 25: 269).

Bearing in mind the findings of current research on innovations, we can supplement and interpret Marx's contention as follows. Improvement innovations ("improved methods, etc.") are, in the first place, introduced during periods of upswing and steady growth, whereas pseudo-innovations ("swindling") are introduced during periods of transition from upswing to depression, and basic innovations ("new methods of production") during periods of depression. Therefore, basic innovations *per se* cannot bring about an upswing because they first have to prove their profitability. But they set off the new upswing because other entrepreneurs also have to switch to the profitable "new methods of production". To which the following should be added:

> Improvements occur in rapid succession once new machinery is introduced. Thus there is a continuous devaluation of a large part of the old machinery, or it even becomes totally useless before its period of circulation is really up, or before its value has been recouped in the value of commodities it has produced. As the period of reproduction shrinks, so does this danger, and the more capable is the capitalist (after he has regained the value of the machinery within this shortened period of time) of introducing new improved machinery and selling the old cheaply. This can, in turn, be used profitably by another capitalist because he has, *ab initio*, purchased it at a reduced price [MEGA, 1975, II(3.1): 305, author's translation].

As soon as the "new method of production" is applied generally – and this can take one or two industrial cycles (so-called Juglars) or even the entire period of an upswing – the surplus profit that was previously possible has, of course, disappeared and a new average profit rate has been established. (Incidentally it is irrelevant whether this is lower or higher than previously, or whether it represents a real fall in the profit rate.) Now, of course, efforts will be made to counteract the fall in the profit rate with improvements, but finally, since every technological system is only capable of being improved within its own limits, "swindling", i.e., pseudo-innovations, will be the order of the day and the "cycle" starts again ("cycle" is in quotes because there is nothing automatic in the transition from a depression to a new upswing).

The enormous difficulty of verifying these thoughts of Marx and Engels – which I have merely compiled and commented on – historically and statistically cannot be ignored, since we have neither adequate data on the development of the profit rate over the last 150 years, nor do we have sufficient detailed information on the structure of net and replacement investments for this period. We therefore have to construct auxiliary variables and check them as to their meaningfulness. It would surely be worth analyzing the changes in the structure of production of goods, particularly of industrial products [as Kleinknecht (1979) has done for the FRG], in order to examine whether production data can be used as lag variables in the substitution of missing investment data. As for the average profit rate, Marx himself proposed a substitute that was intended precisely to give expression to long-term changes, or long waves:

> The average rate of interest appears in every country over fairly long periods as a constant magnitude, because the general rate of profit varies only at longer intervals ... And its relative constancy is revealed precisely in this more or less constant nature of the average, or common, rate of interest (Marx, 1977, 3: 336; MEW, 1956, 25: 378).

Obviously, nominal as well as real interest rates need to be analyzed in view of the inflationary processes that now dominate the scene.

Finally, I would like to add a remark on my own research work. Without having being aware of Marx's statements on long waves quoted above, and without having the benefit of the new angles that a number of the quotes presented here have given me, I had developed and published similar but not so far-reaching ideas that have aroused interest (Kuczynski 1976, 1978a,b, 1979, 1980, 1982, 1985). Now, knowing what Marx and Engels wrote on this subject, I can only refer to what the German composer Brahms said about Mozart's piano concertos: "People like us live off the fact that they are unknown".

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CHAPTER 6

Basic Innovations and the Next Long Wave of Productivity Growth: Socioeconomic Implications and Consequences

Harry Maier

6.1. The Long-Wave Debate

It is not surprising that the debate on the economic long wave started again at the end of a period of rapid economic growth (1950–1973), after more than 25 years of lack of interest. At this time the prevailing overoptimism in the market economies about future economic growth had changed to deep pessimism; the most important sign of this change in public mood was the first report to the Club of Rome, *Limits to Growth* (Meadows *et al.*, 1972; Maier, 1977). At the end of the economic upswing in the early 1970s the economic debate about the long-wave phenomenon started with the same questions that were posed earlier this century (Parvus, 1901; Kautsky, 1901/2; van Gelderen, 1913; De Wolff, 1921; Kondratieff, 1926; Schumpeter, 1912, 1939), to which we still have no satisfactory answers:

(1) What are the causes of changes in the periods of long-term fluctuations in economic growth?
(2) Are economic upswings and downswings with periods of 50–60 years the result of endogenous changes in the economy or are they the result of exogenous factors, such as wars, revolutions, extreme forms of class struggle, etc.?
(3) Does the emergence of these upswings and downswings that have occurred over the last 200 years mean that there is a strict law of economic development that we have to accept fatalistically without being able to influence its speed or socioeconomic consequences?

Table 6.1 shows the last four long waves in the development of productive forces. One source of confusion is that we are often unable to assess the importance of the various factors that influence the long-wave phenomenon and its interrelationships. Changes in the rate of economic growth over time are obviously connected with the development of social relations of production, with changes in political and government institutions, and with the intensity and forms of social inequalities. The uneven development of productive forces in different countries is the cause of changes in the balance of power, and hence of international tensions and confrontations. On the other hand, all these factors greatly influence the development of productive forces. For example, if a country is unable to implement the necessary changes in social relations of production and political institutions during a period of global productivity growth, it will also be unable to hold its place among economically developed countries.

The search for causes of the periods of upswings and downturns in the economy can be reduced to the question of why are some circumstances more favorable to growth and increases in productivity than others? Obviously, there are radical changes in the relationship between the quantitative extension of the utilization of elements of production (labor, equipment, raw materials, land, the environment) and improvements in their efficiency. The latter is the most important factor in an economic upswing. This can be illustrated with the following growth equation:

$$\Delta P = \Delta R + \Delta E \qquad \Delta E > \Delta R$$

where ΔP = growth in production, ΔR = extension of the utilization of elements of production, and ΔE = the contribution of improvements in efficiency to production. During a slowdown phase the influence of efficiency improvements on economic growth diminishes, and the possibility of speeding up economic growth by quantitatively extending the elements of production also diminishes due to steep increases in the prices of raw materials and foodstuffs (the "revolution of value").

Both processes – the slowdowns in efficiency growth and the "revolution of value" – have common roots: insufficient innovations in leading branches of the economy. Innovations are both components and dynamic elements of productive forces. The diminishing contribution of efficiency to economic growth is the result of a development process itself, in the course of which the efficiency potential created through basic innovations is absorbed.

The capitalist expression of this process is the tendency of the general rate of profit to fall. This law is, as Karl Marx expressed it, "a mystery whose solution has been a goal of all political economy since Adam Smith" (Marx, 1971 edn, Vol. 3, p. 213). He also explains why it is possible that the profit rate of some producers who are able to implement innovations can increase: "A capitalist working with improved, but not as yet generally adopted methods of production sells below the market price, but above his individual price of production; his rate of profit rises until competition levels it off. During this

Table 6.1. The four long waves of economic growth in the world economy and their socioeconomic implications.

Period	*Economic growth* *Upswing*	*Slowdown*	*Social characteristics*	*Basic innovations*	*Changes in the function of labor*	*Changes in the utilization of resources*	*Main growth industries*
1790–1849	1790–1823	1824–1849	Free compensation capitalist system	Machine tools, steam engine	1st and 2nd step of mechanization, substitution of manual driving function (energy)	Rapid growth of pig iron, growing demand for coal	Textiles (spinning)
1849–1894	1850–1872 (Δ 2.54% per year	1872–1894 (Δ 2.1% per year	Peak of the free capitalist system	Railroad, iron and steel	Further substitution of manual driving function	Peak growth of coal	Textiles (weaving), mining, shipbuilding, railroad, iron and steel
1894–1938	1894–1913 (Δ 3.5% per year)	1913–1938 (Δ 1.6% per year)	Expansion of trusts, oligopolies, and monopolies, monopoly capitalism. The USSR, the first socialist state, is created	Electrical engineering, chemicals, automobiles, communications	Mechanization of the main processes	Rapid growth of rubber production, extension of the use of oil	Electricity, aluminum, chemicals, mechanical engineering
1938–1990	1938–1973 (Δ 3.4% per year)	1973–1990 (Δ 1.5% per year)	State monopoly capitalism, formation of the community of socialist states, expansion of multinational corporations	Plastics, synthetic fibers, radio, television, airplanes, radar, space satellites, electronics	Automation of the main processes in many industries automation is reaching its saturation point	Rapid growth of plastics, synthetic, fibers, oil consumption is reaching its peak	Chemicals, aircraft, automobiles, electrical engineering, electronics

Sources: Haustein and Neuwirth (1982), Kuczynski (1967 and 1986), Ray (1980), and Mandel (1979).

equalization period the second prerequisite, expansion of the invested capital, makes its appearance" (Marx, 1971 edn, Vol. 3, p. 231).

The reason for the revolution of value of natural resources is not that they become scarce in an absolute sense, but that they are scarce in relation to the scientific and technological level of their utilization. This results in sharp price increases for raw materials and a fall in the general profit rate, or, in a socialist economy, in the contribution of efficiency improvements to economic growth. The main result of the revolution of value (Marx, 1971 edn, Vol. 1, p. 108) is the devaluation of existing products and production processes. At the same time, the devaluation process reduces the new value and thus also the surplus value per unit of production, and increases the organic composition of average social capital.

Mandel (1980, p. 9) underlined the importance of the relationship between long waves and fluctuations in the general profit rate in capitalist economies, but he failed to notice the importance of the relationship between technological revolutions and the "revolution of value". Thus, sudden falls in the general profit rate are not discussed in his work. Rostow (1979), however, emphasized the role of "revolutions of value" in explaining the long-wave phenomenon, but he ignored the relationship between the "revolution of value" and the fall in the general profit rate.

In socialist economies profit has lost its key role in decisions on the allocation of resources, but increases in efficiency are a most important precondition for improving living conditions. Under socialism, the contribution of productivity increases toward increasing output has no fixed dimension, but it will diminish through the revolution of value of natural resources and the devaluation of existing products and technologies. It can only be extended through the build-up of new efficiency potential with the help of basic innovations. Federenko (1982, p. 485) has shown that the contribution of efficiency increases to economic growth in the USSR was higher in 1960 (40%) than in 1980 (25%). This indicates that the efficiency potential created by means of basic innovations between 1940 and 1970, in the course of developing productive forces, was absorbed by improvements and rationalization innovations or devalued through new basic innovations.

The key problem in formulating the economic strategies of the USSR and other socialist countries will therefore be in opening up new fields for productivity growth by creating new efficiency potential with the help of basic innovations in the next few decades. The most important criterion for this intensive development of productive forces is to increase the value added per unit of natural resources. Yakovets (1984, p. 75) stressed the importance of understanding the long-wave phenomenon when elaborating long-term strategies for the development of the Soviet economy.

6.2. Innovations and Long-Term Fluctuations in Economic Growth

In order to understand the mechanism behind the periodic fluctuations in the development of productive forces it is necessary to assess the roles of the various kinds of innovations. A distinction between major product, major processes, and incremental innovations is important at the level of the production unit, but at the macroeconomic level it is difficult to distinguish between major product and major process innovations. This is because the product of one firm may be the process equipment, components for assembly, or materials used by another firm, so that at the macroeconomic level the distinction between basic, improvement, and pseudo-innovations is much more important (Haustein and Maier, 1979). Basic innovations create a new efficiency potential, and open fields and directions for economic activities, while improvement innovations absorb this efficiency potential through balancing and improving the given system; most innovations are of the incremental type. Improvement innovations become pseudo-innovations when they are unable to improve the efficiency of the production unit above the average efficiency of the whole system. A growing number of innovation experts currently argue that the fall in industrial productivity growth rates is the result of the absorption of the efficiency potential created by basic innovations between 1930 and 1960. Certainly, a wide range of factors influences industrial efficiency, but if we look at countries where industrial performance is closely connected to innovations, we find that there have been fewer basic innovations and many more improvement and incremental innovations.

In searching for the mechanism behind long-term fluctuations in economic growth it is important to consider accumulation and investment. Forrester and his group have developed a method for analyzing growth rate fluctuations, which concentrates on investment and the relationship between the consumer and capital goods sectors (Forrester, 1977; Graham and Senge, 1982; Sterman, 1984). These are undoubtedly the key to the long wave phenomenon, but we will achieve results only when we are able to determine their relationships to the different kinds of innovation.

In many studies we find very one-sided interpretations of the relationship between investment and innovation. It is usually assumed that innovation is a function of investment: the recommendation for government policy is consequently that all we have to do is to create the conditions for higher returns on investment, but these are very much dependent on the efficiency potential of innovations, which is incorporated in investment. We thus have to distinguish between innovations that are derived from investment (improvement and incremental innovations), and innovations that stimulate investments (basic innovations). These open new fields for investment with high potential efficiency rewards, which is why the recommendation to stimulate investment in order to create new employment opportunities is one-sided. Expansionary investment without adequate innovations will have an adverse effect on the efficiency of investments and only a short-term effect on employment. In recent years in the market economies there has been an important change in the direction of investment toward more rationalization and replacement.

It may be dangerous to ignore both the linkages between expansionary, rationalization, and replacement investments and those between basic, improvement, and incremental innovations. Recommendations that emphasize only expansionary investment without taking into account their interrelationships and linkages with special types of innovation may fail to provide appropriate guidance to innovation managers. Rationalization and replacement investment that are not connected with improvement innovations to util ize the efficiency potential created by basic innovations will render existing jobs vulnerable to attack from innovative rivals or will create jobs with lower efficiency that can only exist because of government protectionist policies.

The question to be answered is how the upswing phase of productivity growth (or its capitalist manifestation, the increase in the general rate of profit) obtains its momentum. Mandel (1980, p. 21) believes that the increase in the rate of profit is the result of the impact of noneconomic factors: "Although the internal logic of capitalist laws of motion can explain the cumulative nature of each long wave, once it is initiated, and although it can also explain the transition from an expansionist long wave to a stagnation long wave, it cannot explain the turn from the latter to the former."

Mandel claims that, from a Marxist point of view, there can be no mechanism within the system of productive forces that could lead to a new upswing, since for this the system needs an external shock, that is, an increase in the rate of surplus value by political means (e.g., fascism in the 1930s), wars, extension of the field of capitalist operation, competition, or technological revolution. It is surprising that for Mandel "technological revolutions" are exogenous, noneconomic factors in the development of capitalism. From the beginning Marx emphasized the fact that capitalism cannot exist without technological revolutions. "Modern industry never looks upon and treats the existing form of a [production] process as final. The technical basis of that industry is therefore revolutionary, while all earlier modes of production were essentially conservative. By means of machinery, chemical processes and other methods, it is continually causing changes not only in the technical basis of production, but also in the functions of the labourer, and in the social combinations of the labour process" (Marx, 1971 edn, Vol. 1, p. 457).

Mandel's basic assumption seems to be unrealistic because only after a sharp upsurge in the general profit rate with the help of "system shocks" is capital searching for "a reserve of unapplied or only marginally applied inventions and therefore has the material for an upsurge in the rate of technological innovation" (Mandel, 1980, p. 25). As a rule, there is a very high demand for basic innovations in a slowdown phase, when entrepreneurs have two motives for implementing radical innovations: first, to improve their rate of profit or to make extra profits, and second, to avoid a devaluation of capital through the revolution of value. Thus, basic innovations have a better chance of being implemented in a slowdown phase because there are no other ways of improving productivity. In an upswing well established "trajectories of technologies" already exist, so that it is possible to increase productivity with the help of improvement and rationalization innovations.

Each innovation is the result of a fusion of two components: a technological invention (problem solution) and an existing or latent demand with prospects of a sharp increase in productivity. The main feature of an innovation, from a Marxist point of view, is its capability to create an "exceptionally productive force" (*ausnahmsweise Produktivkraft;* Marx, 1971 edn, Vol. 1, p.

302), which must be higher than the average efficiency of the production system as a whole. The length of the slowdown depends on the time needed by the new combination of basic innovations (or new technological bandwagon) to have a significant influence on productivity growth in national and world economies. This requires a rapid diffusion of basic innovations, which must be radical enough to compensate for the devaluation of products and technologies through the revolution of value. This indicates that it is impossible to determine the relationship between basic innovations and long-term economic fluctuations by counting the number of basic innovations. Basic innovations are the dynamic elements of a new combination of productive forces or "new technological bandwagons"; in order to understand the bandwagon effect it is important to investigate the relationship between basic innovations and efficiency growth; such innovations not only create a new level of productivity, but also destroy the efficiency potential of existing products and technologies.

6.3. Basic Innovations and the Next Long Wave

In recent times, two processes have had a marked effect on structural change in the world and in individual national economies:

(1) The radical change in the resource situation during the 1970s; the most significant results of which have been an upward revaluation of natural resources and a relative devaluation of existing products and technologies.
(2) The emergence of a new combination of productive forces, compromising such basic innovations as microelectronics, flexible automation, new energy options, biotechnology, and new materials technology.

Under the pressure of the altered resource situation, this new combination of basic innovations is likely to trigger a radical innovation push in the next few decades that will produce a new global economic structure with qualitatively higher productivity levels. The revaluation of natural resources and devaluation of existing products and technologies is the reason for the current revolution of value that is deeply influencing structural change throughout the economies of the world.

This revolution of value since 1973 has been seen in changes in the relative prices of oil, other primary raw materials, and manufactured goods. The increase in the relative value of natural resources is demonstrated by the movement of the real price of oil (the primary energy source, accounting for 42% of global energy consumption), which in real terms was ten times higher in 1983 than in 1973. Between 1951 and 1971 the relative prices of refined petroleum products fell by 17%, and that of electricity by 43%. Raw materials were relatively much cheaper in 1972 than they were in 1951 (Rostow, 1979, p. 6).

The decline in the relative value of manufactured goods and production technologies is reflected in the fact that the prices of mass-produced goods are currently at their lowest levels for 30 years. It is well known that today it is almost impossible for the producers of machines based on traditional electronics to make any profits on the world market. On the other hand, manufacturers who have been able to incorporate modern microelectronics into their products have been rewarded with high growth rates in both production and value added.

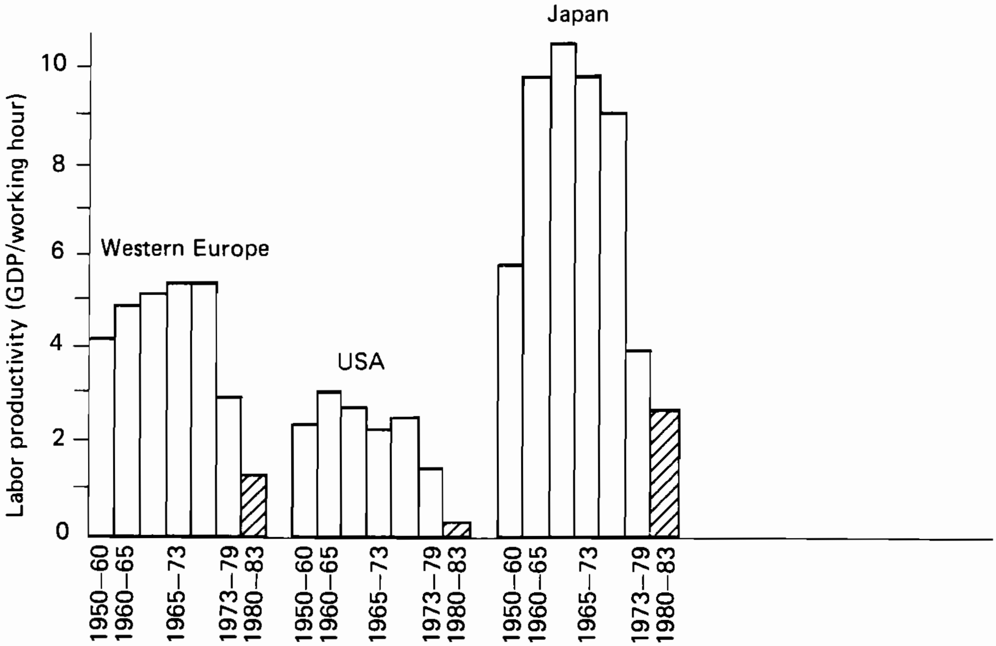

Figure 6.1. Development of labor productivity in Western Europe, the USA, and Japan (UN, 1982).

Currently, the growth of value per unit of natural resources is 100 times higher in the newer, microelectronics-based areas of machine engineering than in traditional parts of the industry. This simultaneous revaluation of natural resources and devaluation of existing products and technologies has so far dominated the opposing effects of the emerging new combination of basic innovations, which will tend to restructure the world economy and increase productivity. This is why productivity growth rates in all industrial countries have been declining in recent years (see *Figures 6.1* and *6.2).*

The present decline in productivity growth rates, which is of course not conducive to equalizing productivity levels worldwide, cannot be explained simply in terms of the absolute levels of productivity reached. Instead, we need to look for other fundamental factors that tend to produce similar

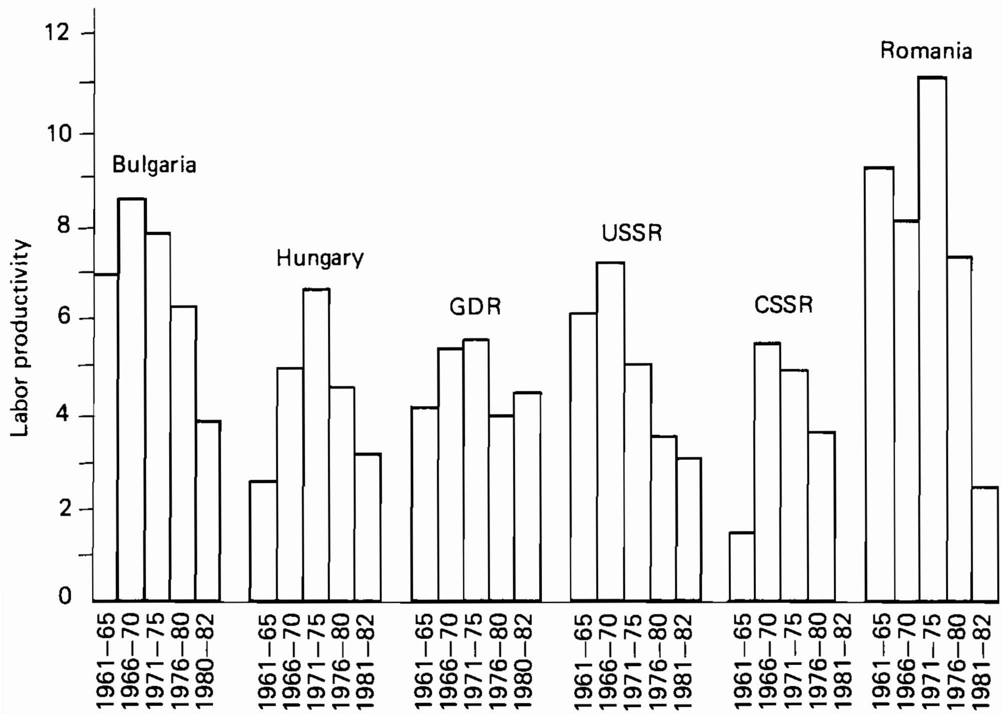

Figure 6.2. Development of labor productivity in the European CMEA countries (*Statistical Yearbook 1984*).

effects in all countries, regardless of their level of development. From the historical point of view, we can point to the fact that the potential for increased efficiency created through basic innovations in the 1940s and 1950s has largely been exhausted; there appears to have been a lack of basic innovations in recent years that could launch a new wave of productivity growth.

It is not overoptimistic to assume that through the new growth industries (technological bandwagons) based on the new combination of basic innovations, we will again see a significant increase in productivity in the next few decades, which will result in higher average productivity in the economies of the developed countries. The largest increases in productivity growth will be achieved in the electronics industry, including flexible automation, telecommunications, office automation, and computerization of production processes; the energy complex; biotechnology; new materials; integrated technologies for the industrialization of developing countries; and social and technical innovations in the fields of communications, the home, health care, and leisure.

Future productivity will depend very much on the creation of a new potential for greater efficiency through the basic innovations being made now. But there are many reasons why units show a strong tendency to follow policies of improvement and incremental innovation rather than actively supporting basic innovation, as shown in *Table 6.2*.

Increases in productivity in the firm and national or world economies will be impossible unless social and institutional barriers are first overcome; in this context, fatalistic attitudes are not very helpful. Government policies and company strategies can do a lot to improve conditions to increase productivity and its socioeconomic consequences, especially by

(1) Encouraging firms and corporations to implement basic innovations, especially in the take-off phase.
(2) Strengthening the investment power of firms and corporations.
(3) Formulating long-term strategies to increase contributions made by basic research to innovative production.
(4) Stimulating activities to bridge gaps and to overcome bottlenecks in the development of production forces (especially energy).
(5) Maintaining full employment and a high rate of technological change.
(6) Developing conditions under which the quality of human resources can be improved and become a decisive social and economic force.
(7) Maintaining a strategic perception of the global dimension of the new combination of basic innovations and their social consequences.

It would be disastrous in this time of growing global interdependence to learn only by crisis and to ignore the existing socioeconomic barriers to the next economic upswing. Three main barriers will have to be overcome if there is to be a new wave of growth in the world economy: accumulation, the arms race, and the uneven development of the world economy.

6.3.1. The accumulation problem

The problem of accumulation has always been a key issue in creating and utilizing a new efficiency potential. At present, the problem can be characterized as follows:

(1) The growing expenditures necessary for the creation and diffusion of basic innovations. For example, the cost of developing the new generation of microprocessors is currently in excess of $250 million, which is much more than was necessary for the first generation in the early 1970s. Government programs in the USA, the UK, France, and the FRG provided more than $200–300 million between 1981 and 1985 to support microelectronics research work. In the field of medicine, expenditures on cancer research were higher in the past ten years than the total spent so far on all medical research (Rescher, 1981, pp. 92–93). Current expenditures on nuclear fusion research are much higher than those on nuclear fission in the 1940s and 1950s. Fusion research projects around the world will each require more than half a billion dollars. The first experimental fusion reactor in the 1990s will cost more than $3–4 billion, i.e., much more than the cost of the first experimental fission reactor,

Table 6.2. Implications at the company level of adopting either improvement or basic innovation strategies.

	Areas of impact implications of policy	
Unit	*Improvement*	*Basic technological change*
Marketing	Demand relatively low, wellknown, and predictable Risk of failure low Acceptance rapid Well-known marketing used	Demand high and relatively unpredictable Risk of failure high Acceptance initially slow New marketing systems necessary
Production	Existing labor, skills, and patterns of cooperation used to a maximum Significant risk in quality and process planning	Existing labor, skills, and patterns of cooperation becoming obsolete Problems of quality, costs, and effects new and unpredictable
Research and Development	Existing R&D potential used Basic research not needed R&D risk relatively predictable	Advanced R&D potential needed New research fields and disciplines needed R&D risk high and unpredictable
Management	Familiar management systems used and well tried organizational solutions adopted	New management skills and organizational solutions needed
Society	Unpredictable problems relatively rare or nonexistent	Legal and social acceptance unpredictable

more than the total R&D expenditures of many small- or medium-sized industrial nations, or more than 30% of the R&D expenditures of all developing countries in 1980 $11.7 billion).

There is a connection between the growing expenditures on implementing basic innovations and the danger of basic innovations for the next economic upswing being monopolized by some developed market economies. As a result, we might have an extremely deformed and short upswing, with many international tensions and confrontations. Thus, detente and international cooperation is an important precondition for the next upswing in the world economy.

(2) The upswing of productivity growth in the 1950s and 1960s created some serious disproportions, particularly between economic growth and energy supply. This was one of the causes of the revolution of value in the early 1970s. Notable are the anticipated shortage of natural resources, such as energy and minerals, and the inadequacy of technology to substitute artificial resources for scarce natural resources. The International Institute for Applied Systems Analysis (IIASA) energy

study (Häfele, 1981) showed that traditional sources of energy, such as oil, coal, and gas, which currently account for more than 90% of our primary energy supply, will not be able to satisfy more than 65% of demand by the year 2030. The remaining 35% will have to come from new resources, such as nuclear power, solar energy, synthetic fuels, biogas, etc., which will only be possible if there is a change in the entire structure of energy production, distribution, and consumption with the help of basic innovations. But we will have to implement these innovations using land resources which are even more marginal, and by making the environment more vulnerable and safe disposal of waste more difficult.

To achieve the necessary shift from an energy system based on cheap oil and gas to one based on coal, nuclear, solar, synthetic fuels, etc., will require a considerable increase in the average net investment rate. The worldwide investment required for the exploration, production, conversion, transportation, and distribution of primary and secondary energy was approximately $143 billion in 1975, and will increase to between $925 billion and $1400 billion by the year 2030 (*Figure 6.3*).

(3) One important result of the investigation of the relationship between innovations and the long-wave phenomenon is that it is much easier to maintain full employment with a high level of technological innovation than vice versa (Freeman *et al.*, 1982), although a high level of innovation does not automatically guarantee full employment. It depends on the direction of the innovation process and the degree of workers' participation in this process, especially in the case of flexible automation, which will be one of the most important technological bandwagons of the next upswing.

Special-purpose automation, the predominant type of automation in the past long wave, is now reaching saturation in terms of its contribution to productivity growth (Haustein and Maier, 1981, 1985). This has no doubt been a decisive factor in the decline of productivity growth rates in the industrialized countries. Producers who invested heavily in this type of automation during the 1960s and 1970s (e.g., automobile, chemical, electrotechnical industries, etc.) have recently faced increasing economic difficulties, and have to realize that their highly productive technology was unable to produce goods that achieved an appropriate profit rate and return on investment. The reason for such miscalculations was an inadequate understanding of the limits of traditional automation in increasing productivity.

Special-purpose automation is an effective method for the mass-production of standardized products, but it is not suitable for highly innovative products. In the industrialized countries the automation coefficient of equipment (the share of automated and semi-automated equipment in total equipment by value) has now reached 50–60%. The automation coefficient of labor, however, has failed to exceed 12–18%, and is showing a strong trend toward saturation. There are three reasons for the trend toward saturation in special-purpose automation:

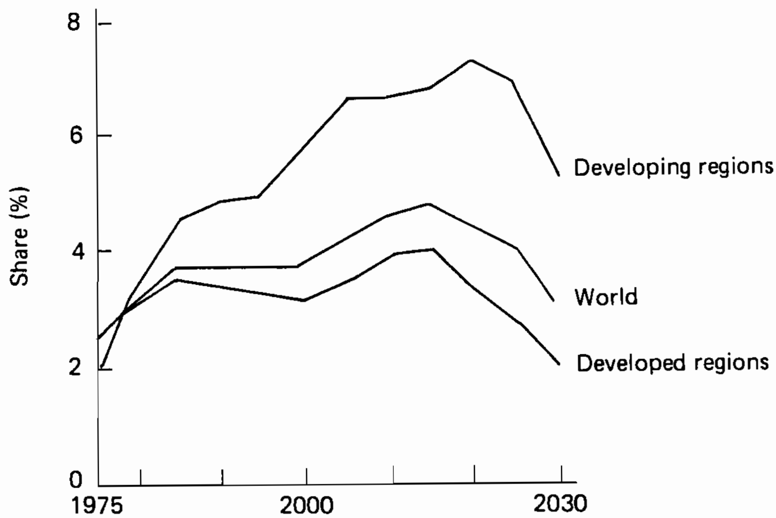

Figure 6.3. Share of total energy investment in GNP.

(1) All industrialized countries continue to produce many products in small- and medium-sized batches.

(2) There is a contradiction between automated production processes and product innovation. Normally, special-purpose automation emerges in the saturation phase of the innovation cycle when the dynamic efficiency of products is declining and moving rapidly toward average efficiency. Thus, the production of high-technology products cannot be automated, since this type of automation creates a productivity push only for mass-produced goods. But the danger exists that this type of product will be devalued very rapidly through the innovative success of new products.

(3) Special-purpose automation is only feasible in the main production process. Outside the traditional fields of application are the auxiliary processes, production and quality control, transport and storage, production management, inspection, and product design. Automation of the main production process at first improves productivity rapidly, but later this growth slows down because of the growing costs of the auxiliary processes.

Key elements in flexible automation were introduced in the last two decades within the development of traditional special-purpose automation: numeric control (NC) machines, industrial robots, and flexible manufacturing systems. These elements have been islands in the production system, with low levels of utilization, but microelectronics has given them a remarkable push, especially through cost reductions and the increasing size of computer memories. Before the application of microelectronics about 30% of the total cost of NC machines was in control systems, but this has declined rapidly despite the machine's increased computing and programming capability. These developments have meant that complex systems can be built and programmed at reasonable cost and convenient size. Today the control system accounts for 15–17% of the total costs of each NC machine; the same is true of robots, whose commercial and technical history began in 1962.

The most important advantage of flexible automation is the effective production of highly innovative products in the rapid growth phase of the innovation cycle and the reduced vulnerability of production systems to innovation. But flexibility, the most important characteristic, is very difficult to assess, especially in view of the short-term nature of decision making, which stresses maximization of productivity, returns on investment, and financial control. A conventional transfer line produces a few specified parts at the lowest possible costs. Thus there will only be an advantage to using flexible automation if the firm is able to manufacture highly innovative products in an early phase of their life cycle. The assessment of the economic efficiency of flexible automation requires a high level of strategic management. Normally, firms tend to underestimate the importance of flexibility. In the short term it may be much better to use special-purpose automation, but the long-term results of such decisions may be disastrous.

Two strategies of flexible automation can be differentiated: one is the concept of the unmanned factory, adopted from special-purpose automation, and the other is to make best use of existing workers by designing an efficient system appropriate to people's skills. Flexible automation can easily be adopted to different products, machining processes, and sequences, with the aim of responding quickly to new market requirements and customer demands. The human being is the most flexible and the only creative factor in a production system. By experience we know that the price for the elimination of humans to obtain the unmanned factory is a significant reduction in flexibility. But a new combination of advanced information technology and skilled production work on the basis of flexible automation is not only socially preferable, but is also clearly able to improve long-term efficiency and the value added of products. The concept of the unmanned factory ignores the fact that flexible automation is an integrated information system; it is not clear why we should concentrate on the better use of the information-processing capability of NC machines and robots, while at the same time wasting the much higher information-processing ability of the human being. According to Mike Cooley, an expert in the field of flexible automation, "A human being using total information processing capability can bring to bear synaptic connections of 10^{14}, but the most complicated robotic device with pattern recognition capability has only about 10^3 intelligence units. Why do we deliberately design equipment to enhance the 10^3 machine intelligence and diminish the 10^{14} intellect? Human intelligence brings with it culture, political consciousness, ideology and other aspirations" (Cooley, 1980, p. 19).

Flexible automation needs a more highly qualified workforce that is able to manage tasks of high complexity. In many cases, shopfloor workers do not do special kinds of work, but must be able to manage, maintain, repair, and program the process. Ray and Lamp (1983, p. 8), using data from 155 FRG companies applying computer numeric control (CNC) machine tools, point out that 78% of machines are programmed in the planning department, but only 22% on the shop floor. The crucial bottleneck is not felt to be information-processing skills, but knowledge and experience with tools, materials, feeds, speeds, faults, and breakdowns (Sorge *et al.*, 1981). The success of flexible automation relies strongly on craft worker skill, which is why a reduction of the differences between the skills and qualifications happens within the logic of flexible automation.

The full utilization of the efficiency potential of the hardware of flexible automation is dependent on the ability to conceive and develop new software. Until now, software costs have not benefited from the experience curve effect that has reduced hardware costs so dramatically. Software development is evolving away from its present skilled-craftsman service context toward an industry that offers well defined, rationally produced commodities.

The case of flexible automation demonstrates that there are different options for using and implementing this kind of basic innovation. Thus, it is one of the most important tasks of innovation research to discover new options for implementing basic innovations in a way that is socially acceptable and will lead to solutions to the fundamental problems facing mankind.

6.3.2. Basic innovations and the arms race

The most important political problem connected with the creation of the conditions for a new wave of productivity growth is to prevent that new combination of basic innovations from becoming part of the arms race. The continued arms build-up is serving to destroy many natural and creative resources, and is consuming vast sources of investment and R&D expenditure that could otherwise be used for solving the vital problems of mankind, such as to help the development of Third World countries, to solve pollution problems, to stop the destruction of tropical forests, the extension of deserts, acid rain, etc. If the new basic innovations are incorporated into the arms race there will be a short and deformed upswing in productivity in the US, Japan, and some West European countries, and the situation in developing countries will deteriorate further.

In 1984 worldwide military spending reached $600 billion (constant 1979 US dollars; Leontief and Duchin, 1983). According to the Leontief world model of military spending (baseline scenario), assuming that the proportion of GNP allocated to military purchases in 1980 remains unchanged to 1990 and 2000 in all regions, military spending will reach $1100 billion (constant 1979 US dollars) by the year 2000. A scenario of reduced military spending and increased aid transfer to developing countries shows: "For each dollar of reduced military spending, however, it is the poorest of the less developed regions whose GNP and per capita consumption increase the most" (p. 42). Analogously, results of a scenario of increased military spending show: "It is the poorest of the less developed regions whose GNP and personal consumption fall the most ... for each dollar of increased military spending" (p. 51).

Multilateral agreements on arms control and disarmament, the creation of an atmosphere of peaceful coexistence between nations, and the improvement of economic, scientific, and technological cooperation between world regions will be the most important contributions to the implementation of the new wave of economic growth.

6.3.3 The uneven development of the world economy

The upward revaluation of natural resources and the relative devaluation of existing products and technologies have had severe consequences for the Third World. The increase in oil prices caused serious deterioration of the balances of many developing countries. The main problem for these countries is to find productive linkages with the new innovations and the emerging new technologies that will be the driving forces of economic growth in the 1980s and 1990s. At present productivity in the developing countries is 15–20 times lower than in the developed countries. Traditional technology transfer (usually involving products and technologies in the saturation phase of the innovation cycle) from the developed to developing countries is unable to create such a linkage, since it is unable to improve the position of developing countries within the world market. In 1982 developing countries spent more than $35 billion on this type of technology transfer, but their positive impact on the economic situation of these countries was obviously very low.

An important precondition for the productive linkage to the new combination of productive forces is the development of the scientific and technological potential of the developing countries themselves. Between 1970 and 1980 the number of scientists and engineers in R&D institutions of these countries increased by nearly 200% and R&D expenditure by nearly 900%. These increases are significant, but until now there has been an enormous gap between developed and developing countries in the ratio of scientists and engineers per 10,000 inhabitants and per capita R&D expenditures. The share of the developing countries (including China), amounted only to 6% of the world's R&D capacity in 1980, and only 2.3% per capita.

At present, not only are the levels of technology in developing countries low, but there are also great disproportions in internal technological development. Sophisticated firms and producers, often multinational corporations, are islands in an ocean of preindustrial production. These sophisticated elements in national economies are not integrated into the national division of labor, but are isolated groups, more closely linked to foreign than to national control. The production of the modern sectors in developing countries tends to be oriented toward the demands and needs of the companies of some developed country. Standing apart as they do, the sophisticated sectors of developing economies are often disruptive; they not only fail to accelerate development, but also often tend to destroy the traditional technological basis without creating a new one able to meet national needs in the medium or long term. These sophisticated elements are present to maximize profits and to exploit the unsatisfactory human resource situation in these countries.

Such a "dual economy" is a reflection of, and to some extent and apology for, this situation, but it is not able to show the way to the establishment of an integrated national technical basis, with a workable relationship between different technological levels.

Table 6.3 shows several technological levels that may exist in any country. In all countries the lower-level systems A to C exist side by side. But in the industrialized countries the production volume of technologies A and B is very low and the various technological levels function as parts of an integrated national economy. The concept of intermediate technology is largely directed toward developing semi-mechanized technologies (class B), but this cannot help a developing country to increase its standard of living.

Table 6.3. Levels of technology.

Level	*Technology*		
A	Manual drive, task execution, control and logical functions	a1 a2 a3	Drop spindle Spinning wheel Improved spinning wheel
B	Substitution of mechanical for human energy (power tools)	b1	Spinning wheels with external drive power
C	Substitution of mechanical for human energy and task execution	c1 c2 c3	Self-activating Ring machine Open-end spinning
D	Complete substitution of mechanical–technical for human operation, including control and logical functions	d1 d2	Special-purpose automation equipment Flexible automation

It is also not possible to jump from technology level B to level D. Most developing countries have adequate investment resources, skilled workers, or infrastructure to utilize technology D. This technology is also not appropriate for creating a national technical basis that is capable of producing enough goods for the population and simultaneously securing adequate employment. The developing countries are thus faced with the problem of allocating their limited resources and investments between different levels of technology in such a way as to optimize their utilization of domestic natural and human resources and thus produce the goods and services necessary to meet the demands of their population.

The problem is to integrate such technologies within the national technological system; both extreme approaches of "small is beautiful" and "big is wonderful" are inappropriate. Such a system must include hard and soft, large and small, high and low technologies in appropriate proportions in order to be able to improve economic efficiency and to help them to use the benefits of the international division of labor.

The main problem for planners in developing countries is thus to seek a combination of technological levels that will lead to well proportioned development. This combination could have the following features:

(1) The use of surplus manpower in labor-intensive activities.
(2) The concentration of imported advanced technology on the key operations of core processes. All other processes should be based on labor-intensive technologies.
(3) The use of the limited stock of advanced equipment for demonstration and education.
(4) The transfer of replaced production equipment to small-scale firms.
(5) The promotion of high-quality production strategies.
(6) The establishment of a closed technological cycle from raw materials to final products on the basis of the national division of labor.
(7) The discouragement of unintegrated investment and technological conservatism.

At present, developing countries pay dearly for technology (more than $35 billion in 1982), but the results of this transfer have not helped to solve more serious problems. The reasons vary – the most important are the social forms in which this transfer takes place, the inappropriate nature of much of the transferred technology, and social conditions that make them unable to absorb new technologies. Two key measures that would help to ensure the better use of technology include: assurances that the transferred technology can be integrated into the national system of division of labor; and the creation of a scientific and technological basis that can effectively absorb the technology.

The creation of a scientific and technological base able to meet domestic needs is crucial for the linkage of developing countries with the new combination of productive forces. The efficiency of such a base depends on:

(1) The balance between basic, applied, and development research. Without basic research it is difficult to react to and communicate with new scientific and technological developments. The economic, social, and cultural sciences are currently underestimated in most developing countries, but they are crucial in the design and implementation of development strategies that are directed toward social and cultural needs. Government R&D policies must be employment-oriented, to avoid a "brain drain", frustration, and deskilling of highly educated people. It is very difficult and dangerous to speed up the scientific and technological development of a country if the culture remains non-scientific and non-technological. The educational system must help to discredit obscurantism and superstition and to promote scientific understanding.
(2) More should be done in short-term basic and applied research in civilian sectors related to the national economy, especially agriculture, rural

industry, natural resources, health, and scientific education. In the expensive innovation fields, such as nuclear energy, electronics, etc., stress should be laid on adaptation and utilization strategies.

(3) It is important to select and encourage a group of frontier technologies and a few advanced areas of research (energy conservation, biomass conservation, solar energy, malaria and leprosy eradication, biological control of plant diseases, birth control, environment, social and economic development planning, etc.).

(4) For most developing countries it will be difficult to establish the necessary research capacities from their own resources, so that cooperation between the developing countries on the regional level is very important.

The purpose of this chapter has been to show that we are faced with serious problems if there is to be a new wave of productivity growth for the majority of the world's population. There is no "invisible hand" that can solve these problems for us; we have to solve them ourselves. And it will be a great and creative challenge to all of us, and to our children and grandchildren.

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CHAPTER 7

Structural Crisis as a Phase in Long-Term Economic Fluctuations

S. Menshikov

7.1. The Structural Crisis and Its Manifestations

Historically, the downswing phase of the economic long wave has been associated with deeper cyclical crises and the overall deceleration of economic growth. Other important phenomena that occur during this phase include long-term stagnation in traditionally important branches and sectors of industry (while other, newer branches may expand at an accelerated rate); long-term disorders in the monetary sphere, finance, and international trade; and breakdowns in existing forms of organization and methods of regulating the capitalist economy.

All of these phenomena may be considered as fairly isolated and autonomous occurrences, in which case they may be described as a series of coincident long-term or structural crises. Menshikov (1984) has suggested that they be treated rather as components or manifestations of one aggregate structural crisis of the economy. Such a crisis indicates that further overall economic expansion at or above the average long-term growth rates is impossible without a fundamental change in the sectoral output structure, the system of interindustrial and technological ties, the international division of labor, major forms of industrial organization, and existing methods of market and government control.

Basically, the crisis occurs when the old economic structure comes into conflict with demands of new technology, but is not yet ready for change. The inertia of the existing structure serves to delay readjustment and transition to new conditions, making it painful and quite slow to develop. While the old structure prevails, growth rates stagnate, and there is disruption in markets and the monetary sphere, so that business conditions are generally unfavorable. The structural crisis is overcome when the old economic structure finally begins to recede and new branches and sectors develop. Fundamental changes in the economic structure cannot be accomplished within a short time limits. Common to all manifestations of the structural crisis is that they transcend the limits of one business cycle, i.e., 8–10 years. Naturally the time needed to overcome particular crises will vary; some drag on for two cycles and more, others for even longer.

During its history, capitalism has experienced several structural economic crises, each involving a far-reaching change in structure consistent with a certain level achieved in the development of productive forces. The change over from manufactory to factory (in the late eighteenth century), the spread of corporate property (from the 1820s), the onset of the monopoly stage (starting with 1870s), the rise of state monopoly control (1920s and after), and the appearance of transnational state monopoly capitalism (from the 1970s) have all been brought about by the objective need to overcome successive structural crises. In other words, structural crises are an outcome of the basic contradiction of capitalism between the social character of production and the private form of appropriation.

This chapter does not purport to analyze all the forms and manifestations of the structural crisis, but deals with some of the causes of long-term fluctuations in economic growth, which largely determine the onset of structural crises. In this analysis we draw upon the writings of Karl Marx and his ideas on the nature of long-term fluctuations.

7.2. Marx on Long-Term Contradictions

One feels that those involved in the debate on long cycles were mistaken in virtually ignoring or bypassing Marx's observations on long-term structural contradictions of capitalist reproduction. For example, in his *Theories of Surplus Value* (1863), Marx clearly referred to different ways in which contradictions of reproduction are overcome by: (1) short-lived and relatively weak recessions; (2) cyclical and deeper-running crises; and (3) long-term processes that take several cycles to resolve.

> Productivity changes and alters the conditions of production. The conditions, in their turn, alter productivity. The discrepancies thus produced show themselves up partly in surface fluctuations which level off within a short space of time, and partly in a gradual build-up of divergences which either lead to a crisis and to a forcible apparent reversion to earlier relations or only very gradually make their way for themselves and get recognized as the changed conditions of production (*Collected Works*, Vol. 26, pp. 544–545).

The "changed conditions of production" are, of course, qualitative or structural changes, which may also follow a repetitive or fluctuating path.

Of particular importance is Marx's early discovery that the payback time of fixed capital lies at the material foundation of periodic fluctuations in the economy. Having made this famous conclusion, he quite unequivocally pointed to the active part of fixed capital, i.e., capital invested in machinery and equipment, as the material foundation for the medium-term cycle of 7–10 years. But having done that, he next turned to capital invested in buildings, roads, irrigation networks, etc., with cycles of 20–50 years (*Capital*, Vol. 2, p. 187). Analyzing in particular the replacement of capital operating "for example, as buildings, railways, canals, etc. only as a general condition for the process of production," he pointed out that replacement in that case was "practically infinitesimal". In other words, such components of fixed capital (infrastructure) do not require replacement in every cycle of medium duration and are replaced *en masse* at longer time intervals.

Marx went on to stress the particular importance of large-scale renewals of capital having a long service life. Analyzing the consecutive stages of the Industrial Revolution in the late eighteenth and early nineteenth century, he called attention to a "revolution in the general conditions of the social process of Production", that is, in the means of transportation and communications, and to its reverse effect on the whole process of reproduction and technological progress (*Capital*, Vol. 1, pp. 384–385).

Far from overestimating the significance of individual components of fixed capital involved in generating periodic fluctuations in production, Marx attached far greater importance to the role of technological progress and the changes it brought about in the composition of capital and in the profit rate. Unlike later long-wave theorists, he did not link technological progress with long-term fluctuations alone, but showed its integral connection with the medium-term cycle.

Consequently, every new medium-term cycle represents yet another stage of technological progress, but this is not a balanced and uniform movement, monotonously repeating itself from cycle to cycle. Marx distinguished intensive movements "involving more effective means of production" and extensive movements, which means "nothing beyond expanding the field of production" upon the existing technological base. Indeed, this is borne out by the history of economic fluctuations. Some medium-term cycles are dominated by minor modifications and modernization of existing machinery and technology, with new models of machinery replacing old ones. Other cycles involve deeper changes from one generation of technology to another. Finally, still other cycles see a large-scale introduction of basically new types of machinery and technology, laying the groundwork for technological revolutions, which, like chain reactions, spread from sector to sector, embracing the whole economy and fundamentally revamping its technological base. It is these periods that witness a fundamental replacement of fixed capital invested in the "general conditions of reproduction", that is, transportation, communications, durable industrial structures, production of basic structural materials, energy and power resources. Such changeovers may span decades.

The alternation of qualitative leaps by quantitative evolution of technology takes place, Marx maintained, within the framework of the business cycle as well as outside it, and is itself repetitive.

> There are intervals during which technical revolutions are less notable and accumulation appears to be, above all, a movement of quantitative expansion upon the new technical base already achieved. What begins to operate to a greater or lesser extent in such a case, whatever the actual structure of capital, is a law whereby the demand for labor rises in the same proportion as capital does. But just when the number of workers attracted by capital reaches its peak, the products become so plentiful that the social mechanism seems to have come to a standstill in case of the slightest obstacle arising in the way of their sale; it is the process of alienating labor by capital in great proportions and in the most violent way that comes into operation at once; the very disruption of production makes it imperative for capitalists to strain every nerve to save labor. Detailed improvements building up little by little are concentrated under that high pressure, so to speak; they find themselves embodied in the technological modifications which revolutionize the structure of capital throughout the entire periphery of major areas of production (*Collected Works*, Vol. 49, pp. 220-221).

Consequently, the slowdown of technological progress (which Marx described as "intervals") creates a wide range of contradictions that cannot be resolved except through accelerated technological progress and another technological revolution. Such revolutions create new sectors and speed up the overall pace of reproduction. But as new sectors gain momentum, technological modifications become less notable and more ordinary, which leads, once again, to a slowdown of reproduction and to sustained periods of crisis and depression. Technological progress concentrates on labor-saving devices. The "high pressure" of capital overaccumulation and mass unemployment thus created cause the technological base to be revolutionized again, thus closing the circuit.

Long-term fluctuations in technological progress are reflected in the composition of capital. One can see from the above passage that Marx considered the law of increasing organic composition of capital, i.e., the rising ratio of constant capital (invested in the means of production) to variable capital (invested in labor), as a historical trend operating with intervals. On the one hand, "the purely quantitative extension of the factories absorbs not only the men thrown out of work, but also fresh contingents" (*Capital*, Vol. 1, p. 454); this is a time when labor is not particularly saved. On the other hand, at a certain stage of the technological revolution, when savings in both the means of production and labor become the major direction of technological progress, productivity outpaces the capital–labor ratio, and elements of fixed capital become cheaper at a faster rate.

Marx made a special point of discussing "transient fluctuations" in the operation of the law of the tendency for the profit rate to decline. Owing to a set of counteracting factors, this trend "is really manifest only under certain circumstances and within lasting periods of time" (*Capital*, Vol. 3, pp. 239, 262). Long-term fluctuations in the profit rate are reflected in overall rates of expanded reproduction and capital accumulation. With a rising profit rate, production growth rates accelerate, while a sustained fall in the profit rate tends to slow down the rate of accumulation and economic growth, but within certain limits. An excessive increase in the profit rate discourages entrepreneurs from introducing technical innovations, and, conversely, if the profit rate falls below a certain minimum it compels them to resort to new technology as a way out.

When the general profit rate is low, the old technical base of production morally wears out and an opportunity for fundamental innovation presents itself. But in this case, too, entrepreneurs act with caution: a new technological revolution begins with installation of machinery that enables production costs to be reduced, usually at the expense of labor. Only as a second resort, with improved overall business conditions, are new types of goods launched, which give rise to new sectors and to a "quantitative extension of factories".

In the opening stages of a technological revolution, while individual enterprises are still using inventions that are not yet in general use, the profit rate associated with such inventions is high. However, once an innovation has become a common asset, the additional surplus value disappears, while the profit derived from secondary modification and partial modernization of new machinery becomes substantially lower than it was when this machinery was first installed. Consequently, at a certain stage of the technological revolution, the general profit rate must fall again.

7.3. Conclusions for the Long Wave

What main conclusions can be drawn from this analysis for a better understanding of the long-wave mechanism?

First, the long wave is directly associated with technological revolutions, i.e., with widespread qualitative changes in production technology encompassing the whole economy. The principal moving force behind every long upturn is the opening up of new directions in technology, not just new generations of existing directions, and not just new models of an existing generation. In the course of such revolutions new sectors and industries are created and old sectors and industries undergo drastic technological change. What starts as the sporadic introduction of new technologies in a limited number of plants in selected industries, continues as the diffusion of new technologies to a wider range of industries, and finally leads to a general spread of technologies that are now recognized as the norm, rather than the exception. In the course of this change the new technologies themselves are continuously perfected and modernized, so that they become relatively inexpensive and readily available in large quantities.

However, once this stage is reached, further development of the same technological directions becomes less radical and more evolutionary in character, and the benefits from such development become more marginal. All available capital and, perhaps, even more, has been invested in the prevailing technological directions and is tied to their further progress, and it takes a long time for this overall capital to pay back. This point is, perhaps, one of the most crucial. By overall capital we mean not only capital materialized in new production equipment and research facilities, but capital embodied in a new economic *structure*. This includes:

(1) New industries are built up in the course of the technological revolution.
(2) New products – not only production equipment, but also a wide range of consumer and producer goods, including new materials and types (or sources) of energy.
(3) New infrastructure is installed to serve new industries.
(4) New kinds of business organizations are set up.
(5) New government institutions, regulations, and practices are established to support the new economic structure.

All of these structural components have a vested interest in self-preservation and self-promotion. A given economic structure will never resign or give way to another until it has reaped most of its expected benefits, and unless a more profitable alternative is available. For the expected benefits to be reaped and more profitable alternatives to develop takes time. The length of this time depends on two factors: (i) how soon the current technological revolution exhausts its innovating potential and turns into evolution; and (ii) how fast even newer technological directions present themselves as more profitable business opportunities. The change from qualitative technological change to evolution is *sufficient* to start a downturn in the long wave. But the availability of profitable new technology is *necessary* to trigger developments that make obsolete the prevalent technology and consequently the existing economic structure.

However, the long downturn leads to a crisis even before the next technological revolution is ready to start. When a given economic structure is created there is a lot of business activity, which takes a long time to establish, but it is temporary in nature. This includes investment activity that *directly* generates high demand for construction, equipment, and other capital goods, and *indirectly* creates additional demand for intermediate goods, labor, and consumer goods. Once the economic structure has been created, or even when it has passed its peak, this investment activity is substantially reduced, adversely affecting aggregate demand. Excess capacity and high unemployment become lasting features of the economy.

One result is long stagnation in industries that were once growth industries, and even served as instigators of growth in the preceding upturn. Among them are some industries producing final-use goods, such as machine-building, consumer durables, construction, but also and inevitably they include industries producing basic materials and energy. Thus a structural crisis is the logical outcome of a technological revolution, but it also serves as the starting point for a new one.

Second, it is important to understand the mechanism by which changes in technology are translated into long waves and structural transformation through the operation of fluctuations in the profit rate. From Marx's analysis, it follows that the overall average profit rate in the economy, i.e., the ratio of gross profit (including depreciation and taxes) to total fixed capital (including housing), depends basically on two factors: the composition of capital, and the extent to which capital is used (or capacity utilization). The composition of capital depends mainly on technology, as expressed by capital intensity, or the ratio of fixed capital to the amount of labor, and by their relative prices. If one ignores for the sake of simplicity oscillations of the share of labor income in national product, then capital composition will change more or less in line with the output–capital ratio, which can be directly observed by comparing the rates of labor productivity and capital intensity.

Fluctuations of the general profit rate generally follow those of the output–capital ratio. Both rise when labor productivity increases faster than capital intensity, and both fall when labor productivity increases more slowly than capital intensity. It was also shown that the long upswing is positively correlated with the *intensive* phase of technological revolution (when the output–capital ratio rises), and the downswing is correlated with the *extensive* phase of the same, i.e., when the output–capital ratio tends to fall.

Capital or capacity utilization accentuates these fluctuations caused by technological revolutions. The profit rate is positively correlated with capital utilization. Since both movements (output–capital ratio and capacity utilization) have approximately the same timing (the first, perhaps, slightly leading the latter), they tend to superpose and support each other.

We now turn to the inverse relationship: the influence of the profit rate on technological development (cf. *Table 7.1*). The most important point here is the relative profitability of business alternatives and the relative risk involved. The general or prevailing profit rate serves as a gauge against which potential profit and risk associated with new undertakings are measured. The higher the prevailing profit rate the more investment would be expected to go into existing technology, which has proved to be profitable, and into relatively minor improvements. This in itself tends to slow down the growth of profits and eventually to stop it completely.

It is true that when prevailing profit rates are high and financial possibilities are ample, basic research would be expected to be more easily financed. But the time lag between such research and actual resulting innovations makes it more probable that the latter will appear as realistic business opportunities during the downswing, rather than otherwise.

Not only the level, but also the direction of change in the prevailing profit rate is important. While profits are rising, prospects for risk taking and adventure investment are still encouraging, but once the the profit rate starts falling, even though it is still high, the signal is given for more caution, with fewer adventures and risk taking. This inevitably occurs at the crest of the boom period. Therefore technological revolutions are doomed to evolution and routine soon after they have reached their peaks. The upper turning point in the long wave is thus established.

Table 7.1. The influence of the average profit rate on technological development.

Profit rate (level)	*Profit rate (change)*	*Climate for innovations*
Average	Rising	Favorable for spread and improvement of prevailing technology
High	Leveling-off	Favorable for improvements in existing technology
High or average	Falling	Unfavorable except for minor improvements
Low	Leveling-off	Favorable for take-off in basic innovations
Low	Rising	Favorable for the spread of basic innovations

Let us now consider the lower turning point. It is sometimes claimed that Marx did not see it, but the passages quoted above indicate that his logic was quite different. While the prevailing profit rate is falling in the downswing, there is little incentive to invest in new technology that has not yet proved to be more profitable. However, the profit rate finally reaches such low levels that the range of business alternatives, which are seductive due to the potentially much higher profitability, becomes sufficiently large. As Marx underlined, the individual profit rate of the entrepreneur who first introduces a qualitative innovation is substantially higher than that of those who follow his lead and make the innovation a general rule rather than an exception. Risk taking may become the only alternative when the general profit rate is very low and when profits may indeed be nonexistent.

It is true that at this point in the downswing financial possibilities are limited for large investments in new technologies. However, once innovation investments take off, even in relatively small amounts, they help slow down and finally halt the downward trend in general profits. The latter may be still low, but once they start to recover, the impulse is given to more modernization in both production technology and new goods. By the time the prevailing profit rate reaches its long-term average, new technology has established itself as the rule, and its spread throughout the economy and the concomitant change in economic structure are assured.

7.4. Observations on the Current Phase

It seems obvious that the new technological revolution, based mainly on microelectronics and bioengineering, is still in its opening stage. The areas in which it has progressed most of all – robots, flexible production systems, office automation – are predominantly labor-saving techniques characteristic of a recession, or structural crisis. What confuses the picture is that this new revolution started fairly early, i.e., at the end of the first and the start of the second regular business cycle within the long recession phase. This does create quite a mixed picture: stagnation in many basic industries, but high growth and spectacular technological progress in others, including those where output is still at or below its 1973 peak. Equally mixed is the international picture where, on the one hand, large differences exist in national and regional growth rates, and, on the other, the instigative effect of the faster-growing countries on the remainder is absent.

With a few exceptions the new revolution has not yet entered the stage when qualitatively new consumer goods start appearing *en masse*, and when a new economic infrastructure is being created. Until this happens one cannot expect the basic industries to recover from stagnation, particularly because the new revolution is also materials- and energy-saving.

Some new forms of organization belonging to the new economic structure have appeared, namely, joint production and mergers by multinationals, internationalization of finance capital, and attempts to coordinate economic policies of different countries, but they have not as yet provided a positive influence. Structural policy and modernization, particularly in the multinationals, has added to mass unemployment; anti-inflationary measures have helped decelerate or reduce real wages; and attempts to alleviate budget deficits have cut into social and welfare programs. All of these are typical of a crisis, rather than a recovery stage.

For example, the American cyclical upturn of 1983–1984 has raised the question as to whether the long-term recovery has already started. But average cyclical growth rates, which are roughly coincident indicators of the long wave, do not support such conclusions (see *Table 7.2*). It can be seen that growth rates in all major countries (excluding Japan in 1979–1984) have gone down, not up, and in Japan there is a repetition of the growth rates of 1973–1979. In all cases, growth has been substantially slower than in 1960–1973, which belongs to the preceding long upturn.

Table 7.2. Average annual growth rates (%).

	OECD	*USA*	*UK*	*France*	*FRG*	*Japan*
GDP						
1960–1973	4.8	4.2	3.2	5.7	4.8	10.5
1973–1979	2.7	2.6	1.4	3.1	2.4	3.6
1979–1984	1.9	2.1	0.7	1.2	0.9	4.2
Industrial production						
1960–1973	5.9	5.3	2.8	5.6	5.1	12.3
1973–1979	1.8	2.7	1.2	2.0	1.3	2.1
1979–1984	1.1	1.4	–0.8	–0.1	–0.1	4.0

There is some evidence of a turnaround in labor productivity. In the USA, output per man-hour in the private sector has grown annually in 1979–1984 by 1.6%, up from 0.8% in 1973–1979. However, the current growth rate of this indicator is still lower than in the upturn (3.1% in 1948–1957, 3.2% in 1957–1966, and 2.3% in 1966–1973). Even more important, fixed capital in the USA continues to rise faster than output, meaning that, as yet, there is no turnaround in the overall output–capital ratio for the economy.

More attention should be given to the continuous analysis of such leading indicators of the long wave as labor productivity, the output–capital ratio, and the general profit rate. These may signal a definite turning point somewhat earlier than it occurs in the growth rates of GNP and industrial production.

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CHAPTER 8

Technological Substitution and Long Waves in the USA

Nebojsa Nakicenovic

8.1. Introduction

The analysis of historical replacement of old by new technologies has shown that most of these processes can be described by simple rules that are captured in the logistic substitution model (see Marchetti, 1979; Marchetti and Nakicenovic, 1979; Nakicenovic, 1984), and that technological substitution, expressed in terms of market shares, follows characteristic S-shaped curves. In order to illustrate and describe the properties of the approach we first give examples of how new energy forms replaced their predecessors, since technological changes in the energy system constitute one of the first and most complete applications of logistic substitution analysis. To further explore this method we then describe similar substitution processes in steel production and the merchant marines.

The application of the logistic substitution model to the above examples indicates that improvements and growth are achieved through a regular but discontinuous process. Each new technology goes through three distinct substitution phases: growth, saturation, and decline. This regular pattern points to a certain schedule and recurrence of structural change in competitive markets. The structural change in the above examples occurred at intervals of about 50 years.

The recurrence of changes every 50 years resembles the long-wave fluctuations in economic development originally described by Kondratieff (1926). One of the most extensive explanations of the long wave was given by Schumpeter (1939), for whom innovations come in clusters and are not evenly distributed or continuously absorbed, due to the basic principles that govern the process of capitalist development. The clustering of technological and entrepreneurial innovations leads to the periodic emergence of new industries and subsequent growth, but this growth necessarily leads to limits and eventual decline. Thus, wave-like forms of economic development are generated with phases of growth and senescence at intervals of about 50 years.

A hypothetical relation between the 50-year period in the introduction of new technologies and saturation of old ones, and the 50-year period in the changing phases of growth and decline that is associated with the long wave must be verified empirically before the exact nature of the two phenomena connected with the process of technological change can be related to each other. This analysis essentially consists of the use of a phenomenological approach to extract long fluctuations from the time series in an attempt to filter out the long-waves and to compare the fluctuation patterns thus derived with the dynamics of technological substitution. The changing phases of the long-wave fluctuations are illustrated with the same examples as those for technological substitution: energy consumption, steel production, and the merchant marine fleet.

All of the examples illustrate the American experience. Thus, while the results are equivalent to similar examples for some other industrialized countries and the whole world, it is inconclusive whether they may also be of a more general nature. Unfortunately, historical data cannot be reconstructed from available records for too many different cases, although the UK has been analyzed with equivalent examples. All of the reported examples and historical data for the USA (and also the UK) are given in Nakicenovic (1984).

8.2. Technological Substitution

Substitution of an old way of satisfying a given need by a new path has been the subject of a large number of studies. One general finding is that substitution of an old technology by a new one, expressed in fractional terms, follows characteristic S-shaped curves. Fisher and Pry (1971) formulated a very simple but powerful model of technological substitution [1].

8.2.1. Primary energy consumption

The analysis of the competitive struggle between various sources of primary energy has been shown to obey a regular substitution process that can be described by relatively simple rules (Marchetti, 1977; Marchetti and Nakicenovic, 1979; Nakicenovic, 1979). The dynamic changes in this process are captured by logistic equations that describe the rise of new energy sources and the senescence of old ones. *Figure 8.1* shows the primary energy consumption in the USA since 1850; data are plotted on a logarithmic scale and show exponential growth phases in consumption of the most important sources of primary energy by piecewise linear secular trends. Thus it is evident that energy consumption grew at exponential rates during long time periods, but

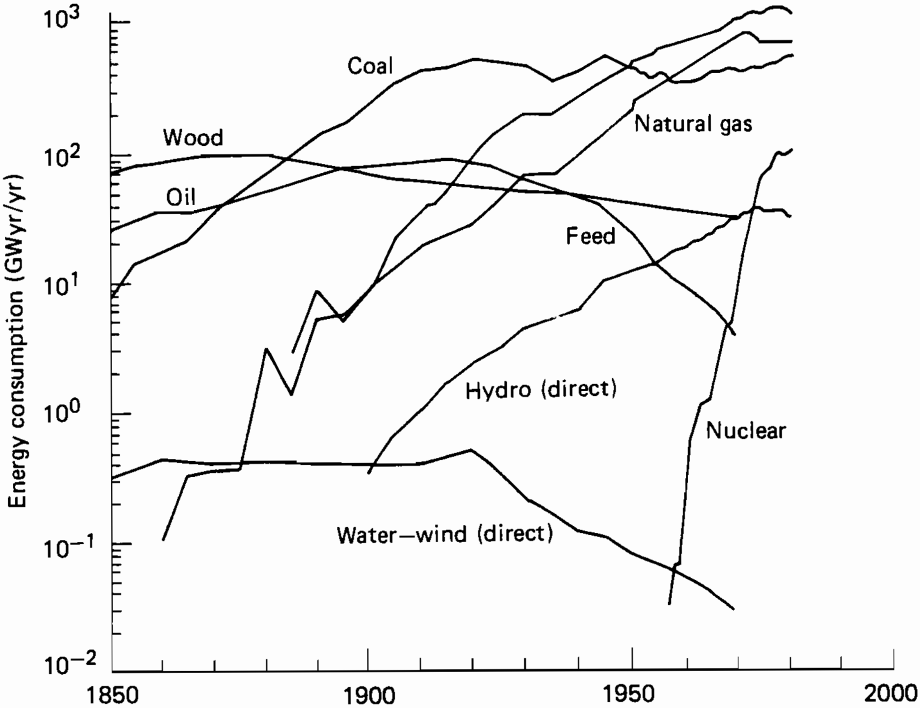

Figure 8.1. Primary energy consumption in the USA since 1850.

no other regularities are directly discernible. However, the evolution of primary energy consumption emerges as a regular substitution process when it is assumed that energy sources are different technologies competing for a market. Unfortunately, the Fisher–Pry model cannot be used to describe the evolution of primary energy consumption, since evidently more than two energy sources compete for the market simultaneously.

In dealing with more than two competing technologies, we must generalize the Fisher–Pry model, since in such cases logistic substitution cannot be preserved in all phases of the substitution process. Every competitor undergoes three distinct substitution phases: growth, saturation, and decline. The growth phase is similar to the Fisher–Pry model of two competitors, but it usually terminates before full substitution is reached. It is followed by the saturation phase, which is not logistic, but which encompasses the slowing down of growth and the beginning of decline. After the saturation phase of a technology, its market share proceeds to decline logistically [2].

Figure 8.2 shows the primary energy substitution for the USA. Data and model estimates of the substitution process are plotted on a logarithmic scale using the quantity $f/(1-f)$ versus time (f representing fractional market shares). The piecewise linear secular trends indicate logistic substitution phases. The departure of historical market shares from their long-term

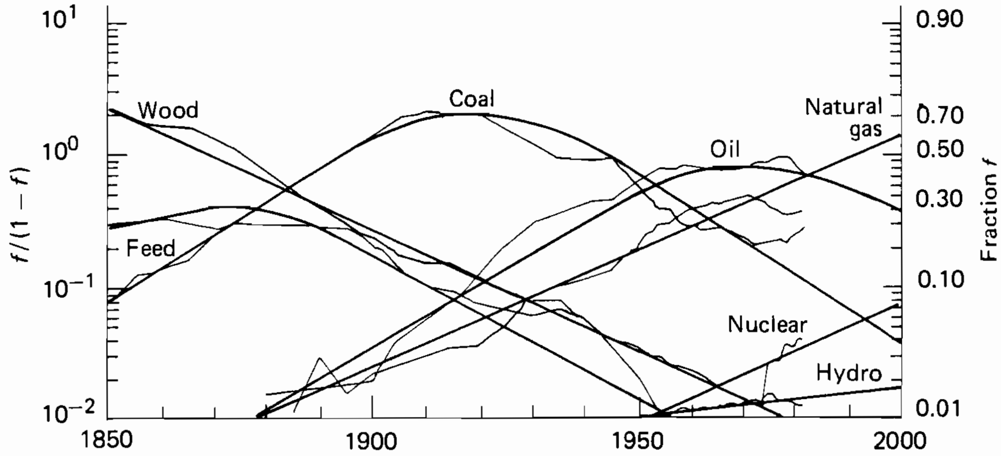

Figure 8.2. Primary energy substitution in the USA since 1850.

paths, described by the logistic substitution model, sometimes last for over two decades only to return to the trend after the prolonged perturbation. This is the case with the market shares of coal and oil during the 1940s and 1950s, and fuelwood and animal feed during the 1860s and 1870s. This may also indicate a possible absorption of the departure of coal and natural gas market shares from their long-term paths during the last ten years.

Animal feed reached its highest market share in the 1880s, indicating that draft animals provided the major form of local transportation and motive power in agriculture despite the dominance of railroads and steamships as long-distance transport modes. Horse carriages and wagons were the only form of local transport in rural areas and basically the only freight transport mode in cities. It is curious that the feed and crude oil substitution curves cross in the 1920s as if to suggest the simultaneous substitution of the horse carriage and wagon by the motor vehicle (see Nakicenovic, 1985).

The substitution process clearly indicates the dominance of coal as the major energy source between the 1870s and 1950s after a long period during which fuel wood and animal feed were in the lead. In the USA, wood remained the principal fuel for the railroads up to the 1870s, although railroads are considered the symbol of the coal age. The last phases of railroad expansion up to the 1920s, the growth of steel, steamships and many other sectors are associated with and based on the technological opportunities offered by the mature coal economy. After the 1940s, oil assumed a dominant role simultaneously with the maturing of the automotive, petrochemical, and other modern industries.

Figure 8.2 shows natural gas as the dominant energy source after the 1980s, although crude oil still maintains about a 30% market share by the end of the century. For such an explorative "look" into the future, additional assumptions are required because potential new competitors, such as nuclear or solar energy, have not yet captured sufficient market shares to allow estimation of their penetration rates. The starting point for market penetration of nuclear energy can be dated back to the 1960s, when nuclear power acquired slightly less than a 1% share in primary energy. In order to explore the behavior of the logistic substitution model when the competition between energy sources is extended into the future, we assumed that nuclear energy could double its current market share of about 4% by the year 2000. This leaves natural gas with the lion's share in primary energy, advancing its position to the major source of energy after this century.

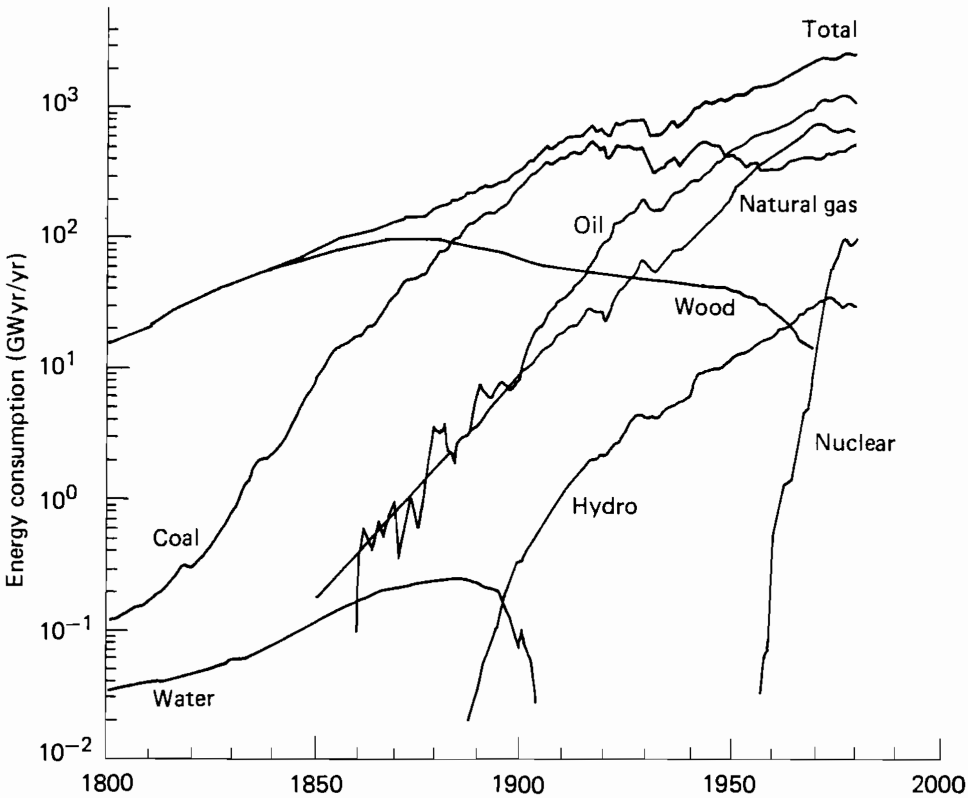

Figure 8.3. Primary energy consumption since 1800.

The evolution of fossil energy use in the USA has a longer recorded history than the use of traditional energy sources such as draft animals and wind power. *Figure 8.3* gives the annual consumption of all fossil primary energy sources, fuel wood, and direct uses of water power starting in 1800, while *Figure 8.4* shows the substitution of these energy sources. In this example, the logistic substitution model describes with great precision the evolution of primary energy consumption. Due to the dominance of fuelwood as the major source of energy during most of the last century, the information loss

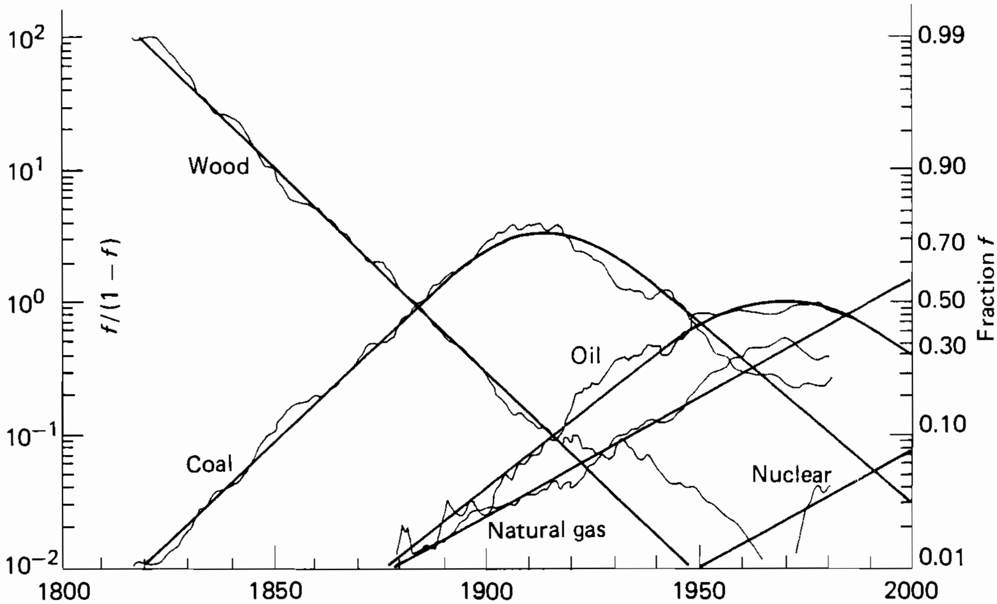

Figure 8.4. Primary energy substitution since 1800.

associated with the lack of adequate annual estimates of energy use (feed requirements) of draft animals is not very large. Direct use of water power is included in the data set, but due to the low contribution to total energy supply, when expressed in terms of its actual energy inputs, water power is not observable at the 1% level.

The regularity of this substitution process is due not only to the fact that the penetration rates of various energy sources remain constant over periods of about a century, but also due to the fact that the saturation levels of energy sources are much lower than the full market takeover. The introduction of new energy sources and the long time constant lead to maximum market penetrations of between 50 and 70%. New energy sources are introduced before the dominant ones have even reached a 50% share. In addition, the maxima are roughly spaced at intervals of about 50 years, which corresponds to the time constant of about 50 years for market share increases from 10 to 50%.

8.2.2. Steel production and the merchant marine fleet

Figure 8.5 shows that steel production increased rapidly during the second half of the nineteenth century, after Henry Bessemer patented the first high-tonnage process for steel production in 1857. *Figure 8.6* shows the actual technological substitution in steelmaking according to the process

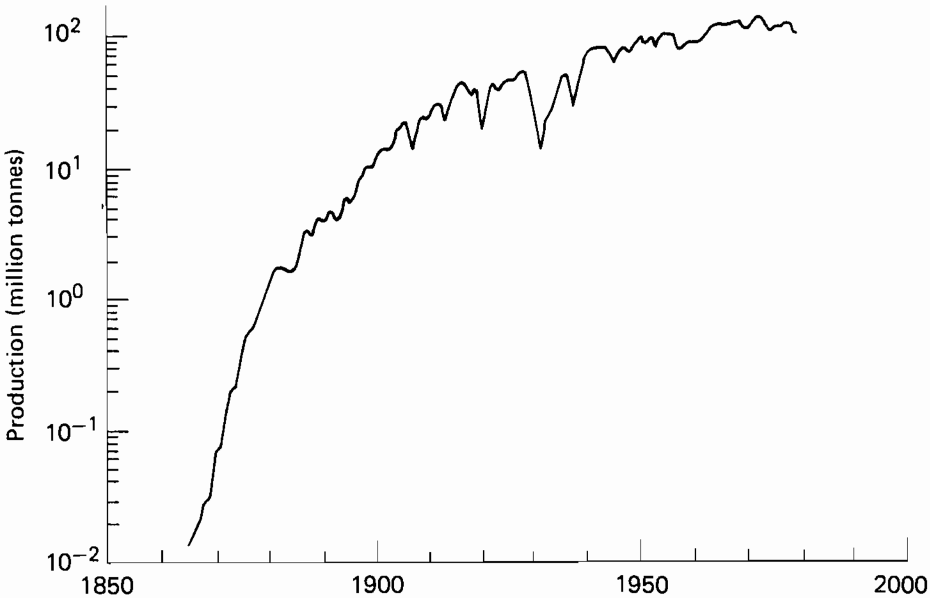

Figure 8.5. Steel production in the USA since 1850.

used; prior to the introduction of the Bessemer process, all steel was produced by the traditional crucible methods used since antiquity. *Figure 8.6* shows that the Bessemer process replaced traditional methods within two decades, supplying almost 90% of all steel by the 1880s. The next improvement in steelmaking was the introduction of the open-hearth furnace, which supplied 50% of all steel by the end of the century. The use of the open-hearth process continued to increase during the first decades of this century and by the 1950s it accounted for more than 90% of the steel produced. The first open-hearth process to be used widely was based on acid chemistry, although later the basic open-hearth also found extensive use. The basic systems have a decided advantage in flexibility with regard to raw materials consumed and grades of steel produced. The steelmaking processes were further improved by the use of oxygen for excess combustion instead of air; this offers many advantages, such as faster melting and reduced checker chamber capacity. Consequently, the Bessemer process was also extended to basic chemistry and oxygen use, the most spectacular application originating in Austria as the Linz and Donawitz (L–D) process, now generally referred to as basic oxygen steelmaking.

This process of technological substitution has continued over the last 40 years with the introduction of the basic oxygen and electric steel methods. The electric arc process was introduced as early as 1900, so that it gained

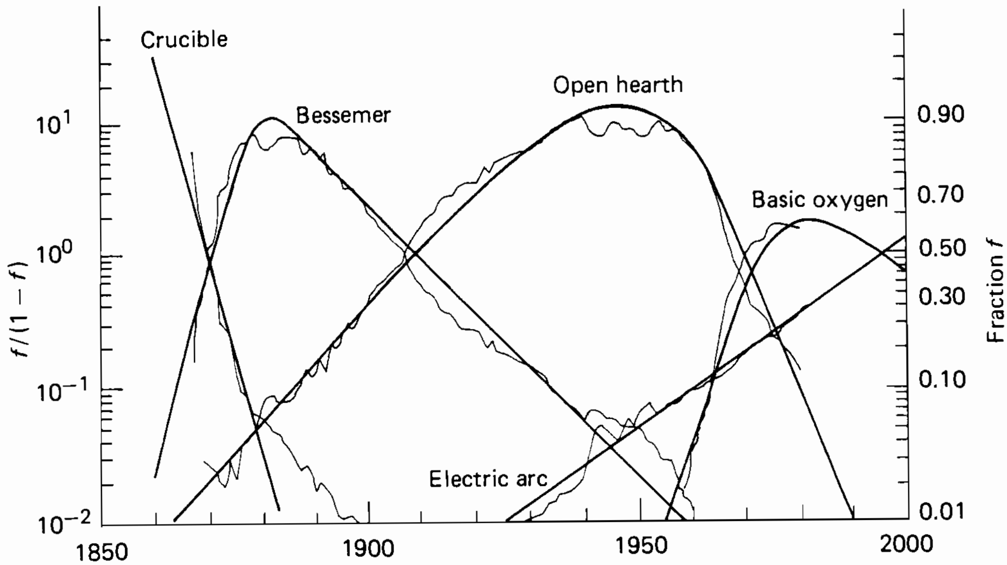

Figure 8.6. Technological substitution in steel production in the USA since 1850.

importance before the basic oxygen process, but the latter process expanded faster, probably because it is technologically similar to the open-hearth and Bessemer basic variants. During the 1960s, the basic oxygen process showed very rapid share increases, reaching more than 50% of the market in the 1970s. The electric process is gaining importance and will probably overtake basic oxygen within the next two decades due to the saturation of demand for domestic steel in the USA. The dwindling total production leads to higher and higher percentages of scrap iron and steel inputs instead of iron ore. The electric process has the advantage that it is suitable for making many grades of steel and can almost exclusively use recycled scrap iron and steel (Miller 1984). Thus the stagnating demand for steel favors the electric process since it allows for almost exclusive use of recycled inputs and flexible steel production in smaller mills.

This example illustrates that the evolution of steelmaking technologies portrays a regular pattern that is similar to energy substitution. Before returning to the analysis of recurring periods in technological change and long-wave fluctuations in economic development, we first consider the substitution process in the US merchant fleet. As an example of the evolution of one of the oldest modes of transport, the substitution process covers a period of 200 years and includes fundamental transformations of propulsion systems, increased speed and size of vessels, and changes in construction methods and materials.

Traditional ship propulsion, in use ever since ancient times, was wind power, and the traditional construction material was wood. But with the development of the steam engine and the relatively high energy density of high-quality coals, it was possible slowly to replace sails with steam engines. The first designs were of a hybrid type employing both steam and wind power.

With the increase in the size of vessels along with the expansion of overseas trade, and with the growth of the iron and steel industries, wood was increasingly replaced by iron and later steel as the basic construction material. In fact, the number of vessels remained practically constant from the late eighteenth century until the 1940s at about 25,000 ships, doubling during the last three decades. During the same period the total registered tonnage of the merchant fleet increased by almost two orders of magnitude, implying that the average vessel is about 100 times larger today than in 1800. This enormous increase in the tonnage capacity of an average vessel can only be explained by continuous improvements in propulsion systems, construction materials, and design.

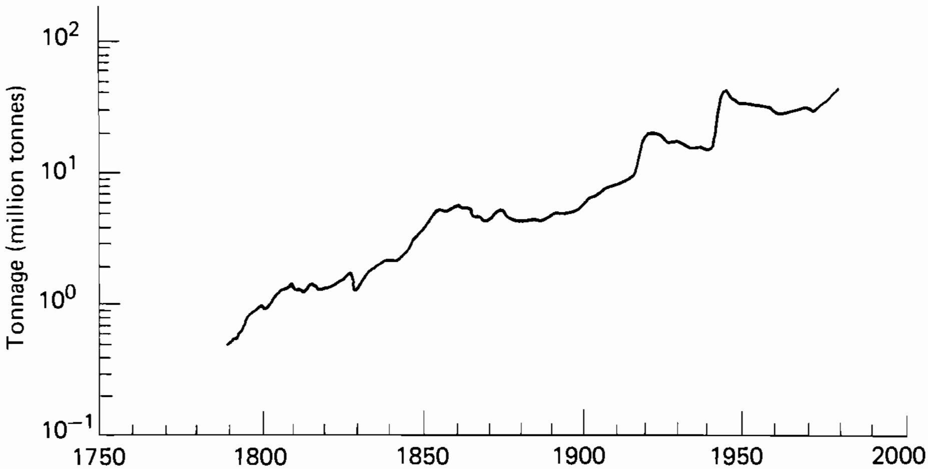

Figure 8.7. Tonnage of merchant vessels.

Figure 8.7 shows the tonnage growth of the US merchant fleet since 1789, and *Figure 8.8* shows the substitution of sailing by steamships, both coal- and oil-fired, and later the market penetration of motor, diesel, and semi-diesel ships in terms of their respective tonnage. Sailing ships dominated the merchant fleet until the 1880s, although steamers had acquired a 1% share of the total tonnage in 1819, more than 50 years earlier and only two years after coal reached a 1% share in primary energy (see *Figure 8.4*). By the 1920s steam vessels constituted more than 90% of merchant tonnage: thus the replacement of the traditional sailing ship took 100 years. During the same decade motorized ships were introduced and their share of total tonnage has increased ever since, although even today they have not acquired much more than one-tenth of the fleet tonnage. Consequently, steamships remain an important type of merchant vessel and are projected in *Figure 8.8* to stay in that position throughout this century, although today they are fueled by oil

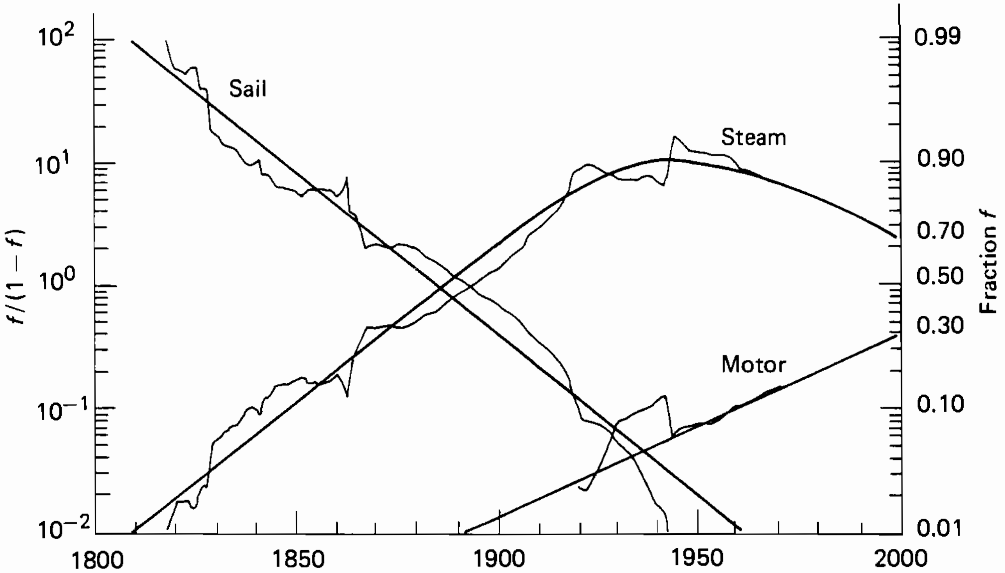

Figure 8.8. Substitution in merchant vessels by propulsion system.

and in some cases use steam turbines instead of coal-fired atmospheric engines. During World War II, the share of motor ships increased sharply, but this perturbation was reabsorbed during the 1960s to return to the long-term trend indicated by the logistic substitution model.

The application of the logistic substitution model to the historical replacement of older by newer forms of energy, steel production, and propulsion of merchant vessels indicates that technological improvements and growth are achieved through a regular process. From the time of its first commercial use, each new technology grows logistically until it reaches a saturation phase and then proceeds to decline logistically while being replaced by a newer and more promising technology. During each phase of the substitution process the dominant technology appears to be strong and unassailable, but with time it decays as emerging competitors "attack" the newly exposed position of the mature technology. In general, the saturation point is determined by the dynamics of the introduction of new technologies. The limits to growth of an older technology are usually encountered before the complete market takeover due to the inherent performance superiority of the new technology. They are imposed by the structure of a given market that is in turn related to overall economic and social development and not necessarily to mere resource depletion. Once these limits are reached, further growth becomes economically and socially unviable. Thus, technological and economic changes have a regular pattern and rules that point to a certain rhythm and schedule in the structural change of human activities.

Horse riding, wood fires, and sailing ships have become aesthetic and recreational activities in the developed economies after they have been replaced by new technologies, while they still constitute a daily necessity in many developing parts of the world as means of transportation and sources of energy.

8.3. Long Waves and Technological Change

We have seen that technological advancement is an evolutionary process. Technological change and diffusion follow regular substitution patterns characterized by successive alternation of growth and senescence with a duration on the order of 50 years for large systems and infrastructures. It is therefore only natural to ask whether the whole process of economic growth and development can also be considered as a series of leaps with periods of rapid growth and periods of relative stagnation that are related to the rise and fall of dominant technologies and economic sectors. From history we know that this is at least an approximate description since a number of serious depressions and crises, as well as periods of unusual prosperity and great achievements, have been recorded since the beginning of the industrial age.

This hypothetical connection between technological substitution and the long wave must be verified empirically before the exact nature of the two phenomena connected with the process of technological and economic development can be related to each other. Here we examine and document the evidence for the presence of long waves in economic development of the USA. Examples for other countries are reported elsewhere (Nakicenovic, 1984; Marchetti, 1981; Bianchi *et al.*, 1983). The analysis essentially consists of the use of a phenomenological approach to extract long fluctuations from historical records in an attempt to filter out the long waves and to compare the fluctuation patterns thus derived with the dynamics of technological substitution.

Kondratieff (1926) and Schumpeter (1935) used a similar approach in the search for invariants in the dynamics of long waves. They assumed that every sequence of annual economic (or other) quantities and indicators can in principle be decomposed into two components – the secular trend and the fluctuations around this trend. In practical terms, the method consists of first eliminating the secular trend from nonstationary time series and then determining the residual time-series fluctuations. The second stage consists of eliminating all other fluctuations shorter than the long wave. In general, trend elimination from time series that are not stationary is usually more difficult than the decomposition of the stationary series into fluctuations. Specifically, it is not always obvious which method of trend elimination should be used. We have used three different methods: moving averages over sufficiently long time periods, exponential, and logistic growth curves. In many cases we have applied more than one method of trend elimination in order to test the sensitivity of the obtained results with respect to such changes, since each method is associated with some problems and specific disadvantages.

8.3.1. Wholesale commodity prices

The regularity of fluctuations in price data was the phenomenon that first stimulated Kondratieff and other long-wave researchers to postulate the existence of long waves in economic development. These waves are pronounced in the wholesale price indices for all commodities in the USA, as well as other industrialized countries such as the UK, France, and the FRG. *Figure 8.9* shows the wholesale commodity price index for the USA from 1800 to 1982. Wholesale prices appear to be stationary with long fluctuations over almost the whole historical period. Only after the 1940s can a pronounced inflationary trend be observed that had a magnitude greater than any previous fluctuation.

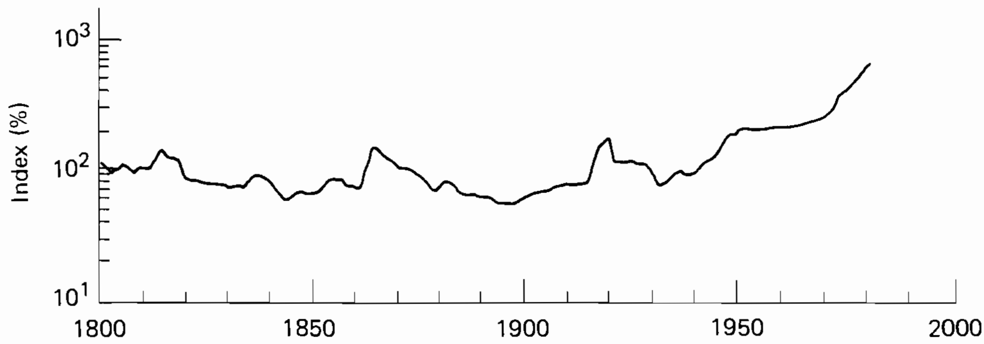

Figure 8.9. US wholesale price index since 1800.

The pronounced price peaks of the 1820s, 1870s, 1920s, and the increases during the last decade are spaced at 40–50-year intervals. These recurring long swings in prices are, in our opinion, not the primary causes of the long-wave phenomenon, but rather a good indicator of the succession of alternating phases of the long wave. We consider that the long swings in price movements indicate the phases of growth and saturation with increasing price levels, and phases of recession and regenerative destruction with decreasing price levels.

In order to obtain a clearer picture of the succession of the long waves in price indices, we have decomposed the time series into fluctuations and a secular trend. Since the secular trend does not indicate a simple functional form, we have used a 50-year moving average method to eliminate it from the time series. We have smoothed the resulting residuals (i.e., the relative difference between the actual price level and its secular trend expressed as a percentage) with a 15-year moving average in order to eliminate business and other cycles shorter than the long wave. The resulting series of smoothed and unsmoothed residuals is shown in *Figure 8.10* for the USA. The average duration of the two fluctuations between the 1840s and 1940s is about 50 years with small variance in the duration and amplitude. The occurrence of peaks and troughs varies by not more than a few years.

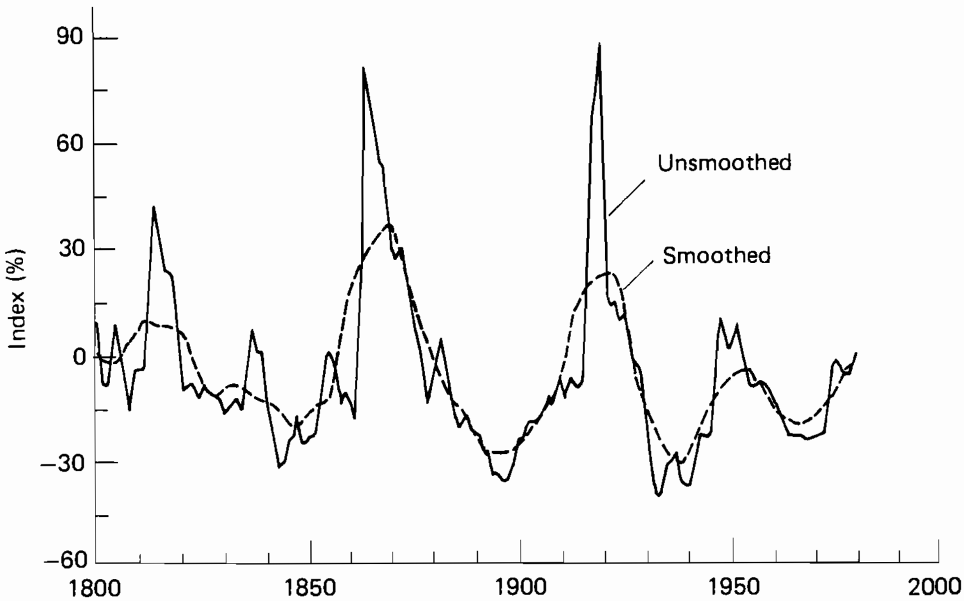

Figure 8.10. Long waves in wholesale prices since 1800.

8.3.2. Primary energy consumption

Energy use is one of the rare quantitative indicators that can, at least in principle, be compared over long periods of time in spite of many technological changes and substitutions of old by new sources of energy. This is possible because the use of different energy sources can be expressed in common energy units. In the context of long waves we are interested in relative changes in the levels of energy use over time, and at least three distinct phases can be observed in the growth of primary energy consumption in the USA (see *Figure 8.3*). After rather stable long-term growth rates, a phase of more rapid growth started in 1900 and continued until 1930. After a short interruption the rapid growth resumed a few years later and continued to the 1970s.

The secular trend of primary energy use in the USA can be captured by a number of functional forms. Stewart (1981) used the logistic growth curve to eliminate the secular trend, basing his estimate on five-year averages of primary energy consumption, and the resulting fluctuations around this trend showed pronounced long waves. The drawback of this approach is that he used shorter time series starting in 1860, so that only the last and the current wave were displayed. Our data base goes back to 1800 and extends over one more wave. We use our extended data base (from *Figure 8.3*) and employ three estimation methods of the secular trend: the geometric 50-year moving average, and the logistic and exponential growth curves. *Figure 8.11* shows the historical primary energy consumption in the USA (from *Figure 8.3*) with two alternative secular trends: the logistic fit with a saturation level of about 8 TWyr/yr to be reached after the year 2050 and an exponential fit that would lead to astronomical consumption levels in the far future. Being the simplest of the three secular trends, the moving average is not shown in the figure in order not to obscure the other two trends.

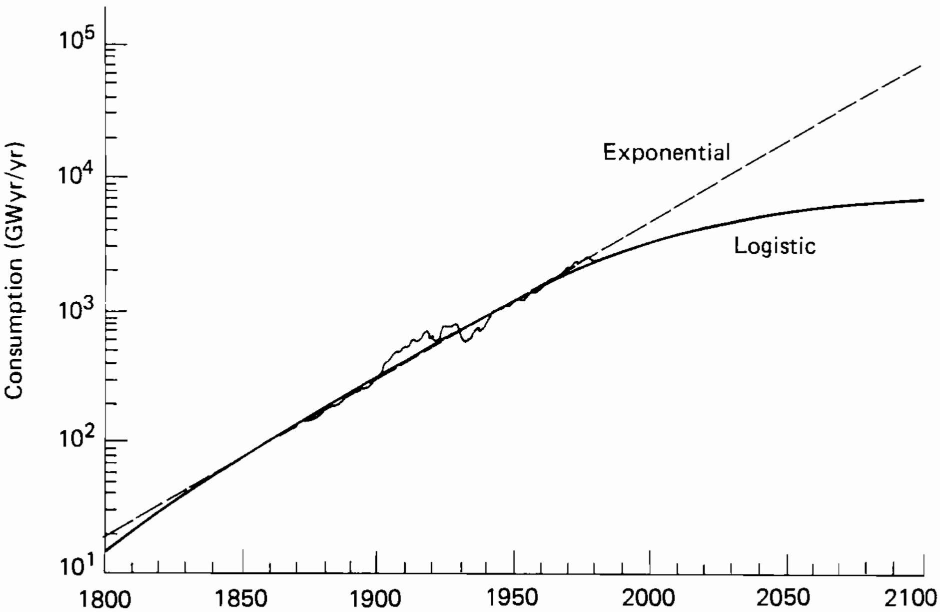

Figure 8.11. **Primary energy consumption (with two secular trends).**

Figure 8.12 shows the residuals, smoothed with a 15-year moving average, resulting from the three alternative methods of estimating the secular trend (logistic and exponential estimates and the 50-year geometric moving average). The fluctuations show the same regular and parallel movements as the long waves in prices (see *Figure 8.10*). The second upper turning point in energy consumption is not as pronounced as that in price movements, and it occurred approximately a decade earlier. The first two fluctuations in primary energy consumption around the secular trends, however, may be to some extent obscured by the fact that especially fuelwood, the most important of all traditional energy sources during this period, with a 90% market share (see *Figures 8.2* and *8.4*), was estimated primarily on the basis of per capita use and population growth. In fact, fuelwood consumption (see *Figure 8.3*) is very smooth, reflecting a continuous and regular secular trend in population growth. Thus, since the fuelwood time series do not represent actual use, but

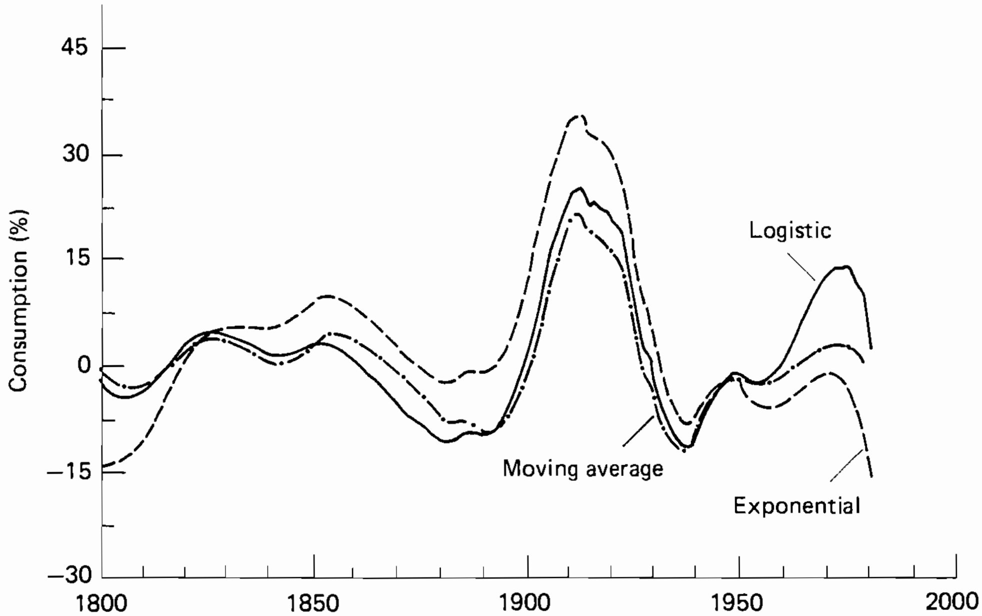

Figure 8.12. Long waves in primary energy consumption (three estimates).

rather serve as an indicator of the relative importance of its use, some of the fluctuations observed in other energy sources may be obscured and not contained in the data.

It should be noted that the turning points of the fluctuations are relatively invariant to the estimation method. The amplitudes of the fluctuations, however, do depend on the estimation method, especially the amplitude of the last upper turning point in 1975. It is lowest in the case of the exponential fit since the low energy growth rates during the last ten years are below the trend of the exponential growth curve. It is also interesting to note that the lower turning point of the first wave in *Figure 8.12* is dated at 1897 by the moving average method and in 1883 in the case of the exponential and logistic methods. This confirms the fact that the moving average method is not well suited for timing the turning points of the long wave. Despite such relatively small changes in the dating of this turning point and a larger variance in the amplitude of the last wave, the parallel fluctuations of all three long-wave curves indicate that the broad features of the fluctuations in primary energy consumption are not a function of the method used to eliminate the secular trend from the data. Apparently, all three methods are suited for trend elimination in this particular context, and since the moving average is the easiest to compute, this sensitivity analysis offers an *a posteriori* justification for using the simplest method of trend elimination in other examples.

The consumption levels of fossil energy sources are known with greater certainty than those of older, traditional energy sources. This is especially

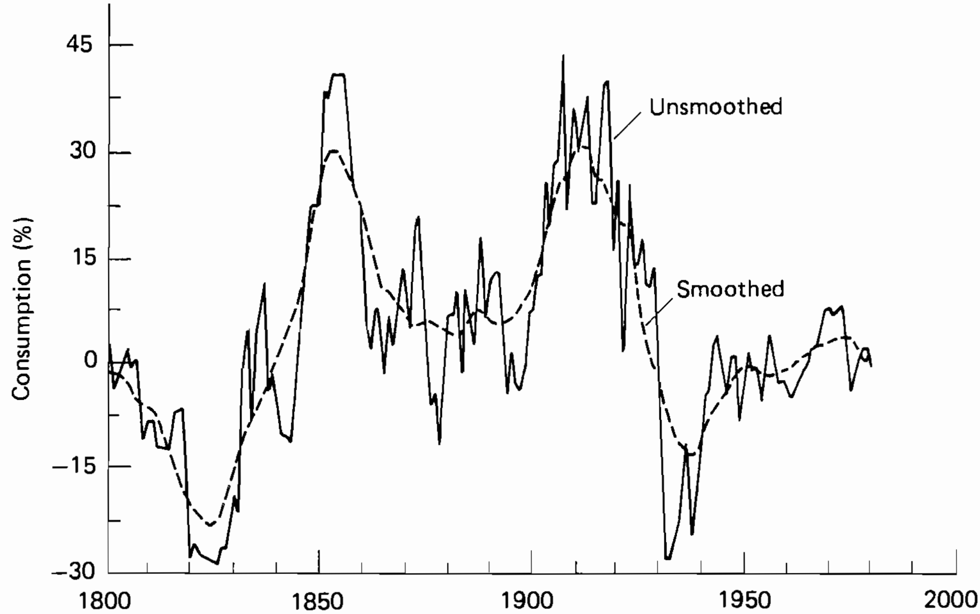

Figure 8.13. Long waves in fossil energy consumption.

critical in the USA, where fuelwood was the major source of energy during the last century. *Figure 8.13* shows the fluctuations in fossil energy use (i.e., fuelwood was eliminated from the data set given in *Figure 8.3*). The pronounced fluctuations indicate the long wave more clearly than the total primary energy consumption from *Figure 8.12*. As mentioned earlier, fuelwood consumption (see *Figure 8.3*) is very smooth, probably because population growth was one of the most important secular trends used to estimate the data. Thus, during the last century when fuelwood was the most important source of energy, it obscured some of the fluctuations present in fossil energy sources. Without fuelwood, primary energy consumption exhibits pronounced long-wave movements.

8.3.3. Efficiency of energy use

There are many ways of determining the efficiency of energy use. The most obvious indicators are the efficiencies of primary energy conversion to secondary and final energy forms. Another possibility is to estimate the efficiency of energy end use, e.g., the amount of fuel needed for travel or for space conditioning. All of these efficiencies have improved radically since the beginning of the Industrial Revolution along with the introduction of more efficient technologies. In some cases the improvements span almost an order of magnitude. For example, in 1920 the average efficiency of natural gas power plants in the USA was 9%, whereas today the best gas turbine power plants can operate with efficiencies of almost 60%. Over longer periods the improvements are even more impressive. For example, the second law efficiency of prime movers increased by two orders of magnitude since 1700, that of lamps by almost three orders of magnitude during the last century, and so on (see Marchetti, 1979). All of these efficiency improvements of individual technologies are translated into more effective use of energy and other materials at the level of overall economic activity. Some efficiency increases result from improved technologies and others from substitution of old by new technologies.

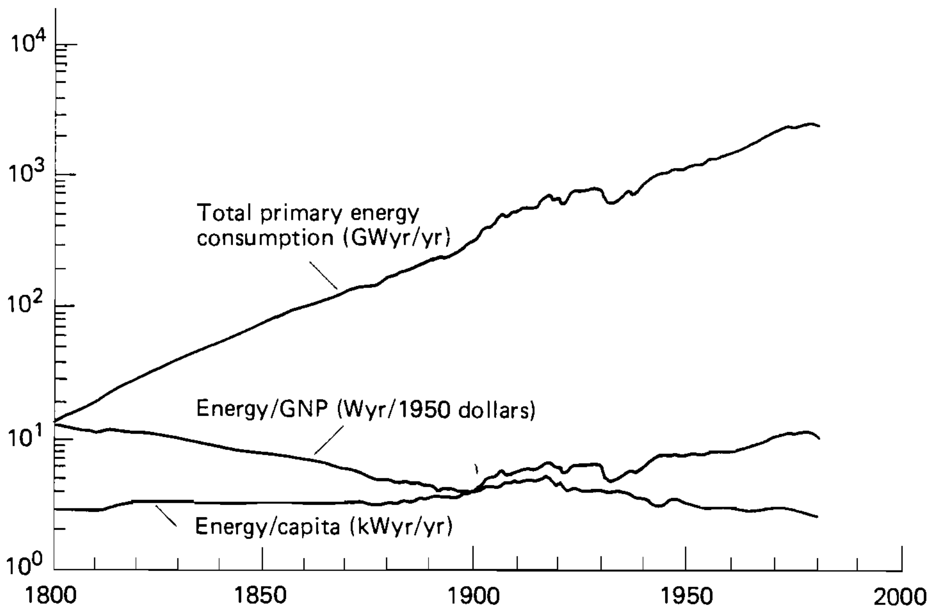

Figure 8.14. Primary energy, GNP, and energy intensity.

The extent of these changes and improvements can be expressed at an aggregate level by the amount of primary energy consumed per unit GNP in a given year. *Figure 8.14* shows the total primary energy consumption (from *Figure 8.3*), per capita consumption, and the ratio of energy consumption over GNP (energy intensity) for the USA. The average reduction in energy consumed to generate one dollar of GNP was about 0.9%/year over the last 180 years. The ratio decreased from more than 10 kWyr per (constant 1958) dollar in 1800 to slightly more than 2 kWyr per dollar in 1982. Thus, a regular decline in the energy intensity of the whole economy prevailed over a long historical period, indicating that energy conservation is a historical process that was discovered as a concept only during the last decade.

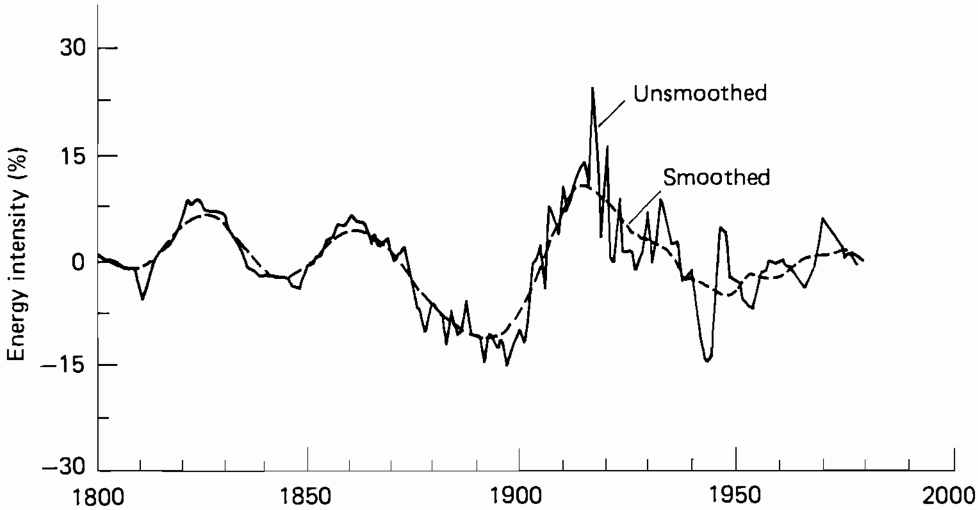

Figure 8.15. Long waves in energy intensity.

Figure 8.15 shows the fluctuations in energy intensity in the USA after the elimination of the secular trend by a 50-year geometric moving average. The fluctuations show pronounced long-wave movements and a high degree of synchronization with the price swings; during downswings in prices the energy intensity of the economy decreased more rapidly, and during the upswings less rapidly. Thus during a downswing in economic activity general rationalization measures of individual enterprises cause larger energy savings compared with the average historical reductions. As competition intensifies during a recession and depression, energy savings become an important factor in cost reduction. With recovery, new demands and prospects of continued economic growth release many pressures associated with saturating markets. Entrepreneurs in the new growth sectors must intensify their activities in order to meet new demand, and low energy intensity ceases to be an important competitive criterion. New technologies and energy forms offer possibilities for continued expansion in new markets so that relative energy use intensifies. Toward the end of the prosperity period the growth process encounters limits once more. These are reflected in saturating demand and general price inflation illustrated by the long wave in wholesale price movements (see *Figure 8.10*). Thus, during a downswing energy use reductions become important, not only due to efforts to cut costs as a reaction to saturating demand, but also due to a host of social constraints. Many energy technologies, along with other economic activities, become socially and environmentally unacceptable toward the end of the period of prosperity. This means that some diseconomies that were socially acceptable during the growth phase become internalized as additional economic costs or as explicit limits to further expansion. These causes of additional costs appear to offset the benefits of the economies of scale achieved during the expansion phase. In fact, with the demand reductions during the downswing, the large capacities that offered economies of scale become sources of additional costs as excess capacity.

The relationship between primary energy consumption patterns and the long wave appears to extend beyond the parallel changes in the relative level of energy consumption and energy intensity with the fluctuations in other long-wave indicators such as wholesale prices. A comparison of *Figures 8.2* and *8.14* indicates that the upper turning points of energy intensity fluctuations correspond to the saturation points of primary energy sources. The upper turning point that occurred in 1860 is related to the saturation in animal feed substitution, the 1915 turning point to the saturation in coal substitution, and the turning point of the 1970s to the saturation of crude oil. In addition, new energy sources reached 1% market shares during times of low energy intensity (during the 1880s and the 1950s). Thus, the dynamics of energy substitution in the USA indicate a close relation to the succession of the long-wave fluctuations.

8.3.4. Physical indicators: Steel and ships

In addition to primary energy substitution, we have shown the examples of technological substitution in steel production and merchant ships. Now we will consider these two examples again in the context of the long wave. *Figure 8.16* shows long-wave fluctuations in steel production derived from total steel production since 1860 (given in *Figure 8.5*) using a 50-year geometric moving average to eliminate the secular trend and a 15-year moving average to smooth the fluctuations of annual residuals. It can be seen that long-wave movements in steel production are out of phase with respect to the price swings. The lower and upper turning points precede the corresponding turning points in prices by about one to two decades. This probably means that the markets for steel are more sensitive to the first signs of economic changes and thus respond before other sectors to the emergence of favorable or unfavorable conditions. The reasons for this advanced response of the steel industry may be relatively simple. It is possible that steel, as one of the most important industrial materials, is by and large used in capital-intensive goods that have relatively long lifetimes. Typical examples from the last century are railroads and ships; today they are power plants, refineries, large buildings, factories, automobiles, etc. Even small reductions in the demand for these goods, if they occur simultaneously, would have an important effect on steel production. Thus it is possible that the first signs of economic change may be visible in fluctuations in steel production because the effect of smaller reductions in other sectors is amplified when translated into demand for steel. If this is actually the case, then one could use fluctuations in steel production as an early warning of the upcoming turning points in the long wave.

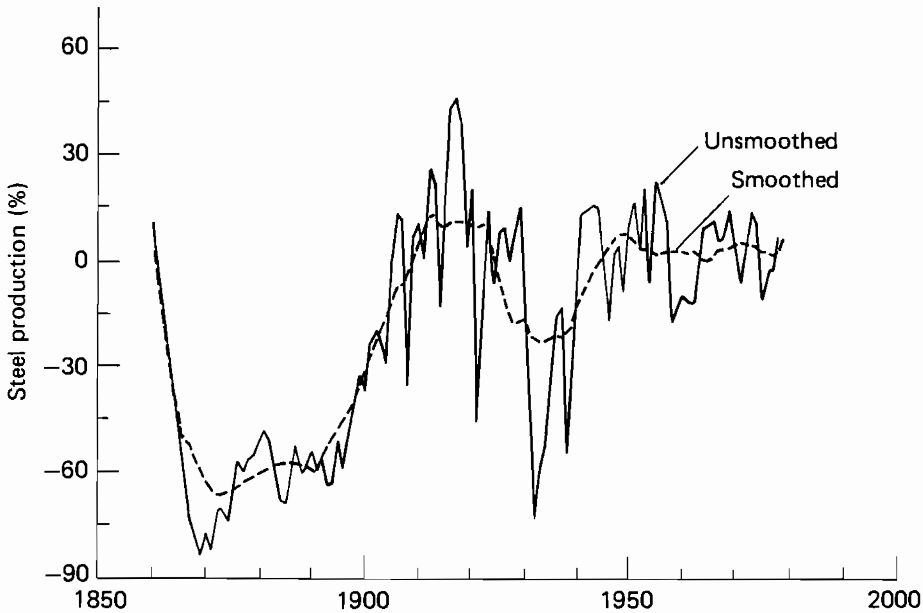

Figure 8.16. Long waves in steel production.

Figure 8.17 shows the long-wave fluctuations in the tonnage of merchant vessels. The same data were used as in *Figure 8.7* where we considered the technological substitution by type of vessel employed by merchant fleets. The fluctuations correspond to the long waves in prices, although a major irregularity occurred after the last wave. A second peak follows immediately after the upswing and downswing between the 1890s and the 1930s. This second peak rises during the 1940s, reaches a maximum in 1950, and then declines in the 1950s and 1960s. It is interesting to note that this second peak can also be detected in other indicators, but it is not so pronounced as in this case. For example, the fluctuations in primary energy consumption also portrayed such a peak over the same period, but it appeared to be only an acceleration and deceleration during the upswing phase of the long wave that was initiated in 1944 with a global peak in the 1980s. Even the wholesale price index shows a subdued fluctuation over the same period with a local peak in 1955, a decline, and a renewed rise after 1971. Although this fluctuation is also present in some other long-wave indicators, it is much less pronounced than in the case of merchant fleet tonnage. Thus, it is not clear from the empirical evidence alone whether the current long wave should be divided into two waves of shorter duration, or whether this intermediate fluctuation is an integral part of a single long wave initiated in 1944. If the first alternative

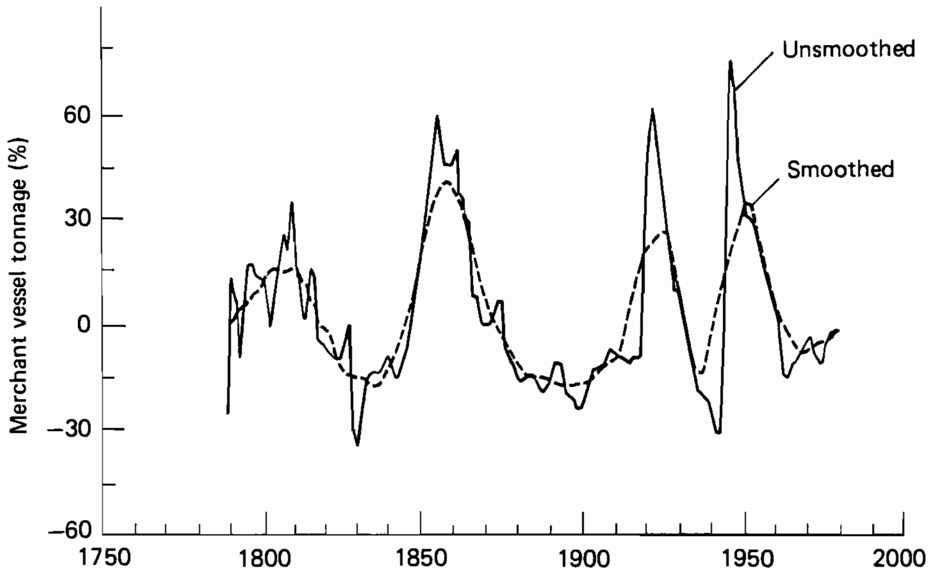

Figure 8.17. Long waves in the tonnage of merchant vessels.

8.4. Dynamics of Change

At the risk of overgeneralizing, we can state that there is strong evidence that symmetric or at least similar changes in patterns of energy consumption and price levels occur from one long wave to another, although the historical content and individual manifestations may change profoundly so as to make the symmetry apparent only at a higher level of abstraction. In order to understand the actual mechanisms behind the long-wave phenomenon and change in technology, we must acquire better statistical and analytical descriptions of various mechanisms and causal relationships of what we generally call historical experience. This would also imply that we need to understand the course of specific events and their individual manifestations that lead, for example, from a period of rapid growth after World War II to the oil shocks of the 1970s, saturating world markets, changing industrial structure, increasing national debts in many parts of the world, and the economic slowdown of the last decade. For the time being, we can only observe that the particular circumstances change from one long wave to another, but that the sequence of fluctuations and structural change at a higher level of abstraction indicate a striking regularity. The annals of business cycles (see, for example, Thorp and Mitchell, 1926; Mitchell, 1927) show that the severe crises or so-called Great Depressions occur regularly during the downswing of the long wave. It suffices here to mention the Great Depressions and financial panics of 1819, 1874, and 1929 in the USA that with small variance occurred throughout the rest of the world. This immediately suggests an obvious historical manifestation of the prolonged periods of stagnation, but this does not answer the question of whether these Great Depressions are a necessary characteristic of the downswing.

8.4.1. Synchronization and recurrence

The analysis of technological substitution in steel production, merchant vessels, and energy showed that the same basic approach can be applied to describe the observed structural changes. In all three cases older technologies were replaced by new ones with regular, recurring patterns. *Figure 8.18* shows these three substitution cases. Besides the now obvious similarity in substitution patterns, it should be observed that the timing of the saturation phases is also synchronized in the three examples. In order to facilitate the comparison we have shifted the curves in time so as to align the saturation phases. In comparison with the saturation of coal in the example of primary energy substitution, the saturation of open-hearth steel technology and steamships lags by about 20 years. Once the curves are shifted in time by two decades, as shown in *Figure 8.18*, other saturation phases correspond to each other as well. For example, the saturation of hay as the energy source for animal feed was reached in the 1870s and the saturation of Bessemer steel about 20 years later. A similar correspondence can be observed for the last saturating technologies – crude oil and basic oxygen steel.

The substitution of other merchant vessels by motor ships corresponds to market penetration of electric steel and natural gas with a lag of about 20 years; this may be indicative of the continuing synchronization of the dynamic substitution processes in the future. It should be noted that the lag of 20 years spans a shorter period of time than the duration of the upswing or downswing phases of the long wave. Although the timing of the introduction of new technologies at the 1% level differs in the three examples, the change in leadership from the old to the new dominant technology is strikingly similar. The open-hearth steelmaking process emerged as the dominant technology (in 1907) about 21 years after coal replaced fuelwood as the major source of energy (in 1886). The lag was even shorter in the case of steamships, which overtook sailing ships in 1892. Thus all three takeovers took place within two decades. A similar correspondence can be observed again 50 years later. Crude oil surpassed coal in 1950, and basic oxygen steel overtook the open-hearth process in 1969 – again a lag of two decades. Just as in the case of the long-wave fluctuations, we find that the substitution dynamics can be characterized by coordinated 50-year phases of change in market domination from old to new leading technologies and energy sources.

A possible explanation of this similarity in substitution patterns is that the specific changes that led to the replacement of old by new technologies and energy sources were interrelated; e.g., the new steel processes and

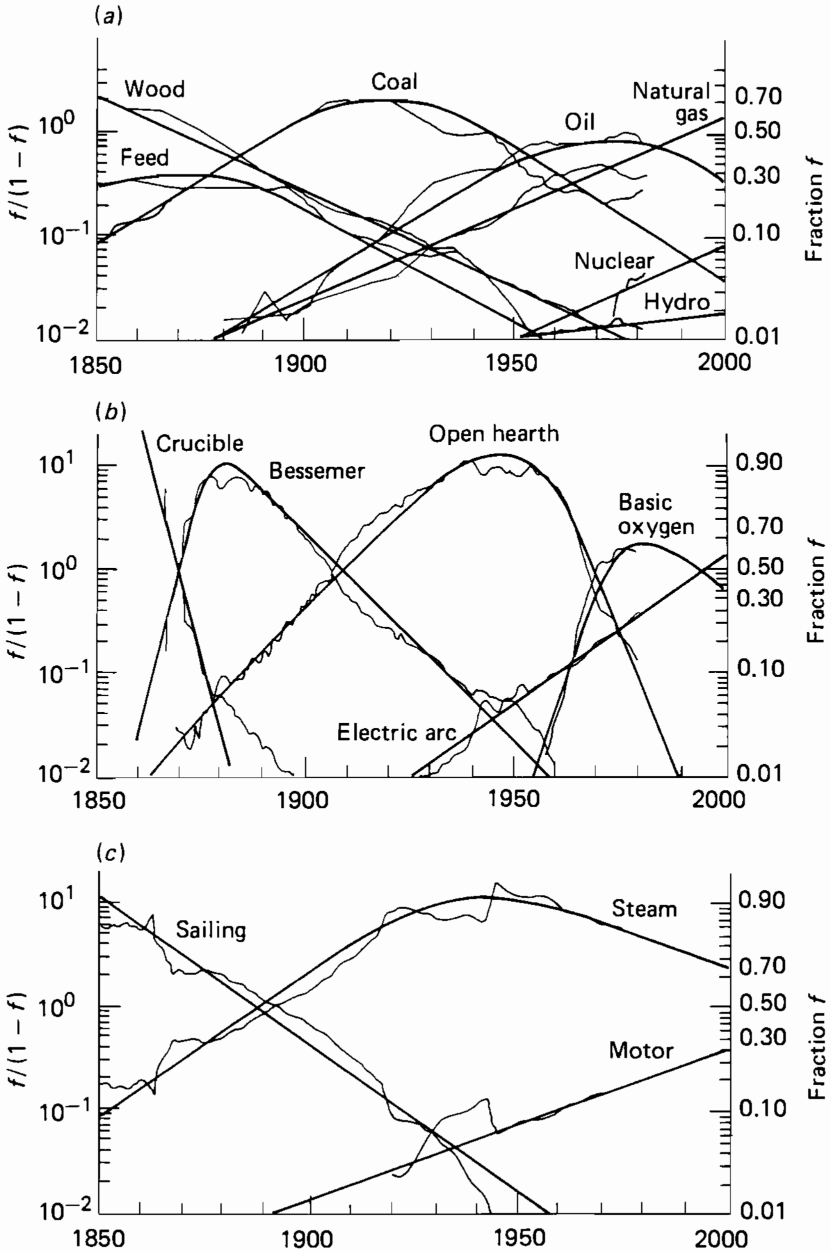

Figure 8.18. Technological substitution: (*a*) energy, (*b*) steel, and (*c*) merchant vessels.

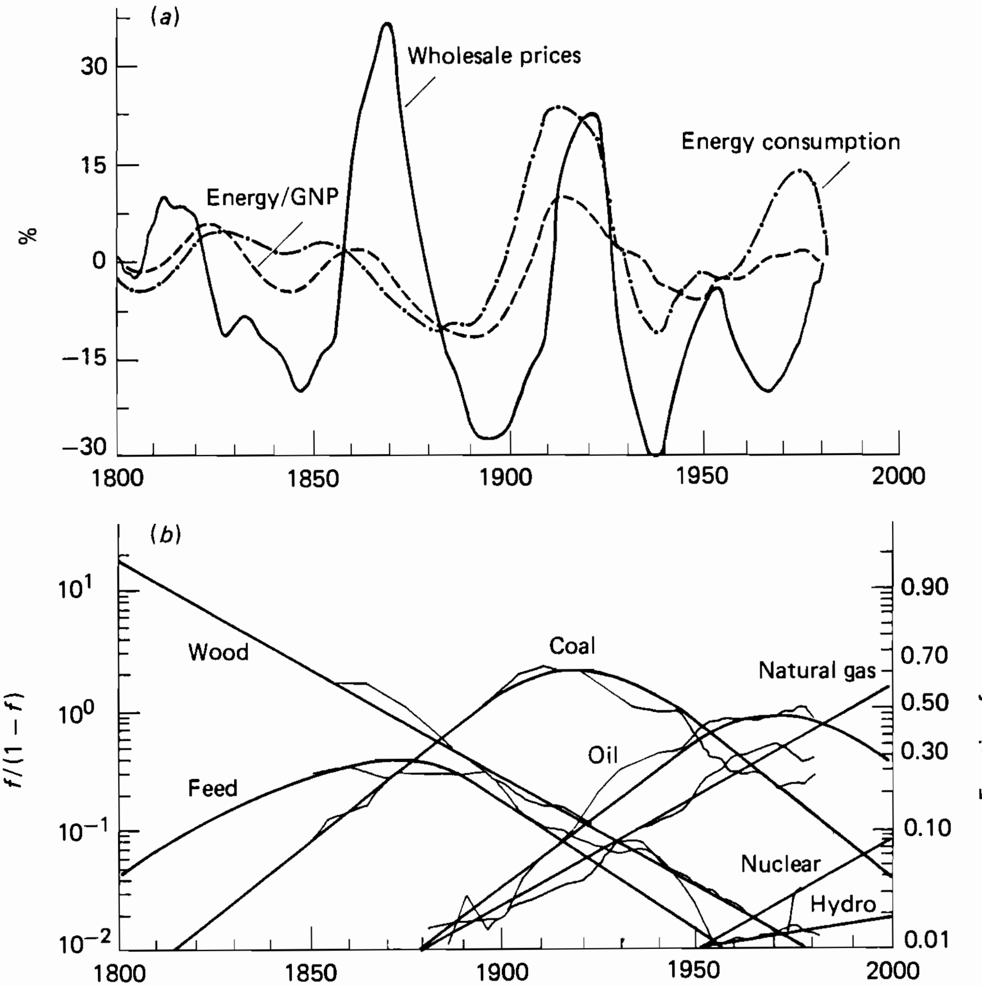

Figure 8.19. (*a*) Long waves and (*b*) substitution dynamics.

marine propulsion systems were dependent on new energy technologies. On the other hand, the new energy sources could only be developed with increased intensity of energy use, such as in the new industrial and urban complexes that emerged as the availability of transport possibilities and basic materials increased (symbolized here by steel and merchant vessels). This kind of interdependent lacing of technological development and demand growth indicates that a certain degree of synchronization in the substitution processes could be expected. This of course still leaves the question of the precise nature of the 50-year time constant unanswered. Since we have already shown that the three substitution processes appear to be synchronized after allowing for a 20-year lag in the timing of crucial market saturation and takeover events, we now consider the timing of long-wave fluctuations and energy substitution (taking it to be indicative of other technological substitution processes).

Figure 8.19(a) shows the long waves in energy consumption, energy intensity, and wholesale prices (from *Figures 8.12, 8.15, 8.10*), and *Figure 8.19(b)* shows energy substitution (from *Figure 8.2*). *In toto, Figure 8.19* summarizes the results of the phenomenological analysis of the dynamics of technology and long waves in the USA. A careful examination of the timing and patterns of changes shows that they are all in tune. The saturation periods of energy technologies coincide with the peaks in prices and energy intensity. The period of decline from saturation to loss of dominance (i.e., loss of the highest market shares) lasts on the order of 25 years, or about as long as the downswing phase of the long wave, which is characterized in *Figure 8.19* by the fluctuations in energy consumption, intensity, and the price index. By symmetry, the upswing of the long wave is paralleled by the growth of the new energy source from newly acquired dominance to saturation.

8.5. Conclusions

The fact that all of the events that characterize profound changes in technology and economic structure occur in tune is striking, but it leaves many questions unanswered. For instance, we have observed that technological substitution in steel production and merchant vessels lags by about two decades behind equivalent events in energy substitution. This would imply that these other dominating technologies do not saturate during the end of the prosperity phase, but rather during the onset of the downswing. Perhaps this is an artifact of the choice of technological substitution processes in that they are very closely related to the changes in the structure of the energy system. Yet, given the sparse statistical records, it is difficult to find other examples that span equivalent historical periods.

Nevertheless, the importance of the energy system and related infrastructural developments appears to be crucial with respect to the observed pulses in economic activity. For example, the construction of great canals throughout Europe and the USA during the eighteenth and early nineteenth centuries was initiated by the ever-increasing need to transport timber and other goods in larger quantities over longer distances. Later, railroads were associated with a similar boom period basically due to the same reasons – the concentration of production in urban areas required a more efficient transport system that also helped in the acquisition of new and larger markets. Thus, canals and railroads expanded existing markets and "created" new ones for new products. In terms of the energy system, the large canals are associated with the transport of fuelwood that was at that time the primary source of energy in many industrial activities such as iron smelting. The railroad era is very closely related to the widespread diffusion of steam- and coal-related industries.

In terms of the long-wave fluctuation, we name the upswing phase from 1773 to 1810 the "age of canals" and the upswing from 1840 to 1869 the "age of railroads". Accordingly, we name the upswing from 1895 to 1920 the "age of electricity" because of its significant contribution to the rapid development of new industries and communications technologies. The last upswing, from 1945 to the 1970s, we symbolically identify with the automobile, aircraft, and petrochemical industries. Unfortunately, it is not possible to time this last turning point with any precision; but in view of the empirical evidence in the synchronization of technological substitution processes, energy efficiency, and other indicators, it probably occurred during the "oil crises" of the early 1970s that mark the saturation of crude oil and its eventual replacement as the dominant source of primary energy. Let us assume for the sake of naming a particular reference year that it in fact occurred in 1973. If this were actually the case, and assuming the continuation of the long-wave fluctuations, the next turning point can be expected sometime around the turn of the century. Going further into the future, the following upswing phase can be expected to last until the 2030s.

The overall picture that emerges suggests that each upswing phase is associated with large infrastructural development. This development first opens many new product and factor markets and toward the end of the prosperity phase leads to eventual saturation of these markets and full adoption of the technologies that were introduced during the recovery period. This was the process that occurred between the end of World War II and the initiation of a downswing 10–15 years ago. Some of the developments of the current downswing period we can already anticipate. For example, the energy intensity curve in *Figure 8.15* indicates that during the next decades we can anticipate further relative improvements in the energy efficiency of the economy (i.e., reductions in the amount of primary energy consumed per monetary unit of GNP in real terms). Thus, we can expect further dissemination of energy efficient technologies and institutional measures during the downswing phase until the end of the century.

As far as energy technologies are concerned, the market penetration analysis suggests natural gas as the best candidate for eventual dominance as the major energy source during the upswing period after the 1990s. Natural gas is the cleanest fossil fuel and from that perspective alone it is attractive. It could also become a very efficient source of electricity and clean fuels. Widespread use of natural gas would require new infrastructures for production, long-distance transport, conversion to fuels and electricity, and distribution to the final consumer. Thus, construction of large grids and new industries based on natural gas would be required. Candidates for future growth sectors related to the wider use of natural gas range from technologies for control and management of large distribution grids for transport and distribution of energy and other goods, to bioengineering technologies that would allow for greater efficiency and low-temperature chemical and industrial conversion and production processes based on methane and electricity. Thus, enzymes and microchips may be the hardware that could allow the transition to a methane-based energy system. These are just some of the possible candidates, but they are consistent with the apparent requirements that emerge from the overall pattern of economic pulses and technological substitution dynamics since the beginning of the Industrial Revolution. Before these and other new technologies can expand during the next upswing, the next decades will bring a period of renewal and "gales of creative destruction". A period of rapid (relative) deflation can be expected, together with prolonged unemployment and further economic slowdown. These are the selection mechanisms that in the past distilled the successful from a wide range of promising new technologies and entrepreneurial innovations. The existing patterns will have to be destroyed before new ones can emerge, and their destruction will mark the beginning of renewal and a promise of prosperity.

Most of these speculations on the nature and timing of future events is based on the dynamics of equivalent changes in the past. Some of the patterns of these dynamic changes can be projected into the future. Our analysis of market substitution mechanisms has indicated that the invariance in the timing of market saturation and takeover times also allows *ex post* projections over periods that span the duration of the long wave (see Marchetti and Nakicenovic, 1979). Similarly, our analysis of the long swings in many indicators, ranging from energy efficiency to price fluctuations and Marchetti's invention and innovation pulses (see Marchetti, 1981), provide strong historical evidence that these events are precisely timed and invariant.

Perhaps the most important question is why the clock that tunes such events as the dynamic changes in technology and long waves in economic activity operates on a 50-year scale. Since we have shown that the events that mark structural changes are synchronized and follow a logical order, the question of the time scale and invariance is crucial. If it were answered all the other events, since they occur in logical order apparently as required, would fit the grand pattern like pieces of a puzzle.

Notes

[1] The basic assumption postulated by Fisher and Pry is that once a substitution of the old by the new has progressed as far as a few percent, it will proceed to completion along the logistic substitution curve:

$$\frac{f}{1-f} = \exp(\alpha t + \beta)$$

where t is the independent variable usually representing some unit of time, α and β are constants, f is the fractional market share of the new competitor, while $1-f$ is that of the old one.

[2] We assume that only one competitor is in the saturation phase at any given time, that declining technologies fade away steadily at logistic rates not influenced by competition from new competitors, and that new competitors enter the market and grow at logistic rates. The current saturating competitor is then left with the residual market share (i.e., the difference between 1 and the sum of fractional market shares of all other competitors) and is forced to follow a nonlogistic path that joins its period of growth to its subsequent period of decline. After the current saturating competitor has reached a logistic rate of decline, the next oldest competitor enters its saturation phase and the process is repeated until all but the most recent competitor are in decline. A more comprehensive description of the model and the assumptions is given in Nakicenovic (1979).

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CHAPTER 9

On the Long-Term Dynamics of the Rate of Return

R.M. Entov and A.V. Poletayev

9.1. Introduction

Relatively little work has so far been done on the long-term dynamics and fluctuations of key economic indicators. This can be explained by the absence of reliable and comparable statistical data, and by the number of significant technical difficulties involved in attempting to isolate long economic cycles using short time series data (see Petzina and Roon, 1981).

Several hypotheses regarding the nature of long waves and their underlying economic mechanisms have been advanced over the last few decades. Alongside statistical verification of the general hypothesis on the existence of long waves (for those who believe that the data do not allow a rejection of this hypothesis, more detailed empirical investigations are necessary) are analyses that isolate the most probable assumptions concerning the nature of long waves in economic development. As a first step, it is useful to consider empirical evidence on fluctuations in the main economic indicators, such as cost and profit, the rate of return, interest rates, relative prices of various groups of commodities, etc.

In this chapter we discuss a number of problems related to the formation of statistical series that characterize long-term fluctuations in the rate of return in the USA. Empirical analyses have been made of the rate of return, but up to the mid-1970s the problem of its long-term dynamics was not discussed [although a series for 1926–1958 was calculated by Stigler (1963)]. Two exceptions were Gillman (1957) and the Labor Research Association (1948), whose estimates of rate of return dynamics were based on censuses of manufacturing industries, but in both cases the estimation methodologies raise substantial objections.

Within the framework of the discussion begun by Nordhaus (1974), several alternative appraisals of the long-term dynamics in the rate of return of US non-financial corporations were made, but only for the postwar period. For example, Wolff's original (1979) calculations were made on the basis of balances of the US economy between 1947 and 1967. Problems related to the methodology of empirically estimating the rate of return have been investigated, but the problem of long-term fluctuations has not been discussed. The few exceptions are Kleinknecht (1981) on the FRG, Menshikov (1985) on the USA, and Sautter (1978) on Japan.

In this chapter we discuss the possibilities of estimating various annual characteristics of profitability in US manufacturing industries in 1850–1983, and non-financial corporations in 1897–1983. Evidently, not all the estimates mentioned correspond strictly to a theoretical concept of the rate of return, but nevertheless they do give a general impression of long-term trends (for the period 1929–1983 it is possible to ensure that the fluctuations in these indicators reflect exactly the basic changes in profitability).

The period under investigation does not exceed 135 years. This, together with incomplete data (in the best case, for the first part of the period considered, it is only possible to make discrete estimates, while for the second part continuous annual data series were available), means that the use of "strong" methods of cycle isolation, such as spectral analysis, is virtually impossible. The general outlines of trajectories calculated may confirm the existence of long waves, but they do not allow conclusions to be drawn on their periodicity.

Fluctuations in the rate of return form a central element in the long wave mechanism described by Marx (see Menshikov and Klimenko, 1985); the estimates made may be considered as empirical confirmation of this concept. At the same time, the trends exposed may show the existence of a number of factors (wars, changes in corporate taxes, inflation etc.) that have considerably modified the cyclical nature of changes in the rate of return. Within the framework of these calculations, certain hypotheses are put forward on the existence of a general mechanism of lowering (raising) costs, which ensure long-term periodic increases (decreases) in the rate of return.

Marx showed that in most economic situations an increase in the rate of return forms the necessary condition for a further expansion of production. Proceeding from a number of general considerations, it is possible to assume that long waves of changes in the rate of return should lead in relation to long waves in the development of production. In principle, our results confirm this hypothesis. The lags revealed in a cyclical development of production cannot be considered constant: their value depends to a great extent on the general conditions of the economic development.

9.2. Problems of Estimation

An empirical analysis of the dynamics of profitability encounters serious statistical complications. Such estimates could be made on the basis of accounts of the US joint-stock companies, but before the introduction of taxes on profits at the turn of the century, such accounts were published only occasionally. In addition, in spite of the fact that in the late nineteenth century corporations produced more than half of total manufacturing output, there were no aggregate data on profits and available estimates were restricted to non-representative company samples. This situation prevailed even after the introduction of taxes on profits, so that relatively reliable and complete aggregate information on the profits and assets of joint-stock companies are only available from the 1920s.

The Censuses of Manufactures, another source of data, were performed every 10 years before 1900, every five years between 1899 and 1919, and every two years between 1919 and 1939, so that estimates can be made of profitability in manufacturing industries since 1849–1859 (before 1900 the censuses covered the period 1 June to 31 May). However, the census data have a number of significant deficiencies: (i) they are confined to manufacturing industries; (ii) they do not provide continuous data series (this is particularly important in estimating profitability, which is subject to intense short-term fluctuations); and (iii) profits are not separated from overhead costs [1]. At the same time, it is known that by the turn of the century overhead expenditures constituted a significant and growing part of costs.

Numerous theoretical complications are involved in the choice of methodology to appraise changes in profitability. First, profits can be considered as an operational income or as a holding income – the different components of income are correspondingly included (see Shoven and Bulow, 1975). From our point of view, an interpretation of profit as an income from operations appears to be more acceptable within the framework of this analysis of long-term fluctuations in profitability. However, the consistent use of an "income from operations" concept requires a range of corrections to the primary statistical data in order exclude those types of income that arise as profits (losses) from revaluation of inventories, income from changes in the value of capital assets, etc. Also, data on the amount of amortization that should be estimated on the basis of the replacement value of fixed capital require correction (until recently, in the US accounting system, amortization was estimated from the historical cost of fixed capital).

Second, opinion varies as to whether it is necessary to include in profits the net interest payments of non-financial corporations, imputed incomes and costs (including imputed interest), dividends obtained from companies, incomes from foreign subsidiaries, etc. An essential problem is whether profits should include taxes, particularly taxes on profits. In this chapter net interest payments and taxes are included [2], but dividends obtained by non-financial corporations are excluded (to eliminate repetition).

The methodology of calculating the rate of return is debatable (particularly the estimation of the volume of advanced capital). When analyzing long waves, a sum of assets has been used because the rate of return calculated for the equity capital characterizes the conditions of movement of individual industrial capital [3].

Taking into account a lack of direct estimates of assets, we have used a number of "substitutes" for advanced capital assessments to estimate the rate of return. Indicators of fixed capital, reproducible assets (including investments in inventories), and tangible assets (including investments in real estate) are usually used as such substitutes, and may be considered appropriate only if there is reason to believe that the structure of assets remains more or less stable.

Another indicator – the share of profits in sales (or the ratio of profits to annual costs) – may also be used to assess profitability dynamics. It is evident that the differences in the dynamics of this indicator and the rate of return are defined mainly by the rate of capital turnover, one index of which may be the ratio of annual production costs to advanced capital. Our calculations showed that over the last 50 years the ratio of annual production costs to assets showed mainly short-term fluctuations defined first of all by the course of a business cycle. Taking into account the incompleteness of data and the need to use a number of approximate indicators, we believe that profitability dynamics should be investigated on the basis of a system of indicators. Attempts to isolate any "solely correct" indicator of the rate of return and to limit ourselves to its consideration would be unjustified from either a statistical or a theoretical point of view.

9.3. Empirical Results

The first group of estimates was obtained for the rate of return dynamics of US non-financial corporations, which currently produce over 60% of the GDP in this country. Even at the turn of the century this sector played a dominant role in the US economy: in the 1890s, about 78% of all investments were made by corporations (70% in manufacturing and mining, 99% in public services, and 30% in commerce, other services, and construction; see Goldsmith 1955) [4]. Several of our estimations of the rate of return of non-financial corporations are shown in *Table 9.1* and *Figure 9.1*. The methodology is described in detail in *Appendix I*, and below we explain briefly the indicators used.

Indicator I is the ratio of profit after tax (net income) to tangible assets (fixed capital, inventories, and land) for the beginning of the year. Continuous annual observations are available from 1897. In order to exclude violent short-term fluctuations, we calculated the mean cyclical values of Indicator I (between minimum values corresponding to the business cycle troughs of the National Bureau of Economic Research – see *Table 9.1*) with the center in a given cycle.

Indicator II is analogous to indicator I, but the profit before tax is used in the numerator.

Indicators calculated for total assets may be considered as another and slightly better approximation of the rate of return. However, for the period before 1946, we have only estimates obtained by Goldsmith for the end of 1900, 1912, 1922, 1929, 1933, 1939, and 1945. These years are not entirely

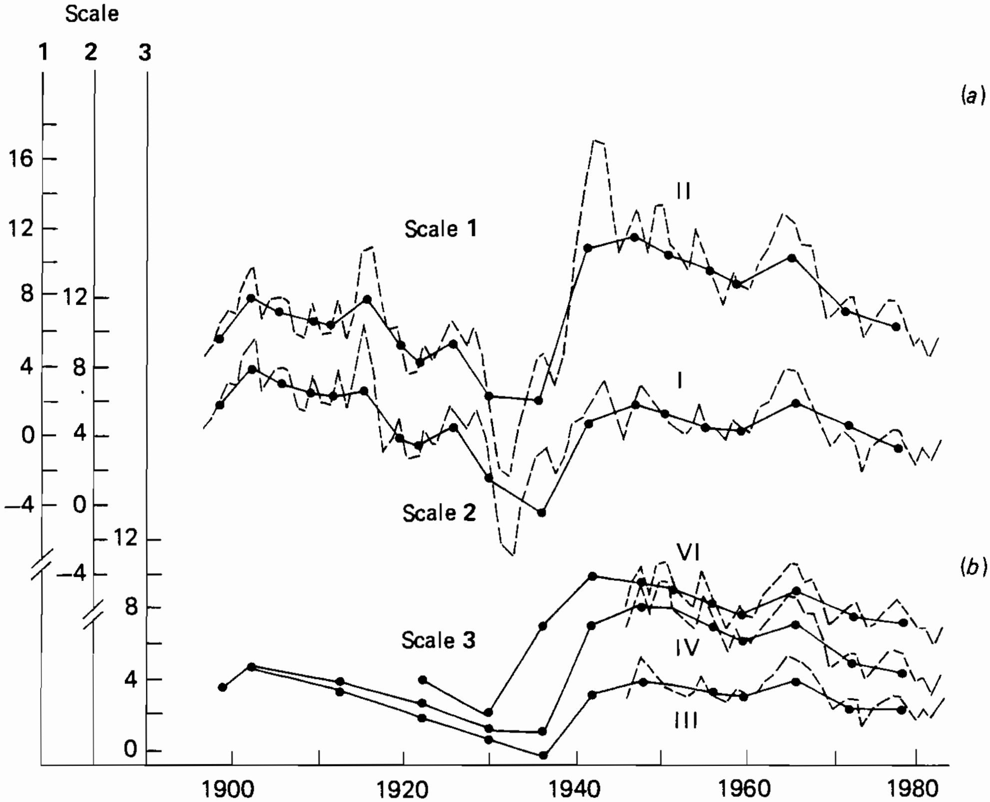

Figure 9.1. Alternative estimates of the rate of return in US non-financial corporations (%). (*a*) On tangible assets and (*b*) on total assets. Solid curves are cyclical averages. Sources: See Appendix I; roman numerals relate to appropriate columns in *Table 9.1*.

comparable in their cyclical characteristics, and the corresponding discrete estimates for a disclosure of long-term fluctuations in the rate of return dynamics should be used taking this into account [5].

The following procedure was used to obtain discrete estimates before 1946. Estimates of the rate of return on assets were divided by a coefficient equal to the ratio of the rate of return on tangible assets in the same year to an average cyclical value of the rate of return on tangible assets (for a corresponding cycle). It was assumed that the estimate related to the center of the corresponding cycle. The rate of return for tangible assets in 1901 (we use the ratio to assets at the beginning of the year as theoretically preferable) is evidently a local cyclical minimum. The estimate for this year was used to calculate mean cyclical indicators for the periods 1897–1901 and 1901–1904 (see *Table 9.1*).

Table 9.1. Cyclical averages[a] of alternative estimates of the rate of return in US non-financial corporations (%).

Period	On tangible assets		On total assets			
	Adjusted net income	*Adjusted net income plus tax*	*Adjusted net income*	*Adjusted net income plus tax*	*Adjusted net income plus tax plus net interest*	*Adjusted net income plus tax plus net interest plus foreign profits*
	I	II	III	IV	V	VI
1897–1901	5.9	5.9	3.6	3.6	–	–
1901–1904	8.0	8.0	4.8	4.8	–	–
1904–1909	7.0	7.0	–	–	–	–
1909–1911	6.4	6.4	–	–	–	–
1911–1914	6.2	6.3	3.8	3.9	–	–
1914–1919	6.6[b]	8.0	–	–	–	–
1919–1921	3.6[c]	5.3	–	–	–	–
1921–1924	3.4	4.3	2.0	2.6	3.5	4.0
1924–1928	4.6	5.5	–	–	–	–
1928–1933	1.5	2.1	0.8	1.1	1.8	1.8
1933–1938	0.5	2.0	–0.3	1.0	6.7	7.0
1938–1946	4.7	10.9	3.2	7.2	9.7	9.9
1946–1949	5.7	11.6	4.0	8.1	8.7	9.2
1949–1954	5.0[d]	11.3	3.6[d]	8.1	8.7	9.2
1954–1958	4.4[e]	9.7	3.2[e]	7.0	7.7	8.3
1958–1961	4.2	8.6	3.0	6.1	7.0	7.5
1961–1970	5.8	10.4	4.0	7.2	8.5	9.1
1970–1974	4.4	7.0	2.3	4.9	6.8	7.6
1974–1982	3.1	6.1	2.3	4.4	6.5	7.3

[a]According to rate of return troughs. [b]1914–1918; [c]1918–1921; [d]1949–1953; [e]1953–1958.
Sources: see Appendix I.

Using this method, four indicators of the rate of return on total assets were calculated (there are continuous observations since 1946): *indicator III* has profits after tax in the numerator; *indicator IV* has profits before tax in the numerator; a sum of net interest payments by non-financial corporations (excluding imputed interest where possible) was added to the numerator of *indicator V*; and *indicator VI* includes foreign profits.

All indicators show approximately the same dynamics: the rate of return of non-financial corporations fell between 1900 and the mid-1930s, rose to the late 1940s–early 1950s, and after that fell again up to the early 1980s.

The second sector for which we calculated estimates of profitability was US manufacturing industry. Profits were estimated on the basis of data provided by King (1919, 1930) and Kuznets (1941, 1946), and from official statistics on income data for 1929 (profits of corporations and net income of non-incorporated businesses). Alternatively, census data were used: profit was defined as a residual of the value added excluding wages of all workers (up to 1889–1890, only wages of production workers; see *Appendix II*).

Three indices were used as values to which profits were related. The first is the value of fixed capital at historical cost (according to data provided by King, Kuznets, and Creamer *et al.*,). The second is the total assets (at historical cost, according to data provided by Goldsmith and Creamer *et al.* and at replacement cost according to Creamer *et al.*). The results are shown in *Table 9.2*. All estimates confirm the growth of profitability in manufacturing industry from 1880 to 1900 and its subsequent decline up to the end of the 1920s (calculations for later periods were not made using these data). Estimates for 1850, 1860, and 1870 (based only on data on fixed capital provided by King) appear to be unreliable.

In the third case, the profits in manufacturing industry were related to the volume of sales (for before 1929, we used the sum of expenditures on raw materials and value added). For from 1919 profits were adjusted for "paper" income from revaluation of inventories [see *Figure 9.2*(c)]. Before 1919 we have only discrete estimates that can considerably distort long-term dynamics, as shown above. However, from our calculations, the dynamics of this indicator in the twentieth century correspond on the whole to rate of return dynamics in the non-financial sector. As for the nineteenth century, separate estimates may be interpreted as evidence for the growth of the share of profits in sales during 1850–1860, its fall in 1860–1880, and its growth again in 1880–1900.

It should be noted that all the estimates given are approximate; at best they give only an impression of trends of changes in the rate of return. Nevertheless, a combination of results obtained allows us to speak of the existence of protracted alternating periods of rising and falling profitability. At the same time, our calculations show no strict periodicity nor stable amplitude is observed in the rate of return fluctuations. For example, if in the first half of this century the rate of return showed intense fluctuations (and was even negative during the crisis of 1929–1933), after World War II there has been a moderate falling trend, more distinct since the mid-1960s. Periods

Table 9.2. Alternative estimates of rate of return[a] in US manufacturing industry (%).

	On fixed assets at historical cost			On total assets		
				At historical cost		At replacement cost
Year	King	Kuznets	Creamer	Goldsmith	Creamer	Creamer
1850	64.2	–	–	–	–	1860
1870	76.5	–	–	–	–	–
1880	19.1	36.7	–	–	14.4	15.5
1890	39.9	39.3	37.2	–	18.3	18.6
1900	45.8	45.8	43.3	20.4	22.4	21.1
1909	–	–	–	10.1	11.0	10.4
1910	32.3	–	–	–	–	–
1912	–	24.7	–	–	–	–
1914	–	–	–	9.4	10.3	–
1918	–	16.6	–	–	–	–
1919	–	–	–	10.4	11.4	7.3
1922	–	12.0	–	–	–	–
1929	–	–	16.8	–	7.8	8.0

[a]Columns 1–5, income of non-incorporated businesses plus net income (before tax) of manufacturing corporations. Column 6, as above, plus inventory valuation adjustment. Sources: see Appendix II.

of rising and falling rate of return differ in duration and intensity. An especially significant influence on the value and dynamics of the rate of return was exerted by wars, such as the Civil War, the two world wars, Korea, and Vietnam. Such fluctuations due to wars and peculiarities in the development of the business cycle thus make it difficult to isolate the long waves in the rate of return dynamics.

9.5. Concluding Remarks

If our results are not statistical artifacts, then they raise a number of problems. First, according to our analysis, the periods of growth in the rate of return include a considerable part of the downswing phases of long waves [6]. One possible explanation lies in the fact that the rate of return is a leading indicator of long waves [7].

Another problem is related to the mechanism of the rate of return movements. During a business cycle, the dynamics of costs conditioned by raw materials and wages is characterized by stable regularities, but it was impossible to trace these in long-term fluctuations in costs and profits [8] (see *Figure 9.2*).

A lack of analogy in superficial mechanisms of the formation of cyclical fluctuations and long waves in profitability dynamics does not mean an absence of more profound analogies. In particular, as proved by Marx, a

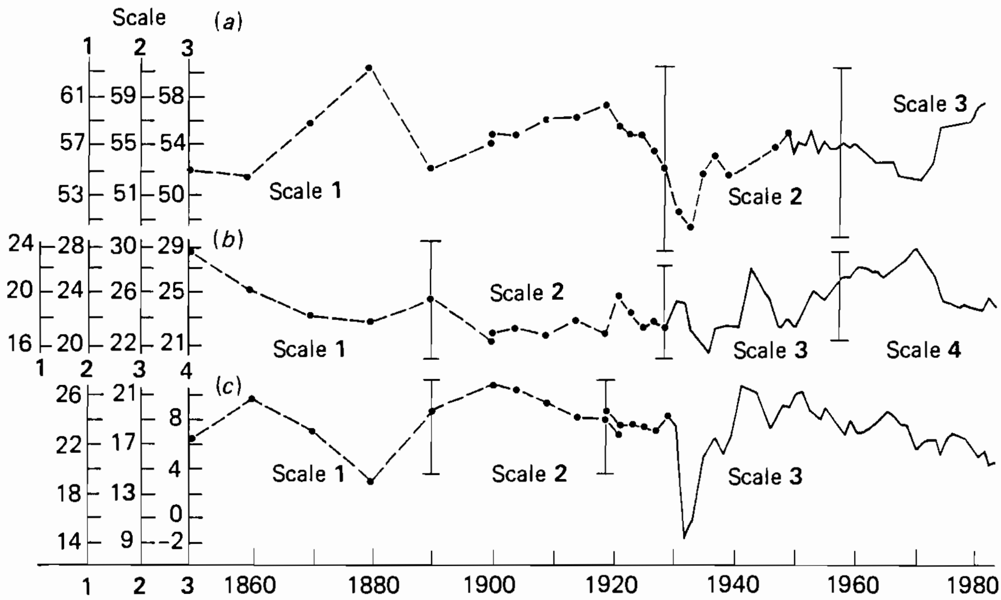

Figure 9.2. Price structure in US manufacturing (%). (*a*) Material costs, (*b*) labor costs, and *c*) profits. Source: See *Appendix II*. Profits include taxes, net interest, and inventory adjustments.

long-term, even cyclical, fall in the rate of return is conditioned by an over-accumulation of capital. Changes in the rate of return are closely related to the law of capitalist crises. Declining profitability engendered by the development of a productive labor force constitutes a law that at a certain time collides severely with the development of the productive labor force and that can only be overcome by means of crises (Marx, 1975, Ch. 15).

This cyclical crisis is always engendered by an explosion of all the contradictions of the capitalist mode of production, but not all of these contradictions may find a complete (temporal) resolution during the course of the cyclical recession. Some conflicts take a long time to reach the crisis point, in which case they are "transferred" from one cycle to another while gradually becoming aggravated. A prolonged accumulation of these disproportions inevitably paves the way for more destructive crises and changes of general conditions of the economic growth.

A further problem is related to the investigation of mechanisms of the influence of long-term fluctuations in the rate of return on the general course of development of the capitalist economy. It is evident that the relation between the rate of return dynamics and other economic indicators is not linear. A period of intensive economic growth may continue for a certain period of time alongside a declining rate of return. In addition, the latter may stimulate the introduction of new, more efficient techniques and technologies, but at the same time may restrain new investments due to financial restrictions and low expectations of return on new investments. The process of accumulation of capital and conditions of the functioning of the capital market play a significant role in the mechanism by which the rate of return influences the process of accumulation. In this connection, the correlation of long waves with changes in industrial profits and interest rates is of special concern.

Notes

[1] Only one component of overhead costs – salaries of non-production workers who are employed directly within enterprises – can be estimated beginning from the census of 1889/1890.

[2] Otherwise, distribution processes that represent an independent object of investigation are placed in the forefront.

[3] It is natural in using accounting data on the amount of assets to make corrections that are conditioned by the transition from the historical to the replacement value of tangible assets.

[4] When estimating the rate of return in this sector we used Goldsmith's estimates for the period 1897–1947 and data from the Flow of Funds section of the Board of Governors of the Federal Reserve System thereafter. Statistical data on national income and GNP were obtained from the Bureau of Economic Analysis of the US Department of Commerce.

[5] The instability of results obtained when using discrete observations may be demonstrated as follows. If we take the ratio of adjusted profits before tax to assets in replacement prices ***for the end of the year*** then, for example, in 1900 the rate of return of non-financing corporations was 4% and in 1912 it was 3.5%, i.e., it was tending to fall. If we take the ratio of profits to assets ***for the beginning of the year*** then the rate of return grew from 4.1% in 1901 to 4.9% in 1913, i.e., it was rising.

[6] Just because of this, we cannot accept such an approach to the analysis of long waves that excludes long-term trends in changes in the rate of return from empirical analysis, and simply suggests that we should proceed from the fact that production dynamics themselves are characteristics of these changes (see Mandel, 1980, pp. 8–11). Mandel also suggests the use of interest rates as indicators of the rate of return (pp. 19–21), but our estimates suggest the direction of changes in interest rates over long periods is ***opposite*** to the rate of return changes. Even Mandel's factual material may confirm that in a number of cases both indicators (the rate of production expansion and the interest rate, which are both used as rate of return characteristics) moved in opposite directions over the same period.

[7] During the business cycle the rate of return begins to fall at the end of the growth phase, before the onset of a recession. The leading role of the rate of return in the downswing phase is expressed less obviously because this phase is short, but in this case it is also possible to assert that the rate of return, or profitability, to be more precise, begins to rise before production starts.

[8] As shown in ***Figure 9.2,*** increases in profitability may be accompanied by reductions in both the share of material costs in prices (1880–1890) and in the share of labor costs (1850–1860, 1890–1900). Conversely, both an increase in the share of material costs in prices (1860–1880, 1900–1919, 1970–1980) and in the share of labor costs (1951–1970) may be typical for periods when the rate of return falls. At the same time (e.g., in the 1870s and

1970s), reduced profitability and lower labor costs may occur simultaneously, and in 1950–1970 the drop in profitability was accompanied by a fall in the share of material costs. The growth of the share of profits in prices may be accompanied by both a growth in the share of labor costs (1880–1890) and a growth in the share of material costs (1890–1900, 1933–1950).

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Appendix I. US non-financial corporations

Profit Estimates

(1) Adjusted net income (without profit taxes)

  (a) 1897–1919: Goldsmith (1955), vol. I, pp. 917, 937, 939; with different adjustments (pp. 914–915, 937, 941, 946, 953).
  (b) 1919–1928: Kuznets (1941), vol. I, pp. 312–313, 316–317; with different adjustments (vol. I, pp. 310–313; vol. II, tables IV, VIII).
  (c) 1929–1983: [6], [8], table 1.13.

(2) Profit taxes

  (a) 1909–1919: Goldsmith (1955), vol. I, pp. 917, 937; vol. III, pp. 434–435.
  (b) 1929–1983: [6], [8], table 1.13.

(3) Net interest payments

  (a) 1919–1929: Kuznets (1941), vol. I, pp. 318–319.
  (b) 1929–1946: [6], table 1.13.
  (c) 1946–1983: [6], [8], table 8.7.

(4) Foreign profits

  (a) 1923–1929: Kuznets (1941), vol. I, pp. 318–319
  (b) 1929–1983: [6], [8], table 1.12.

Capital Estimates

(1) Tangible assets at replacement cost (beginning of year)

  (a) 1897–1946: basic points, Goldsmith (1963), vol. I, table III–4b; interpolation and extrapolation up to 1897, Goldsmith (1955), vol. III, pp. 14–15, cols. 5, 6, 11, 16, 22.
  (b) 1946–1983: [2], pp. 36–43.

(2) Total assets at replacement cost (beginning of year)

  (a) 1901–1946: basic points, Goldsmith (1963), vol. I, table III–4b.
  (b) 1946–1983: [2], pp. 36–45.

Appendix II. US manufacturing

Profit Estimates

(1) Profits with overhead costs (1890–1921, without non-production workers' salaries), census years

  (a) 1850–1919: [4], pp. 214–215.

(2) Net income (without corporate taxes on profits)

(a) 1850, 1860, 1870, 1880, 1890, 1900, 1910: King (1919), p. 263.
(b) 1909–1919: King (1930), pp. 108, 278.
(c) 1919–1929: Kuznets (1941), vol. I, pp. 312–313, 316–317.
(d) 1929–1983: [6], [8], table 6.16, 6.20.

(3) Inventory valuation adjustment

(a) 1919–1929: Kuznets (1941), vol. II, table VII.
(b) 1929–1983: [6], [8], table 6.18.

(4) Taxes on profit

(a) 1919–1929: [7], p. 336; Kuznets (1941), vol. I, pp. 312–313, 316–317.
(b) 1929–1983: [6], [8], table 6.22.

(5) Net interest payments

(a) 1850, 1860, 1870, 1880, 1890, 1900, 1910: King (1919), p. 261.
(b) 1909–1919: King (1930), p. 186.
(c) 1919–1929: Kuznets (1941), vol. I, pp. 318–319.
(d) 1929–1983: [6], [8], table 6.19.

Capital estimates

(1) Fixed assets at original cost (end of year)

(a) 1850, 1860, 1870, 1880, 1890, 1900, 1910: King (1919), pp. 256, 258.
(b) 1880, 1890, 1900, 1912, 1918, 1922: Kuznets (1946), pp. 202, 213, 220.
(c) 1890, 1900, 1929: Creamer (1960), p. 248.

(2) Total assets at original cost (end of year)

(a) 1900, 1909, 1914, 1919: Goldsmith (1955), vol. I, p. 927.
(b) 1880, 1890, 1900, 1909, 1919, 1929: Creamer (1960), p. 241.

(3) Total assets at replacement cost (end of year)

(a) 1880, 1890, 1900, 1909, 1919, 1929: Creamer (1960), p. 252.

Sales and Costs Estimates

(1) Sales

(a) 1850–1929 (census years): [4], p. 214 (value of shipments).

(b) 1929–1958: [4], pp. 260–261.
(c) 1958–1983: [5], p. 289.

(2) Labor costs

(a) 1850–1889 (census years): [1], p. 5 (production workers' wages).
(b) 1889–1929 (census years): [1], p. 5 (total industrial wages).
(c) 1929–1983: [6], [8], table 6.5.

(3) Material costs

(a) 1850–1947 (census years): [4], pp. 214–215.
(b) 1947–1961: [3].
(c) 1961–1981: [1], p. 5.

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CHAPTER 10

Empirical Research and Forecasting Based on Hungarian and World Economic Data Series

Béla Sipos

10.1. Introduction

Estimates have been made of many basic economic elements to demonstrate the existence of Kondratieff cycles. With time series data for over 100 years, the existence of such cycles could also be proved. We have analyzed Soviet and Hungarian industrial and agricultural sectors, as well as the world economy. With the exception of Hungarian agriculture, long waves have been

Table 10.1. Hungarian industrial production and foreign trade, and parameters of the approach using a second-degree parabolic curve.

		Parameters				
Industry	*Period*	b_0	b_1	b_2	R^2	*Degrees of freedom*
Iron ore	1876–1982	0.17678	–0.00212	0.00001	0.9461	104
Iron	1876–1982	0.07646	–0.00289	0.00004	0.9886	104
Steel	1920–1982	0.16892	–0.00727	0.00009	0.9957	60
Hard coal	1890–1982	0.29114	–0.00732	0.00008	0.9637	90
Brown coal/ lignite	1890–1982	0.57200	–0.00261	0.00019	0.7650	90
Bauxite	1927–1982	0.24498	–0.00864	0.00009	0.9920	53
Aluminum	1937–1982	0.02690	0.00056	–0.00001	0.9998	43
Cement	1946–1982	0.13007	–0.01038	0.00013	0.9955	34
Crude oil	1937–1982	–0.58747	0.01262	0.00005	0.9922	43
Electricity	1926–1982	3.80145	–0.12651	0.00107	0.9928	54
Exports	1882–1982	0.24018	–0.01298	0.00015	0.9524	98
Imports	1882–1982	0.25901	–0.01409	0.00016	0.9460	98

Table 10.2. Kondratieff cycles in Hungarian industry and foreign trade (in kg/capita).

	First period		*Second period*		*Third period*	
Industry	*Upswing*	*Downswing (peak point)*	*Upswing*	*Downswing (peak point)*	*Upswing*	*Downswing (peak point)*
Iron ore	1880(?) (−82.18)	[1906] (117.54)	1924 (−75.44)	[1978](?) (26.67)		
Iron	1880 (−34.74)	[1910] (43.02)	1948 (−39.29)	[1974] (23.77)		
Steel		[1926](?) (12.34)	1946 (−28.97)	[1966] (21.35)		
Hard coal	1894 (−9.53)	[1910] (36.34)	1948 (−43.55)	[1966] (121.47)	[1978](?) (−86.82)	
Brown coal/ lignite	1894 (−85.78)	[1911] (296.99)	1946 (−405.02)	[1962] (692.63)	1978(?) (-412.29)	
Bauxite	1932 (−8.76)	[1940] (21.62)	1948 (−16.97)	[1952] (8.23)	1960 (−12.40)	1975 (18.89)
Aluminum		[1941](?) 0.29	1949 (−0.73)	[1964] (0.48)	1978(?) (−0.22)	
Cement		[1951] (9.43)	1959 (−11.30)	[1964] (3.56)	1972 (−7.83)	[1977] (14.29)
Crude oil		[1943] (13.98)	1949 (−17.10)	[1966] (13.75)	1978(?) (−3.36)	
Electricity	1930(?) (−7.12)	[1939] (47.42)	1948 (−41.13)	[1975] (73.34)		
Exports	1886(?) (−85.55)	[1914] (82.67)	1966 (−129.49)	[1978](?) (173.03)		
Imports	1886(?) (−92.58)	[1914] (92.04)	1965 (−147.75)	[1978](?) (203.47)		

proved. Similar fluctuations can be expected in the future. It is likely that the downswing in the Kondratieff cycle began in the 1970s, and coincided with a downturn in a century-old trend-curve. The downswing could end at different times for individual items. The start of the next upswing can be expected in the 1995–2000.

On behalf of the Tannery of Pécs, I began business cycle research in order to make price forecasts. The importance of periodic fluctuations in prices was proved, when the company saved a large amount of hard currency through taking into consideration the probable price movements of hides. At the core of this examination were the seasonal fluctuations caused by the business cycles. In the course of my research, I used the findings of the Farkas Heller school, the members of which had studied Soviet long-wave researchers. On Lenin's initiative, the first Institute for Business Cycle Research was established in 1920, with N.D. Kondratieff as director. By 1925, there were three institutes for long-wave research in the USSR, and 30 years later Hungarian historians started to deal with the works of Kondratieff.

The business cycle in the leather industry changed in the late 1970s. The amplitude and the length of the cycle increased dramatically (especially

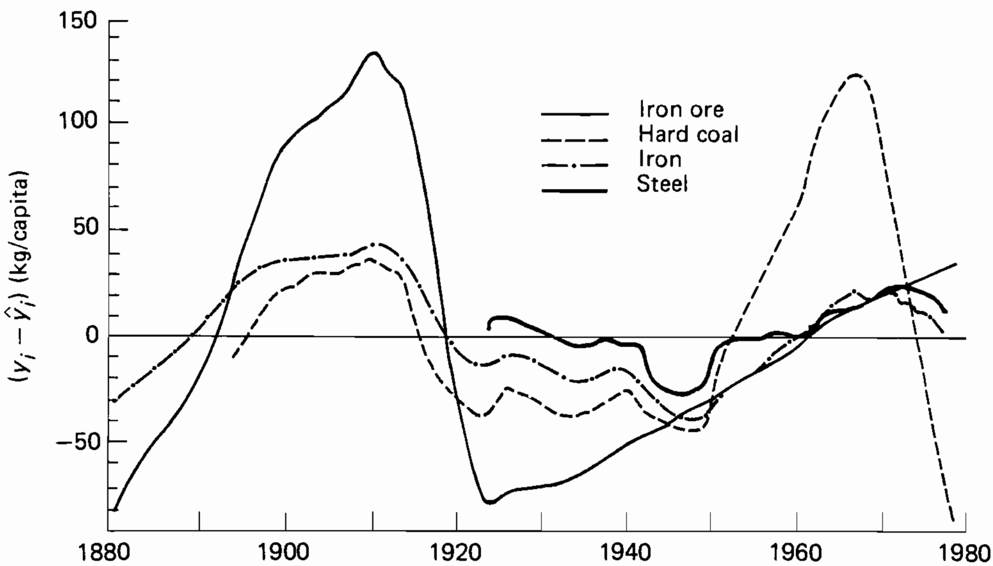

Figure 10.1. Kondratieff cycles in Hungarian iron ore, hard coal, iron, and steel production ($\hat{y}$ estimated on the basis of a second-degree parabolic trend; $\hat{y}$ = a nine-year moving average of $Y_t - \hat{Y}_t$). Production time series were divided by population to obtain tonnes/capital. The nine-year moving averages representing the long wave are multiplied by 1000 to give kg/capita.

the upswing), probably due to the coincidence of a long-term wave and short cycles. In this chapter I attempt to summarize the first results of our research on Hungarian and world economic cycles.

10.2. Hungarian Industry and Foreign Trade

Industrial production and foreign trade data are presented in *Table 10.1.* (Note that data for iron ore and iron production cover 106 years, while those for cement production cover only 36 years). The Kondratieff cycles in Hungarian industrial output are shown in *Table 10.2,* and the results are presented graphically in *Figures 10.1–10.3.*

Table 10.3 is based on the results in *Table 10.2,* and summarizes more clearly the periods of the Kondratieff cycle. In general, two cycles can be traced.

The question marks in *Tables 10.2* and *10.3* show that the upswing probably started earlier, and that the downswing will continue to fall.

For bauxite, cement and electricity production we obtained very short periods (from 12–17 years; consequently, there are Labrousse cycles with periods of 10–12 years and Kuznets cycles with periods of 20 years). The

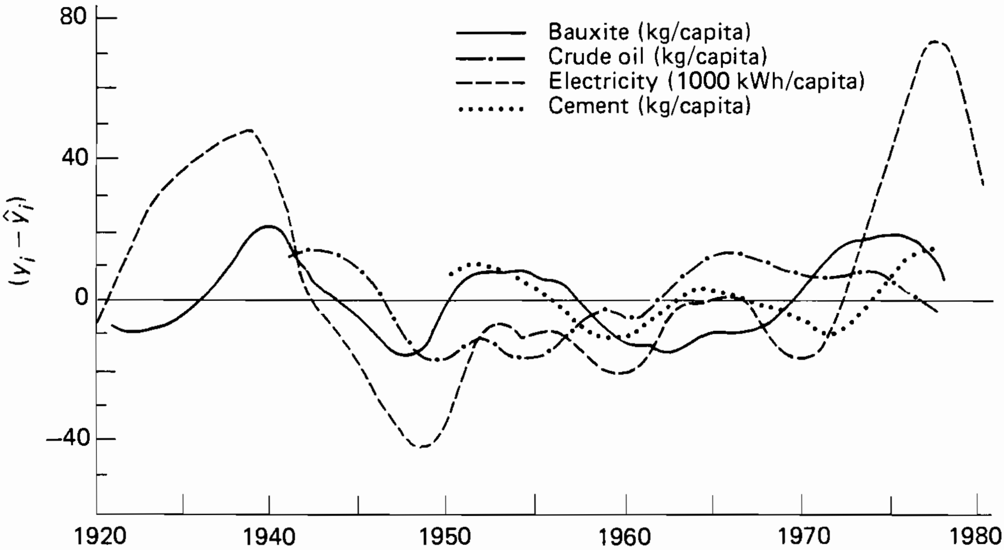

Figure 10.2. Kondratieff cycles in Hungarian bauxite, crude oil, electricity, and cement production ($\hat{y}$ estimated on the basis of a second-degree parabolic trend; nine-year moving averages).

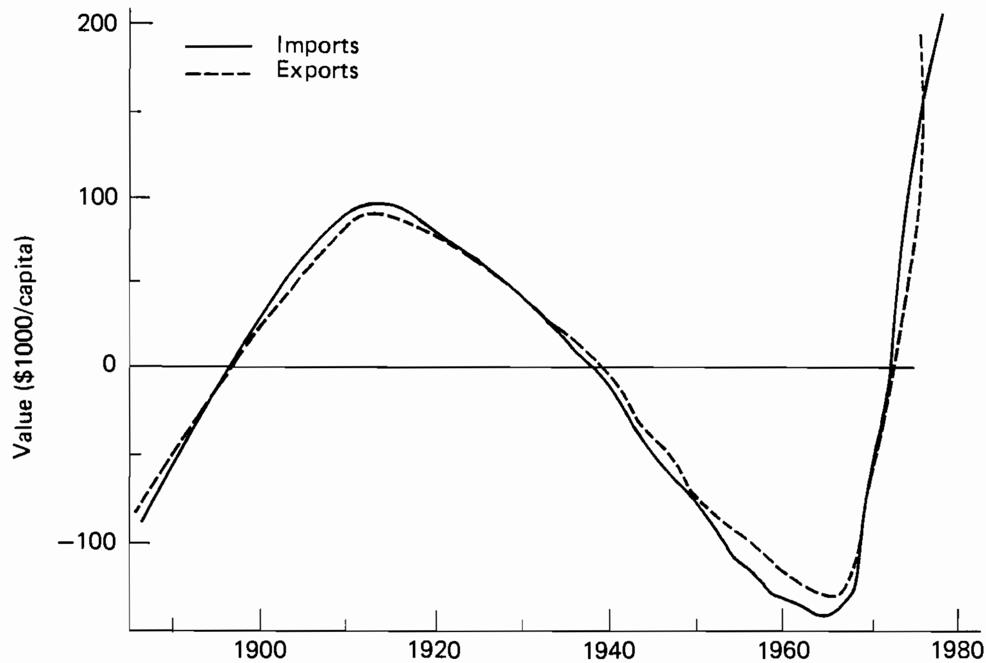

Figure 10.3. Kondratieff cycles in Hungarian exports and imports (nine-year moving averages).

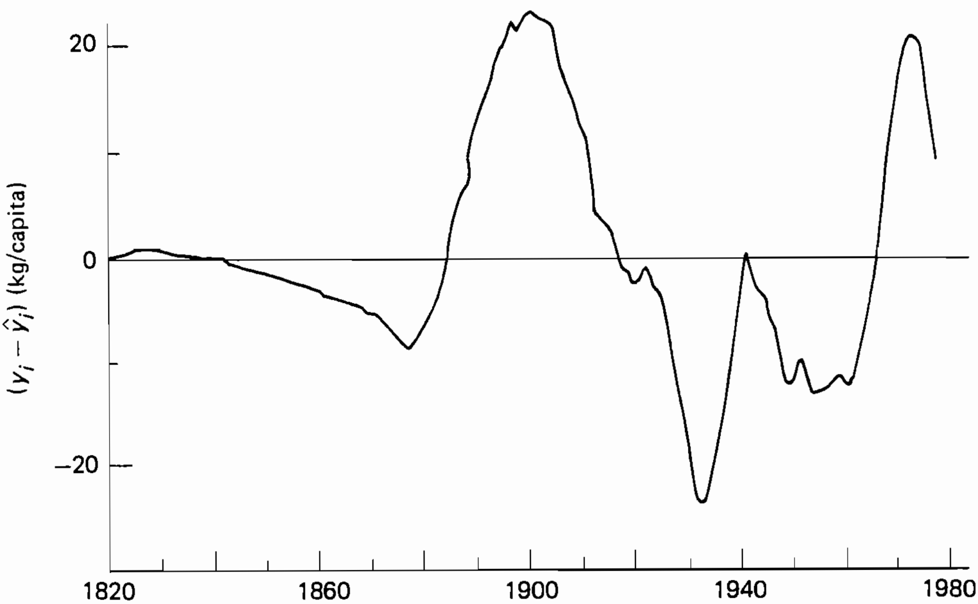

Figure 10.4. Kondratieff cycles in output of the Mázaszászvár coalmine.

average length of the first period (except for bauxite, cement, and electricity production) is 62.83 years with a deviation of 15.05 years (see footnote, *Table 10.3)*. The relative deviation (deviation/average) is 23.95%, so that the lengths of individual periods differ from the average of 23.95%. The upswing was shorter (24.16 years) than the downswing (32.50 years).

The second period length is 30 years, so that the period of the Kondratieff cycle has been halved. This result could be considered an estimate, because only the upswing of the second period is known for iron ore, iron and steel, and exports/imports. The end of the downswing can only be forecast with large uncertainly. The long cycles of output of the Mázaszászvár coalmine between 1817 and 1983 are also similar (see *Figure 10.4)*.

The years 1902, 1910, and 1917 were disastrous, and output fell significantly. 1875, 1933, and 1960 were the low points in the long cycle, whereas the maxima occurred in 1900, 1950, and 1978. The amplitudes before 1945 were at about the same level; after 1945 they diminished, the waves became irregular, and in the 1970s a downswing began. A survey at the level of the firm (on the basis of 166-year data) has shown that the period of the Kondratieff cycle has become remarkably shorter (Sipos, 1985, pp. 249–250).

In our analysis of agriculture, the production of potatoes, wheat, and maize has been studied, together with the analysis of 50-year time series data on pig and cattle populations. However, with these series, long-term trends can be determined only up to 1945. Since that year, the large farm estates have been broken up, and agricultural output has fluctuated irregularly.

Table 10.3. The periods of the Kondratieff cycles in Hungary (year).

	First period			*Second period*		
Industry	*Total*	*Upswing*	*Downswing*	*Total*	*Upswing*	*Downswing*
Iron ore	44(?)	26(?)	18		54	
Iron	68	30	38		26	
Steel			20		20	
Hard coal	54	16	38	30(?)	18	12(?)
Brown coal/ lignite	52	17	35	32(?)	16	16(?)
Bauxite[a]	16	8	8	12	4	8
Aluminum			8	29(?)	15	14(?)
Cement[a]			8	13	5	8
Crude oil			6	29	17	12
Electricity[a]	17	9	8		27	
Exports	80	28	52		12	
Imports	79	28	51		13	
Average	51.25	20.25	22.92	24.46	18.91	11.66
Deviation	24.93	8.89	17.48	9.89	13.05	3.20
Average[a]	62.83	24.16	32.50	30.00	21.22	13.50
Deviation[a]	15.05	6.08	15.83	14.82	12.96	1.91

[a]Bauxite, cement, and electricity production are not taken into account because the length of the period is less than 20 years, and is thus not a Kondratieff, but may be a Kuznets cycle.

10.3. World Production

In making calculations for the world economy, corrections for population were not made due to incomplete data. Changes in the state boundaries were not significant so that the corrections mentioned above were unnecessary. Results are shown in *Figures 10.5* and *10.6*. Data are available for the world output of hard and brown coal for the period 1894–1983 *(Figure 10.5)*, and for bauxite/aluminum production for 1932–1983 *(Figure 10.6)*. The lowest point of the long wave occurred in 1945 for coal and in 1960–1962 for bauxite and aluminum production. It can be seen that before World War I there was a strong upswing in coal output, followed by a fall during the war.

World War I was followed by a long upswing, which turned into a long, sharp downswing. The depression of the 1930s emerges as a downswing in the cycle, which continued to the end of the 1940s. The brown coal and the lignite cycles have recovered since 1960, as has that for hard coal production, but in the latter the upswing was caused by the increases in the price of oil.

The long waves in world aluminum and bauxite production are similar (see *Figure 10.6*). The first upswing occurred in the late 1930s, with a minimum in

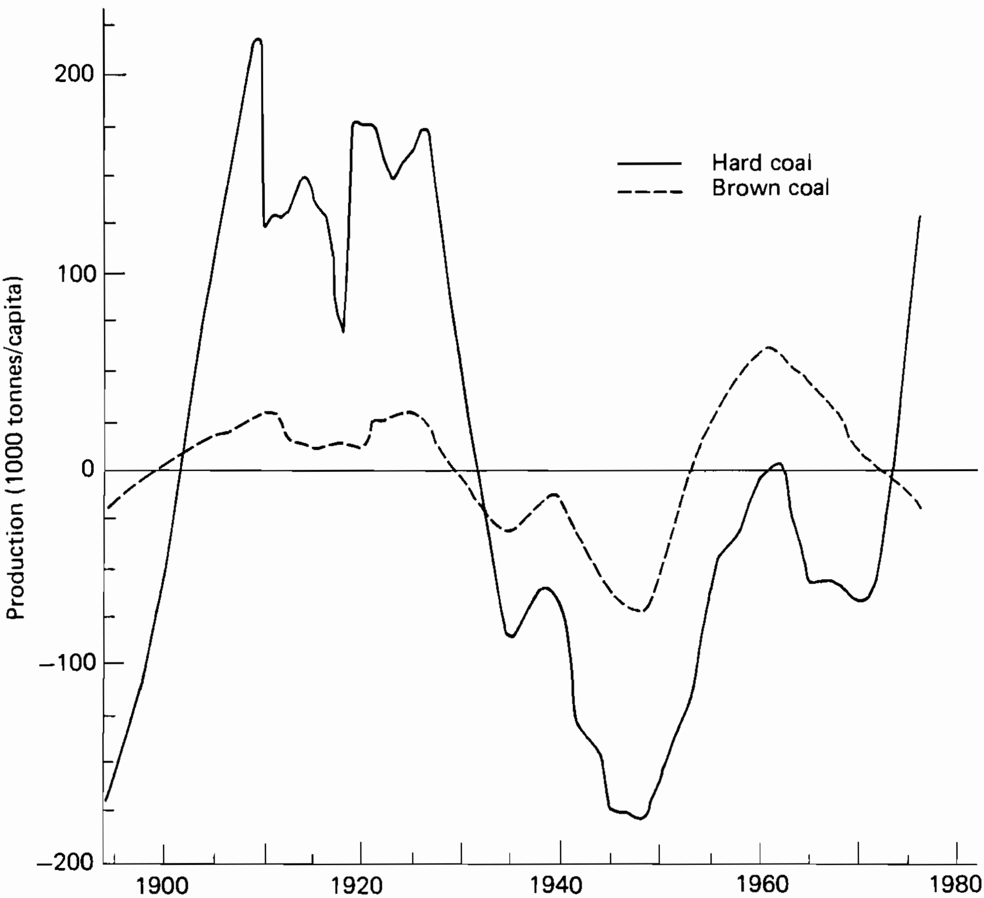

Figure 10.5. Kondratieff cycles in world hard coal, brown coal, and lignite production ($\hat{y}$ estimated on the basis of a second-degree parabolic trend).

1961. From then we can trace an upswing in the cycle, but in the late 1960s there was a minor decline. The calculations of production of Hungary, the USSR, and the world prove that long waves in industrial production and, within this, in the production of the raw materials show similar time trends.

10.4. Calculation Method

In choosing the trend we represented the differentials of the original data, which are usually located along a line $Y_t = G_0 + G_1 \cdot t$. If we denote the trend of the original data $Y_t = \hat{b}_0 + \hat{b}_1 t + \hat{b}_2 t^2$, then $G_0 = b_1$ and $G_1 = 2\hat{b}_2$. The quadratic parabola was chosen because the line is derived from it. Having calculated the estimated values of the parabola $\hat{Y}_i$ from the original data Y_i, we used a nine-year moving average of $(Y_i - \hat{Y}_i)$, which we represent by $\hat{y}$.

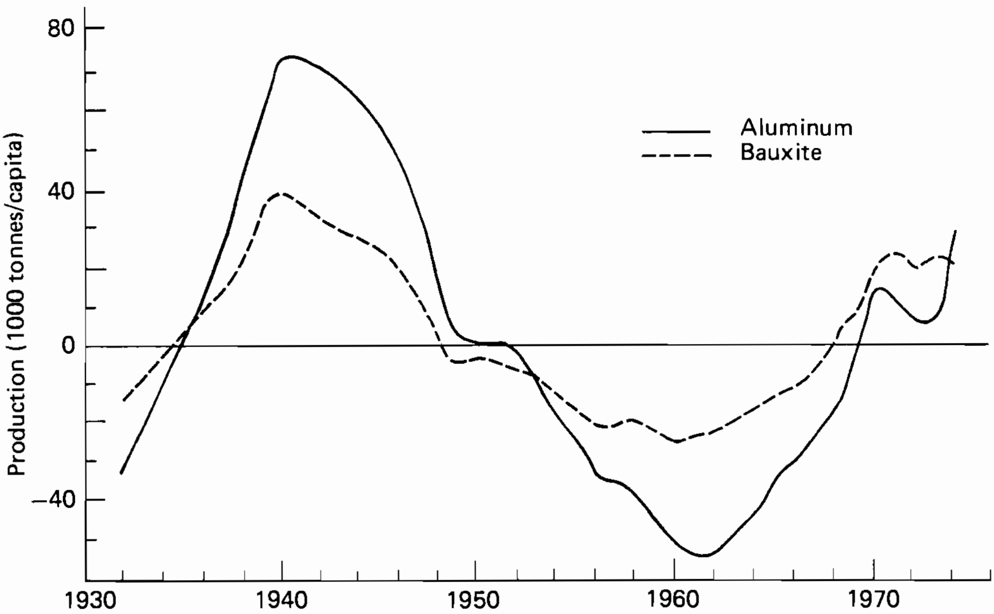

Figure 10.6. Kondratieff cycles in world aluminum and bauxite production ($\hat{y}_i$ = the value of the *i*th timepoint estimated by the parabolic trend).

The authenticity of parabola parameters was also verified by a *t*-test. We noted that the elimination of the trend by a first-, second-, or third-degree parabola does not significantly affect the trends in the Kondratieff cycles.

We are now processing 40,000 sets of data from 30 countries, with the support of the Hungarian Academy of Sciences. Because of the elimination of the 20–25-year Kuznets cycle, we also use a 21-year moving average, using a dynamic analysis of delayed relations.

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CHAPTER 11

The Economic Long Wave: Theory and Evidence

John D. Sterman

11.1. Introduction

The economic malaise of the 1970s and 1980s has revived interest in the economic long wave or Kondratieff cycle (Kondratieff, 1935, 1984). 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, 1985a,b). 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 chapter 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 chapter presents some of the basic corroborative evidence to show how the NM endogenously generates a wide range of economic data.

11.2. Behavioral Foundations

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

11.2.1. 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 decision making and physical structure 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.

11.2.2. Disequilibrium dynamics

The model does not assume that the economy is always in equilibrium, or that it moves smoothly from one equilibrium to another. Although individuals may be striving for balance, 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 ways people perceive and react to imbalances, and the delays, constraints, and inadequate information that often confound them.

11.2.3. 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):

> 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 (p. 198).

Behavioral modeling emphasizes the heuristics used by real people to make adequate decisions in a reasonable period of time, given the constraints of human cognitive capabilities and the limited information available.

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 decision making 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 the behavior of a system accurately, decision making must be portrayed as it is and not as it might be if people were omniscient optimizers. An extensive empirical literature documents these heuristics and numerous systematic biases that often occur, providing a firm foundation for behavioral modeling in economics [2].

11.3. Multiple Modes of Behavior

Figure 11.1 shows the behavior of important economic variables in the USA 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%/year since 1800. GNP also exhibits the short-term business cycle, 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).

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 in the early 1980s are the highest since the Great Depression. Consumer prices likewise fluctuate over 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 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% of GNP in the 1920s to about 35% in the 1980s, and with the increasing reliance on deficit financing and monetization of the public debt.

Interest rates likewise rise and fall within a roughly 50-year period. Note that interest rates are approximately in phase with the price level. Like prices, interest rates have risen above historic levels in the last decade as inflation reached double-digit rates.

The data reflect the interaction of several distinct modes of behavior, including long-term population growth and technological progress, the business cycle, the relative growth of government, postwar inflation, and the long

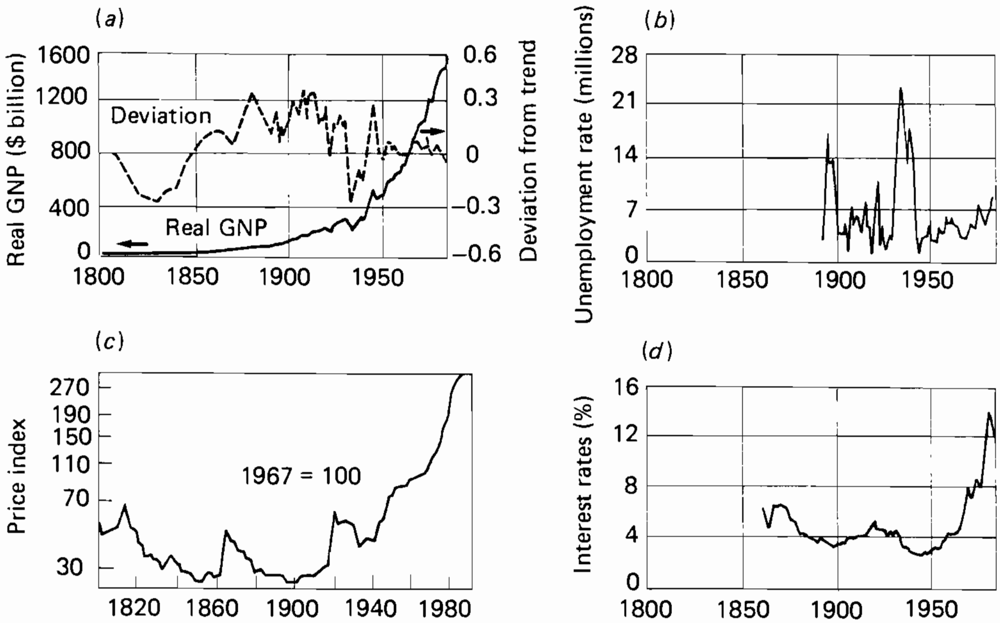

Figure 11.1. Behavior of economic variables in the USA, 1800–1984. (*a*) Real GNP (1972 dollars); (*b*) unemployment rate; (*c*) consumer price index; (*d*) interest rates (Homer, 1977: 1860–1899, average yield on higher grade railroad bonds; 1900–1975, prime corporate bonds; 1975–1984, Moody's AAA bonds.

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 [3].

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 *Figure 11.2*, which shows a simulation of the NM from 1800 to 1984. All the macroeconomic aggregates are generated endogenously (see *Table 11.1*), as are a host of variables at the sectoral level. The only exogenous variables are population (which in the simulation shown is assumed to grow at a uniform rate of 2%/year); 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. 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

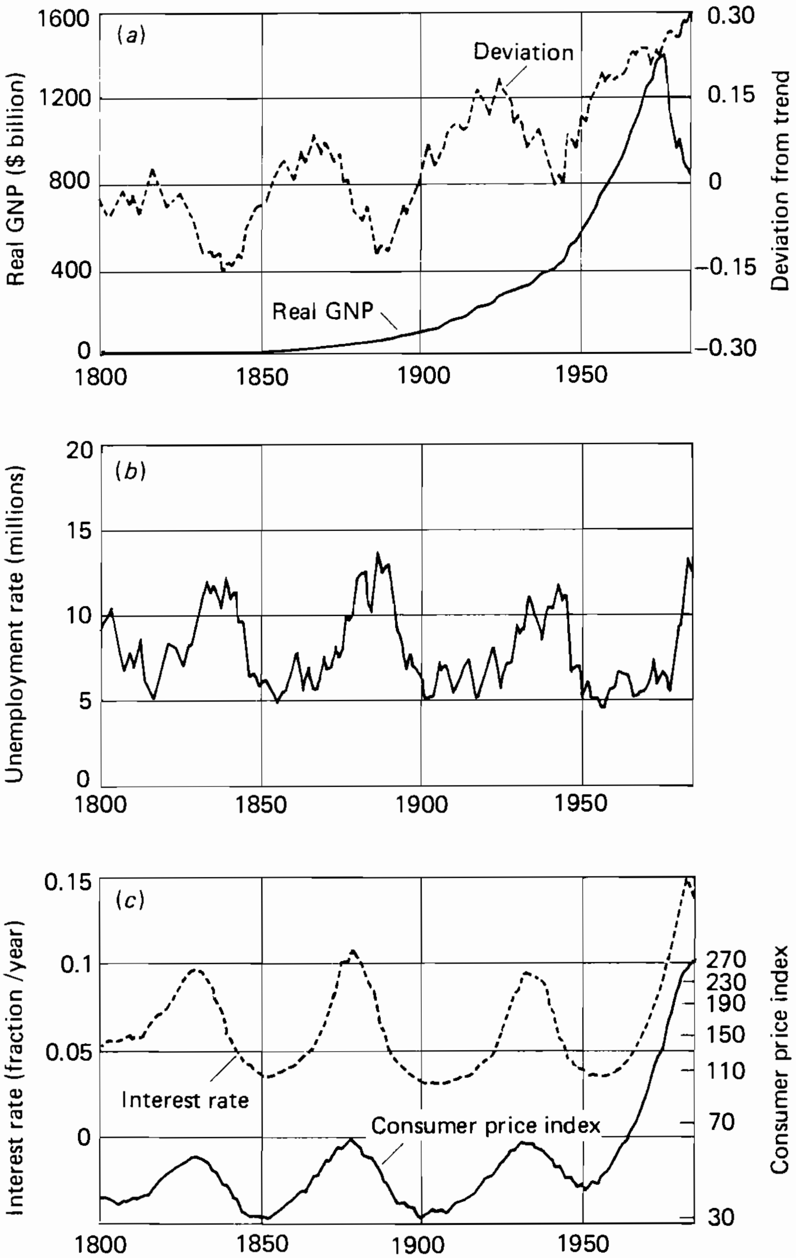

Figure 11.2. Simulated economic variables in the USA, 1800–1984. (*a*) Real GNP; (*b*) unemployment rate; (*c*) consumer price index and interest rates.

Table 11.1. Major variables in the National Model (NM).

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

wave, is the endogenous result of the interaction of the system components. It is not driven by the exogenous variables. Yet, the simulation captures the major patterns in the development of the economy over almost 200 years [4].

11.4. Origin of the Long Wave

The long wave is characterized by successive waves of overexpansion and decline 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 excess.

How does the long wave arise? In particular, how does overexpansion of the capital-producing sector of the economy arise? The explanation is 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 demand. 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).

11.4.1. Amplification of demand by individual firms

Production systems amplify changes in demand. Consider a retailer of consumer goods in stationary equilibrium who experiences a sudden, unanticipated step increase in orders, say, of 10%. In the long run, the retailer will increase orders to its suppliers by 10% and will probably hold 10% more inventory to provide the same coverage of demand. But during the adjustment period, orders placed with suppliers must exceed the long-term level: delays in reacting to the change in demand and in receiving new goods from suppliers mean retail inventories must fall. Backlogs will rise. Retailers must therefore 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.

But the situation is worse: a higher volume of business requires a larger stock of inventory to maintain the same coverage ratio, causing additional orders. Further, the lead time for supplies may rise, since suppliers face delays in ordering their own parts and materials, hiring new workers, and expanding capacity. Faced with rising delivery times, firms may hedge by ordering still more and placing orders with more than one supplier, a process described as early as the 1920s by economist Thomas W. Mitchell (1923). 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 for the present, and forecast still more roughly for the future ... This fact gives hopeful or despondent moods a large share in shaping business decision ... 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, raw materials, machinery manufacturing, etc.) are the farthest removed from final demand and hence experience the most instability.

The amplification of demand by stock adjustments is a fundamental characteristic of production, 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 15–25 years [5].

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 with 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, 1985b). Yet the long wave is a 50-year fluctuation which does not die away. The long period, large amplitude, and persistent nature of the long wave arise from a wide range of self-reinforcing processes that operate in the economy as a whole. These positive feedback loops couple different firms to one another and to the household and financial sectors of the economy. The effect of these self-reinforcing processes is to further amplify the oscillatory tendencies of individual firms, stretching out the period and increasing the the amplitude of the fluctuations. Analysis of the model isolates several independent processes that contribute to the 50-year cycle of overexpansion and decline.

11.4.2. 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 stocks, 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 11.3 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 highlight the long wave. In the simulation 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 [6]. 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 15–20 years. The long wave is by far the largest in real investment. The large amplitude of investment relative to consumption reflects 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 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 [7]:

$$1/(1 - COR_k / ALC_k),$$

where COR_k = capital/output ratio of the capital sector (years), and ALC_k = 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

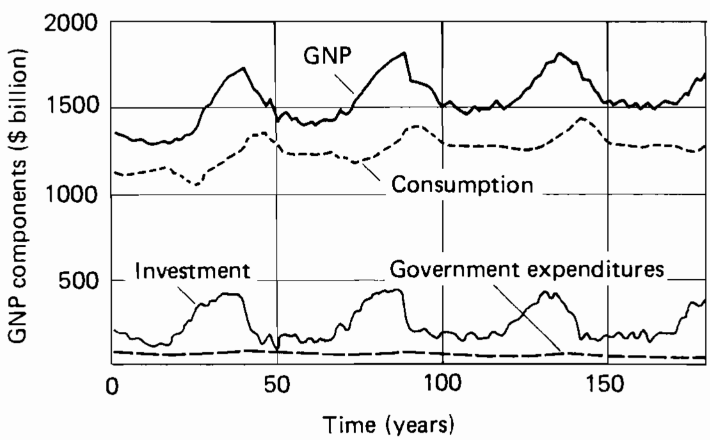

Figure 11.3. Simulation: behavior of real GNP, consumption, and investment.

(approximate values for the aggregate economy) gives an equilibrium multiplier effect of 1.18. In the long term, an increase in the demand for capital from the rest of the economy yields an additional 18 percent 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 term, 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.

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 11.4* shows the effect of inventory and backlog pressures on desired production in 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.

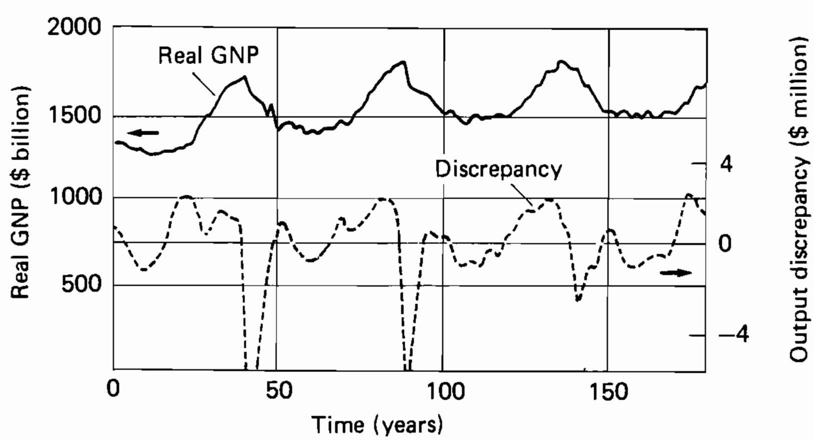

Figure 11.4. **Simulation: effect of inventory and backlog pressures on desired production in the capital sector.**

Amplification Caused by Rising Lead Times for Capital

As shown in *Figure 11.5*, the delivery delay for capital rises well above normal during the long-wave expansion. Delivery delay tends to peak 4–10 years in advance of real GNP and drops well below normal during the downturn. Backlogs rise as demand for capital outstrips capacity during the long-wave expansion. 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 demand for capital. In addition, longer lead times force capital producers to order farther ahead, further augmenting orders.

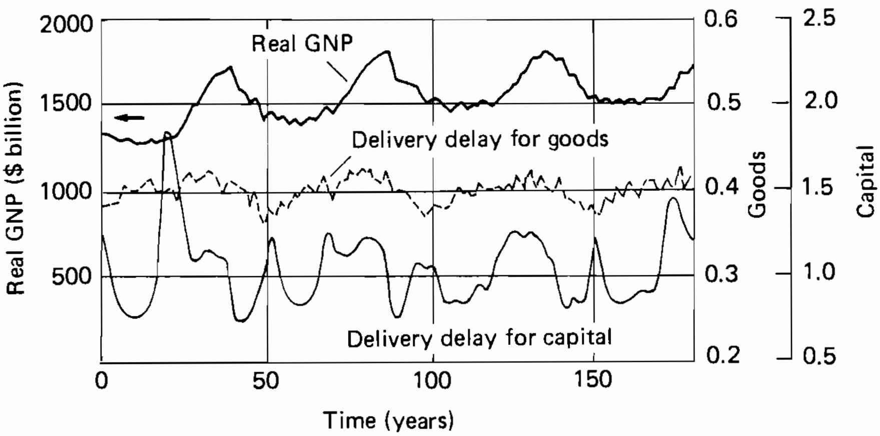

Figure 11.5. Simulation: delivery delays for goods and capital.

The delivery delay for goods likewise fluctuates with the long wave. Capital is scarce during the long-wave expansion 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 much less than that in the delivery delay for capital, showing the powerful role of self-ordering in destabilizing the capital sector.

The availability of capital also exhibits the 20-year Kuznets or construction cycle, which creates smaller and narrower peaks in delivery delay between the major surges that 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. The slowdown in growth and drop in delivery times in the USA between 1958 and 1962 were probably a manifestation of the Kuznets cycle (Zarnowitz, 1962).

Amplification Caused by Growth Expectations

Growing demand, rising backlogs, and long lead times during the long-wave expansion 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. During the downturn, pessimism further undercuts investment. As shown in *Figure 11.6*, capital producers' long-term expectations of growth in demand for capital fluctuate substantially over the long wave. Note that growth expectations in the capital sector peak 2–8 years before the peak of real GNP. Due to perception lags and institutional inertia, growth expectations are highest just before real investment peaks and begins to decline (compare *Figure 11.6* with the timing of real investment shown in *Figure 11.3*). Thus growth expectations exacerbate the excess capacity that develops at the peak of the long wave.

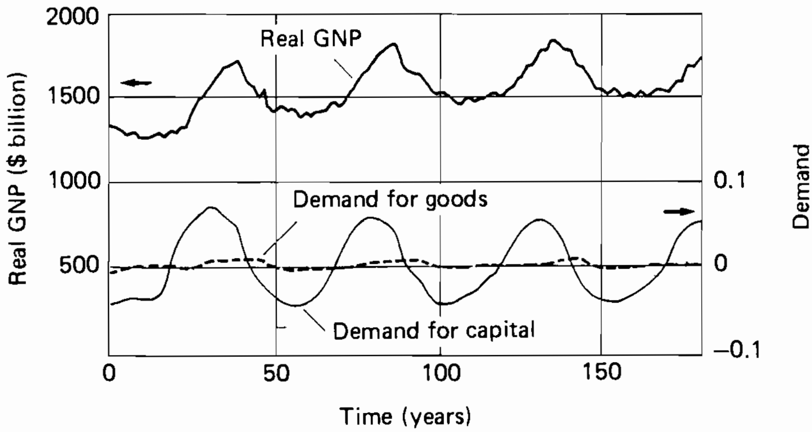

Figure 11.6. Simulation: expected long-term growth in demand.

The Sufficiency of Self-ordering

The positive feedback loops created by self-ordering significantly reinforce the 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 with 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-term growth until the excess capacity depreciates – 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 US 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 satisfy long-run demand, fill pent-up demand, and rebuild the capital and infrastructure, the capital-producing sector had to expand beyond the long-term 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. By the late 1960s, the capital stock had been largely rebuilt, and investment began to slow to levels consistent with replacement and long-term 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.

The capital self-ordering component of the long-wave theory predicts a growing margin of excess capacity, especially in heavy manufacturing industry, as the economy moves through the long-wave peak and into the downturn. Excess capacity has in fact been one of the dominant symptoms of the malaise of the 1970s and 1980s, and has been amply documented elsewhere. *Figure 11.7* shows the aggregate index of industrial production and capacity for the postwar period in the USA. As predicted by the theory, utilization rates were high during the expansion period of the long wave, peaking in the mid-1960s. But since 1966 the growth of industrial production has slowed markedly while capacity continued to grow. And as predicted by the theory, the excess capacity is concentrated in capital goods, raw materials, and other basic industries. As of the end of 1984, despite two years of vigorous business cycle expansion, industrial production in more than half the key sectors of the US economy had not yet recovered the levels attained around 1979, the peak of the previous cycle. More than 20 industry groups were producing at

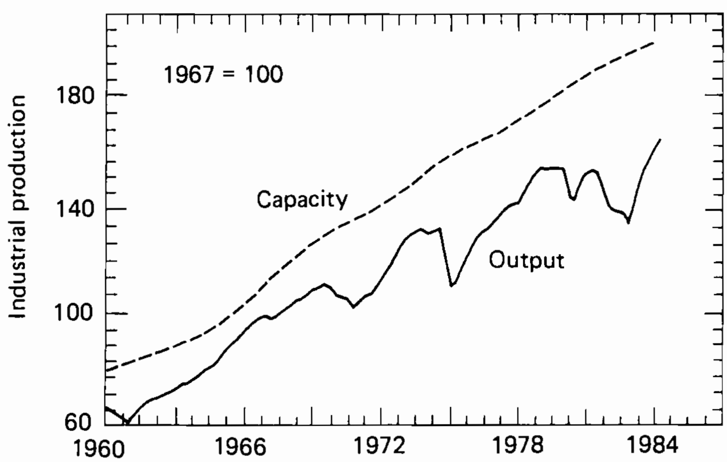

Figure 11.7. Data: industrial production and capacity in the USA, 1960–1984.

rates less than 80% of their peak *production* rate, including the steel, metals mining, automobile, rail and farm equipment, building equipment, and other capital-producing sectors.

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, 1985b). Players of a simple role-playing simulation game of the self-ordering process also generate long waves, even with perfect information (Sterman and Meadows, 1985). Self-ordering thus seems to be a sufficient cause of long waves [8].

11.4.3. The role of labor and wages

Self-ordering, though it may be sufficient to generate the long wave, is not the only process at work. Other positive feedback loops operate through the labor markets to add additional amplification (*Figure 11.8*). At the end of the downturn period, labor is in abundant supply and real wages are relatively low (*Figure 11.9*). As the economy expands, firms throughout the economy expand employment. Employment growth in the capital-producing sector, stimulated by self-ordering, is particularly rapid. As employment rises, the labor market tightens. Real wages rise. As the long-wave expansion matures, high and rising real wages provide a powerful economic incentive for firms to substitute capital for labor. Employment growth slows, but the demand for capital is further stimulated as firms invest in labor-saving technology, further reinforcing the demand for capital and the pressure on wages, and adding additional amplification to the direct self-ordering feedbacks. But just as the rise in wages strengthens the growth of investment in the expansion, so too does it reinforce the decline in investment during the downturn. As excess capacity in the capital sector begins to depress employment, real wage growth slows.

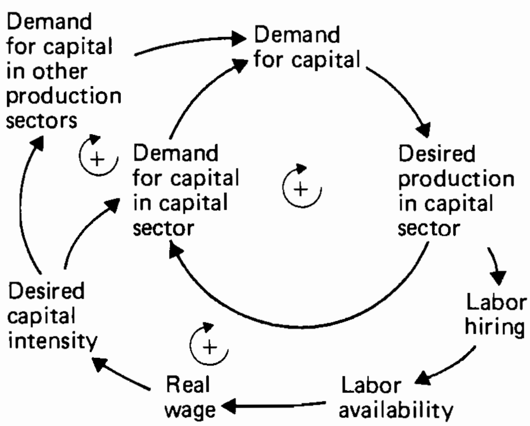

Figure 11.8. Reinforcing loops involving capital self-ordering and capital intensity.

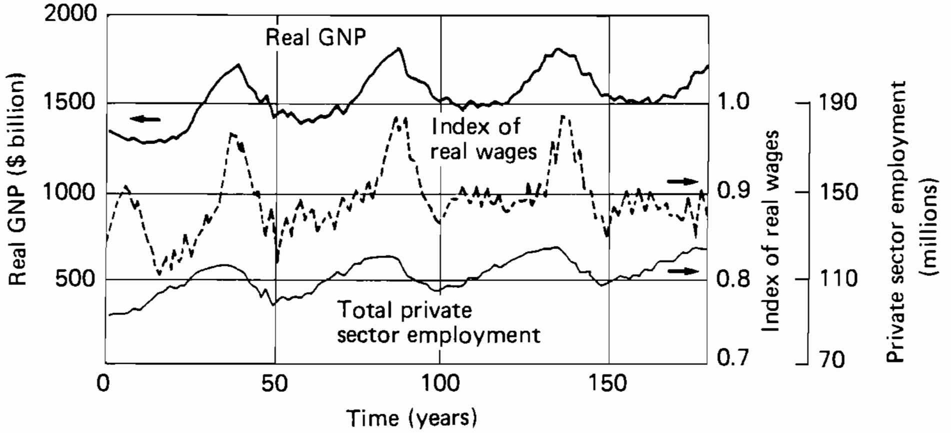

Figure 11.9. Simulation: employment and real wage.

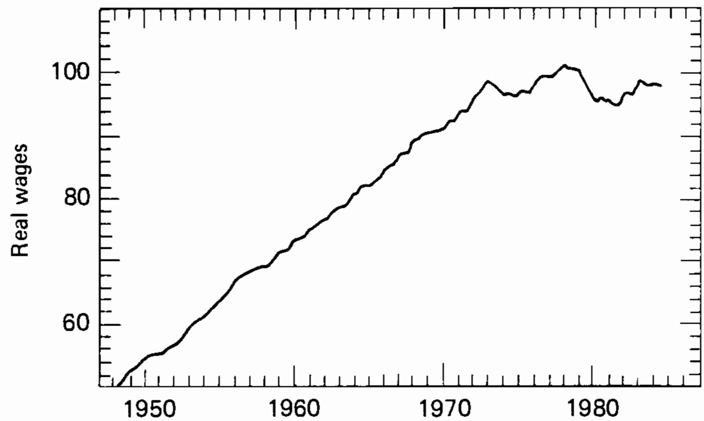

Figure 11.10. Data real wage in the USA, 1947–1984.

Low real wages during the trough of the long wave further undercut 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, the historical record should show higher than average real wage growth during long-wave upturns and lower than average real wage growth during downturns. Real wage growth has in fact fluctuated significantly over the long wave with the phasing predicted by the theory. *Figure 11.10* shows the real wage in the USA since World War II. Between the end of the war and 1972 (the upturn period of the long wave), real wages grew by an average of 2.6%/year. Since 1973, real wages, though fluctuating with the business cycle, have been stagnant. The average rate of growth of real wages over the 115-year period since 1870 is 1.7%/year, a reflection of technological progress (*Table 11.2*). But the rate of growth is far from uniform; during

Table 11.2. Real wage[a] growth in the USA, 1870–1984.

	Period	*Growth rate (%/year)*
Average	1870–1894	1.69
Downturn	1870–1894	0.95
Upturn	1894–1923	2.01
Downturn	1923–1938	0.97
Upturn	1938–1973	2.76
Downturn	1973–1984	0.01

[a]Real wage = nominal wage index/consumer price index.
Sources: Consumer price index:
1870–1946: *Historical Statistics of the United States, Colonial Times to 1970*, HSUS Series E135.
1947–1984: Bureau of Labor Statistics (BLS), *CPI for urban wage earners and clerical workers.*
Nominal wage index constructed from:
1870–1900: *Average annual earnings, nonfarm employees*, HSUS Series D-735.
1901–1946: *Annual earnings of employees excluding armed forces*, HSUS Series D-724.
1947–1984: *Compensation per hour, employees in nonfarm business sector*, BLS.

periods of long-wave downturn, real wage growth averages less than 1%/year, while during the upturns it exceeds 2%/year.

The theory also predicts systematic variations in the mix of capital and labor as factors of production. In particular, the early phase of the long wave expansion should involve the simultaneous expansion of labor and capital. As real wages rise and firms substitute capital for labor, employment should stagnate while capital stock and output continue to grow. Such patterns have been documented for the USA, Europe, and Japan [*Figures 11.11*(*a*) and *11.12*(*a*); see also Freeman *et al.*, 1982]. Compare these against *Figures 11.11*(*b*) and *11.12*(*b*), which show the shifting balance of labor and capital generated by the NM simulation shown in *Figure 11.2.* Although the growth of population and technology causes both labor and capital to rise, the long wave causes significant fluctuations in their relative rates of growth. Between the 1890s and 1918, employment in the USA doubled; capital stock increased even faster. But between 1918 and 1929, employment grew by only about 5%, while capital stock increased by one-third. Employment collapsed between 1929 and 1933, while capital stock peaked in 1931 and fell only gradually during the 1930s. The cycle ended with the gradual recovery of employment as capital stock fell.

The postwar long-wave cycle exhibits the same pattern. Employment in US manufacturing grew by some 5 million between 1950 and 1969, and capital stock more than tripled. But since 1969 manufacturing employment has stagnated (though it fluctuates strongly with the business cycle), while capital stock nearly doubled once more.

Like the historical data, simulated labor and capital rise together as the long-wave expansion begins [9]. Labor growth then slows as wages rise and workers become scarce. At the long-wave peak, labor falls sharply, while capital, due to construction lags, continues to increase for a few more years.

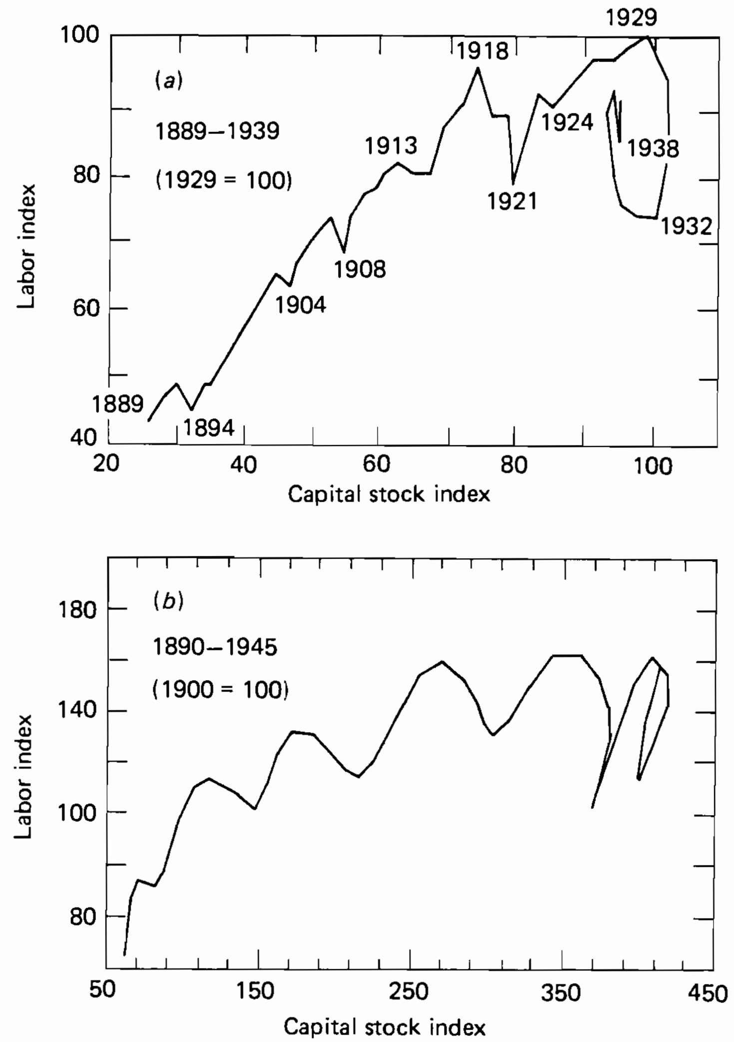

Figure 11.11. **(a) Actual capital/labor mix in the USA, 1889–1939 (Kendrick, 1961, p. 328). (b) Simulated labor/capital mix in the capital sector, 1890–1945.**

During the downturn, capital stock declines while employment remains depressed. Finally, the decline in real wages causes employment to rise while capital continues to decline, completing the cycle [10].

The feedback process described above also accounts for the slowdown of productivity growth in recent years. During the long-wave expansion, capital stock per worker is rising rapidly, and productivity grows. But eventually, the "capital deepening" process begins to suffer from diminishing returns, slowing the growth of productivity though capital–labor ratios continue to rise. Finally, the decline in investment in the downturn period reduces the growth of capital per worker, further slowing productivity gains.

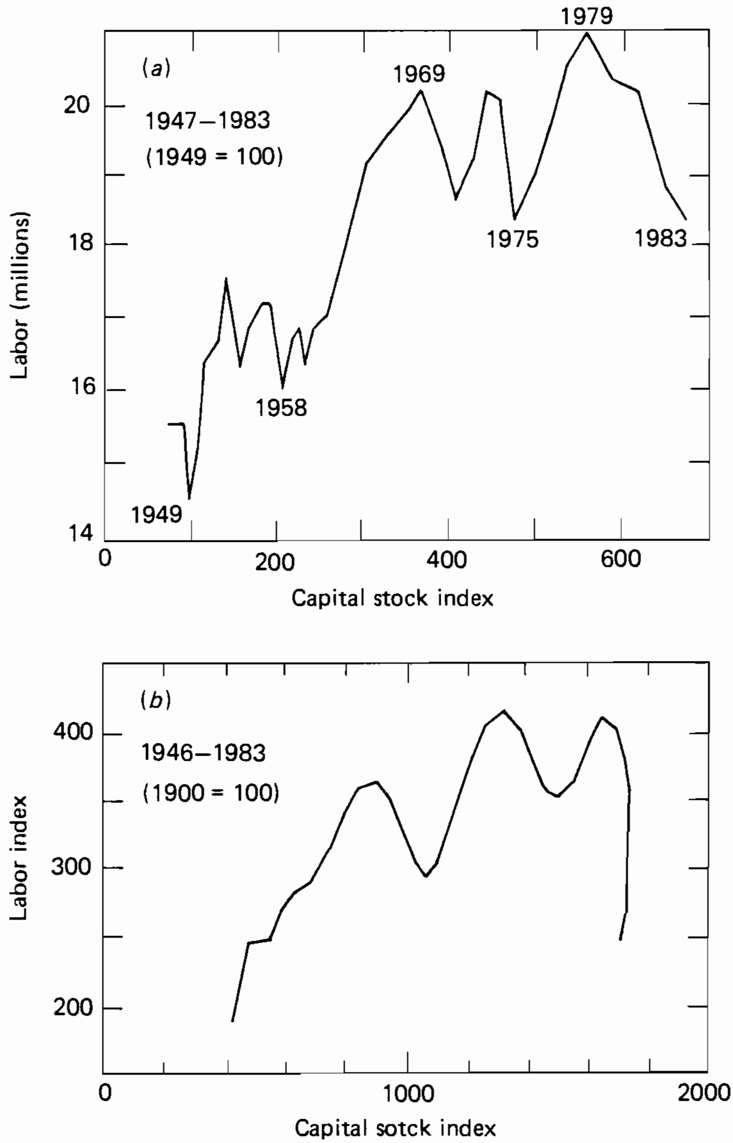

Figure 11.12. (*a*) Actual labor/capital mix in the USA, 1947–1983 (US Dept. of Labor; Dept. of Commerce, Bureau of Economic Analysis, investment expenditures). (*b*) Simulated capital/labor mix in the capital sector, 1946–1983.

11.4.4. Real interest rates and inflation

Another major mechanism that contributes to the long wave revolves around the dynamics of interest rates and inflation. *Figure 11.13*(*a*) shows the real interest rate from 1960 to the present [11]. Real rates declined gradually

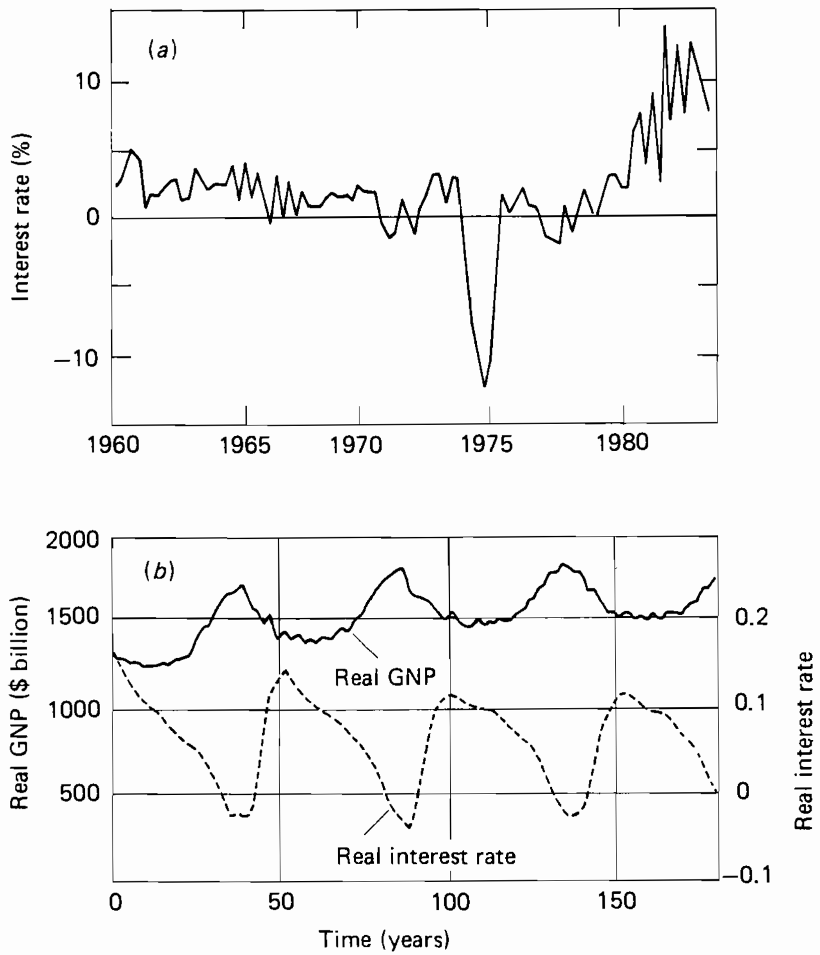

Figure 11.13. **(a)** Data: real interest rate in the USA, 1960–1983. **(b)** Simulation: real interest rate.

from 1960 to the mid-1970s, when they were generally negative. After 1979 real rates rose sharply and remained at the high levels.

The high level of real interest rates has been blamed on restrictive monetary policies and high government deficits. Yet the NM generates the same 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 11.13(b)* 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 summarized in *Figure 11.14*. During the long-wave expansion, the demand for goods and especially capital is growing faster than

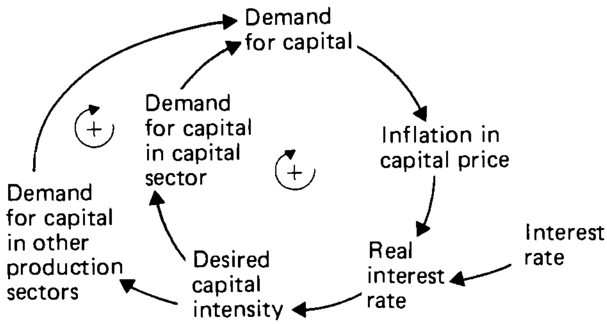

Figure 11.14. Reinforcing loops involving capital demand, inflation, and real interest rate.

capacity, putting upward pressure on prices. As firms come to expect high and rising prices for their products, the expected profitability of investment projects increases relative to the costs of financing. Investment projects that would not be acceptable in a period of stable prices become more attractive when insufficient capacity is forcing prices up. In effect, inflation in the prices of capital and durables lowers the real interest rate, 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 rise in the inflation rate for these assets further reduces real interest rates. During the downturn, the process reverses: caught between growing excess capacity and falling demand, the prices of capital, land, housing, and other assets fall; inflation subsides. The investment climate rapidly changes: firms can no longer expect inflation to boost future revenues, so the expected present value of investment projects falls relative to the cost of financing. Such increases in the real interest rate further discourage investment, creating still more downward pressure on prices, and reinforcing the rise in real interest rates.

If the real interest rate dynamic described above plays a significant role in the long wave, the historical record should show low real interest rates in the expansion periods of the long wave and high real interest rates during the downturns. *Table 11.3* verifies the expected pattern. Because real rates of interest can be measured many ways, the real rate is calculated for both commercial paper and for long-term corporate bonds, using both the wholesale and consumer price indices as measures of the inflation rate. The results are consistent. In the three long-wave downturns since 1870, average real interest rates have been significantly higher than during the intervening upturns. The results are robust with respect to the particular interest rate or measure of inflation used.

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 data in *Table 11.3* show that nominal interest rates incorporate inflation only imperfectly and with a long lag. At the beginning of the

Table 11.3. Real interest rates in the USA, 1870–1984.

Interest rate	*Commercial paper*		*Long-term corporate bonds*	
Deflator	*WPI*	*CPI*	*WPI*	*CPI*
Downturn 1870–1894	8.0	7.3	7.0	6.2
Upturn 1894–1923	1.6	2.2	0.9	1.5
Downturn 1923–1838	4.3	4.1	5.4	5.2
(1923–1932)[a]	8.0	6.7	8.3	7.0)
Upturn 1938–1979	−1.1	−0.7	−0.1	0.3
(1950–1979)[b]	0.6	0.6	1.3	1.2)
Downturn 1979–1984	10.2	9.7	10.9	10.5

[a]1923–1932 reported to remove effects of Roosevelt's reflationary New Deal policies after 1933. [b]1950–1979 reported to remove effects of World War II.

Sources:

Wholesale price index (WPI)
- 1870–1890: WPI, all commodities, HSUS Series E52.
- 1891–1970: WPI, all commodities, BLS.
- 1971–1984: Producer Price Index, all commodities, BLS.

Consumer price index (CPI):
- 1870–1947: HSUS series E135.
- 1947–1984: CPI, all urban consumers, BLS.

Commercial Paper:
- 1870–1900: Annual average, commercial paper (Homer, 1977, Table 44).
- 1901–1936: Prime commercial paper, 60–90 days (Homer, 1977, Table 51).
- 1937–1975: Annual average, prime commercial paper (Homer, 1977, Table 51).
- 1976–1984: Commercial paper, bank discount basis, 6 monthly (Federal Reserve).

Corporate Bonds:
- 1870–1890: Adjusted average of higher grade railroad bonds (Homer, 1977, Tables 42, 43).
- 1891–1975: Prime corporate bonds (Homer, 1977, Tables 45, 47, 49).
- 1976–1984: AAA corporate bonds (Moody's).

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 expand capacity, thus 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 excess demand is highest, while prices and nominal interest rates continue to rise until the excess demand 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 11.1*(*c*) and (*d*) show that, historically, prices and nominal interest rates have in fact moved in phase, with inflation leading nominal interest rates. *Figures 11.2*(*c*) and *11.15* show that simulated prices and interest rates exhibit the same pattern.

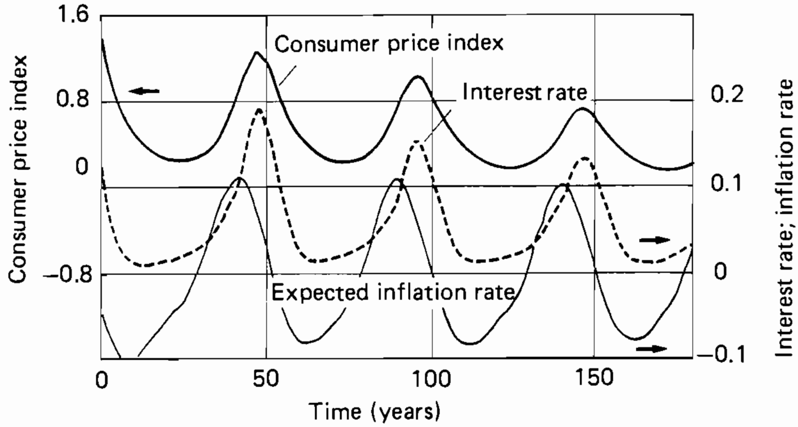

Figure 11.15. Simulation: determinants of real interest rate.

Sensitivity analysis shows the positive feedback loops surrounding interest rates and inflation to be powerful destablizers 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.

11.4.5. Debt/deflation spiral

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

As shown in *Figure 11.16*, 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. Vigorous growth, high rates of capacity utilization, high profitability, and low real interest rates all encourage expansion of external financing. Debt relative to GNP rises and the money supply expands.

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. In such a debt/deflation spiral (Fisher, 1933), defaults and liquidations reduce the stock of money, squeezing nominal

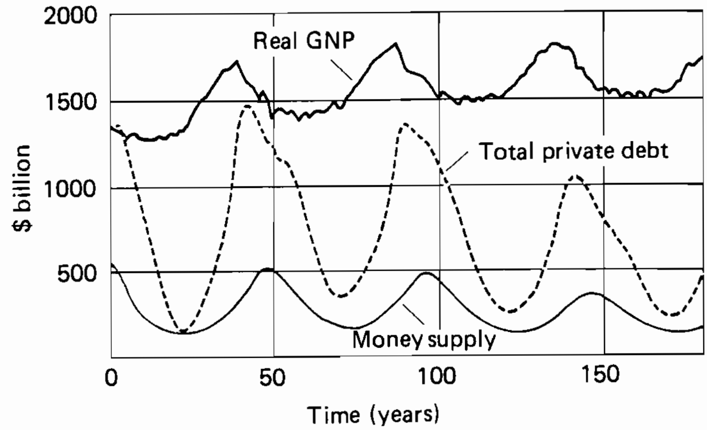

Figure 11.16. Simulation: debt and money supply.

incomes and wealth, forcing further cutbacks in aggregate demand and further price cuts. The dynamics of such speculative manias and panics have been beautifully described by Kindleberger (1978).

As an example, consider the postwar behavior of farmland prices in the USA [*Figure 11.17(a)*]. Between 1950 and 1970, farmland prices rose slightly faster than the aggregate rate of inflation. The real rate of interest a farmer or speculator faced when contemplating the purchase of additional acreage was therefore slightly less than the real interest rate for the economy as a whole. *Figure 11.17(b)* shows the real rate of interest on farmland, computed as the prime lending rate less the rate of inflation in the price of farmland. In the early 1970s, aggregate inflation accelerated dramatically, with interest rates lagging behind. But farm price inflation rose even faster. Between 1973 and 1981, farm price inflation averaged 13.5%/year, compared with 7.7% for the economy as a whole. Despite rising interest rates, a prospective buyer of farmland faced a real interest rate as low as *negative* 16%/year, making farmland one of the best inflation hedges and stimulating demand still further. By 1980 farmland prices had risen so far that revenues from agricultural use could barely cover the debt service. The only motivation for purchasing farmland at such prices was speculative – the expectation of continuing price rises. But with the high debt burdens acquired during the speculative frenzy, depressed agricultural prices, and the decline of aggregate inflation, the demand for land softened. Prices started to fall. Declining prices increased the supply of farmland as speculators attempted to liquidate their holdings and as defaults and foreclosures resulted in distress sales. With the prime rate remaining well above 10% and rapid *deflation* in the price of farmland, the real interest rate on land jumped to over *positive* 20%. As farmers become increasingly unable to pay interest and principal, bank failures and the collapse of other lending institutions increase. The same scenario is being played out to varying degrees in the energy markets, in certain housing markets, and in basic commodities. In all cases, the price rises of the 1970s

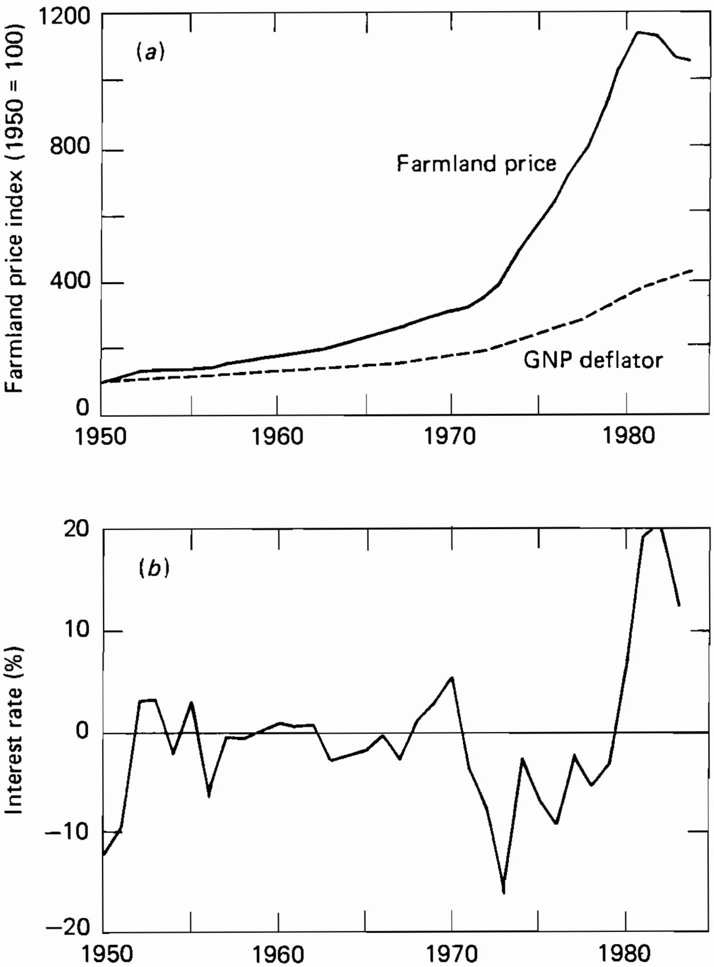

Figure 11.17. (a) Index of US farmland prices and GNP deflator, 1950–1984. (b) Real interest rate on farmland (prime lending rate less inflation on farmland prices).

encouraged the expansion of debt. The end of the inflation is followed by a wave of rescheduling agreements, defaults, and the collapse of the more highly leveraged and least diversified lending institutions.

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 bank and business failures, the collapse of major institutions such as Continental Illinois, the Ohio and Maryland bank holidays, and the current Third World debt crisis are all manifestations of the pressures that may trigger the debt/deflation dynamic on a broader scale.

11.4.6. Technological 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; Rosenberg and Frischtak, 1983). Fifty-year long waves in innovation have been independently identified by several investigators (*Figure 11.18*; Mensch, 1979; Hochgraf, 1983; Kleinknecht, 1984). Renewed commitment to R&D and other policies to stimulate "leading edge" high-technology 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).

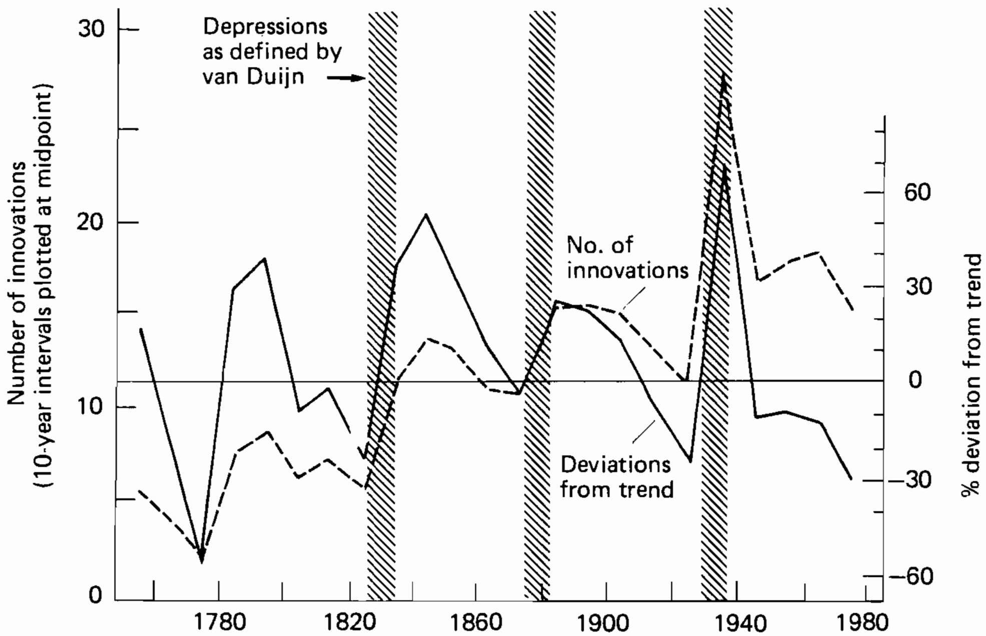

Figure 11.18. Surges in major innovations, worldwide (Hochgraf, 1983).

In contrast to the innovation theories of the long wave, the National Model suggests that 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, pp. 283–284):

> 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.

Although innovation is not necessary to explain the long wave, there is little doubt that each long wave is 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, remain 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.

11.4.7. Social and organizational innovation

Just as the long-wave downturn provides a window of opportunity for technological innovation, so too it creates the opportunity and motivation for social and organizational change. During the long-wave expansion the economy "works" – growth is rapid, unemployment low, optimism the norm. Existing organizations and social contracts are successful. Changes originating within organizations tend to be minor, consisting of "improvement" rather than "basic" innovations. The prevailing attitude is "if it works, don't fix it." Indeed, economic success during long-wave expansions fosters the growth of overhead, unnecessary layers of management, and a decline in entrepreneurship and innovation. But during a downturn, the tried and true no longer works. It becomes clear that the future will no longer be more of the past. Competitive pressures intensify. Individual firms, whole industries, and even nations find they must change or face long-term decline.

Thus it is during the long-wave downturns that the most radical organizational and social innovations occur. But as with technological change it is not immediately obvious what ought to be done. One measure of the organizational flux today is the frenzied search for excellent companies, new management techniques, entrepreneurship, an industrial policy. Past long-wave downturns have also been periods of radical organizational innovation. Although hard data are scarce, one indication of the changes in the organization of industrial society is given by the pace of mergers and acquisitions. *Figure 11.19* shows mergers and acquisitions in the USA since 1895. Three distinct merger waves are visible, with the peak in activity corresponding to the late expansion and early downturn periods of the long wave (Nelson, 1959; Eis, 1969). The British data show similar merger waves (Hannah, 1974).

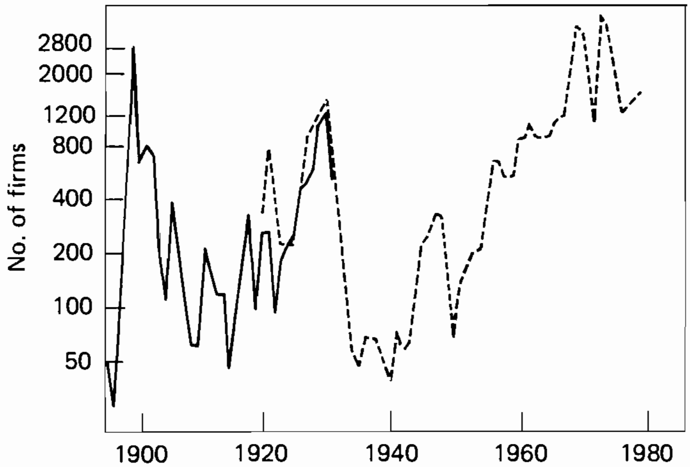

Figure 11.19. Number of firm disappearances by merger and acquisition in the USA, 1895–1980 (Nelson, 1959; Eis, 1969; FTC Report on Mergers and Acquisitions).

Why should merger activity be highest during long-wave downturns? Consider the frequency of merger activity in terms of means, motive, and opportunity. The means: at the end of the long-wave expansion opportunities for physical investment become limited. Overcapacity, declining profitability, and high real interest rates dampen physical investment, reducing cash outflow. However, firms continue to collect depreciation on past investments, hence cash flow improves and liquidity rises. Flush with cash, firms can build a "war chest" to position themselves for takeover bids or to protect themselves from hostile offers. (The cash surplus arising from the decline in investment has also been used to buy back outstanding shares, pay high dividends, or to pay "greenmail".) The motive: since growth through investment in physical capacity becomes unprofitable at the long-wave peak, there is a strong temptation for firms to continue their growth by merger or acquisition. Through merger and acquisition, firms in declining industries can diversify into emerging sectors such as microelectronics and financial services. Most important, competitive pressures intensify during the long-wave downturn. Faced with excess capacity and declining demand, individual firms cut prices in an attempt to maintain market share, sometimes leading to price wars. As the weaker firms are forced out of business, they are bought up by the stronger firms, who by consolidating control of the market can restrict output and support profit margins. The opportunity: concentration of economic power through merger and acquisition is normally viewed with suspicion by government. Antitrust and anti price-fixing laws normally constrain the opportunities for industrial reorganization through mergers and takeovers.

However, as the prosperity of long-wave expansion gives way to stagnation and decline, government becomes less willing to enforce antitrust and other regulations that might impair the ability of the private sector to recover. For example, the Sherman Antitrust Law was passed in 1890 in response to the concentration of economic power that built to a crescendo between 1870 and 1900. Before 1870, the majority of firms were small, owner-run, operated in a local market, and neither vertically or horizontally integrated. The last 30 years of the century saw the birth of the modern, limited-liability, professionally managed, integrated corporation and the greatest concentration of economic power in industrial history. But because these same decades were a period of long-wave downturn that included three severe depressions, two major financial panics, and unemployment that reached as high as 18% (Rezneck, 1968), the government was reluctant to pursue antitrust too aggressively. Similarly, it was not until 1897, as the economy began to recover from the depression of 1894, that the Supreme Court outlawed price-fixing agreements and other forms of collusion between firms. As the economy continued to grow robustly during the first decade of the new century, sentiment against the trusts increased. William Jennings Bryan called for federal regulation of interstate railroads. The Democratic party of New York demanded the nationalization of the coal industry in the wake of the 1902 attempt of the coal industry to break the mineworkers union (Mowry, 1958). In 1902 the government initiated a suit under the Sherman Act against the Northern Securities Company, a railroad holding company whose investors included Morgan, Rockefeller and other members of the capitalist elite. The government won the dissolution of Northern Securities and, when upheld by the Supreme Court, the floodgates of antitrust were at last opened. This was the Progressive Era, the era of the trustbusters and muckrakers. During this expansion period, the government initiated dozens of suits against major conglomerates, succeeding in the break-up of such giants as Standard Oil and American Tobacco, and bringing such powerful industries as the railroads under federal regulation for the first time. Not surprisingly, the data show a sharp decline in merger activity after 1902.

During the 1920s, the government was similarly reluctant to regulate the investment trusts and other financial innovations that sprang up during the great bull market. But after the market crash and depression, the inevitable backlash against the excesses of the roaring 1920s brought the financial industry under federal and state regulation, including the forced divestiture of investment and commercial banking, the creation of the Securities and

Exchange Commission, federal deposit insurance, and a host of other regulatory measures.

In like manner, the stagnation of the 1970s fostered deregulation of numerous industries in an attempt to restore economic growth and competitiveness. Yet even as the Administration continues to deregulate industry and to tolerate the growing merger wave, the forces of the coming regulatory backlash are already visible. For example, the panic and run on Ohio's state-insured thrift institutions, triggered by the collapse of an unregulated government securities dealer, led immediately to calls by some members of Congress for *re*-regulation of the banking and securities industry and to the forced switch to federal insurance for the state-insured thrifts.

The long wave thus modulates the pace of economic and social evolution by altering the incentives for organizational change within and among firms, and between the private sector and government. During expansions, organizations are successful and change is incremental. The organizational theories of the day are reified, overhead grows, rigidity develops. As expansion gives way to stagnation and then decline, the old ways increasingly fail; new theories become attractive. Industry needs and finds opportunities for change. Government permits many such changes to avoid garnering the blame for the stagnation. But after the worst of the downturn has passed and recovery starts, the government exerts more pressure on the private sector to redress the excesses of the previous period. The downturn thus creates a window of opportunity for change. As with technological innovation, the particulars of the social changes in each long-wave downturn are quite different.

11.4.8. 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 USA and the UK reveal statistically significant 50-year value cycles in both countries that coincide 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 student 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 effects of social value shifts on the severity and length of the long wave remain *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; Bergesen, 1983; Thompson and Zuk, 1982). Long-wave research should broaden the boundary of analysis to include the effects of the long wave on international relations, including trade, foreign aid, and conflict.

11.5. Conclusions

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 that 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 decision making 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) *Self-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 involve capital self-ordering, labor market interactions, and real interest rate dynamics.

Other processes such as technological innovation, organizational change, and social progress also change substantially over the course of the long wave. These changes in the surface structure of the economy are captured and entrained by the pulse of the long cycle, which itself is caused by the deep structure of the economy. That deep structure consists of the interactions between the physical system and the behavior of human decisionmakers.

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.

Acknowledgments

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Notes

[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). Common fallacies of causal attribution include the gambler's fallacy and the regression fallacy. See Morecroft (1983) on the connection of bounded rationality and system dynamics. Nelson and Winter (1982) also apply bounded rationality to macroeconomic modeling.

[3] 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 waves established through examination of the numerical data.

[4] Although population and technological progress are exogenous, they are assumed to grow at absolutely uniform fractional rates. Thus, the long wave and its timing in the simulation are not due to exogenous variables.

[5] 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).

[6] Exogenous random noise is still active in the simulation.

[7] 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: $PR_k = INV_g + INV_k$; (ii) production is related to capital stock by the capital output ratio: $PR_k = C_k/COR_k$; and (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: $INV_k = C_k/ALC_k$. See Frisch (1933) and Sterman (1985b).

[8] Sterman and Meadows (1985) describe a participatory simulation game that vividly demonstrates how self-ordering and investment behavior can create long waves. Players manage the capital-producing sector of the economy and attempt to match production capacity to the demand for capital. The game can be played manually or on personal computers. It has been used successfully with students, professional economists, and corporate executives. Copies of the game and floppy disks suitable for the IBM PC are available from the author at: System Dynamics Group, E40-294, MIT, Cambridge MA 02139.

[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] 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.

[11] The real interest rate shown in *Figure 11.13 (a)* is given by the yield of three-month Treasury bills less the rate of inflation as measured by the implicit price deflator.

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CHAPTER 12

The Crucial Influence of Structural Change on Long-Term Fluctuations in Economic Growth

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12.1. Introduction

The observation that growth and change are two indivisible notions applies to nearly all aspects of reality, ranging from human life and scientific knowledge to economic development. It is therefore not surprising to see that this relationship has been an important object of study in many sciences. In some of them this attention has resulted in theories in which the notions of growth and change, their determinants, and consequences were integrated in a fruitful way. It is questionable, however, whether economics belongs to these sciences. Of the two notions, growth has been studied intensively, while change normally has been assumed away or treated only marginally. Maybe the reason for this difference in treatment has to be sought in the fact that economic growth, as opposed to structural change, is relatively easy to recognize, to measure, and to influence, whereas structural change is a slow process that is difficult to distinguish. This development, however, has been at the cost of the awareness that both economic growth and structural change are closely interrelated and cannot develop or function well, in the long term, without each other. In short, without growth no change, without change no growth. (For similar opinions, see Lindbeck, 1983; OECD, 1985.)

In this chapter I argue that (in the long term) no acceptable rate of economic growth – acceptable in terms of a country's employment situation – is possible without an adequate rate of structural change. Furthermore, this process of change shows an alternation of periods with faster and slower levels of development, ultimately causing the long-term fluctuations in economic growth known as long waves. After a short discussion of structure and structural change, the determinants and the consequences of the process of structural change are analyzed, and their influence on long-term economic development, creating wave-like fluctuations, is described.

12.2. Economic Structure and Structural Change

At any given time, a national economy is capable of producing goods and services: whether or not this capability is fully used depends on the decisions of the relevant economic actors and on the way the decision-making process is organized. What and how much can be produced depends on the available economic structure, i.e., on the precipitations of decisions made in the past. By "structure" we mean a whole array of elements that can be treated as constant in the short term, such as the environment, the volume and quality of the labor force, existing capital stock, and the level of technological knowledge.

However, the notion of economic structure must not be confined to the production side alone. Based on the assumption that final demand is the sole end and purpose of the economic process, the volume and composition of intermediate and final demand are elements that also have to be taken into account. Demand also has a strong influence on the structure of the external relationships of a country. Availability, as well as demand preferences due to price or quality, shape the volume and content of the imports of a country, in the same way as the interplay between the internal structure of production and external demand shape its exports. Both demand and, to a lesser extent, external relations have the same characteristic quality as economic structure: they change slowly.

This broad concept of economic structure, with its attention to production, consumption, and external relations determines the growth possibilities of a country. As will be made clear below, all the aspects mentioned here, although treated as constants in the short term, show gradual changes over a longer period of time. When these changes are one-way and normally irreversible, then they can be called structural changes. Mentioning a structure inevitably means some kind of sectoral division. Depending on the question to be investigated, several criteria can be used to divide an economic structure. Differences in long-term growth, productivity, income elasticity, innovativeness, competitive pressures (internal or external), are all criteria according to which a structure can be divided into more homogeneous parts (see, for example, Rostas, 1948; Salter, 1969; Pratten, 1976; Wohlin, 1970; Carlsson, 1981).

The basic level to be distinguished is that of an individual product, be it a good or a service. For each product, it is possible to sketch a product life cycle, indicating the several periods of introduction, rapid growth, stagnation, and decline. During such a cycle, changes occur with respect to demand and thus output, to productivity, and to price. Aggregating these individual life cycles gives the economic development at the level of a firm, an industry, or a sector. Of course, each higher level makes the underlying changes within a certain unit invisible, but it is clear that they must be fulfilled to realize the required economic growth.

To give a first impression of the extent of the phenomenon of structural change, *Tables 12.1* and *12.2* show some data at a very high level of aggregation. *Table 12.1* gives the distribution of employment and value added in the three main sectors of an economy: agriculture, industry, and services.

Table 12.1. Development of employment share and value added share of agriculture, industry, and services, 1960–1983, for some major industrial countries.

		Employment share			*Value added share*		
Sector	*Region*[a]	*1960*	*1972*	*1984*	*1960*	*1972*	*1984*
Agriculture	OECD	21.6	12.7	9.1	6.5	5.0	3.0
	EC	21.1	12.0	8.9	8.4	5.7	3.7
	USA	8.5	4.4	3.3	4.0	2.8	2.0
	Japan	30.2	14.7	8.9	12.6	5.5	3.2
	FRG	14.0	7.7	5.6	5.8	3.0	1.9
	UK	4.7	3.0	2.6	3.4	2.5	1.9
	France	23.2	12.2	7.9	10.6	6.5	3.9
Industry	OECD	35.4	36.4	31.3	39.9	38.4	34.4
	EC	39.8	40.8	34.3	43.5	41.1	35.8
	USA	35.3	32.5	28.5	38.3	34.1	31.7
	Japan	28.5	36.3	34.8	44.5	45.6	40.8
	FRG	47.0	47.8	41.3	53.1	47.1	37.2
	UK	47.7	42.9	32.9	42.8	38.8	36.4
	France	38.4	39.6	33.0	39.0	38.2	34.4
Services	OECD	43.0	51.1	59.5	53.6	56.6	62.2
	EC	39.1	47.1	56.7	48.1	53.5	60.6
	USA	56.2	63.1	68.2	57.7	63.1	66.3
	Japan	41.3	49.0	56.3	42.9	49.0	56.0
	FRG	39.1	44.5	53.1	41.0	49.9	60.9
	UK	47.6	54.1	64.5	53.8	58.7	61.8
	France	38.5	48.1	59.1	50.4	55.4	61.7

[a]OECD = mean of the 24 member states. EC = mean of the 10 member states.
Source: OECD (1986), *Historical Statistics, 1960–1984.*

Even at this high level of aggregation, neglecting all the intrasectoral changes, major developments have occurred over the period considered. For instance, for the OECD a decline in the employment share for agriculture, from 21.6% to 9.1%, and for industry, from 35.4% to 31.3%, gave way to an increase in the employment share for services from 43.0% to 59.5%. Individual countries showed similar changes.

Another remarkable structural change occurred in the external relations of countries. Although with important differences between countries in

Table 12.2. Exports and imports of goods and services, as a percentage of GDP, 1960–1984, for the major OECD countries.

	Export			*Import*		
Region	*1960*	*1972*	*1984*	*1960*	*1972*	*1984*
OECD	11.6	14.0	18.2	11.1	13.4	18.7
EC	19.9	23.1	31.9	19.7	21.7	30.9
USA	5.1	5.7	7.5	4.4	6.1	10.5
Japan	10.8	10.6	15.1	10.4	8.3	12.4
FRG	19.0	20.9	31.1	16.5	18.9	28.6
UK	21.1	22.2	29.1	22.5	22.2	29.0
France	15.0	17.2	25.4	12.9	16.3	25.2

Source: OECD (1986), *Historical Statistics, 1960–1984.*

level, the trend toward stronger integration among the developed countries can be clearly distilled from the figures in *Table 12.2. For the whole OECD area, the* export or imports of goods and services as percentage of GDP increased considerably, from 11.4% to 18.2%, in less than 20 years.

These structural changes, as represented in *Tables 12.1* and *12.2,* occurred in a period in which indicators as real GDP per capita and the rate of employment initially showed very prosperous results. Eventually, however, the situation has deteriorated rapidly, as can be seen from *Table 12.3.*

Table 12.3. Development of GDP per capita and standardized rate of unemployment, 1960–1984, for the major OECD countries.

Indicator	*Region*	*1960–1967*	*1967–1973*	*1973–1979*	*1979–1984*
Real GDP	OECD	3.9	3.9	1.9	1.1
per capita	EC	3.5	4.3	2.2	0.7
	USA	3.2	2.5	1.6	0.9
	Japan	9.1	8.0	2.5	3.1
	FRG	2.9	4.5	2.6	1.0
	UK	2.3	3.0	1.4	0.5
	France	4.3	4.7	2.7	0.6
Standardized	OECD	2.7	3.1	4.9	7.4
rate of	EC	2.3	2.9	4.9	9.4
unemployment	USA	4.2	4.4	6.7	8.2
	Japan	1.2	1.2	1.9	2.4
	FRG	0.6	1.0	3.2	6.0
	UK	2.5	3.4	5.3	10.7
	France	1.2	2.5	4.6	7.9

Source: OECD (1986). *Historical Statistics, 1960–1984.*

With these data in mind, giving a first indication on the direction and the importance of the process of structural change, in the following section we will describe and analyze the determinants and consequences of this process.

12.3. Determinants and Consequences of Structural Change

In describing the process of economic development in an open economy, a process in which economic growth, structural change and increasing internationalization are essential features, it is useful to base the analysis on the development of an individual product, along a product life cycle (see van Paridon, 1985). Depending on the characteristics of each product and on the behavior of the relevant actors, product life cycles differ with respect to the duration, potential market size, the process of market expansion, demand for labor, capital, and other inputs, etc. At a given time, an examination of a national economy reveals a whole spectrum of products, all at different points in their respective product life cycles. Some products are still in the introductory phase, others are in the phase of rapid growth, while the remainder can be placed in the phases of stagnation or decline. When this observation is compared with an earlier one, it is possible to observe the changes that have occurred.

On the one hand, these changes are caused by developments on the supply side. Because of technological progress, both disembodied through "learning by doing", for instance, and embodied through investment (both of which vary for each product/industry/sector), changes can occur in the structure of productivity, in turn causing changes in the price structure and the demand for labor and other inputs. The level of investment depends strongly on the rate of profit, i.e., on the performance of the product in an earlier period. The higher the rate of profit, the better are the opportunities for new investments and so for productivity increases, thus improving the market chances of the product. Because of structural differences in productivity development between products and in the opportunities to utilize embodied technological progress, this process must give rise to major changes in the structure of productivity, relative prices, and employment.

On the other hand, demand also exerts an influence. Preferences for individual products – for final demand, intermediate use, or for investment – depend on the way the quality of a product is appreciated by the buyers, on the per capita income level, on the necessity to use certain products as inputs or as investment, and on the relative prices. In the long term, price elasticity is judged to be less decisive (see Goergens, 1975). This preference can be represented by the income elasticities of the products. Because of differences in income elasticity between several products/industries/sectors, growth in income must result in a change in the structure of total demand.

For an individual product, a "virtuous circle" of development can now be outlined. This process is based on the ideas of Kaldor; for a description see Thirlwall (1983). High output in an earlier period has resulted in high profits. These profits are used for new investments, embodied with the most recent available technological knowledge, also allowing organizational changes. This allows productivity increases and an improvement of the price/quality relationship, which can expand output sales once again. Continuation of this process depends on productivity increases on the one side, and on market expansion, creating further economies of scale, on the other, i.e., on the way the several market signals are recognized and incorporated in the production process and marketing strategy. Of course, a "vicious circle" of development is also possible, due to bad starting conditions or hitches that may occur in the cumulative process.

The cumulative way of reasoning can be equally well applied at the level of the national economy, with two adjustments. First, at that level, the individual cycles are interconnected through intermediate deliveries and investment. A higher demand for one product can create a higher demand for inputs (backward linkages), or a new product or a technology can create new (market) possibilities in those sectors that use this innovation through investment or intermediate deliveries (forward linkages). This mixture of individual product life cycles, all of which gradually change over time, and also of changing input–output relations result in a complex pattern of structural change at the level of the national economy from the supply side. This complexity is reinforced on the demand side by changes in the pattern of consumption, described in Engel's law. An increase in per capita income, a consequence of a sufficient rate of economic growth, results in changes in the consumer preferences, and so in income elasticity. Normally, the income elasticities of existing products decline over time; new attractive products start with a high income elasticity. With these points in mind, a cumulative process of economic development can be sketched, as shown in *Figure 12.1*.

In this process, economic growth and structural change are treated as inseparable elements, each one a necessary condition for the fruitful development of the other. The main point is that necessary changes to create new products and/or new markets have to be realized – in the right volume, in the right direction, and at the right time – to maintain a sufficiently high rate of economic growth and adequate level of employment, bearing in mind that productivity increases and/or stagnating demand reduce labor requirements in the production processes for existing products. As long as these changes are realized, the prospects for economic growth can be considered favorable, economic growth that in turn creates the basis for further structural change.

So far, a closed economy has been assumed. With *Table 12.2* in mind, this cannot be called a realistic description of the actual economic development. The introduction of external economic relations has several consequences. Each country can try to make use of export opportunities to expand their markets, thus benefiting from further economies of scale. At the same time, each country has to be aware of competition in internal markets. Of course, some products have to be imported to satisfy intermediate or final demand, if no substitutes are available. For most industrial products and services, however, the more industrialized countries have the option of producing them themselves or importing them, which implies that they can compete on foreign as well as domestic markets in order to realize their expected sales. This relationship means a further strengthening of the relationship between economic growth and structural change [this description resembles certain export-led growth theories, such as that of Lamfalussy (1963)].

The consequence of economic growth may be that consumers develop a stronger preference for imported products. Further, other countries can

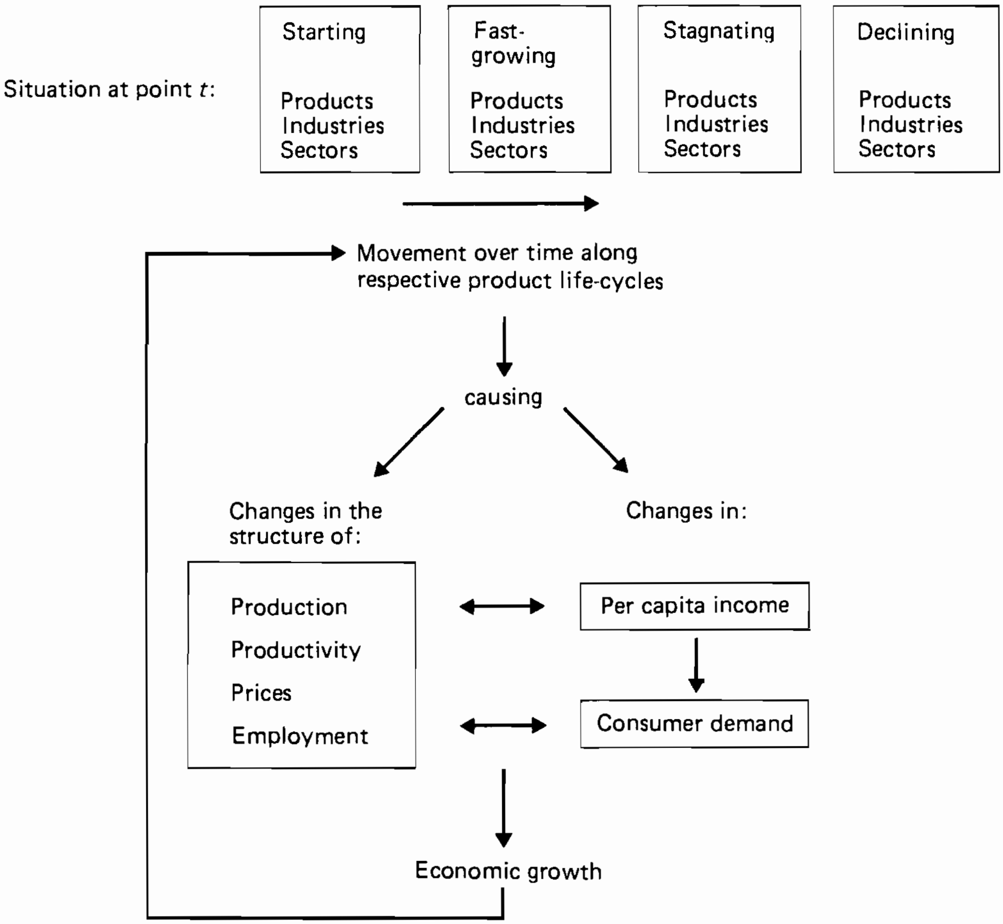

Figure 12.1. The relationship between economic growth and structural change in a closed economy.

show higher growth rates, which may imply that the price/quality characteristics of their products show relative improvements, making their products even more attractive to domestic consumers. A country now also has to take into account changes in demand in all other relevant countries. Besides these demand-oriented effects, there is a very strong supply-oriented element that makes the growth/change relationship crucial. Countries differ in their level of technological knowledge, and in their factor rewards, more or less according to their per capita income levels. Countries that are in a leading position then have to ensure that sufficient new products/technologies are developed in order to keep that position. The countries that follow try to improve their positions by increasing their level of technological knowledge, buying patents or licenses, or by allowing direct investment/joint ventures, and to profit from their relatively lower factor rewards, especially for labor. In this way they start to compete on those markets that have so far been out of reach to them. This process can be recognized at every level of development.

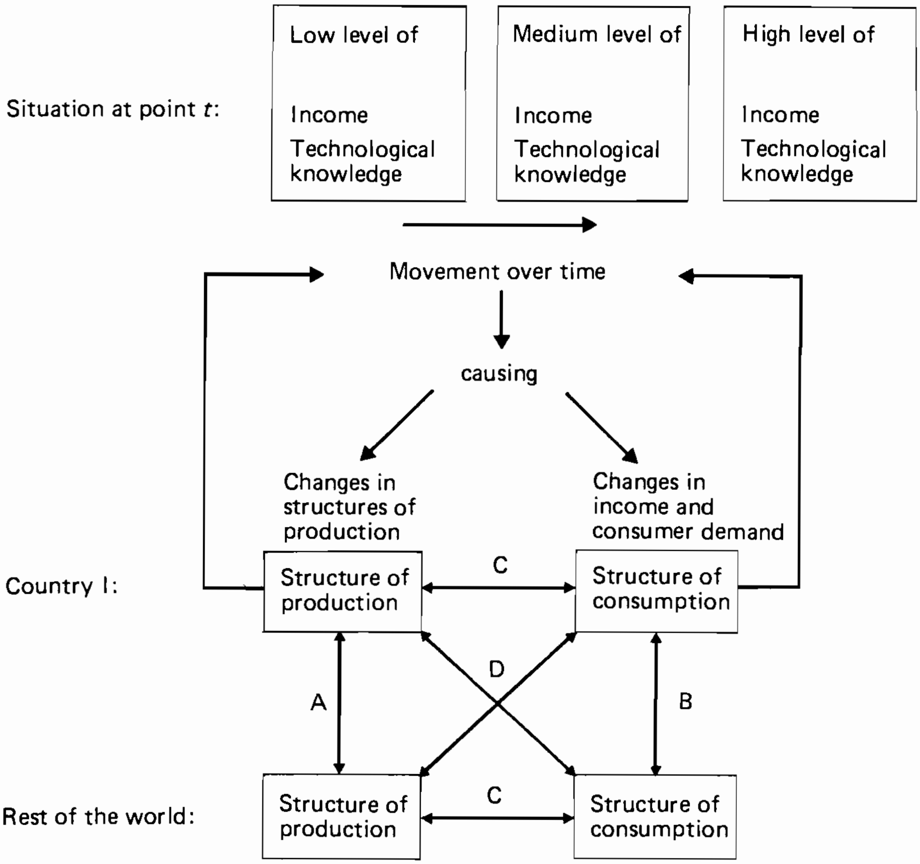

Figure 12.2. **The relationship between economic growth and structural change of production and consumption in an interconnected world.**

Figure 12.2 gives a schematic representation in which A gives the external relations with respect to intermediate demand, direct investments and technology streams, creating international trade and/or capital movements. Not so important is the international "keeping up with the Joneses" effect under B. With C the internal relationships between consumption and production are given, while D gives the same relationship but now between different countries, implying international trade in final products.

The description of the determinants and consequences of structural change thus yields a picture of a complicated and important relationship between economic growth and structural change. In the following, a possible explanation of the long-wave phenomenon is given, which stresses the impossibility of continuing the two interrelated processes of economic growth and structural change over a longer period of time.

12.4. Long Waves: Long-term Growth Fluctuations Caused by Structural Change

The influence of structural change on long-term fluctuations can be attached to the four phases usually discerned in a long wave: recovery, prosperity, recession, and depression. *Figure 12.3* shows a wave-like pattern of economic development, seen as smoothed deviations of the long-term trend. The dating of the phases is connected with the points of inflection of this cycle, and three possible courses of the recession (and depression phase) are given. In these last phases human decisions determine the length of the phases, making their course less determined than in the phases of recovery and prosperity, where technology ultimately determines the course.

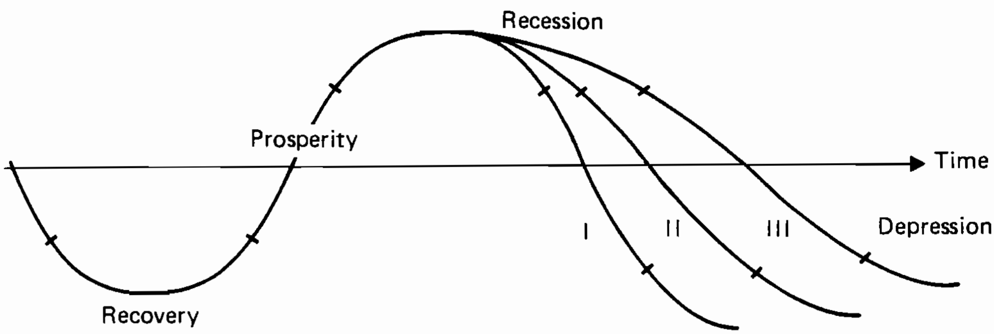

Figure 12.3. Possible courses of a long-wave development, showing smoothed deviations of the long-term trend, and the timing of the various phases.

The recovery phase begins when the several necessary conditions for growth are fulfilled. These conditions concern the economic structure of a country in the broadest sense, the motivation of the economic actors to react to necessary changes, and the development of relative factor costs. The most important condition that has to be met is that there should be a close correspondence between the output produced and the intermediate and final demand, with regard to volume, quality and price, at home and abroad: what can be produced, can be sold. The preceding depression phase has especially influenced the production structure; old declining sectors are trimmed, disinvestment in unprofitable sectors has taken place, and labor has moved out. These processes of scrapping involve high economic and social costs, and at first meet heavy resistance. After a time, this resistance declines and changes are reluctantly accepted. This process of scrapping has also to take place within the existing institutional framework, where adjustment is needed to cope with changing requirements.

As soon as these adjustments are realized, a period of economic recovery can begin, but this requires two other necessary conditions: sufficient motivation of all relevant actors and a favorable international economic climate. The process of starting new investment projects, of taking risks, of moving to other sectors or locations, of looking for something new, is strongly connected with a determinant that is not often mentioned in economic theory – motivation (see Neuberger and Duffy, 1976, for a clear exception). This relates to the way economic actors are willing or forced to bring about those changes or to cooperate in their fulfillment; without motivation the process of change will end in deadlock. In this respect, the postwar "reconstruction" comes to mind as an example, as does the way the Japanese are involved as participants in the economic process. The risk of new investments is also reduced because of the decline in factor costs, as a result of a prolonged situation in which supply of factors of production exceeds demand.

Such a situation in which old, non-profitable parts are scrapped, motivation is high, and factor costs are relatively low, can positively influence investment and so bring about a process of economic recovery. An added impetus can be given by governments, such as through increasing investment in infrastructure. But such an economic recovery is only possible on a global scale, when all these requirements are fulfilled in most of the developed countries. Only then will the urgently desired situation of higher demand on a global scale, with all its connected advantages, be realized. It was this necessary resemblance between the industrialized countries in the postwar period that boosted their economic recovery.

The transition from the recovery to the prosperity phase can be characterized by definitive breakthroughs of certain new sectors and/or technologies whose development had previously been hampered because of the high risks for investment, and the still unknown technological possibilities and potential markets. As soon as those temporary, but often large, problems are overcome, demand increases, which stimulates further investment, raising productivity and so lowering relative prices. Some of these new sectors develop into leading ones and influence the economic structure profoundly through backward and forward linkages. The whole economy shows a relatively high growth rate. So far, this higher demand has not resulted in frictions on the several factor markets. As long as all available factors are not yet completely utilized, prices remain at their initial levels. Only when demand and supply more or less balance, an upward pressure on prices begins. On the one hand, this stimulates final demand once again because of higher wages, but on the other it implies higher production costs. This increase in costs can sometimes be neutralized through higher productivity, but for many sectors, especially the service-oriented and sheltered ones, only price increases can restore the old level of profits.

The rise in factor costs, followed by more general price increases, stimulates the search for process innovations at the cost of product innovations.

This change is strengthened because of the growing stock of accumulated investments that can only remain profitable through streamlining the production process and removing all redundant elements. Disinvesting and moving the capital to other, more promising products/industries/sectors becomes a more difficult strategy. These are the first signs of rigidity, just at a time when major adjustments are needed.

Two other processes put even stronger pressure on adjustment. First, the fall in unemployment means an increase in real wages, and thus in per capita income, creating structural changes in demand toward those (new) products with high income elasticities. These changes in demand are normally attended by stronger preferences for imported products, because of unique, non-price characteristics (this is in line with the trade approach; see Linder, 1961). Of course, similar developments can be noted in other countries with respect to their products.

The second impetus for major adjustments emanates from developments in other countries in two different ways. During recovery and prosperity, countries can follow a cumulative growth process, either a virtuous or a vicious circle of development, as described above. Those countries with a virtuous circle of development show high growth rates, and favorable productivity and export development, and thus encourage new investments and necessary adjustments. As long as these changes occur in the right volume, in the right direction, and at the right speed, the process can continue without major problems. When these changes fail, however, the country can end in a vicious circle of development with less prosperous results and prospects. Once in such a circle, extraordinary measures are required to break out of it.

Another external influence has a different source. As the phase of prosperity continues, the resources to realize more process innovations gradually dry up. Some countries try to overcome such a position by diverting their research and development expenditures and investments into new directions, making use, if possible, of knowledge created elsewhere. Those countries that do not anticipate in this way makes themselves economically more vulnerable, because firms can decide to invest in other countries. One reason to adopt such a strategy may be to lower transport costs or to be closer to an important market; another reason can be to profit from differences in the level of technological knowledge in two ways. Firms can invest in countries with higher levels of economic development, normally with more advanced technological knowledge, for instance, to upgrade their own technological possibilities or to be close to markets that are receptive to high-technology products. Or they can invest in countries with lower levels of economic development, particularly with much lower labor costs. In both ways, profits are higher than they would be otherwise. At the same time, this development creates new competitors on already stagnating markets.

All in all, changes in demand, cumulative differences in growth rates between countries, and increasing competitive pressures from other countries, both at the high and at the low technology markets, are arguments for stronger adjustments in the economic structure of a country. And just when firms are exhibiting a more conservative investment behavior, creating a negative influence on overall demand and expectations, several sectors are starting to lose in competition with other countries, profits are undermined, and unemployment starts to rise, making workers reluctant to move. Instead of realizing the adjustments necessary to turn the tide, all the economic actors have good reasons to choose a more defensive attitude to prevent further erosion of their position. It is this stalemate that induces the economic contraction into the downward phases.

The recession phase can be characterized by the ever-widening gap between required and actual structural changes. Economic actors try to protect their interests, also by invoking government assistance through subsidies, employment guarantees, and trade protection measures. Wages remain high at first. On the whole neither the capital nor the labor market function as required. Besides increasing rigidities on those markets, the institutional framework (designed in the recovery and fast growth phases) also starts to show signs of rigidity. It was built for different purposes, not for coping with new circumstances. As long as one country or an unimportant minority of countries is hit by these recessionary tendencies, the situation at the global level can still return to more prosperous development. But as more and more countries show these tendencies, further aggravations of the economic situation become visible because of a trade slump or an unexpected oil price increase, for instance, and the depression phase is ushered in.

The main process in the depression phase is that of the adjustment of the economic structure to a new global equilibrium between demand and supply. These adjustments range from a downward movement of real factor rewards to the reconstruction of certain sectors. It will be clear that the costs of this process, personal as well as social, are considerable, implying a strong resistance to such measures. It is not only a long and painful process, it can also be dangerous. Nationalistic feelings and the search for scapegoats sometimes predominate if no realistic alternative is available. Such a realistic policy alternative has to be effective and acceptable: effective in realizing the necessary changes and in implementing new promising activities than can generate new growth and employment; and acceptable in the sense that the public is aware of the fact that this policy, with its current sacrifices, is necessary to create the right conditions for renewed economic prosperity.

12.5. Concluding Remarks

In this chapter the importance of structural changes in long-term economic development has been analyzed. After showing some important changes (albeit at an aggregated level) in the economic structure of the major industrialized countries, the determinants and the consequences of structural change were analyzed. It is clear that structural changes are a multiform phenomenon, working on several levels, on the supply and demand side, within and outside national economies. The main conclusion is that economic growth and structural change are strongly interdependent, in such a way that a positive development of the one is a necessary condition for a positive development of the other. In other words, growth is stimulated by structural change and influences it at the same time, while the achievement of structural change is necessary to continue the process of economic growth.

The process of structural change is embedded in a theoretical explanation of long-term fluctuations in the economic process. Roughly, structural changes in the production structure show long-term fluctuations in such a way that the production structure changes relatively more during the depression and recovery phases and relatively less during the prosperity and recession phases. Long-term economic growth enters its upswing when the production structure, after a long and painful process of adjustment, more or less balances the consumption structure in combination with a balance of payments equilibrium. Then, because of important changes in technology, of the emergence of new leading sectors, and of changes in the volume and content of the external economic relationships, the production structure changes considerably. Inevitably, the time comes when the process of structural change in the production structure slows down because of increasing rigidities on several markets, the lack of new products/technologies to provide employment and to guarantee further economic growth, the exhaustion of possibilities to increase productivity, and the increased competition on the world market. This slowdown takes place at a time when major adjustments are needed. When a majority of the economically more important countries are caught in such a web, a depression is inevitable.

A solution is possible only when all those countries break the circle as described in this chapter. This requires a radical and deliberate long-term economic policy, both at the national and the international level. It has to be radical to realign the structure of production with that of demand. It has to be deliberate in its weighing of present adjustment costs and future returns. It has to be on both the national and international levels to restore a more stable pattern of economic development within each country and, equally, more reliable economic relationships among countries. Doing nothing or reacting inadequately will only prolong the depression. This chapter has, it is hoped, given some insights toward designing such a policy. The depression of a long wave is not necessarily unassailable.

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CHAPTER 13

The Law of Value and Structural Shifts in a National Economy

K.K. Val'tukh

The purpose of this chapter is to describe methods and first results of analyses of interconnected changes in production expenditures and in production structure, taking into account direct material and labor costs. In accordance with the theory of value, they are to be combined and generalized in the total labor input coefficient w:

$$w = wA + \mathbf{l} \tag{13.1}$$

where $w = (w_1,..., w_j,..., w_n)$; $j = 1,..., n$ is an index of production items; n is the number of production items; $A = \{a_{ij}\}$ is a quadratic matrix [1] of material input–output coefficients; a_{ij} $(i = 1,..., n)$; and $\mathbf{l} = (l_1,..., l_j,..., l_n)$ is a row vector of direct labor input coefficients. Data from input–output tables are used, together with analogous information on the intersectoral distribution of labor inputs.

Calculations have been performed for market economies; w can be considered as a first and sufficiently correct approximation of commodity values. Dynamic input–output tables were used to analyze essential interconnections between structural changes in productive inputs and in gross outputs in so far as one part of gross output, e.g., material input compensation fund **H**, is presented in each table as a vector that depends on matrix A:

$$\mathbf{Q} = \mathbf{H} + \mathbf{Y} \tag{13.2}$$

where $\mathbf{H} = A\mathbf{Q}$; $\mathbf{Q} = (Q_1,..., Q_i,..., Q_n)$ is a column vector of gross output; **H** is a column vector of the part of gross output destined for material input compensation; and **Y** is a column vector of net output. Since the coefficients of matrix A are simultaneously used to calculate w, it is possible to analyze the interconnected changes in the structure of commodity output and values.

In market economies, the law of value forms a socioeconomic mechanism of technological progress. It is a process of change in individual technologies toward reducing the value of individual commodities, which can be expressed by

$$w_j^k = wa_j^k + l_j^k \tag{13.3}$$

where w_j^k are individual total labor expenditures per unit of product j by firm k; $k \in E$, where E is a set of firms in a given economy; $a_j^k = (a_{1j}^k, \ldots, a_{nj}^k)$ is a column vector of direct material input–output coefficients in firm k; l_j^k is an analogous direct labor input coefficient; and w is the value vector [see equation (13.1)]. Given w for the economy, technologies reveal a tendency to decreasing w_j^k values. Let values $w_j(t)$ and $w_j^k(t)$ be considered given for a time period t. Then it can be predicted that there will be a general tendency to expand for technologies k such that $w_j^k(t) < w_j(t)$. Changes of technologies are nothing else than some interconnected changes in coefficients a_{ij}^k and l_j^k. It should be added that changes in various technologies' shares in production, taken independently of shifts in a_{ij}^k and l_j^k, cause changes in the generalized coefficients a_{ij} and l_j because the latter are average quantities:

$$a_{ij} = A_{ij} / Q_j$$

where

$$A_{ij} = \sum_{k \in E_j} a_{ij}^k Q_j^k \qquad Q_j = \sum_{k \in E_j} Q_j^k$$

Analogously,

$$l_j = L_j / Q_j \qquad L_j = \sum_{k \in E_j} l_j^k Q_j^k$$

where E_j is a set of firms k such that $Q_j^k > O$ (by convention all production expenditures of multiproduct firms are directly and completely distributed among all outputs). Changes in the coefficients comprising matrix A and vector **l** are thus functions of changes in technological coefficients a_{ij}^k and l_j^k, and in the shares of technologies in production (outputs Q_j^k). Changes in the technological system influence shifts in the production structure through the process of forming the compensation fund **H**.

Table 13.1. Input–output table for 147 US industries, 1963. Large groups by hourly labor productivity growth rates (billions of constant 1972 dollars except where noted).

	A_{ij}						L_i	W_i	Q_i in current prices
$i \backslash j$	I	II	III	H_i	Y_i	Q_i	(millions of workers)		($billions)
I	78.3	47.1	30.3	155.7	329.0	484.7	24.2	39.7	333.3
II	66.2	116.5	37.1	219.8	200.2	420.0	17.1	33.8	325.7
III	48.7	52.2	93.6	194.5	133.5	328.0	13.5	25.6	276.0
Total	193.2	215.8	161.0	570.0	662.7	1232.7	54.7	99.1	935.0

Table 13.2. Input–output table for 147 US industries, 1973. Large groups by hourly labor productivity growth rates (billions of constant 1972 dollars except as noted).

	A_{ij}						L_i	W_i	Q_i in current prices
$i \backslash j$	I	II	III	H_i	Y_i	Q_i	(millions of workers)		($billions)
I	105.4	67.6	53.8	226.7	461.0	687.7	33.2	47.9	747.4
II	83.6	158.1	71.5	313.2	308.9	622.1	19.8	37.7	666.4
III	71.2	94.6	166.9	332.7	248.3	581.1	14.5	29.6	639.4
Total	260.2	320.3	292.2	872.6	1018.2	1890.9	67.6	115.1	2053.3

Hence, the law of value determines the direction of shifts in the production structure through changes in structure of both production and non-production requirements. These are the result of technological progress which, in turn, tends to reduce commodity values. In a market economy the law is also an economic mechanism through which structural shifts in production occur; this is the well known competitive market mechanism "demand–supply–prices". Interconnections between commodity values, growth rates, and structural shifts in production are discussed here. An elaborated analytical scheme has been applied to input–output statistics for the USA, 1959–1975, in particular, for 1963–1973. In limited aggregated form, the results of calculations are shown in *Tables 13.1–13.4* (in constant 1972 dollars) [2].

Table 13.1 is an input–output table for 1963 for three groups of industries obtained by aggregating the initial 147 industry input–output table. *Table 13.2* is an analogous table for 1973. *Table 13.3* shows increment rates derived from the transition from *Table 13.1* to *Table 13.2*. *Table 13.4* presents increment rates of a set of coefficients indicated. Increment rates are designated by I; for example, IA_{ij} is an increment rate of A_{ij}; i.e., $IA_{ij} = (A_{ij}^{1973}/A_{ij}^{1963}) - 1$, etc.

There are 153 sectors in the original data, but non-commodity sectors such as banking, credit agencies, insurance, real estate, and nonprofit organizations were excluded from our calculations since the set of processes is considered from the point of view of the theory of value (i.e., the law of commodity prices). Correspondingly, material expenditures in these sectors are only a part of net output **Y**, and are not part of compensation fund **H**. The 147 commodity-producing industries (including services), as shown in *Tables 13.1* and *13.2*, have been aggregated into three groups (I–III) using an index of the growth rate of hourly labor productivity. Group I contained 47 industries with the lowest growth rates, and groups II and III contained 50 industries each, with middle and highest labor productivity growth rates. Regularities can be determined from such highly aggregated data.

In theory, the main goal of technological progress is to increase labor productivity. The data are of sufficiently high precision to test this theory.

Labor productivity growth rates are thus taken as an indicators of technological progress. *Table 13.3* shows that technological progress estimated in such a way increases more rapidly in expanding sectors of the economy: increment rates of production IQ grow from group I to group III, and the groups were constructed based on labor productivity indices. The same can be seen in *Table 13.4* (column 5), where average labor productivity growth rates are calculated per worker (instead of hourly).

These observations are theoretically important: increases in output are achieved with the use of advanced technology, the spread of which is faster in such industries that are able to meet rising demand for their products by increasing output at a correspondingly rapid rate. Higher growth rates in industrial production are achieved by firms that introduce advanced technology, and these firms are obviously characterized by higher labor productivity growth rates.

Table 13.3. Input–output table for 147 US industries, 1963 and 1973. Large groups by hourly labor productivity growth rates. Increment rates of flow (%).

	IA_{ij}								IQ_i
$i \backslash j$	I	II	III	IH_i	IY_i	IQ_i	IL_i	IW_i	*in current prices*
I	35	44	78	45	40	42	37	21	124
II	26	36	93	42	55	48	16	12	102
III	49	83	78	71	86	77	7	15	132
Average	35	48	81	53	53	53	24	16	119

Table 13.4. Input–output table for 147 US industries, 1963 and 1973. Large groups by hourly labor productivity growth rates. Increment rates of coefficients (%).

	IA_{ij}					
$i \backslash j$	I	II	III	$I(Q_i/L_i)$	Iw_i	Ip_i
I	−5	−3	0	4	−15	58
II	−11	−8	9	28	−24	38
III	5	22	0	65	−35	31
Average	−5	0	2	23	−24	43

Moreover, the demand for labor falls as production growth rates increase: $IL_I = 37\%$, $IL_{II} = 16\%$, and $IL_{III} = 7\%$ (see *Table 13.3*). The higher is the output growth rate, the higher is the share of labor productivity in the production increment. An additional statistical corroboration of this assumption is that technological progress is achieved more rapidly in expanding industries in order to economize expenditures on labor, and thus the demand for labor.

The use of additional labor resources in production was a feature of the first (conservative) group of industries. Hence, the industrial structure of labor is a much more conservative economic phenomenon than the output structure. Moreover, it is clear that the real increases in jobs achieved by conservative technologies was the source for the growth in output of group I (without noticeable increases in labor productivity; see *Table 13.4*). But it may be justified to assume that national economic development can be achieved without a large technologically conservative sector. In the absence of such a sector, it can be questioned whether there would be an increase in employment; it is theoretically not excluded that in capitalist economies, the higher the growth rate, the higher will be the rate of unemployment. Note, however, that in Japan in 1960–1970 the analogous third group of industries achieved high growth in output with real employment reduction (P.N. Tesla's unpublished calculations). The cause could be the interconnection between increases in growth rates and the use of new technologies that are less labor-intensive than previous ones.

The increase of some industries share in gross national output **Q** originates in their increased share in the entire fund of material production expenditures. For example, in group III the sum of material expenditures (in

1972 dollars) grew in the period considered by 81%, with an average increase in fund **H** of 53% (*Table 13.3*). This is an example of the theoretical law of the tendency for firms to produce goods that are then used in other fast-growing (progressive) industries. Increases in the output of progressive industries can be achieved without increases in labor expenditure; but this is connected with the use of an increasing proportion of all material resources. The opposite (relatively high incremental rates of labor expenditures with low rates of material ones) is characteristic of conservative industries (group I, see *Table 13.3*). It can thus be concluded that in the USA in 1963–1973 there was a combination of two essentially different types of technological development. There is an additional factor of high increases in material expenditures in group III, i.e., an increase in the total of input–output coefficients (see *Table 13.4*), but this is not an essential property of technological progress [3].

Note that each large group shown in *Tables 13.1–13.4*, includes industries belonging to various sectors of the economy (e.g., agriculture, metallurgy, machinery etc.). It is remarkable that such groups (constructed on the basis of indicators of labor productivity increases) have tight internal production connections (see *Tables 13.1*, and *13.2*). In 1973 the internal flow $A_{I,I}$ = \$105.4 billion, which accounts for more than 46% of the total H_I; the corresponding quantities for group II was \$158.1 billion (more than 50%), and for group III \$166.9 billion (50%). Roughly the same picture can be seen for 1963. Internal (diagonal) flows within the groups form 40–60% of their entire material expenditures. Each group therefore represents a relatively autonomous part of the economy (at least as far as material expenditures are concerned). This conclusion should be considered together with the above observation that various types of technological progress are characteristic of the different groups.

Consider flows $A_{III,III}$ for 1963 and 1973. The incremental rate $IA_{III,III}$ = 78%, with IH_{III} = 71% (*Table 13.3*). A growing proportion of products from group III is used to produce these products. This could be interpreted as an example of the theoretical law of the tendency for progressive industries to produce resources for their own consumption or for the sake of their own production. The accelerated technological progress in group III and this law are essentially interconnected. At the same time, one can ask whether the effect of the operation of this law is the tendency to exhaust the efficiency of progressive technologies and, consequently, the production of corresponding resources.

There are obviously some shortcomings in observations based only on input–output data, so if possible these should be combined with analyses based on fixed capital investment and stock information. We use such data for the US economy for the same period (in 1972 dollars) in *Tables 13.5–13.7* [4] (no data on circulating capital were available). In *Tables 13.5–13.7* the following notation is used: K = fixed capital, Ke = capital in equipment; Kc = capital in structures; I = fixed investment; Ie = investment in equipment; Ic = investment in structures.

Calculations show that the larger increases in labor productivity require faster growth of the capital–labor ratio [*Table 13.7*, columns $I(K_t/L_t)$ and

Table 13.5. US output, fixed capital, investment, and labor force in 1963. Large groups by annual labor productivity growth rates.

Group	Q_i	K_i	Ke_i	Kc_i	I_i	Ie_i	Ic_i	L_i (millions of workers)	Q_i / L_i	K_i / L_i	Ke_i / L_i
	(billions of 1972 dollars)										
I	603.4	319.2	123.6	196.7	27.2	14.2	13.5	31.4	19.2	10.15	3.93
II	342.5	307.7	107.8	205.2	19.2	8.4	10.8	10.6	32.4	29.11	10.20
III	274.7	362.2	188.5	173.7	21.4	15.2	6.2	12.1	22.6	29.82	15.52
Whole economy	1220.6	989.1	419.9	575.6	67.8	37.8	30.5	54.2	22.5	18.26	7.75

Table 13.6. US Output, fixed capital, investment, and labor force in 1973. Large groups by annual labor productivity growth rates.

Group	Q_i	K_i	Ke_i	Kc_i	I_i	Ie_i	Ic_i	L_i (millions of workers)	Q_i / L_i	K_i / L_1	Ke_i / L_i
	(billions of 1972 dollars)										
I	884.3	547.6	221.0	326.3	42.5	27.1	15.9	42.5	20.8	12.89	5.20
II	529.5	467.1	173.9	293.1	36.6	20.2	16.3	12.3	43.1	37.98	14.14
III	459.2	519.8	298.6	230.2	40.2	30.7	9.5	12.2	37.6	42.54	24.44
Whole economy	1873.0	1534.5	693.5	849.6	119.3	78.0	41.7	67.0	28.0	22.9	10.35

Table 13.7. Large groups by US labor productivity growth rates, 1973/1963. Increment growth rates of data in *Tables 13.5* and *13.6* (%).

Group	IQ_i	IK_i	IKe_i	IKc_i	II_i	IIe_i	IIc_i	IL_i	$I(Q_i / L_i)$	$I(K_i / L_i)$	$K(Ke_i / L_i)$
I	47	72	79	66	56	91	18	35	9	27	32
II	35	52	61	43	91	141	51	16	33	31	39
III	67	44	58	33	88	102	53	1	66	43	57
Whole economy	53	55	65	48	76	106	37	24	23	25	34

$K(Ke_i / L_i)$]. This should be considered together with the fact that the capital–labor ratio is initially higher in rapidly expanding industries [see *Table 13.5*, columns K_i / L_i) and (Ke_i / L_i)].

At the same time it is observed that in group III, in contrast with the others, increments in the capital–labor ratio are smaller than that of labor productivity, so that the capital–output ratio falls. Thus, group III demonstrates that new, progressive technologies tend to increase their output–capital ratios simultaneously the largest growth rates in the output–labor ratio. The opposite can be seen in group I industries, which show properties of traditional technological expansion: a decrease in the output–capital ratio with a very low labor productivity growth rate.

These contrasting properties highlight the similarity between the growth rates for fixed capital and the labor force: both rates are highest in group I and lowest in group III (*Table 13.7*, columns IK_i and IL_i). Progressive industries are those that utilize advanced technological equipment, which enables production to be increased without a concomitant demand for additional labor.

We now reconsider the input–output data: w_i were calculated for each of the 147 industries, and then $W_i = w_i Q_i$ ($i = 1, \ldots, 147$) were aggregated into three groups (*Tables 13.1, 13.2*, quantities W_i), and then I_{wi} were calculated:

$$Iw_i = I\frac{W_i}{Q_i} = \left[\frac{w_i\ (1973)}{W_i\ (1963)} : \frac{Q_i\ (1973)}{Q_i\ (1963)} - 1\right] \quad i = \text{I, II, III}$$

(see *Table 13.4*). These are now analyzed in comparison with

$$Ip_i = \frac{(IQ_i + 1) \text{ in current prices}}{(IQ_i + 1) \text{ in constant prices}} - 1 \quad i = \text{I, II, III}$$

(IQ_i in current and constant prices, see *Table 13.3*; Ip_i in *Table 13.4*). The following properties of price formation can be stated:

(1) Inflationary property: "+" for Ip_i, "−" for Iw_i, i = I, II, III. It is highly improbable that this is caused by the fall in value of real money (gold).

(2) The notion of value as the theory of price dynamics is corroborated: the ranking of Ip_i is identical to that of Iw_i (see *Table 13.4*). It is remarkable that, in turn, rankings of the increment rates of total values are the same as those of increments in labor productivity (the latter being ranked in inverse order), in exact correspondence with the theory of value. It should also be noted that the transition from group II to group III is connected with the increase in the ratio $(Ip_i + 1)/(Iw_i + 1)$: 1.81 for group II and 2.0 for group III (calculated using data from *Table 13.4*). The highest production growth rate is connected with a lag in the reduction of relative prices compared with the reduction of relative value. This lag is theoretically expected, and forms a mechanism whereby progressive industries increase their profitability (in comparison with the

average for the whole economy), which is a necessary condition for their accelerated growth.

(3) An increase in labor productivity is a major factor in reducing total value: on average, labor expenditures per unit of production in the whole economy were reduced by 19%, with the average reduction in total value of 23% (*Table 13.4*). The additional reduction in the total value is caused by structural shifts in material expenditures toward the use of materials produced by progressive industries, with relatively rapid reduction in the values of corresponding products.

Acknowledgments

The author would like to express his gratitude to A.V. Shcherbinskaia and L.G. Krivoshapova for their fruitful assistance in making calculations.

Notes

[1] Strictly speaking, since matrix A is used to evaluate w, we should include among coefficients a_{ij} those that describe elements of fixed capital removal (or depreciation) per unit of output in each industry. In our calculations, however, we use matrices A that do not include such specific coefficients a_{ij}. The error could be estimated as non-essential since the dynamics of coefficients w, and not their absolute magnitudes, are being analyzed.

[2] See *Historical and Projected Input–Output Tables of the Economic Project* (1979), Vols. 1A, B (Washington); *Time Series Data for Input–Output Industries* (1979), BLS Bulletin 2018 (Washington).

[3] Some different types of corresponding processes were revealed in calculations by P.N. Tesla (for Japan, 1960–1970) and V.V. Krupchatnikova (for the FRG, 1954–1972). A rapid output growth in an analogous third group of industries was connected with a combination of rapid labor productivity growth and moderate reductions in the total material input–output ratio.

[4] From *Capital Stock Estimates for Input–Output Industries: Methods and Data*, US Department of Labor, Bulletin 2034 (Washington) pp. 46–117. There is no information for the 147 industries. In order to combine the data for them with those on fixed capital, the information on 147 industries was reaggregated into 25 large sectors, one public sector, and the rest private sectors. Statistics on the fixed capital containing data on the private sectors only were first aggregated in the analogous 24 sectors; all data then were aggregated into three large groups by annual labor productivity (per worker) growth rates.

PART II

Technical Revolutions and Long Waves

CHAPTER 14

Long Waves and Regional Take-Offs in Italy and Great Britain: Preliminary Investigations into Multiregional Disparities of Development

Giuliano Bianchi, Stefano Casini-Benvenuti, and Giovanni Maltinti

14.1. Introduction

The multiregional differentiation of Italian development is a manifold one:

(1) Differentiation of forms, structures, and levels of growth (namely, industrialization as measured, e.g., by the ratio of industrial employment to total labor force); a differentiation leading to the recognition of the coexistence, at ȧny given time, of regions at different stages of development.
(2) Differentiation in terms of the pace and direction of structural changes so far undergone.
(3) Differentiation of the reactions of Italian regions to short-term cycle shocks and to the impact of international and national processes and policies.

According to these differentiations (and to corresponding similarities), Italian regions may be grouped into "families" according to their different industrial take-off times. Preliminary investigations have proved the plausibility of a possible link between these take-off times and long-wave impulses (Becattini and Bianchi, 1982). So, from this point of view, the long-wave approach, normally felt as far away regional analysis, seems to be not only relevant and fruitful to regional analysis, but also specifically "addressable" to the very core of regional science: the explication of spatial (both quantitative and qualitative) disparities in socioeconomic development.

Two major points must be underlined here. First, despite the low level of attention so far paid to the inherent "multiregionality" of economic development, Pollard's warning should be remembered: "industrial growth is essentially a local rather than a national affair" (Pollard, 1981). Second, the regional level seems to be a particularly appropriate and suitable level for analyzing whether and how long-wave impulses may affect the economic performance of a given system: indeed, at this level long-wave up- and downswings can be assumed and, in general, treated as exogenous. Within this frame of reference a new exercise has been developed in an attempt to apply to regions in the UK the methodology already applied to Italian ones (Bianchi *et al.*, 1983).

14.2. Assumptions

A previous work (Bianchi *et al.*, 1983) was based on two assumptions: (i) regional development is expressed by industrialization processes; and (ii) industrialization processes can be meaningfully measured by means of a simple, and single, indicator: the ratio of industrial employment to population. Assumption (i) is a standard assumption in studies of long-term movements of economies after the Industrial Revolution. Assumption (ii) perhaps needs to be justified in order to make clear that the simple indicator adopted here is not due to lack of data (a well known difficulty in long-term analyses) nor that other indicators (e.g., total or per capita values of industrial output or GNP, etc.) might (if available) have been more appropriate.

Where the analysis is specifically addressed to the shift in the economic basis of a given system from agriculture to industry, and from industry to services, the control variable is the sectoral composition of labor force. Normally the transition of a national (or regional) economy from agriculture to industry means a tremendous increase in per capita agricultural output accompanied by a dramatic reduction in the rural labor force. The so-called post-industrial society is characterized by rapidly decreasing levels of industrial employment but not necessarily by decreasing volumes of industrial output, which are normally maintained and very often expanded.

14.3. Preliminary Findings

14.3.1. Italian regions

The principal findings of the numerical exercise carried out on regional industrialization process in Italy over the last 120 years (1861–1981) may be

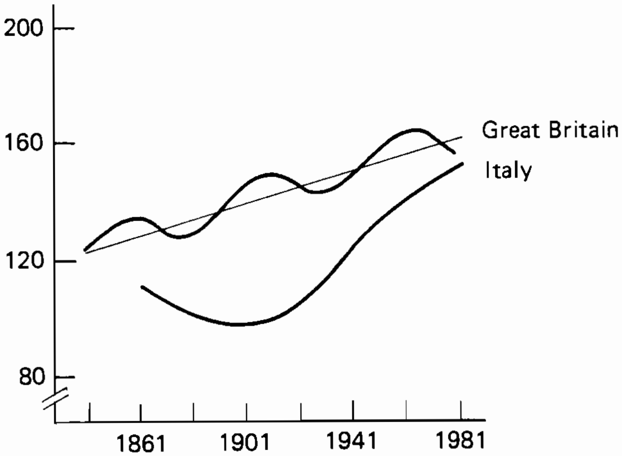

Figure 14.1. Industrialization in Italy (1861–1981) and Britain (1841–1971): industrial employees per 1,000 inhabitants.

summarized as follows. Observed data of our variable (industrial employees out of 1,000 inhabitants) when plotted (see *Figures 14.1* and *14.2*) suggest an interpretation of the evolution of the regional industrialization process as it followed five different stages (more or less corresponding to those of Rostow, 1978):

Table 14.1. Parameters of function (14.1): Italian regions 1861–1981.

Region	*a*	*b*	*c*	*u-Theil*
Piemonte	48.9	1.20	164.4	922
Lombardia	53.3	0.47	182.4	965
Veneto	92.5	0.58	140.4	948
Liguria	28.4	2.10	122.8	947
Emilia Romagna	97.7	1.30	139.3	940
Toscana	97.4	0.95	156.3	961
Umbria	94.6	0.72	117.1	946
Marche	99.8	1.50	126.3	929
Lazio	....	....	.....	...
Abruzzo	99.2	3.20	95.4	907
Campania	90.6	31.60	110.6	934
Puglia	68.7	85.20	104.9	921
Basilicata	100.7	3.60	91.7	929
Calabria	.....	....	....	...
Sicilia	196.0	0.50	144.1	928
Sardegna	75.9	3.00	79.1	937
Italy	84.2	2.20	126.7	968

(1) An initial decline in total industrial employment.
(2) Stagnation of industry before the actual take-off.
(3) Rapid growth starting from the take-off.
(4) A reduced employment increase during industrial maturity.
(5) Decline of a "post-industrial" economy.

The logistic function that is often used for this kind of phenomenon does not permit the inclusion of the first and the last stages, so a similar function has been adopted that is able to consider all five stages:

$$I = \frac{t - a}{e^{b(t-a)}} + c \tag{14.1}$$

where I = industrialization level in terms of industrial employees per 1,000 inhabitants; t = reference year; a = the year when the growth rate begins to decrease; b = annual growth rate; and c = the long-period level of industrialization (maximum). Function (14.1) fits very well with the actual data for the Italian regions, with few exceptions, as the Theil index shows (*Table 14.1*). The estimated function suggests the following:

(1) Within the same period, regions exist at different stages of development.
(2) The take-off period seems to influence the long-term level of industrialization (according to the implicit rule: "the earlier the take-off, the higher the level").
(3) After 1981, the level of industrialization does not increase in any region.

The parameter values and the trend of the regional curves identify four main clusters of regions (see *Figure 14.2*):

(1) The oldest industrialized region (Liguria) is now declining to a lower level of industrialization.
(2) The next oldest industrialized regions (Piemonte and Lombardia) have reached a post-industrial maturity, with a high long-term industrialization level already attained.
(3) The "second-comer" regions are in a phase of early maturity, with no increase in industrialization, at a lower level than the previous ones (Veneto, Emilia Romagna, Toscana, Umbria, Marche).
(4) Regions of miscarried development (Campania, Calabria, Sicilia) have long-term industrialization levels that will remain very low.

14.3.2. British regions

The same methodology has been (tentatively!) applied to British regions (using data for 1841–1971), but the functional form estimated for Italian regions did not fit onto British data, which fluctuate up and down around a secular growth trend (see *Figure 14.3*), so a new function, able to represent both the secular trend and periodical fluctuations, has been estimated.

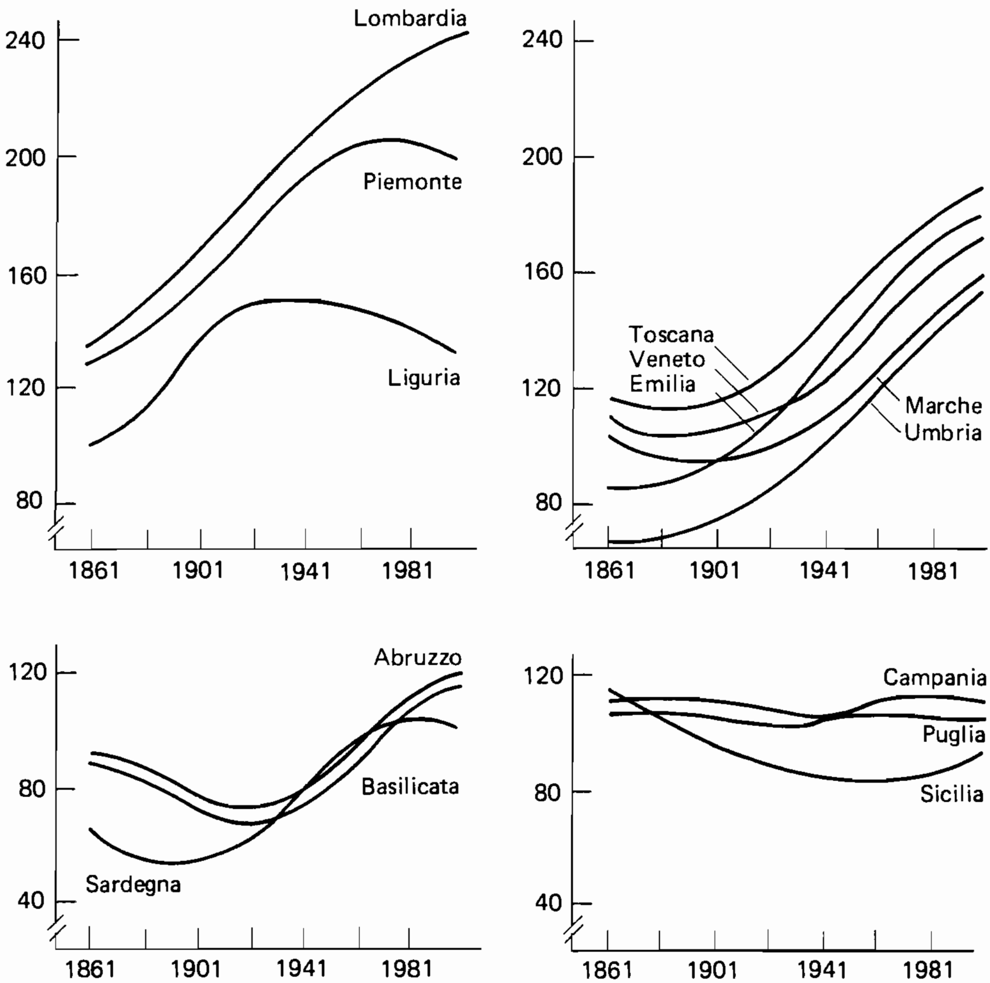

Figure 14.2. Industrialization in Italian regions, 1861–1981: industrial employees per 1,000 inhabitants,

$$I = a' + bt + c' \sin(dt) \tag{14.2}$$

where t = reference year; I = industrialization level (as above); a' = initial industrialization level; b = annual growth rate; c' = amplitude of fluctuation band; and d = time interval between two fluctuations. Function (14.2) proves to fit quite well with observed data (*Figure 14.3*); parameter values are shown in *Table 14.2*.

Table 14.2. Parameters of function (14.2): British regions 1841–1971.

Region	*a*	*b*	c^a	d^b
South East	85.67	4.24	8.94	51.37
East Anglia	67.36	2.90	10.30	115.64
South West	82.89	2.07	7.83	57.67
West Midlands	141.04	7.51	7.69	51.17
East Midlands	134.60	3.55	6.56	52.07
North West	222.13	-1.53	4.76	51.87
Yorkshire	207.73	-1.36	4.95	51.47
North	83.99	3.43	13.74	53.07
Wales	55.01	3.87	17.18	52.87
Scotland	139.16	0.76	2.16	46.18
Great Britain	123.94	2.82	6.06	51.57

[a] *c* is expressed as a percentage of *a*.
[b] *d* is expressed in years.

Also here it is possible to group the regions into clusters which seem to make sense:

(1) The "overdeveloped" regions have levels of industrialization that have fluctuated around a sloping downward trend since the beginning of the period considered here (Yorkshire and Humberside, the North East).
(2) The most "dynamic" regions (East and West Midlands) have levels that fluctuate around a rising long-period trend (not necessarily reaching, however, the starting level of other regions).
(3) Some regions took off later (Wales, South East, North) and have moved along a rising trend, whose maxima generally remain lower with respect to the starting point of the previous group.
(4) Finally, there is a mixed group whose main feature is a narrower fluctuation band (Scotland, South West, East Anglia).

The provisional results of the simple numerical exercises so far presented do not of course allow us to go beyond a preliminary testing of research hypotheses. Nevertheless, once we have recalled cautions and warnings contained in Bianchi *et al.* (1985), it is legitimate to list hypotheses not disproved by the tests based on the British and Italian case studies.

14.4. Testing Research Hypotheses

We are looking for the existence of meaningful ties between long waves and regional take-offs. Therefore our task is not to explain the national take-off, which we take as given, but to assess why certain regions participate *in* and contribute *to* the national take-off, whereas other regions do not. Our idea is that the interplay of socioeconomic structural characteristics (which are to some extent measurable), regional (both formal and informal) institutions, and local "social culture" selects regions more apt and/or ready to grasp the

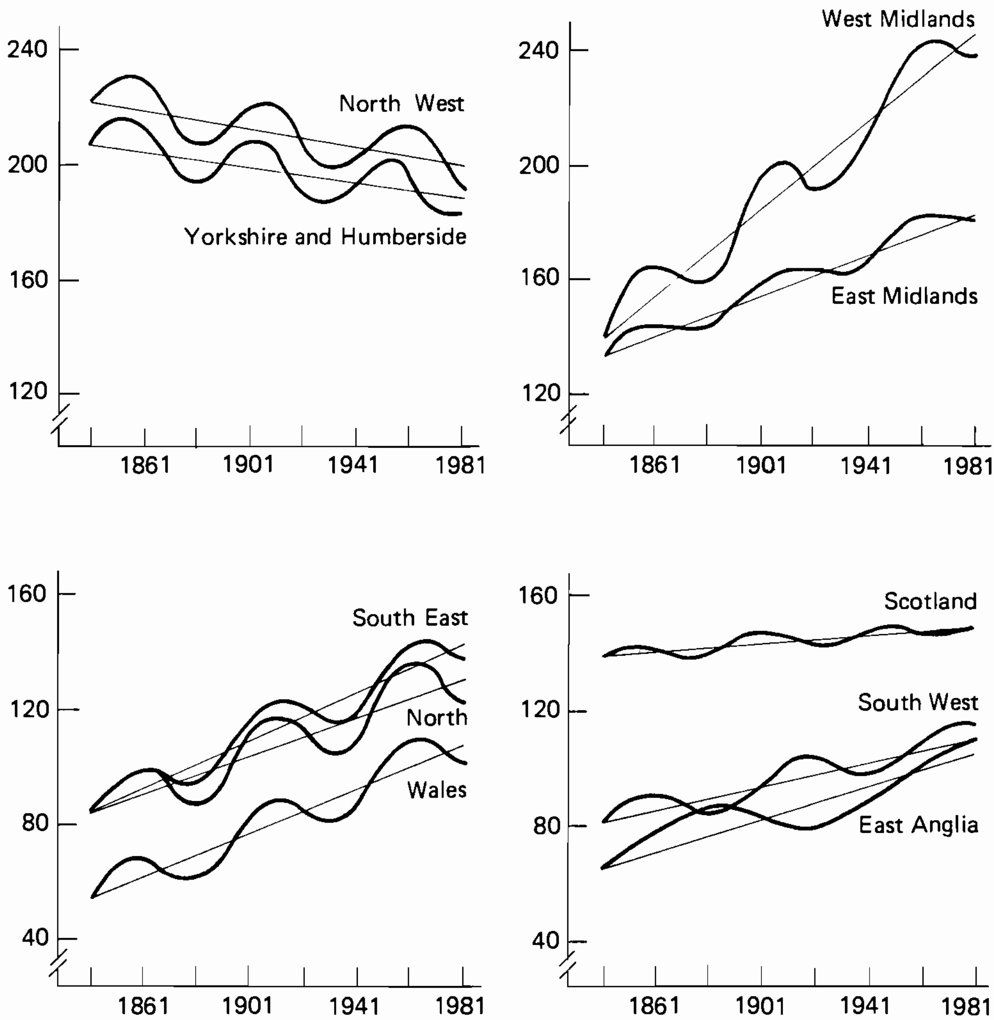

Figure 14.3. **Industrialization in British regions, 1841–1971: industrial employees per 1,000 inhabitants.**

opportunities of the international long wave and national take-off (Becattini and Bianchi, 1982, 1984).

With reference to the national level, it has been argued (and, to some extent, proved) that national take-offs usually take place during the upswing phase of a long wave. This thesis has been integrated into the hypothesis that says "after a country has taken-off, it will be less affected by the next downswing" (van Duijn, 1983). These long-wave "behavior rules" also seem to be confirmed at a regional level:

(1) The North West, Yorkshire, Humberside, Scotland, and the East Midlands took off during the first Kondratieff upswing.
(2) The West Midlands took off during the second Kondratieff upswing.
(3) The South East, Liguria, Piemonte, and Lombardia took off during the third Kondratieff upswing.
(4) Toscana, Emilia Romagna, and Veneto took off during the fourth Kondratieff upswing.

It should also be noted that no region (either in Britain or Italy) took off during a downswing phase, and regions that took off within a given long-wave upswing (Liguria, Piemonte, Lombardia during the third upswing, and Toscana, Emilia Romagna, Veneto, during the fourth) have been less affected by subsequent downswings (or have not been affected at all).

Our indicators suggest the idea of a "ceiling" on regional growth, in terms of industrialization levels, according to the implicit rule "the earlier the take-off, the higher the level". Indeed, only earlier developed regions reach the level of more than 200 industrial employees per 1,000 inhabitants (West and East Midlands, Lombardia, Piemonte), the level from which the North West and Yorkshire have moved since 1841. This is not the place to attempt an explication; the research has not yet reached the stage of empirical proof. However, we may generally assume the influence of saturation processes, from which stem increasing flows of external diseconomies, not to mention the increasing levels of interregional competition as the number of regional take-offs increases. A final remark on this point is that should a "ceiling" constraint really operate, it would depend on the interplay of local factors.

Another hypothesis can be derived from the data analyzed so far. Because none of the regions considered has increased its level of industrial growth in the 1980s, the current long wave seems to act as a "wall" against any further regional growth (of industrialization). As we have already pointed out (Bianchi *et al.*, 1983), should this statement be true, two consequences would follow: entire regional trajectories through take-off/development/ maturity would be contained within the present long wave; and thereafter, trajectory lengths, given the end point (*dies ad quem*), would only depend on the starting point (*dies a quo*: take-off date).

This "celling and wall" hypothesis corresponds to the idea that the current long-wave downswing will close the whole "hypercycle" consisting of the four Kondratieff waves. As far as the Italian and British regions are concerned, it is true that the maximum level of industrialization has already been or is about to be reached, whereas the effects of the industrialization era seem to be exhausted, thus giving rise to the so-called "post-industrial age". It is worth stressing that the "wall hypothesis" would depend (this time almost entirely) on international, worldwide factors and processes. The "ceiling and wall" hypothesis – naive though it might appear – deserves some attention, especially from the point of view of the possible consequences of coping with the existence and effects of international and interregional disparities. This is briefly discussed below.

Some explanation of the different functional forms of industrialization processes assumed in Britain (and British regions) and Italy (Italian regions) is required. In both cases growth trajectories move through a five-stage sequence from initial decline to post-industrial phase. In Britain, owing to the length of the time trajectories, national and regional growth processes are affected by the upswings and downswings, which induce fluctuations around the long-term trend. This latter looks like a sinusoidal fluctuation around a straight line and does not assume, as in the Italian cases, the quasi-logistic form due to the lack of data from the take-off phase (around 1780) up to 1841, the starting year of our statistical series. On the other hand, the Italian curves seem to be unaffected by the long-wave impulse, given the proximity (in time) of the take-offs, so that we may assume that the secular trend and cyclical fluctuations overlap.

14.5. Final Remarks and Proposals

> On the one hand it is obvious that all economic activity ... occurs within time and space. On the other hand, it is also fairly obvious that almost all economic theorizing has ignored both time and space. In one sense, it was a major objective of classical theory, ... and even more so of the neoclassical variant, to abstract the analysis precisely from time and space ...
>
> As we all know, the question of the appropriate spatial unit of economic analysis has come to the forefront of social science in the last two decades. The state as the appropriate unit has come under challenge in two spatial directions. Some of us have argued for the epistemological priority of a larger space called "a world-economy". And others have argued in favor of a smaller space called "a region". These two opposite thrusts are quite compatible with each other, in that both insist on the importance of economic boundaries and of the necessity of determining them on the basis of economic criteria (Wallerstein, 1985).

This authoritative statement works splendidly as the motto for an attempt to interrelate pulsations of the world economy, such as long waves, and local change processes, such as regional take-offs of industrialization. Regional long-wave analysis still plays a marginal role within this research field, whereas it seems to be one of the more promising and fruitful directions for study.

Spatial effects of long-wave impacts are relevant to multiregional analysis, in order to explain the coexistence, within one country, of regions at different phases of development. Naturally, to study the spatial effects of long-wave impact means to stress the time dimension of spatial analysis in the sense that spatial disparities in growth are dependent, to large extent, on the scattering of take-offs over time.

Interregional disparities and regional take-offs (as the main outcome of a long-wave impulse) are also interdependent from another point of view. *Figures 14.1–14.3* and *Tables 14.1–14.3* show that British regions, even if they

Table 14.3. Interregional disparities: variant coefficient (%).

Year	*Great Britain*	*Italy*
1841	40.9	–
1851	38.4	–
1861	37.1	27.7
1871	36.6	30.4
1881	34.9	28.8
1891	34.7	38.3
1901	33.0	36.2
1911	34.5	38.5
1921	35.6	41.9
1931	35.8	37.7
1936	–	34.7
1951	29.8	34.2
1961	27.4	–
1971	20.1	25.7
1981	–	24.8

have very different starting points, tend to converge. On the contrary, the variance among Italian regions increases considerably over the first part of the period here considered (1861–1921). Thus another behavioral issue of regional systems worthy of investigation is the relationship between take-off time and disparate structures and trends.

If the "ceiling-and-wall" hypothesis has a basis in reality, we should assume that, whereas in the past a sequence of long-wave upswings and downswings could lead to equilibrated regional growth levels, the possible lack of a new Kondratieff could consolidate the current states of interregional disparities. However, the "ceiling and wall" hypothesis requires careful testing not only on the basis of empirical data, but also taking into account the industrial to post-industrial transition: "ceiling and wall" seem to limit only levels of industrialization; nothing can be said about growth-driven sectors such as service sectors.

A final comment must be made to replicate the warnings of our previous work: "the authors of this paper are not so candid as to believe that regional development processes might be represented by means of simple functions". Nevertheless, what we really believe is that regional behavior and differences in regional take-off times are meaningfully related, as exercises so far developed about British and Italian regions have (preliminarily) demonstrated. Thus it may be worthwhile to go into them more deeply with further research. Our intention (and hope) is to be able to promote a joint effort aimed at expanding the exercise to French and German regions, and to replicate within British, French, and German case studies the factoral analysis applied in order to identify the propensity of various Italian regions to capture the opportunity of long-wave impulses.

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CHAPTER 15

The Pathway of Dynamic Efficiency: Economic Trajectory of a Technical Revolution

Heinz-Dieter Haustein

15.1. Introduction

Technological progress is a highly uneven process in space and time, creating and absorbing a new efficiency potential. Among the underlying causes we find historical pushes to the organic composition of capital, realized by technical revolutions. The problem of technical revolutions has a long tradition in Marxist thinking, dating back to a letter from Engels to E. Bernstein in 1883 about the coming "electrotechnical revolution" (Marx/Engels, Vol. 35, p. 444). Substantial contributions to the problem were made by Soviet historians (Milonov, 1922), and in the 1950s the difference between the Great Industrial Revolution and technical revolutions was noticed. Quantitative estimates of long waves in the history of technology are also not recent inventions. One of the first attempts to draw a general historical curve of technological progress was made by Lilley (1952).

15.2. Revolutions in Productive Forces and Technical Revolutions

Technical revolutions consist of bunches of basic innovations that bring about changes in the value structure and in the profit rates of the whole production system. These are not the same as major revolutions in the productive forces, such as the use of fire, the transition to agriculture, the Industrial Revolution, or the scientific–technological revolution; such big changes in productive forces create a new societal mode of production, and they are themselves realized in certain qualitative steps, called technical revolutions. Thus, in the Industrial Revolution there were upheavals in productivity such as steam power, railways, and the electrotechnical and chemical industries.

Table 15.1. Hierarchy of revolutionary changes in productive forces.

Order of change	*Category*	*Example*	*Changes in demand*	*Changes in economic structure*
7	Revolution of productive forces	Scientific–technological revolution	Restructuring of the whole system of needs	Creation of a completely new mode of production
6	Technical revolution	Revolution in information technology on the basis of micro-electronics	New demand complexes	Massive renewal of existing productive capital. Creation of new growth complexes, chain reaction
5	Basic innovation	Microprocessor	Major modification of the demand system	Creation of new industries
4	New major generation	16-bit microprocessor	New types of demand	Substantial changes within existing industries
3	New partial generation	Gate-array chips	Major modification of existing demand lines	New production lines
2	New products and processes	Motorola 16-bit microprocessor	Partial modification of existing demand lines	Exceptional value
1	Improved products and processes	–	Extension of existing demand	More value added

Technical revolutions establish new technological systems within the existing principal mode of production and bring about changes in labor functions, demand, resources, and organizations on a wide scale. Kuczynski (1975) has drawn a clear line between the two kinds of revolutionary changes in the production system. He pointed to the fact that some technical revolutions play an extraordinary role in creating transitions to new modes of production. His approach was heavily disputed, but since then all further technological and economic developments have proved the substance of his arguments.

Technological progress is a spiral or knotted line of qualitative and quantitative relations (Hegel, 1812), where changes of different orders and magnitudes are superposed and linked together (see *Table 15.1*). Changes of the first order are simply improved products and processes. At the next level are new products and processes, e.g., a new incandescent lamp with a higher efficiency and longer lifetime. Changes of the third order are transitions to a partially new generation, e.g., the development of halogen lamps. At the next level are major new generations, e.g., the transition from incandescent to gas discharge lamps. Changes of the fifth order or basic innovations contribute directly to a technical revolution. For example, the basic innovation of the electric lamp was an important element in the electrotechnical revolution, but it was not a technical revolution itself. Basic innovations are unevenly distributed over the 40–50 years of a technical revolution; some help to create the new upswing (key technologies), and later others help to exhaust the efficiency potential of the revolution itself and to prepare for the next change of the fourth order. Such revolutions bring about major changes in industrial structures and a massive renewal of fixed capital in all spheres of production. At the same time, they are linked with substantial changes in labor functions and resource systems.

Generally speaking, lower-order changes have two functions toward the higher-order changes. They help to create an efficiency potential for the higher-order change, and later they exhaust the efficiency potential of those higher changes. The superposition of logistic curves is the geometric equivalent of such an evolution. Thus it is not so important to identify single innovations as to determine their position within the pattern of change within the entire production system.

When our innovations research began at IIASA in 1979, we chose an approach that was quite different from the current line of thinking. Looking at the great stock of innovation studies, we saw two main gaps: the first was the microeconomic approach taken in most of them; the second was the fact that innovation had been considered a single process, a single "technological" change in the narrow sense of the word.

An innovation can be regarded as a change in the technological system that has a great impact on the given socioeconomic system or subsystem, such as that of demand (e.g., for lighting); resources (e.g., energy sources); and resource-processing cycles from primary to final stages (e.g., the wood cycle). These large systems have three goals: (a) to ensure their continuing existence and function by counteracting inhibiting factors; (b) to balance the inner and outer relations of the system to reduce bottlenecks; and (c) to find new ways of ensuring long-term efficiency in a changing environment. From this point of view (the impact of a given technological change on a large system), we can identify three controlling functions: continuing, compensation, and push (Haustein and Maier, 1979).

Thus a basic innovation is a technological change that contributes considerably to the productivity push of a new technical revolution. These are major changes in the production and consumption system of a society, representing a discernible step in a revolutionary change in productive forces that has two main features:

(1) Each change is caused by a bottleneck or gap in the production system. For example, railways became necessary because of the need for an efficient means of transporting the coal and cotton produced in ever-increasing quantities through the use of machinery.

(2) Each change appears in one area of the production system and then passes through a chain or network, step by step, affecting the whole production system, and later, lifestyles and consumer patterns (see *Figure 15.1*). For example, the spinning machine led to the mechanization of weaving, and later to the improvement of bleaching, textile printing, and dyeing (Marx, 1867, p. 506). The steam engine proved to be the appropriate power source for these processes. Machinery soon developed to the point where machines could be produced with machines: as the demand for steel for produce machinery increased, more coal was needed to produce the steel, and so on.

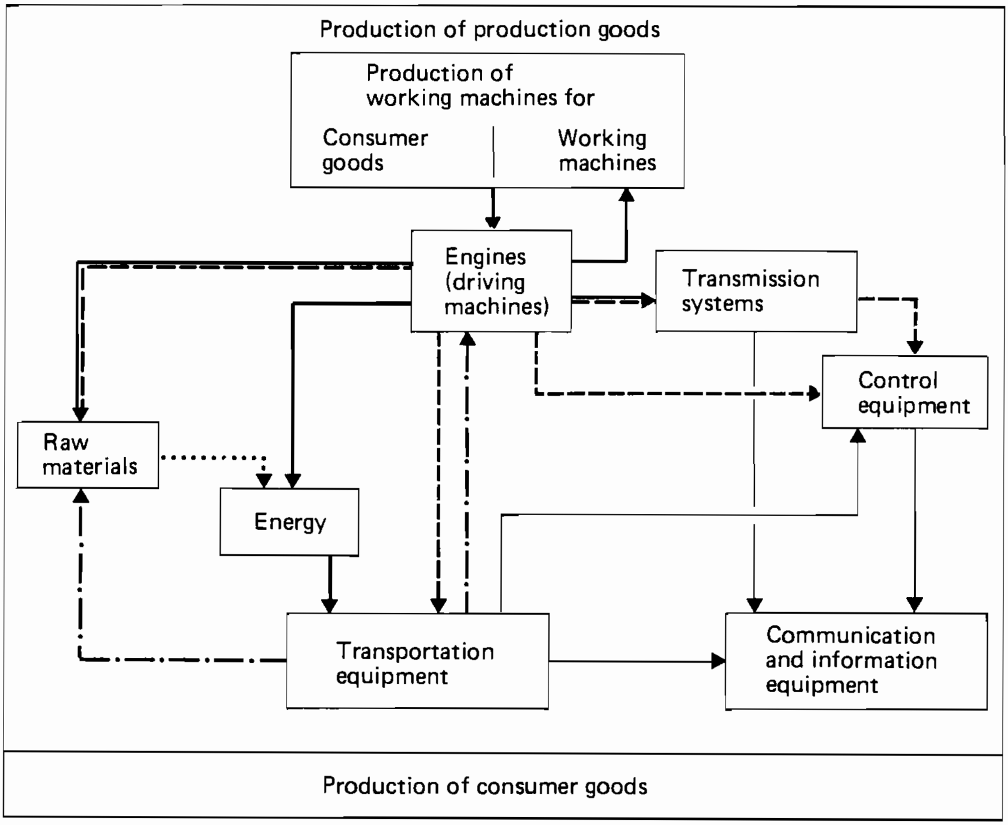

Figure 15.1. **The two production sectors and their inner feedbacks.**

The balance of industries in input–output relations is one thing, whereas the balance of the technological level of industries is another. Using historical examples of many industries and such indicators as productivity, automation coefficients, patent applications, etc., we have tried to analyze the factors that create and destroy a technological equilibrium (Haustein and Neumann, 1965; Haustein, 1975).

Table 15.2 gives an overview of general periods of industrial development since 1780 and their characteristics. Each period can be described in terms of changes in resource systems, demand systems, and labor functions, gaps in the production and consumption system as a whole, and the main growth industries. It is difficult to define an exact time-frame for each historical periods, so that *Table 15.2* presents a qualitative judgment based on several sources. Since 1760 we can define five technical revolutions in five major areas:

(1) Textiles; use of steam power.
(2) Railways; iron and steel industry.
(3) Electrotechnology; production, distribution, and use of electrical energy.
(3) Chemicals and petrochemicals industry.
(4) Electronics, information technology.

In *Table 15.3*, 297 innovations are arranged together with their coefficients of importance W and the average times between invention and innovation $\bar{T}$ (weighted $\Sigma W/\bar{T}^2$; see Haustein, 1980; Haustein and Neuwirth, 1982). Two conclusions can be drawn from this quantitative investigation:

(1) Technological progress, measured by the number of innovations, in their sum of importance ΣW, the average time between invention and innovation, and their innovation power coefficient $\Sigma W/\bar{T}^2$ are highly uneven in time and space. Innovation peaks, measured by their number or importance, were reached in the 1880s and 1930s. 1880 seems to be the turning point of the logistic curve, begun in the Industrial Revolution. The realization period T is also quite different, becoming shorter, but sometimes longer. After 1940, with the onset of the transition to a qualitative change in all productive forces, the scientific–technological revolution, T became considerably shorter.
(2) Peaks of innovations in textiles and steam power were observable in the 1790s; railways, iron, and steel in the 1820s; electrotechnology in the 1880s; chemicals in the 1930s; and electronics and information technology in the 1950s. But these areas also had other local maxima connected with upswings in the leading industries. For example, chemical innovations peaked in the 1880s together with the electrotechnological revolution. Thus, technical revolutions are changes in the entire production and consumption system.

A theoretical question that was fervently discussed in the 1970s was the date of the great scientific–technological revolution. We believe that the

Table 15.2. Technical revolutions since 1760 and their characteristics.

Period	*Social characteristics*	*Changes in resources*	*Changes in demand*	*Changes in labor functions*	*Main gaps in the production system*	*Main growth industries*
1760–1830	Early industrial capitalism	Rapid growth of wood products and copper (brass goods)	Increasing food demand	Energetic function	Spinning versus weaving. Power sources. Fabrication of machinery	Textiles, engineering steam engines
1830–1880	Free competition system	Rapid growth of iron. Peak growth of coal (1880)	Increasing food demand	Energetic function	Coal and iron demand. Need for transportation	Coal, pig iron, shipbuilding mass production of machines
1880–1930	Expansion of monopolies	Rapid growth of rubber products	Decreasing expenditures on food (relatively)	Energetic and executive function	Steam power potential exhausted. Exhaustion of natural fibers	Electricity, automobiles, mechanical engineering
1930-1980	Growing state interference. Rapid growth of postwar capitalism. Expansion of multinational corporations	Rapid growth of aluminum. Peak growth of synthetic fibers. Peak growth of oil consumption (1977)	Increasing expenditures on housing. Fast growing demand for durable goods	Energetic, executive, and control function	Need for flexible transportation. systems. Need for better information handling	Chemicals, petrochemicals, automobiles, electronics
After 1980		Alternative energy sources	Increasing expenditures on education	Energetic, executive, control, and other intellectual functions	Environmental problems, quality of life and work	Micro-electronics, bioengineering

Table 15.3. Time frame of basic innovations in five industrial sectors since 1760.

Introduction	Total					Textiles, steam power				Railways, iron and steel			
	No.	ΣW	$\Sigma\frac{W}{T}$	$\bar{T}$	$\frac{\Sigma W}{\bar{T}^2}$	No.	ΣW	$\Sigma\frac{W}{T}$	$\bar{T}$	No.	ΣW	$\Sigma\frac{W}{T}$	$\bar{T}$
1760–1769	2	63.28	5.14	12.3	0.42	1	32.00	1.23	26.0	–	–	–	–
1770–1779	–	–	–	–	–	–	–	–	–	–	–	–	–
1780–1789	6	120.20	7.69	15.6	0.49	3	56.12	2.08	27.0	2	42.32	1.26	34.4
1790–1799	5	110.68	12.40	8.9	1.38	2	43.52	4.00	10.9	1	14.72	0.18	83.0
1800–1809	4	97.28	14.61	6.7	2.19	1	21.76	5.44	4.0	1	21.76	0.21	102.0
1810–1819	3	65.28	1.45	45.0	0.03	–	–	–	–	1	21.76	0.28	79.0
1820–1829	7	133.17	3.14	42.4	0.07	1	31.28	0.95	33.0	3	53.64	1.11	48.3
1830–1839	9	269.64	12.75	21.1	0.60	1	14.72	1.05	14.0	3	41.64	6.71	6.2
1840–1849	8	214.72	5.65	38.0	0.15	–	–	–	–	1	4.80	0.10	48.0
1850–1859	11	230.94	7.81	29.6	0.26	–	–	–	–	1	14.72	0.17	85.0
1860–1869	9	196.16	7.41	26.5	0.28	–	–	–	–	–	–	–	–
1870–1879	11	236.88	6.84	34.6	0.20	–	–	–	–	2	50.84	1.42	35.8
1880–1889	27	636.04	19.29	33.0	0.59	1	31.28	0.76	41.0	1	32.00	0.71	45.0
1890–1899	18	320.80	20.49	15.7	1.30	–	–	–	–	–	–	–	–
1900–1909	13	273.36	22.19	12.3	1.81	–	–	–	–	1	21.16	0.06	22.0
1910–1919	10	240.26	27.19	8.8	3.10	–	–	–	–	–	–	–	–
1920–1929	15	291.52	13.32	21.9	0.61	–	–	–	–	3	29.80	2.72	11.0
1930–1939	28	673.44	29.01	23.2	1.25	1	7.04	0.27	26.0	1	10.24	0.24	42.0
1940–1949	20	299.38	48.75	6.1	8.05	1	3.20	0.19	17.0	2	5.50	0.20	27.5
1950–1959	32	669.94	85.06	7.9	10.70	1	7.04	0.70	10.0	1	10.24	3.71	3.0
1960–1969	36	614.42	124.38	4.9	25.59	–	–	–	–	–	–	–	–
1970–1979	23	332.58	83.73	4.0	20.79	–	–	–	–	1	14.96	2.49	6.0

Table 15.3. cont.

Introduction	Electrotechnology				Chemicals and petrochemicals				Electronics and IT				World industrial production growth
	No.	ΣW	$\Sigma \frac{W}{T}$	$\bar{T}$	No.	ΣW	$\Sigma \frac{W}{T}$	$\bar{T}$	No.fR	ΣW	$\Sigma \frac{W}{T}$	$\bar{T}$	(%/year)
1760-1769	1	31.28	3.91	8.0	–	–	–	–	–	–	–	–	2.2
1770-1779	–	–	–	–	–	–	–	–	–	–	–	–	0.3
1780-1789	–	–	–	–	–	–	–	–	–	–	–	–	5.4
1790-1799	–	–	–	–	–	–	–	–	–	–	–	–	3.3
1800-1809	–	–	–	–	–	–	–	–	–	–	–	–	1.7
1810-1819	–	–	–	–	1	21.76	0.28	79.0	–	–	–	–	2.1
1820-1829	1	2.25	0.03	76.0	2	46.0	1.05	43.8	–	–	–	4.4	
1830-1839	–	–	–	–	1	14.72	0.27	54.0	1	68.00	0.61	111.0	3.5
1840-1849	3	89.52	1.85	48.4	–	–	–	–	–	–	–	–	2.6
1850-1859	1	68.0	0.86	79.0	2	35.88	1.66	21.6	1	49.30	1.87	26.4	5.5
1860-1869	2	53.16	1.34	39.7	5	79.72	2.83	28.2	1	32.00	1.68	19.0	2.5
1870-1879	1	32.0	0.37	87.0	1	31.28	0.56	56.0	2	28.80	2.06	14.0	3.3
1880-1889	8	163.32	5.52	29.6	6	110.64	2.21	50.1	2	31.40	2.63	11.9	4.4
1890-1899	–	–	–	–	4	72.92	3.35	21.8	3	62.68	5.61	11.2	3.6
1900-1909	–	–	–	–	2	42.92	2.50	17.2	2	31.88	4.74	8.7	4.0
1910-1919	1	14.72	1.13	13.0	3	42.68	9.65	4.4	–	–	–	–	0.8
1920-1929	–	–	–	–	4	40.63	1.54	26.4	4	176.56	7.30	24.2	3.2
1930-1939	3	77.28	3.81	20.3	8	125.96	8.09	15.6	5	188.80	5.74	32.9	3.8
1940-1949	–	–	–	–	4	72.92	15.84	4.6	2	9.68	2.09	4.6	2.2
1950-1959	1	21.16	0.52	41.0	4	46.72	8.92	5.2	11	327.40	34.18	9.6	5.3
1960-1969	1	4.84	0.81	6.0	2	35.20	4.69	7.5	13	218.58	56.78	3.8	5.6
1970-1979	1	4.84	0.81	6.0	1	7.04	1.01	7.0	17	259.02	73.60	3.5	3.6

downswing phase of the Industrial Revolution from 1880 to about 1950 was overlapped by the very long upswing phase of the scientific–technological revolution, beginning in the 1940s. But in the 1970s there was a partial downswing, marked by the 1930–1980 technological revolution, and so it is easy to see why some authors after 1970 concluded that the scientific–technological revolution was still far away. This was the time when the microprocessor was born. It is, of course, much better to take notice of downswings than to ignore them.

Another question is, if the scientific–technological revolution is a real complement to the Industrial Revolution, which brought the age of machines? Some authors argue that this age of machines has destroyed the fundamental unity of man and nature, which will be renewed on a higher level by the forthcoming ecological revolution. The technical revolution in information technology by microelectronics may be a first major step in this direction.

15.3. Measuring the Efficiency Impact of a Technical Revolution

If technical revolutions give a push to the efficiency of the production and consumption system, this should be observable in economic indicators. For example, in 1930–1980 the most dynamic industries were oil extraction and refining, automobiles, chemicals and petrochemicals, plastics, synthetic fibers, and electrotechnical industries. But it is hard to determine the key indicator of industrial efficiency – the profit rate on capital – for a period covering more than two decades. We have taken as an example the rate of return on production funds, one of the major efficiency indicators of industry in the USSR. There has been a rapid revolution in chemicals and petrochemicals in the last decades; major structural changes have occurred, and the lag behind leading capitalist countries in this field could be reduced considerably and partially converted into a lead. Using data on production funds and net returns for the 12 branches and the industry as a whole, it is possible to identify the development of average and dynamic efficiencies and their interdependence. The rate of net return on productive funds is the relation between the profit of an enterprise (in current prices) and the productive funds valued on a mixed price basis. Dynamic efficiency is the efficiency of the group of industries representing the leading branches of the chemical and petrochemical revolution. Empirical data are available for 32 years; although this is not quite enough to trace the long efficiency cycle of a technical revolution, it does provide a representative window.

The problem is one of how to investigate this development. A widely used approach is the logistic function or a sequence of logistic functions. Many authors were fond of the idea of finding an escalation function able to reflect any sequence of fluctuations in technological evolution. The ultimate ratio of this approach is, of course, a polynomial of any order, or a function with an empirical foundation. Zeidler (1984) put forward a proposal that I would now like to take up. Insofar as the process will be guided by goals, it is also necessary to bring into the function changes in strategy. Zeidler's model is a generalization of logistic growth. It includes growing and decreasing logistics, and their stepwise development according to different values of the control parameter $u(t)$. It is thus obvious that the limits of the logistics can be higher or lower than their predecessors in sequential periods of time.

15.4. A Model of the Economic Trajectory of a Technical Revolution

Industrial efficiency is influenced by five main factors: the efficiency potential, which can be determined from the diffusion and utilization of a complex of basic innovations and should be given as a goal variable; external and internal control parameters for industrial development; ability to utilize the efficiency potential; and starting conditions. In order to understand the dynamics of these factors, it is necessary to study the growth conditions for net returns R and funds F, generally given by

$$\left[\frac{R(t)}{F(t)}\right] = w(t,F) \left[\frac{R'(t)}{F'(t)}\right] - \left[\frac{R(t)}{F(t)}\right] \qquad (15.1)$$

$$w(t,F) = \frac{\mathrm{d}F}{\mathrm{d}t} = r_F(t)\, k_F$$

$$r_F(t) = \frac{R(t)}{F(t)} \qquad k_F = F'\frac{(t)}{R(t)}$$

where $w(t, F)$ is the growth rate of funds; k_F is a modified form of the accumulation coefficient and is a control parameter established by industrial planners taking into account major strategic decisions and a wide spectrum of political and economic factors. The relation $R(t)/F(t)$ is the net return on productive funds, and is the variable to be analyzed.

We now turn to the differential quotient of marginal values $R'(t)/F'(t)$, which depends on the marginal coefficient of dynamic efficiency g_B or $R'(t)/F'(t)$, for a group of dynamic industries; the marginal coefficient for other industries g_V; and the ratio of the increase in funds for dynamic industries $F_B'(t)$ to those for other industries $F_V'(t)$.

$$\frac{R'(t)}{F'(t)} = (1-u)\, g_V + u\, g_B \qquad (15.2)$$

$$u = \frac{F_B'(t)}{F_V'(t)} \qquad g_V = \frac{R_V'(t)}{F_V'(t)} \qquad g_B = \frac{R_B'(t)}{F_B'(t)}$$

where u is a control parameter within the industry (established in practice by decisions of specialized ministries of industrial branches). g_B and g_V are limits to efficiency growth. These limits are twofold. *Type A*, which represents upper limits under conditions of increasing marginal efficiency and a rapid diffusion of basic innovations. The marginal coefficient peaks before the relation $R(t)/F(t)$; the distance to the upper limit becomes minimal. *Type B* represents lower limits under conditions of decreasing marginal efficiency. Rationalization of existing productive funds on the basis of previous technical solutions leads to higher net returns, but decreasing average efficiency. If we make g_B^* the limit for g_B and g_V^* the limit for g_V, the total marginal efficiency limit is

$$\left[\frac{dR(t)}{dF(t)}\right]^* = (1-u)\, g_V^* + u\, g_B^* = c \tag{15.3}$$

How can c be interpreted? The relation $1/c$ is an indicator of the shortage of investments. During an economic upswing the amount of investments realized increases rapidly, the gap between investment demand and supply closes, and $1/c$ is relatively low.

In capitalist economies low interest rates reflect the same processes, but in a downswing $1/c$ increases, as do interest rates, triggering new basic innovations. In socialist economies, $1/c$ reflects planned normative efficiency, which is much higher in a downswing than in an upswing phase of the efficiency cycle. Letting $\dot{r}_F$ be the time differential of the net return on funds and b = the differential growth rate of net returns, we can determine the efficiency function by

$$\dot{r}_F(t) = r_F(t) \cdot [c - r_F(t)] \cdot b/c \tag{15.4}$$

$$b = R'/R = w(t,R) = k_F\, c \tag{15.5}$$

Therefore

$$\dot{r}_F = r_F(t)\, k_F\, [c - r_F(t)] \tag{15.6}$$

On the basis of equations (15.3) and (15.6) one can study the main factors that determine growth of efficiency: the accumulation coefficient k_F, and the difference between potential and real efficiency $c - r_F(t)$, which depends upon u and the limits g_B^* and g_V^*.

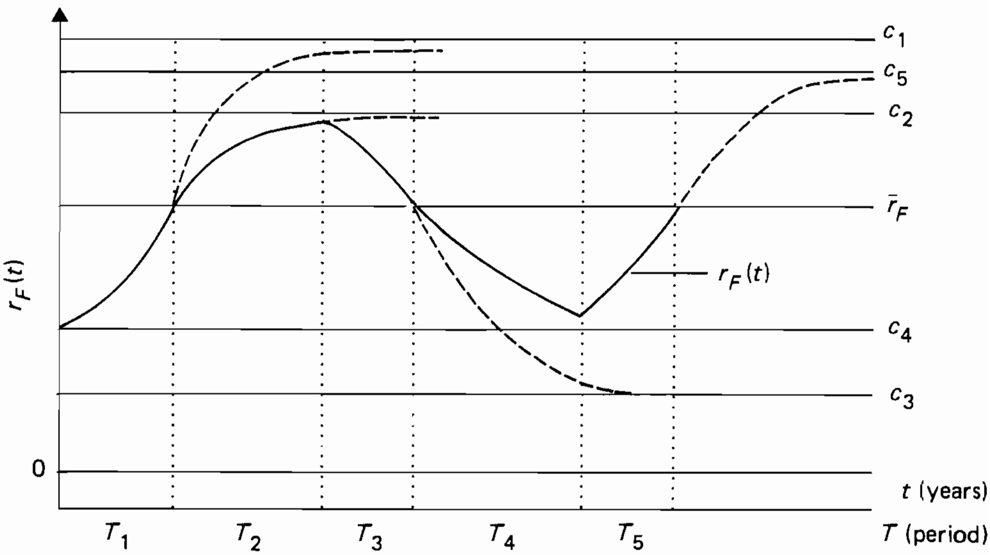

Figure 15.2. Economic trajectory of a technical revolution as a result of interconnected changes in dynamic efficiency, investment strategy, and the accumulation coefficient kF. (Piecewise approximation, using limits $c_1, \ldots,$ for early period. T_1 = introduction, T_2 = rapid growth, T_3 = maturation, T_4 = saturation, T_5 = new introduction).

Figure 15.2 shows the development of average efficiency in comparison with the long-term mean in the four phases of a technical revolution:

(1) Introduction phase, when the real efficiency is lower than the long-term mean.
(2) Rapid growth phase, when average efficiency increases to a maximum value that is higher than the long-term mean.
(3) Maturation phase, when average efficiency falls to the mean.
(4) Saturation phase, when average efficiency falls below the long-term mean.

(Note that the "fifth" phase shown in *Figure 15.2* represents the introductory phase of the next upswing.) But now the question arises as to why downswings in efficiency growth occur. The reasons may be seen in the growth mechanism itself:

(1) Industrial growth always occurs within a limited number of branches.
(2) Growth in output in certain industries is always connected with subsequent diminishing relative growth rates while absolute growth rates are still increasing.

(3) The net returns or profits grow more slowly than turnover, because of the growing organic composition of capital, especially in mature industries. Net returns increase according to

$$R(t) = a_0 \, t^{a_1} \tag{15.7}$$

where a_0 and a_1 are statistical parameters.

The growth of productive funds shows another pattern. New industries normally have a relatively (on average) low organic composition of funds. Thus, the growth rates of funds are high, despite rapid product innovation and low economies of scale. But later, in the maturation and saturation stages, growth rates of funds remain at a high level due to the absence of the inhibiting factors just mentioned. The development of funds therefore follows the function

$$F(t) = b_0 \, e^{b_1 t} \ . \tag{15.8}$$

From (15.7) and (15.8) we derive

$$r_F(t) = \frac{a_0 \, t^{a_1}}{b_0 \, e^{b_1 t}} = c \, \frac{t^{a_1}}{e^{b_1 t}} \qquad \dot{r}_F(t) = r_F \left[\frac{a_1}{t} - b_1 \right]$$

The net returns on funds reaches a maximum at $t = a_1 / b_1$, and decreases asymptotically thereafter,

$$\frac{R'(t)}{F'(t)} = \frac{a_0 \, a_1 t^{a_1 - 1}}{b_0 \, b_1 \, e^{b_1 t}} = r_F(t) \, \frac{a_1}{b_1 \, t}$$

approaching a maximum at $t = (a_1 - 1)/ b_1$.

15.5. Identification of the Trajectory of a Technical Revolution

Our investigation has used data for Soviet industry since 1950, published in the *Statistical Yearbooks* of the USSR. Productive funds and net returns are given for 12 industrial branches (electricity production, oil extraction and refining, gas, coal, metallurgy, chemicals, wood, paper, and pulp). From these we took a group of dynamic industries that included oil extraction and refining, chemicals, and oil petrochemicals, engineering, and metallurgy.

Figure 15.3 shows the development of average efficiency under the impact of dynamic efficiency. The major upswing of the 1950s and 1960s can be clearly seen. The trend from 1960 to 1968 for dynamic industries is

$$\ln r_{F'}(t) = -35.993 + 9.9324 \ln t - 0.11122\, t$$

$$t_{\max} = 89 \quad (r_{F'})_{\max} = 27\%$$

and for R'/F',

$$t_{\max} = 80 \quad (R'/F')_{\max} = 28.5\%$$

In the case of nondynamic industries,

$$\ln r_{F'}(t) = -26.641 + 7.2924 \ln t - 0.08857\, t$$

$$t_{\max} = 82 \quad (r_{F'})_{\max} = 17.1\%$$

and for R'/F',

$$t_{\max} = 71 \quad (R'/F')_{\max} = 18.3\%$$

Using u and the maxima of R'/F', we can calculate the efficiency limit from equation (15.3) as 22%, which is not much higher than the real value in 1970. A similar calculation can be done for the downswing using the variable $1 - r_{F'}(t)$ instead of $r_{F'}(t)$. Now let us look at the partial historical periods of efficiency development in *Figure 15.3*.

From 1950 to 1956 average efficiency is much lower than the long-term mean of 14.62%. The accumulation coefficient $k_{F'}$ is high (near 1), and the control parameter u is increasing from 23%. Concerning $R'(t)/F'(t)$ the dynamic complex is already better than average, but the relative efficiency $r_{F'}(t)$ is still somewhat lower. The planned normative efficiency $(1/c)$ is relatively high.

Between 1956 and 1960 dynamic efficiency reaches the average level (i.e., the relative efficiency = 1). $k_{F'}$ is much lower (near 0.75), but u is considerably reduced after 1958. This leads to the stagnation of $r_{F'}(t)$.

Between 1960 and 1966 relative efficiency grows rapidly to reach a local maximum in its marginal form in 1965. Both $k_{F'}$ and u are stabilized at a lower level. The standard deviation of $r_{F'}(t)$ for the 12 industries is growing. The planned normative efficiency $(1/c)$ is higher than in the earlier period.

Between 1966 and 1970 there is a very rapid growth in $r_{F'}(t)$. $R'(t)/F'(t)$ reaches its highest point in 1967, as does $r_{F'}(t)$ in 1970. u is stable, but $k_{F'}$ is drastically reduced; this is a very plausible reaction. The

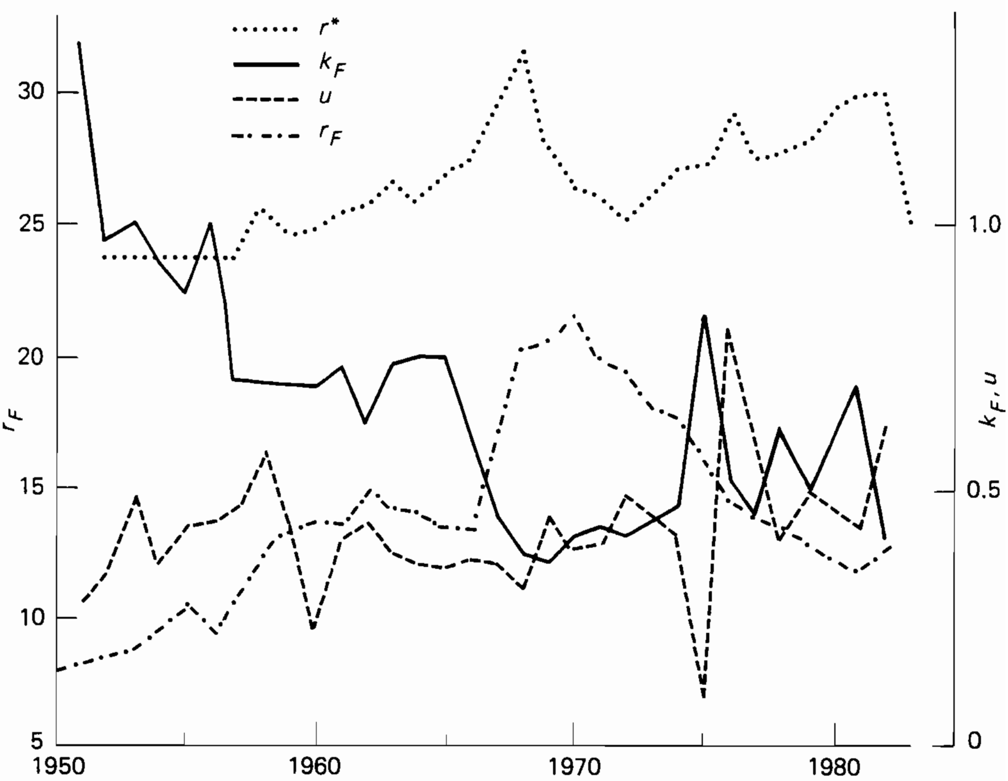

Figure 15.3. Development of net returns on funds r_F, relative efficiency r , and the control parameters u and k_F in Soviet industry, 1950–1982.

standard deviation of efficiency for the 12 industries reaches a maximum in 1968.

Between 1970 and 1976 the dynamic and average efficiencies fall, but not because of a change in u. Average efficiency is still higher than the long-term mean of 14.62%. After 1972 relative efficiency increases as a result of the reduction in average efficiency. The standard deviation of r_F reaches a minimum; $1/c$ is very high. (In 1972 the 24th Party Congress developed the economic strategy of intensification on the basis of scientific–technological progress.)

Between 1976 and 1981 the efficiency downswing becomes slower, but average efficiency is now lower than the long-term mean. Standard deviation of $r_F(t)$ begins again to grow, which is obviously a process of increasing negentropy, and establishes a new efficiency potential for the next upswing. In 1981 the downswing ends and in 1982–1983 $r_F(t)$ begins to grow again.

For the six periods all variables and parameters are given in *Table 15.4*. These were the basis for the estimated values of $r_F(t)$ in *Table 15.5*.

Table 15.4. Estimated parameters for each period.

	Year					
Variable	*1950–1956*	*1956–1960*	*1960–1966*	*1966–1970*	*1970–1976*	*1976–1982*
k_F	1.120	0.834	0.766	0.467	0.525	0.560
u	0.380	0.393	0.367	0.366	0.398	0.479
g_B	0.114	0.221	0.218	0.356	0.082	0.076
g_V	0.105	0.243	0.078	0.474	0.023	0.118
c	0.108	0.243	0.129	0.434	0.046	0.098
$1/c$	9.3	4.3	7.8	2.3	21.7	10.2
a	456.956	392.492	376.998	377.459	167.324	249.098
b	0.2348	0.2005	0.1936	0.1916	0.0843	0.1265
a^*	236.555	282.202	194.241	398.711	47.795	108.482
b^*	0.1210	0.1952	0.0988	0.2027	0.0242	0.0549

a, b Logistic function parameters for dynamic industries.
a^*, b^* Logistic function parameters for the nondynamic industries.

If fluctuations in the dynamic and average efficiency are the objective result of the evolution of a particular historical complex of basic innovations, it becomes clear that forecasts will become less reliable the nearer we come to a new upswing. Two signs of the coming upswing are the growing standard deviation of net returns on funds since 1976 and the end of the downswing in 1981. The core of the new technical revolution will be the diffusion of modern information technology, which is connected with the rapid growth of flexible automation, communications equipment, etc.

Assuming $c = 0.146$ for the first phase of the upswing (with $u = 0.38$, $g_B = 0.16$ and $g_V = 0.137$, and $b = 0.18$), one obtains variant I in *Table 15.6*. However, an accumulation rate of 1.23 would be needed to obtain such a trend, and this is obviously unrealistic; we therefore assume a higher control parameter. If we take $u = 0.55$ and $b = 0.12$, we obtain variant II in *Table 15.6*. Such variants can be created by simulation procedures; on the basis of the philosophy outlined in this chapter, systems dynamics models DYNAFOR A and B have been developed, with which the economic trajectory of a technical revolution can be simulated, using control parameters u and k_F and partial goals for the net returns on funds.

15.6. Conclusions

The long cycle of dynamic efficiency resulting from a technical revolution and its impact on average efficiency is not generally recognized in socialist economic theory, especially in efficiency theory. It is easy to explain cycles in special technological fields, but it is much more difficult to explain longer cycles. But, as the empirical evidence grows, the nature of fluctuations in socialist economies will become clearer. Recently, an investment cycle of 4–6 years has been identified using the example of industries in the GDR, which is

Table 15.5. Estimated and actual values of net returns on funds (%).

Year	*Estimated values*	*Actual values*	*Difference*
1950	7.8	8.0	–0.2
1951	8.3	8.3	0
1952	8.7	8.4	0.3
1953	9.1	8.7	0.4
1954	9.4	9.6	–0.2
1955	9.7	10.3	–0.6
1956	9.6	9.2	0.4
1957	10.7	10.6	0.1
1958	11.9	12.6	–0.7
1959	13.0	13.4	0.4
1960	14.0	13.6	0.4
1961	13.8	13.4	0.4
1962	13.6	14.8	–1.2
1963	13.5	14.0	–0.5
1964	13.4	14.0	–0.6
1965	13.3	13.0	0.3
1966	13.2	13.3	–0.1
1967	16.4	17.1	–0.7
1968	18.4	20.1	–1.7
1969	20.5	20.5	0
1970	21.7	21.5	0.2
1971	20.3	19.8	1.5
1972	19.0	19.3	–0.3
1973	17.9	18.0	–0.1
1974	16.8	17.7	–0.9
1975	15.8	15.8	0
1976	14.3	14.4	–0.1
1977	13.7	14.0	–0.3
1978	13.3	13.5	–0.2
1979	12.9	12.6	0.3
1980	12.5	12.2	0.3
1981	12.2	11.5	0.7
1982	11.9	12.8	–0.9

Table 15.6. Variants of future development in net returns on productive funds.

	Variant	
Year	*I*	*II*
1982	12.8	12.8
1983	13.1	13.0
1984	13.4	13.2
1985	13.7	13.4
1986	14.0	13.6
1987	14.3	13.8

a result of internal delays in the reproduction of fixed capital (Roesler *et al.*, 1983).

This has been well known to industrial planners but it was not reflected in theoretical works, and longer cycles are not accounted for in many works on efficiency and strategic planning. This seems a little strange in view of Soviet history: the first long-range national plan (GOELRO), initiated by Lenin, was connected with the electrotechnical revolution from the outset, and was not a result of pure macroeconomic extrapolations (Lenin, 1920). But a breakthrough in thinking on cycles is not far. Recently, Yakovets (1984) published a study of long technological cycles, in which it was made clear that an historical evaluation and location of industrial growth complexes is vitally important for long-range investment, education, and science policies and strategies.

Ignorance of long cycles contributes in critical decades to devaluation pushes, misguided investments, and delays in monitoring the new upswing. Thinking in cycles is therefore a key to making more efficient decisions.

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CHAPTER 16

Rates of Innovations and Profits in the Long Wave

Alfred Kleinknecht

16.1. Introduction

The severe economic problems in most Western countries during the last decade have helped to reveal a decisive weakness in economic theorizing: none of the different schools of economic thought, whether Marxist or non-Marxist, have a satisfactory theory of ***long-term*** economic development. There is virtually no economic theory or paradigm which, beyond pure speculation, would allow any well founded economic forecast of what will happen to economic growth and employment in the next ten years or so. In judging the character of the present economic crisis, even the most basic questions are still open: Have some medium-term business cycles run out of their normal course since the mid-1970s, due to exogenous shocks and policy mistakes (end of the Bretton Woods system, oil price shock, budget deficits)? Will there be a return towards full employment and price stability once these policy mistakes are corrected and the shocks absorbed, as the McCracken report of the OECD (1977) puts it? Or do the low growth rates since the mid-1970s rather indicate a return to a "normal" long-term growth path once the postwar reconstruction boom had faded (reconstruction hypothesis)? Or, to sketch still another possible interpretation: can the economic problems of the last decade be taken as evidence that capitalism has reached the final stage of its life cycle, its last stage of decadence and stagnation? Are we experiencing the *Final Crisis of Capitalism*?

With the continuation of the current crisis, the McCracken *et al.* (1977) report has lost much of its appeal. The alternative reconstruction hypothesis can explain why there was fairly strong growth up to the 1950s (see

Abelshauser and Petzina, 1980), but it can not explain why the growth boom continued up to the early 1970s. According to Jánossy (1966), the postwar reconstruction period terminated somewhere between 1955 and 1961 in the various European countries concerned. And what about the Final Crisis hypothesis?

During the 1920s, many Marxists took that hypothesis for granted. In particular, the severe crisis after 1929 seemed to confirm that capitalism was facing its definite decline. However, the economic growth boom that took place from the late 1940s up to the early 1970s caused a complete setback to this version of crisis theory. At the same time, adherents of the market system considered the growth boom to be striking evidence of the obsolescence of Marxism.

In recent years, another interpretation of the economic crisis has been gaining appeal: the theory of the long wave in economic life Ironically, theorizing on long waves seems to move itself along a long-wave path. Beginning with the publications by the two Dutch Marxists, Van Gelderen (1913) and De Wolff (1915), up to Kondratieff (1926) and Schumpeter (1939), the prewar years saw a fairly large number of contributions on long waves (for a survey see Barr, 1979). During the euphoric boom of the 1950s and 1960s, however, the subject moved into the background of economic literature. Within the present renaissance of long waves, Schumpeter's (1939) hypothesis proves particularly attractive: the upswing of the long wave is fostered by a thrusting introduction and rapid diffusion of radical innovations. Each long wave is characterized by the emergence of a particular set of basic technologies whose diffusion imparts a deep material change to the reproduction process. Schumpeter's scheme of long waves can be summarized in *Table 16.1*.

Table 16.1.

	Upswing (A-period)	*Downswing (B-period)*	*Innovation*
First long wave: (industrial Kondratieff)	1787–1813	1814–1842	Substitution of steampower for water power, coal, and iron for wood; emergence of the textile industry
Second long wave: (bourgeois Kondratieff)	1843–1869	1870–1897	Railroads, steamships; substitution of steel for iron
Third long wave: (neomercantilist Kondratieff)	1898–1924	1925–	Electrical and chemical innovations, internal combustion and diesel engines

If we were to make a simple extrapolation of Schumpeter's scheme, we would take the interwar period as well as the 1970s and 1980s as (depressive) B-periods, while the late 1940s up to the early 1970s appear as an A-period. A new A-period would have to be expected sometime in the 1990s.

Schumpeter's approach received strong criticism from Kuznets (1940), who not only considered that Schumpeter had failed to prove that radical innovations occur in clusters; he also emphasized that there was no convincing explanation of why such a clustering should occur: Schumpeter seemed to explain the clustering of major innovations as a clustering of heroic entrepreneurs – a ***deus ex machina*** theory. Furthermore, Kuznets doubted whether the alleged 45–60-year Kondratieff cycle existed at all. It is beyond doubt that Kuznets (1940) was right on almost all points when criticizing the shortcomings of Schumpeter's theory. Since the 1950s and 1960s theorizing on long waves has more or less stagnated, and the critical questions raised by Kuznets remain unanswered. On the other hand, Schumpeter's theoretical propositions, if correct, have very far-reaching and important policy implications.

Recently, I have finished a research project on this subject (see Kleinknecht, 1986). In the following, some outcomes of that research are briefly discussed. In a first step, I examine whether the alleged 45–60-year long waves exist at all, and then deal with theoretical and empirical aspects of the cluster-of-innovations hypothesis. Thereafter, I report on findings about patterns of innovation, growth, and profit rates during the post-World War II boom.

16.2. Do Long Waves Exist?

The early long-wave pioneers relied very heavily on long waves in price series or in price-affected series. As Garvy (1943) in his criticism of Kondratieff (1926) pointed out, evidence of long waves in "real" series (production, investment, etc.) is poor. Now that longer time series on industrial production and GNP are available for various countries, several attempts have been made to test the long-wave hypothesis in such indicators of general economic activity. The outcomes of the various tests are contradictory, ranging from full acceptance of the long-wave hypothesis (e.g., Mandel, 1973; van Duijn, 1979; Glismann *et al.*, 1983) to outright rejection (e.g., Van der Zwan, 1980; Van Ewijk, 1981, 1982). Between these two extremes some studies reach very cautious conclusions, neither refuting nor accepting the long-wave hypothesis, but pleading in favor of further research efforts (see, e.g., Kuczynski, 1978, 1980; Metz, 1983; Spree, 1978).

In this chapter the results of a new test on long waves by Bieshaar and Kleinknecht (1984) are outlined. Although we do not claim to have developed *the* ultimately correct and reliable method of testing long waves, we do claim that this test imparts some methodological progress as compared with other tests published so far. In the test by Bieshaar and Kleinknecht (1984), average growth rates for the alleged A- and B-periods of the long waves have been estimated, using the time series listed in *Table 16.2*. We used a generalized least squares estimator (GLS), taking into account a second degree of autoregression in the residues. With the aid of a one-sided t-test (see Schmidt, 1976, p. 18), we tested whether the differences in average growth rates for the A- and B-periods are different from zero. For the timing of A- and B-periods the time scheme by Mandel (1973) was used because, among all modern time schedules of long waves, it is closest to the "orthodox" periodization of long waves (Van Gelderen, De Wolff, Kondratieff). Moreover, the Mandelian time scheme implies a relatively strict periodicity and strong synchronization of the national long waves in a world market context.

Table 16.2. Time series tested in Bieshaar and Kleinknecht (1984).

Country	*Variable*	*Time coverage*	*Source*
United Kingdom	Industrial production	1801–1938 1946–1981	Mitchell (1981) OECD (1983)
	GDP	1830–1979	Glismann *et al.* (1981)
France	Industrial production	1815–1913 1919–1938 1947–1981	Mitchell (1981) OECD (1983)
	Net domestic product	1900–1913 1920–1979	Glismann *et al.* (1981)
Germany	Net national product (NNP)	1850–1913 1925–1941 1948–1979	Glismann *et al.* (1981)
Belgium	Industrial production	1831–1913 1920–1939 1946–1981	Gadisseur (1979) Mitchell (1981) OECD (1983)
USA	GNP	1889–1979	Glismann *et al.* (1981)
Italy	GDP	1861–1979	Glismann *et al.* (1981)
Sweden	GDP	1861–1979	Glismann *et al.* (1981)
World (1)	Industrial production (excl. mining)	1780–1979	Kuczynski (1980) Haustein and Neuwirth (1982)
World (2)	Total industrial production (incl. mining)	1850–1976	Kuczynski (1980)

The results of the test on the Mandelian scheme of long waves are summarized in *Table 16.3*, from which it will be noted that in the post-1974 period, significance levels are relatively low, probably because of the relatively small number of observations. The same holds for the beginning periods of the Swedish and Italian series, both starting in 1861 (instead of 1848), for the USA, 1889–1893; and for France, 1900–1913 (instead of 1893–1913).

Table 16.3 can be summarized as follows.

(1) In both world production series, as well as in the series for Germany, France, and the USA, from 1893 to 1974 the variation in growth rates is consistent with the long-wave hypothesis; i.e., average growth rates for the A-periods (1893–1913 and 1939–1974) are higher than growth rates in the B-period (1913–1939). According to the *t*-test, the differences are significant; for a part, even highly significant. Before 1893, however, there are no significant differences in average growth rates for the A- and B- periods. In some cases, growth rates even vary in the

Table 16.3. Average growth rates for A- and B-periods of long waves, their approximate standard errors, and the significance of differences in average growth rates, according to Mandel's long-wave chronology.

	Country and variable										
Periods[a]	*World ind. prod.* (1)	*World ind. prod.* (2)	*Belgium ind. prod.*	*Germany NNP*	*France ind. prod.*	*France NDP*	*Sweden GDP*	*Italy GDP*	*USA GNP*	*UK ind. prod.*	*UK. GDP*
A: 1792–1825 g:	2.63%	–	–	–	0.13%	–	–	–	–	2.64%	–
SE:	(0.25)	–	–	–	(1.32)	–	–	–	–	(0.25)	–
sign. of diff.:	1.1%	–	–	–	15.4%	–	–	–	–	2.7%	–
B: 1825–1847 g:	3.89%	–	1.99%	–	1.88%	–	–	–	–	3.47%	2.18%
SE:	(0.35)	–	(0.62)	–	(0.59)	–	–	–	–	(0.23)	(0.42)
sign. of diff.:	34.9%	–	98.4%	–	38.8%	–	–	–	–	11.7%	59.3%
A: 1847–1873 g:	3.66%	2.32%	3.85%	2.52%	1.61%	–	3.02%	0.92%	–	3.00%	2.33%
SE:	(0.32)	(0.36)	(0.33)	(0.57)	(0.48)	–	(0.57)	(1.21)	-	(0.20)	(0.25)
sign. of diff.:	66.2%	23.3%	99.9%	34.0%	56.9%	–	85.5%	61.1%	–	99.1%	76.9%
B: 1873–1893 g:	3.38%	2.80%	1.46%	2.95%	1.44%	–	2.20%	0.45%	4.27%	2.02%	1.95%
SE:	(0.42)	(0.37)	(0.41)	(0.61)	(0.62)	–	(0.29)	(0.66)	(2.98)	(0.26)	(0.32)
sign. of diff.:	75.4%	45.8%	99.5%	43.6%	60.3%	–	98.6%	97.0%	46.9%	12.2%	29.7%
A: 1893–1913 g:	3.90%	2.73%	3.48%	2.77%	1.73%	2.81%	3.31%	2.65%	4.01%	1.47%	1.64%
SE:	(0.42)	(0.36)	(0.44)	(0.63)	(0.60)	(1.87)	(0.26)	(0.62)	(0.53)	(0.26)	(0.32)
sign. of diff.:	99.9%	97.5%	99.9%	97.7%	96.9%	91.0%	96.8%	98.0%	99.0%	16.2%	93.8%
B: 1913–1939 g:	1.95%	1.63%	–0.19%	0.83%	–0.01%	–0.42%	2.55%	0.66%	2.16%	1.88%	0.88%
SE:	(0.29)	(0.26)	(0.31)	(0.44)	(0.44)	(0.81)	(0.19)	(0.44)	(0.33)	(0.20)	(0.32)
sign. of diff.:	99.9%	99.9%	99.9%	99.9%	99.9%	99.9%	99.9%	99.9%	99.8%	99.9%	99.9%
A: 1939–1974 g:	4.68%	3.53%	3.30%	4.50%	4.83%	4.32%	4.46%	4.29%	3.80%	3.06%	2.52%
SE:	(0.24)	(0.21)	(0.24)	(0.34)	(0.37)	(0.64)	(0.15)	(0.36)	(0.27)	(0.16)	(0.18)
sign. of diff.:	61.9%	50.8%	79.8%	77.4%	92.5%	52.4%	99.9%	64.3%	74.8%	99.9%	73.0%
B: 1974– g:	3.94%	3.46%	1.95%	2.65%	1.95%	4.04%	–0.14%	3.26%	2.17%	-0.56%	1.64%
SE:	(2.31)	(3.55)	(1.48)	(2.27)	(1.78)	(4.18)	(1.28)	(2.61)	(2.28)	(1.01)	(1.34)

[a] g = estimated growth rate; SE = standard error of growth rate (calculated by a first-order Taylor approximation); sign. of diff. = significance of difference between growth rates for two successive periods.

"wrong" direction; these (inverse) fluctuations are characterized in *Table 16.3* by significance levels of less than 50%.

(2) While in the above series there is a dichotomy between the pre-1890s and the post-1890s, the Belgian series has a highly significant long-wave pattern throughout from 1832 to 1974. This result is remarkable insofar as Belgium is a small and open economy, which is likely to be influenced strongly by the world market.

(3) The Italian and Swedish series also show a significant long-wave pattern not only in the period 1893–1974, but also before 1893. During 1861–1873, however, significance levels are below the 95% level; this might result from the smaller number of observations.

(4) As opposed to all other series considered, the two British series do not fit into the time scheme of long waves. Bieshaar and Kleinknecht (1984) concluded from a graphical inspection of the series that the British data obviously reflect a kind of hegemonial life cycle of rising and declining world market hegemony of British industry (with a "peak" in the 1870s). This hegemonial life cycle can also be seen in the growth rates given in *Table 16.3*.

The results shown by *Table 16.3* are twofold: on the one hand, all series (except the British) show a variation in growth rates between 1893 and 1974 that is consistent with the long-wave hypothesis; on the other hand, the results remain ambiguous as to the pre-1890s. While the two series on world industrial production, as well as the series for the FRG, France, and Great Britain show no long-wave pattern during that period, the series for Belgium, Italy, and Sweden are consistent with the long-wave hypothesis even before the 1890s.

In particular, the result for 1893–1974 contradicts critics such as Van Ewijk (1981, 1982) or Van der Zwan (1980) who state that in aggregate "real" series there are no fluctuations that fit into the scheme of long waves. At the same time, *Table 16.3* also seems to contradict theorists such as Mandel (1973) who take the long wave as a characteristic phenomenon of the *entire* industrial era from the end of the eighteenth century to the present day. In a nutshell, the results achieved by Bieshaar and Kleinknecht show that the long-wave concept appears to be relevant primarily for the eras of *Hochkapitalismus* and *Spätkapitalismus*, and is less important for the infant phase of capitalism. However, this latter conclusion can be objected to on grounds that the statistical quality of the series tested in Bieshaar and Kleinknecht (1984) has not been examined. It is obvious that the series for the nineteenth century are less reliable than those for the present century and that therefore any positive or negative result on long waves for the pre-1890 periods has to be interpreted with the utmost caution.

There is yet another important limitation to the test by Bieshaar and Kleinknecht. We have demonstrated that, during the last 100 years, a number of countries have shown statistically significant fluctuations that fit into the long-wave time scheme; however, this does not say anything about the possible *cyclical* nature of the long-wave pattern. Since we observed a fairly limited number of A- and B-periods, critics may argue that the ups and downs have been caused by historically unique, exogenous factors, and that there is no reason to assume that such movements will continue in the future. In fact, a purely quantitative test cannot help us to decide whether this objection is justified or not.

As Spree (1978), for example, has clearly pointed out, the question of whether or not we can speak of true cycles depends decisively on whether convincing *endogenous* explanations of the upper and lower turning points of the waves can be given. In their early contributions on long waves, the two Dutch Marxists Van Gelderen (1913) and De Wolff (1915) reflected on the possibly endogenous nature of factors such as the opening of new industrial branches, the export of capital into new territories, over-accumulation of capital, expansion and contraction in the capital market, scarcity and abundance of raw materials, migration, discovery of new gold mines, etc. The following section is dedicated to a more thorough consideration of the first topic: the opening of new industrial branches. This point is closely related to Schumpeter's innovation hypothesis.

16.3. Long Waves in Technological Innovation?

In recent years, various attempts have been made to collect long-term historical innovation indicators, and principally to distinguish a few radical breakthroughs in technology from the large stream of smaller piecemeal changes. To put it metaphorically, there is a considerable difference between innovators who introduce improved horse cars and those who abolish horse cars by introducing railways or automobiles. In the more recent literature, a number of imaginative notions have been invented to describe this difference in more general terms. For example, Dosi (1982) recommends that innovations that establish new "technological paradigms" be distinguished from innovations that occur within existing paradigms. Others speak of "basic innovations" versus "improvement innovations" (e.g., Mensch, 1975; van Duijn, 1979; Haustein and Neuwirth, 1982), of "new technology systems" (Freeman *et al.*, 1982), of "new technological webs" (Roobeek, 1984), or simply of "major" or "radical innovations".

All these notions are similar in that, in empirical investigations of innovations, it is very often difficult to distinguish more important from less important cases, whatever notion is chosen. This is not the place to investigate the various sets of innovation data and concepts more thoroughly (see Kleinknecht, 1986, Part II, for that); here we restrict ourselves to documenting the results of various innovation studies for the twentieth century (*Table 16.4*).

These figures clearly contradict the hypothesis that important innovations are distributed randomly over time. A remarkable concentration of innovations occurred, reaching from the second half of the 1930s up to the 1950s. Thereafter, the numbers of innovations seem to decline (with the exception, perhaps, of columns 2 and 4).

Table 16.4. Important innovations in five-year periods during the twentieth century according to various sources and definitions[a].

Period	(1)	(2)	(3)	(4)	(5)	(6)
1900–1904	0	0	1	5	0	1
1905–1909	1	1	0	2	1	3
1910–1914	0	0	7	6	2	3
1915–1919	0	0	1	2	0	1
1920–1924	6	6	3	6	4	2
1925–1929	0	0	0	4	3	5
1930–1934	5	5	6	5	7	6
1935–1939	9	11	8	14	13	12
1940–1944	2	5	6	6	5	10
1945–1949	7	8	5	5	3	6
1950–1954	1	3	5	7	4	6
1955–1959	1	2	2	8	1	3
1960–1964	2	7	4	10	–	1
1965–1969	1	5	1	4	–	3
1970–1974	–	–	1	4	–	–

[a](1) "Radically new products" (excluding scientific instruments) according to the classification by Kleinknecht 1981), based on Mahdavi (1972); (2) "radically new products" (including scientific instruments) according to the classification by Kleinknecht (1981); (3) "basic innovations" according to Van Duijn (1979), based on Baker (1976), De Bono (1974), Enos (1962), Freeman (1974), Jewkes *et al.* (1969), Van der Kooy (1978), Landes (1969), Mahdavi (1972), Mueller (1962), Nabseth and Ray (1974), Robertson (1974); (4) "basic innovations" according to Haustein and Neuwirth (1982), based on various sources (not specified); (5) "basic innovations" according to Mensch (1975), based on Jewkes *et al.* (1959); (6) Mensch's "basic innovations", extended and revised according to the suggestions by Freeman *et al.* (1982).

The reliability of such innovation data has been seriously questioned, however. In particular, the original version by Mensch (1975) of innovation clusters in the troughs of long waves (1880s, 1930s) has met with strong skepticism (see Scholz, 1976; Clark *et al.*, 1981) as to the representativeness of data sources, the selection modes, the exact determination of innovation years, the definition of "basic innovations", etc. (see, e.g., Clark *et al.*, 1981, p. 148). Freeman *et al.*, (1982, p. 49) claim that similar criticisms hold for the set of data used in Kleinknecht (1981).

Critics have suggested a number of corrections and extensions to Mensch's list of basic innovations (see *Table 16.4*, column 6). Moreover, they suggest that the data from Kleinknecht (1981) be grouped differently (see column 2). A comparison of columns 1 and 2, 5 and 6 shows that the results indeed become slightly different. In addition to a concentration of innovations in the late 1930s, there seem to be more cases during the 1940s and 1950s; i.e., in the early upswing phase of the long wave. Nevertheless, even the modified data do not corroborate the position of Clark *et al.*, (1981, p. 150), who emphasize that, due to the high risks and uncertainties of radical innovation projects, it is highly unlikely that such innovations will cluster in the depression phase of the long wave.

Each source of innovation data can be criticized in one way or another. If we are to judge Schumpeter's cluster-of-innovations hypothesis with

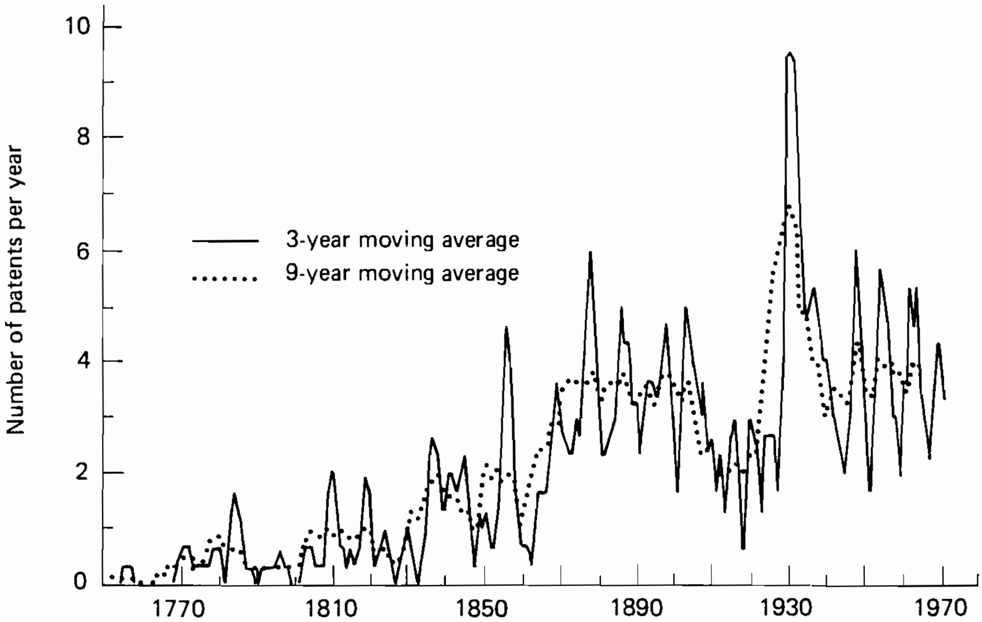

Figure 16.1. Baker's product-related key and master patents according to classification by Kleinknecht (1986).

greater certainty, we should compare as many long-term innovation indicators as possible from different sources. Therefore, in Kleinknecht (1986) another set of innovation data has been analyzed consisting of some 1,000 patents selected by Baker (1976) as being particularly important "key" and "master" patents during the period 1640–1971. Baker started with a list of 363 items. In alphabetical order, these range from the addressograph to the zip fastener. From the numerous patents registered at the British Patent Office, he selected for each of these items what he considered to be the decisive breakthrough patent(s). The use of Baker's patent data as an indicator of the rate of important innovations in the long-term involves a number of methodological problems and drawbacks that cannot be dealt with here (see Kleinknecht, 1986, ch. 4). With the help of a newly developed classification scheme (see Coombs and Kleinknecht, 1984), Baker's 1,000 patent cases have been classified by process- versus product-related patents, the outcomes for the latter being given in *Figure 16.1*. An inspection of the original data showed that, during the period 1640 to 1750, noteworthy fluctuations in the series did not occur. *Figure 16.1* is therefore restricted to the period 1750–1971.

Two long waves of product-related patents are illustrated: the first extends from the late 1870s up to about 1905, covering the depression phase of the second Kondratieff and the early upswing of the third Kondratieff; the second extends from the early 1930s up to the early 1960s. In both cases it seems that the decline in the number of innovations occurred some ten years before the decline of the economic long wave.

Before 1850 fluctuations in the rate of important patents were apparently smaller. The wave from about 1830 to 1855 would fit with the above interpretation of the two waves, since it covers the depression phase of Schumpeter's second Kondratieff and the early upswing phase of the third Kondratieff, although this wave is rather weak. So far, the innovation data in *Figure 16.1* seem to confirm the impression gained from the economic series in *Table 16.3*, i.e., that the concept of long waves might be less relevant for the early phase of capitalism.

Baker's *process*-related patents are not documented here, since their interpretation is more difficult than that of product patents (see Kleinknecht, 1986, Ch. 4). Process-related patents seem to correspond more with the classical medium-term business cycle than with the long wave. In each case, the process series shows peaks not only during the depression phase, but also during the later prosperity phase of the long wave. During the post-World War II period, it appears even that product- and process-related patents moved in opposite directions (*Ibid*, ch. 4). A similar pattern can be found in yet another set of data presented by the critics of the cluster-of-innovations hypothesis and covering 195 "radical innovations" in British industry from 1920 to 1980. The cases are selected from a larger set of some 2,000 innovations, collected by means of interviews with managers in about 50% of British manufacturing industries (see Freeman *et al.*, 1982).

The distribution of these 195 radical innovations over the 1920-1980 period is given in *Figure 16.2*. As Freeman *et al.* indicate, the data may underestimate the innovations of the inter-war period, which has been investigated less thoroughly than the period 1945–1950. War-related innovations may also be underrepresented since the aircraft industry is not included. From *Figure 16.2* it can be concluded that the critics of the cluster-of-innovations hypothesis are not supported even by their own data. A clear peak in the late 1930s is shown. The second peak in the late 1950s is still consistent with the impression gained from other sets of innovation data, especially if we consider that *Figure 16.2* is concerned with *British* innovations. British innovations may in many cases follow the first introduction of an innovation on a world level with some time lag.

To summarize our empirical considerations, it seems that the impression from important innovations in *Table 16.4* is consistent with two other sets of data from independent sources: the product-related key and master patents in *Figure 16.1* and the radical innovations in *Figure 16.2*. The various sets of data contradict the hypothesis that radical innovations are distributed randomly over time. Instead, they appear to be concentrated during the depression and early upswing phase of the long wave.

How can this observation be explained? Why are such risky radical innovations introduced during the depression phase of the long wave, when risks and uncertainties of economic and social development are highest? Why are they less frequently introduced during prosperity phases? An answer could be that in the prosperous periods, not only innovation risks but also incentives for radical innovations are lower. As long as existing product lines

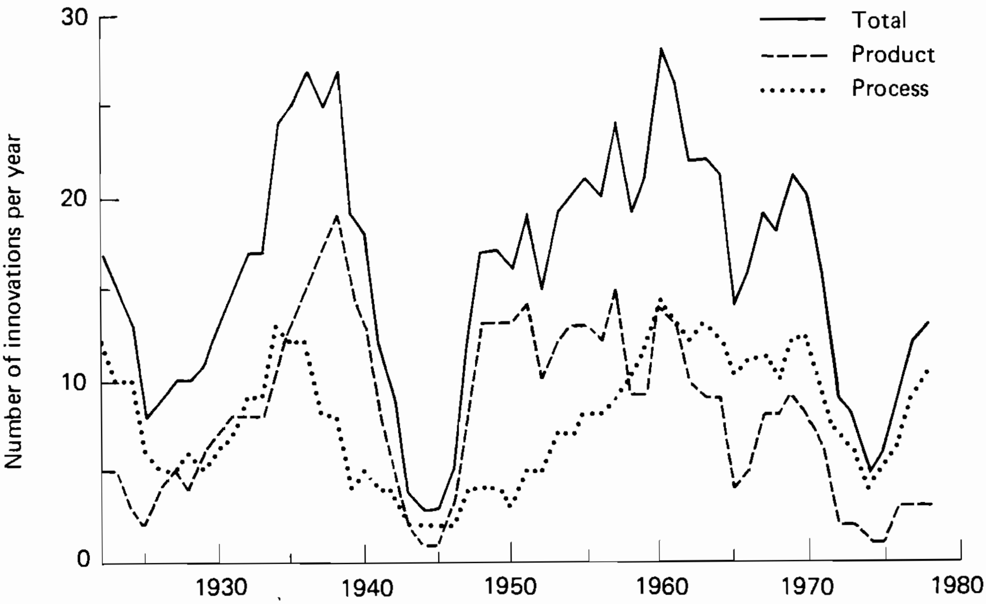

Figure 16.2. 195 radical innovations (five-year moving averages) in British industry according to Freeman *et al.* (1982).

continue to expand, it is more profitable to concentrate innovation and R&D efforts on gradual improvements within those lines. The tendency to concentrate innovative efforts on the gradual improvement of existing technologies rather than undertaking radical innovations can be enhanced by the fact that radically new technologies often represent an uncomfortable substitution competition against existing technologies and industries: in a process of "creative destruction" (Schumpeter) the steam engine competes against the water wheel, and later the steam engine is threatened by the internal combustion engine and the diesel engine; the position of railways has been undermined by automobiles and airplanes; synthetic materials replaced natural fibers; petroleum competes against coal; and so on. Entrepreneurs who have invested in the old technologies are naturally not interested in the emergence of such substitution competition; and they might have ways and means to oppose it.

Rosenberg and Frischtak (1983) have emphasized that firms that adhere to their old technologies are favored by the fact that the educational systems, and especially the training of technicians and engineers, are shaped by the needs of established industries and their political lobby. Moreover, there is the so-called "sailing ship" effect: the emergence of a new competing technology can be considerably impeded by efforts to improve the established technology. Rosenberg (1982, p. 115) cites a number of examples:

> The water wheel continued to experience major improvements for at least a century after the introduction of Watt's steam engine; and the wooden sailing ship was subjected to many major and imaginative improvements long after the introduction of the iron-hull steamship. During the 1920s the competition of the internal combustion engine is said to have been responsible for much technological improvement in steam engines, while in the same period the competition from the radio stimulated experiments that led to the new and improved type of cable that was introduced in 1924. The Welsbach mantle, perhaps the single most important improvement in gas lighting, was introduced after the electric utilities had begun to challenge the gas utilities over the respective merits of their lighting systems. The Welsbach gas mantle brought about a dramatic increase in the amount of illumination produced by a standard gas jet. Not only the diffusion of technologies but also the effort devoted to the development of new technologies may be decisively shaped by expectations as to future improvements and the continued superiority of existing technologies. One explanation for the limited attention devoted to the development of the electric motor for many years was the belief that the economic superiority of the steam engine was overwhelming and beyond serious challenge. The decision to neglect research on the electrically powered car in the early history of the automobile industry reflected the belief, justified at the time, in the total superiority of the internal combustion engine (this neglect may soon be repaired!). Similarly, the limited shift to nuclear sources of power over the past quarter century has been influenced by continued improvements in thermal efficiency based upon the "old-fashioned" but still apparently superior fossil fuel technologies.

How far can this explain the clustering of radical innovations in the depression and early upswing phase of the long wave? According to the sailing ship argument, radically new technologies would have to "wait" until the decisive improvement possibilities of the existing technologies are exhausted, i.e., the power of existing technologies to impede new substitute technologies would depend crucially on their ability to realize further improvements, both in quality and production costs. There are indications that this ability is not equally strong in all phases of the long wave. For example, according to Schmookler's demand-pull argument (1966), innovative activity within existing technological paradigms could be expected to be much stronger in the prosperous phases of the long waves than in the depression periods. Verdoorn's law tells us a similar story. Furthermore, as Freeman (1982) has pointed out, there may be some features of "industry life cycles": in their early phase, new industries and technologies have a high rate of product and process improvements that help considerably to improve sales figures, whereas expanding sales figures and profits give extra incentives for an expansion of R&D budgets, and so on. However, to the extent that technologies reach a certain degree of maturity and standardization, there may be, in the course of time, some law of diminishing returns on further improvement efforts, and hence the sailing ship (exclusion) effect would become weaker.

The effect is likely to be weakest during the long-wave depression with saturated markets and overcapacities. If entrepreneurs are then to obey the ironic statement by Karl Marx, *"akkumuliert, akkumuliert: das ist Moses* *und der Propheten!*", then they have no choice but to face fierce competition within the saturated industries or to take the risk of opening up new spheres of economic endeavor. A long-lasting depression phase is not the most welcome time in which to do this. This may reflect a more fundamental contradiction of the development of technology, at least in its capitalist form: the pressure to switch to new technological paradigms is strongest at a time when uncertainties of economic and social development are highest. A reference to Germany in the 1930s may illustrate what this can imply for society at large.

With our emphasis on clusters of radical innovations being triggered by long-lasting depressions, we do not intend to construct a monocausal explanation of the lower turning point of the long wave. A satisfactory theory of the long wave should be open to include a number of enhancing factors. In this context, the contributions by Freeman *et al.* (1982), Hoeksema (1984), Huber (1982), Perez (1983), Salvati (1983), and Screpanti (1984) are important and point to various aspects of social, political, institutional, or cultural change during a long-lasting crisis. Our argument about profound technological change should be interpreted as part of a more general social "*Strukturbruch*" (Altvater, 1982) that changes not only the technological base but also the "social structure of accumulation" (Gordon *et al.*, 1982). This is not the place, however, to discuss hypotheses about structural change in the "*Überbau*" of society; rather, we continue to focus on changes in the technological base of capital accumulation.

The latter expresses itself in opposite movements of various innovation indicators. Freeman *et al.* (1982, p. 58) have opposed the argument about clusters of innovations, pointing to data on R&D and patenting:

> There is however one further piece of relevant empirical evidence which does have a bearing on the controversy ... If there were evidence that firms responded to depression by stepping up their R and D activities and increasing their applications for patent protection then this would provide rather strong support for the Kleinknecht view of firm behavior, even though these activities could not be directly related to the "output" of basic innovations.
>
> If, on the other hand, the empirical evidence suggests that firms respond to depression by cutting back on their research, inventive and technical development activities generally, then this must cast further doubt on the hypothesis of depression-induced acceleration of basic innovations, ...

As to R&D figures, Freeman *et al.*, refer to data by Terleckji (1963), who found a 10% decline in R&D expenditures in US industry during the period 1931–1934. Moreover, they present a graph on patent applications and patents granted in the USA which shows a considerable decline of patenting activity during the 1930s (p. 60). From both sets of data they conclude that the depression of the 1930s brought down innovative activity. Do these considerations contradict the conclusions reached above?

The contrast between the two can be understood if a distinction is made between *types* of innovation. If we apply Dosi's (1982) distinction, the data on patenting and R&D stand primarily as indicators of the broad stream of innovations taking place within existing technological paradigms. The declining rate of innovation in this latter category is an expression of the increasing frustration with mature technologies in saturated markets and of the growing need for reorientation towards new fields of economic endeavor. The latter is expressed in a high rate of radical innovations. So far, the evidence by Freeman *et al.*, is completely consistent with the data discussed above. This conclusion is supported by data for US manufacturing industries on the opening of new industrial research laboratories. These showed a rapid increase during the period 1929–1936, in spite of the 10% decline of general R&D expenditures (see *Table 16.5*).

Table 16.5. Laboratory foundations within US manufacturing industry (annual averages for sub-periods from 1899 to 1946).[a]

Industry	*1899–1908*	*1909–1918*	*1919–1928*	*1929–1936*	*1937–1946*
Food and beverages	2	3.2	5	6	4
Tobacco products	0	0.1	0.2	0.375	0.1
Textiles	0.4	1.1	1.6	3.5	1.7
Apparel	0	0.1	0.1	0	0.2
Lumber products	0.1	0.1	0.2	0.625	0.5
Furniture	0	0	0.2	0.125	0.1
Paper	0.6	1.5	3.8	3.25	1.3
Publishing	0	0	0.2	0.375	0.1
Chemicals	5.6	8.8	17.8	18.25	10.7
Petroleum	0.3	1.5	2.5	3.875	1
Rubber products	0.2	1.6	1.9	1.625	0.5
Leather products	0	0.4	0.9	0.375	0.1
Stone/clay and glass	1.2	2.4	5.4	4.875	1.2
Primary metals	1.9	3.0	4.2	3.625	1.4
Fabricated metals	1.7	2.4	5.3	4.625	2.8
Non-electrical machinery	1.4	4.9	6.5	7.875	3.0
Electrical machinery	1.8	2.8	5.3	8	4.4
Transport machinery	0.4	1.2	1.6	1.25	2.0
Instruments	0.4	1.7	2.3	4	3.6
Total manufacturing	18.2	37.1	66	73.75	38.8

[a]This table has been reconstructed from Mowery (1981, p. 57). Figures such as "3.2 research labs" indicate that Mowery's figures have had to be divided by years to allow for intertemporal comparisons.

If these data are interpreted as lead indicators of a switch towards new technologies, then they are consistent with other indicators of radical innovations. Moreover, considering that the costs of new research labs are included in Terleckji's figures on general R&D expenditures, we can conclude that budget cuts in the older research labs must have been much more dramatic than is indicated by an overall average of 10%.

In summary, there is no contradiction between the data on radical innovations and those on patenting and R&D. The opposite direction, in which both types of data have been moving during the 1930s, is in line with the argument that the long-lasting depression brought down old industries and technologies and, at the same time, triggered the emergence of new "technological paradigms". If this conclusion is correct, it should be possible to demonstrate that new technologies, emerging during the depression and early upswing period of the long wave, have played a decisive role in fostering economic growth during the subsequent prosperity period. We shall consider this argument in the next section, using data for the postwar period.

16.4. Innovation, Economic Growth, and Profit Rates in the Postwar Boom

The task of determining the contribution to economic growth of individual technologies faces many difficulties. First, the classification of statistical data is rarely fine enough to trace the growth paths of young, innovative industries, and in most cases data on longer timespans are not available. Moreover, the "forward" and "backward linkages" of new industries are difficult to measure. Rostow (1978) tried to make such estimates for the US automobile sector: the difficulties he met in doing so were almost prohibitive.

We have therefore chosen a different approach based on a systematic comparison of innovation and growth rates in various sectors of manufacturing industry. As an indicator of innovation performance, an international sample of 500 innovations for the period 1953–1973 from a National Science Foundation study (see Gellman, 1976) was used. As indicators of growth performance, we used data by the German Institute for Economic Research (DIW, 1973) on industrial production in 30 sectors of manufacturing industry in the FRG from 1951 to 1977. Since the economy of the FRG is open and export-oriented, we would expect that differences in the growth of individual sectors would be correlated with the sectoral distribution of innovations from the international sample. This correlation does indeed exist; i.e., the one-tailed distribution of innovations by sectors corresponds with differences in sectoral growth rates of production; coefficients of correlation vary between 0.51 and 0.91 for various sub-periods between 1951 and 1970. After 1970, with the growth boom fading, the correlation gradually disappears (see Kleinknecht, 1984, p. 258). Moreover, the one-tailed distribution of innovations by sectors during the period 1953–1973 closely resembles the sectoral distribution of radical innovations from the 1930s and 1940s (p. 254). In other words, during the postwar boom, a set of growth industries (including electrical equipment and electronics, chemicals and plastics manufacturing, automobiles, aircraft, or oil refining) had a rate of innovation clearly above the average of total industry in both sets of data. This finding is independently corroborated by the data on new research labs, the above sectors introducing a high and increasing number of new research labs during the interwar period (see *Table 16.5*). The coincidence of a decline of general R&D expenditures in 1931–1934

(Terleckji, 1963) and of an upswing in the figures of new research labs seems to confirm that the interwar crisis triggered a reallocation of innovative resources in favor of new growth industries. The sectoral innovation pattern emerging from the crisis seems to have determined sectoral differences in innovation and growth during the subsequent boom. This argument is further supported by the finding that the one-sided distribution by sectors of the 500 innovation cases remained fairly constant during the entire investigation period (1953–1973).

In a later study the sample of 500 innovation cases was classified according to product versus process innovations. It proved that product innovations were overwhelmingly concentrated within the growth industries. Furthermore, during 1953–1973 a shift occurred within those growth industries from product to process innovations (see Coombs and Kleinknecht, 1984). This finding is consistent with the impression gained from British innovation data by Freeman *et al.* (1982) in *Figure 16.2* above. The shift from product to process innovation within highly innovative industries during the postwar upswing fits the idea of an industry life cycle, suggesting that, with an increasing degree of maturity, growth industries lose their ability to generate employment.

Another possible explanation of the upper turning point of the long wave refers to a decline in profit rates. The possibility of a long-wave pattern in profit rates has been discussed by various theorists, e.g., Fontevieille (1984), Mandel (1973), Menschikov and Klimenko (1985). In their analysis of postwar economic development in the FRG, Altvater *et al.* (1980) have tried to test the Marxian hypothesis of a tendency of the profit rate to fall. They have estimated the following profit rate indicator:

$$p' = \frac{Y(1 - W)}{C}$$

where Y = industrial net production at constant prices, W = the wage rate (i.e., $1-W$ is the gross profit share in industrial production), and C = capital stock. This profit rate indicator depends essentially on two factors: the wage share in production and the capital coefficient, the former being an approximation of the rate of surplus value and the latter approximating the organic composition of capital. The development over time of the capital coefficient depends on the relationship between the rate of increase in capital intensity and the rate of increase in labor productivity. This formula is only a rough approximation of the Marxian profit rate, of course. One of its weak points is the measurement of the capital stock, but nevertheless, it might give a reliable indication at least of the development of profit rates over time (for a detailed discussion see Altvater *et al.*, 1980). From an estimate of p' for all FRG manufacturing, Altvater *et al.* conclude that, after a short increase between 1950 and 1955, aggregate profit rates showed a tendency to fall from 1955 to 1977. Apart from a slight increase in the wage rate, the main factor behind the fall in p' was the increase in the capital coefficient. This result

Table 16.6. Average annual percentile changes per business cycle of profit rates and their determinants in manufacturing industries in the FRG, 1951–1977.

	Rates of change per business cycle					
Industries and indicators	*1951–1955*	*1955–1961*	*1961–1965*	*1965–1970*	*1970–1973*	*1973–1977*
Total Manufacturing						
labor productivity	4.97	3.72	4.78	4.62	4.74	3.69
capital intensity	1.36	5.18	6.65	4.88	6.00	6.02
capital coefficient	−3.36	1.50	1.66	0.28	1.38	2.11
profit share (= 1 − wage share)	0.08	−0.82	−0.56	0.39	0.11	0.08
profit rate	3.61	−2.24	−2.16	0.00	−1.13	−2.05
Selected industries						
Chemicals						
labor productivity	6.40	5.10	8.03	7.18	8.77	1.76
capital intensity	−1.06	1.30	4.10	4.36	5.49	4.12
capital coefficient	−7.03	−3.65	−3.65	−2.61	−3.06	2.36
profit share (= 1 − wage share)	0.70	−0.17	0.97	0.83	2.10	−0.78
profit rate	8.26	3.58	5.36	4.79	5.37	−3.16
Petroleum refining						
labor productivity	9.23	11.22	10.73	6.70	1.96	6.49
capital intensity	−3.60	3.52	7.07	5.73	3.57	11.15
capital coefficient	−11.75	−6.94	−3.25	−0.96	1.62	4.42
profit share (= 1 − wage share)	0.49	0.59	0.35	0.02	−0.07	0.08
profit rate	13.78	8.11	4.64	1.25	−1.66	−4.11
Automobile construction						
labor productivity	14.41	5.52	2.15	4.02	2.50	2.89
capital intensity	3.00	6.47	5.82	3.92	5.37	3.12
capital coefficient	−9.89	0.84	3.65	−0.13	2.91	0.15
profit share (= 1 − wage share)	6.37	0.75	−2.22	−1.56	−1.21	−0.75
profit rate	18.15	−0.12	−5.91	−1.27	−3.35	−1.06

Table 16.6 cont.

Aircraft construction						
labor productivity	39.09	−8.35	3.80	6.12	8.26	−7.06
capital intensity	n.a.[a]	5.58[b]	9.62	8.44	10.71	4.33
capital coefficient	n.a.[a]	−6.01[b]	5.64	2.31	2.20	12.16
profit share (= 1 − wage share)	8.84	−5.99	−6.46	−4.92	2.50	−13.46
profit rate	n.a.[a]	−7.94[b]	−16.79	−10.12	0.23	−22.89
Electrical equipment						
labor productivity	5.00	3.26	4.41	5.04	6.88	5.94
capital intensity	−0.26	3.17	7.04	3.97	6.77	8.04
capital coefficient	−4.85	−0.01	2.48	−0.95	0.00	1.91
profit share (= 1 − wage share)	0.25	−0.80	−0.99	0.15	1.41	1.29
profit rate	5.56	−0.07	−3.45	2.08	1.51	−0.68
Precision engineering and optics						
labor productivity	5.73	2.27	11.56	3.60	1.64	2.57
capital intensity	−0.42	7.93	8.12	3.95	6.97	5.62
capital coefficient	−5.88	5.62	−3.08	0.44	5.16	2.91
profit share (1 − wage share)	1.14	−1.93	−0.38	−1.77	−3.44	−2.43
profit rate	7.34	−7.09	−2.82	−2.15	−8.30	−5.23
Plastics manufacturing						
labor productivity	6.84	8.48	8.75	6.09	7.78	5.38
capital intensity	0.26	6.27	10.40	6.82	6.21	7.55
capital coefficient	−6.17	−2.00	1.50	0.76	−1.57	2.12
profit share (1 − wage share)	1.61	1.85	1.63	0.72	1.57	1.04
profit rate	8.37	4.02	0.13	0.03	3.10	−0.99

[a]n.a. = not available. [b]1956–1961. *Definitions: labor productivity,* real industrial net production per person employed (see DIW, 1973, p. 77); *capital intensity,* capital stock per person employed (see DIW, 1973, p. 124); *capital coefficient,* capital stock per unit of net industrial production (see DIW, 1973, p. 97); *profit share,* $1 - W$ where $W =$ the percentile share of wages and salaries in net industrial production (see DIW, 1973, pp. 5, 40; Altvater *et al.*, 1980, Vol. 1, p. 88); *profit rate,* $Y(1 - W)/C$ *where* Y = net industrial production at constant prices, $1 - W$ = deflated profit share, and C = capital stock (see DIW, 1973, pp. 5, 40, 97).

for industry in the FRG is consistent with estimates of rates of return for a number of other countries (see Hill, 1979).

Based on the calculations by Altvater *et al.* and on data by the German Institute for Economic Research (DIW, 1973) we have computed the annual percentage changes in p' and its determinants (labor productivity, capital intensity, capital coefficients, and profit shares) for successive business cycles in manufacturing industry in the FRG from 1951 to 1977. *Table 16.6* covers the results for manufacturing as a whole and for the highly innovative growth industries. It can be seen that for manufacturing as a whole the "Marxian" process as described by Altvater *et al.* has indeed been working from 1955 onward: p' is declining due to an increase in the capital coefficient. However, the highly innovative industries show a different picture. For example, the automobile industry and electrical equipment have an almost constant profit rate up to 1961. The profit rate in the aircraft construction industry is still increasing during that period. The same holds in the case of the chemical industry, oil refining, and plastics manufacturing, for which the increase of p' even lasts during the 1960s. Only the precision engineering and optics industry follows the path of total manufacturing and shows declining profit rates from 1955 onwards.

A fairly large literature about the "law" of the tendency of the profit rate to fall has made abundantly clear that profit rates crucially depend on the type of technical change. In terms of the above profit rate indicator, "Marxian technical change" would consist of labor productivity growth rates being lower than rates of increase in capital intensity, resulting in an increase in the capital coefficient. The figures in *Table 16.6* suggest that, within highly innovative industries, due to high growth rates of labor productivity, this process of increasing capital coefficients started only in a later phase of the postwar long-wave expansion; i.e., highly innovative industries have ***temporarily*** counteracted a rapid fall in the average manufacturing profit rate during the postwar upswing.

From the above it can be concluded that, in the long term, industrial profit rates depend crucially on the rate of increase in labor productivity. The findings in *Table 16.6* are principally consistent with the idea of an "industry life cycle" (cf. Freeman, 1982): newly emerging industries initially have high rates of both product and process innovations, which foster the growth of sales. Growing sales figures again give extra incentives for expanding R&D, and so on. This process of mutually reinforcing demand-pull and technology-push effects, via capital and labor savings, exert a positive influence on the main determinants of profit rates, i.e., on the capital coefficient and the wage rate. This process may come to an end, however, to the extent that an industry reaches a certain level of maturity and the rate of innovation slackens. In the later stage of the industry life cycle, therefore, the Marxian process of declining profit rates due to an increasing organic composition of capital might become relevant. Moreover, the process of declining profit rates may be enhanced by an upward move of wage rates due to the increasing power of trade unions gained during a long-lasting prosperity period with a tendency towards full employment or even labor scarcity. At the same time, as innovation performance declines, the scope for wage increases that do not negatively affect profit rates will become smaller. However, *Table 16.6* suggests that profit rates are primarily influenced by changes in the capital coefficient, and an increase in wage rates seems to play a less prominent role – at least in manufacturing industry in the FRG.

For a long time it has been standard practice to consider the Marxian theorem of the falling profit rate as a secular concept. However, several authors have recently suggested linking profit rates primarily to the long-wave concept (see Fontevieille, 1984; Mandel, 1980; Menshikov and Klimenko, 1985). Menshikov and Klimenko have produced long-term data for the USA that support the hypothesis of a long-wave pattern in average industrial profit rates, and they are consistent with our data above for FRG manufacturing industry. Certainly, the massive depreciation of capital during the long-wave depression is an important factor that counteracts a secular fall in profit rates. The thrust-wise technological progress associated with newly emerging industries and technologies during the early upswing of the long-wave may be another temporarily counteracting factor that deserves more careful consideration in future research.

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CHAPTER 17

Long Waves, Growth-Retarding Factors, and Paradigms of the New Upswing

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17.1. Introduction

The development process of the postwar years has been a spectacular and unprecedented success, but after 25 years of prosperity the industrialized countries are experiencing a slowdown in economic growth. This adverse development has revived interest in the economic long wave or Kondratieff cycle. The recession, which after World War II was expected to mean a few years of below-average growth, has turned out to be a downswing in a long wave whose upswing occurred in the period 1948–1973. The depression in the long wave currently being experienced is a structural crisis. As noted by Perez (1985), it is a syndrome of a serious misfit between the techno-economic subsystem and the socio-institutional framework; we are now witnessing a negative interaction between these two spheres. In analyzing the current depression we thus concentrate not on the "sources" of the slowdown, i.e., changes in resources and other factors that are the immediate cause of changes in output (e.g., changes in investment, capital accumulation, labor supply, etc.), but instead we focus on the underlying "causes" of the slowdown – the mechanisms that create an atmosphere that determines the adverse development of these sources and thus slows down the growth rate. We believe that these causes, or growth-retarding factors, can give us an insight into the lack of positive interaction mentioned above. A mathematical description of the dependence of the growth-retarding factors on the level of economic development leads to differential equations, the solutions to which show under certain circumstances oscillations resembling long waves.

Empirical evidence and analysis of socio-psychological phenomena enable us to differentiate four sets of growth-retarding factors, which originate from four fields: state, megalomania, isolation, and leveling. We have analyzed the nature of long-term oscillations in these growth-retarding factors and present a socio-psychological feedback system leading to long waves.

17.2. Growth-Retarding Factors

In this analysis three data sets are used to determine the influence of each of the growth-retarding factors on GDP growth rates. All data sets are cross-sections of 19 OECD countries. The first set covers the period 1960–1970, the second 1970–1981, and the third 1960–1981.

17.2.1. Public expenditure

The rapid growth of the public sector in industrialized countries is often cited as an important growth-retarding factor. In many countries, for as long as records have been kept, the ratios of public revenues and expenditures to GDP have tended to grow. When the share of public spending reaches very high levels, then policy troubles are to be expected, not so much because of demand for and the direct allocation of real resources to the public sector, but because the initiative structure is badly distorted both by taxes and social policy, and this tends to paralyze the innovative power of the managerial firm. Polanyi (1968), in a study covering the 1950s through to the 1970s, showed that the average rate of return of nationalized industries was less than one-third that of private industry. Hence if a greater part of the economy is handled by government, and if government activities are less "efficient" (Leibenstein, 1981) than in the private sector, then average productivity will be lower than it would be otherwise.

During the 1960s high government expenditure was one of the most important growth-retarding factors. As the following single regression shows, more than 50% of the differentiations in the level of the average annual GDP growth rate during 1960–1970 (GRGDP 60–70) among 19 countries studied could be explained by the average government final consumption expenditure in the period 1960–1967, expressed as a percentage of GDP (GFCE%GDP 60–67). In the 1970s a number of other factors had negative influence on GDP growth rate. Rather than the level of government expenditure (which was high enough for all countries), some of its derivatives (see below) grew in importance. For the period 1960–1981, however, government expenditure alone was responsible for not less than 45% of the explanation of growth slowdown [see equations (17.1)–(17.3)]. The values in parentheses are the corresponding t-statistics.

$$\text{GRGDP } 60\text{–}70 = 12.08 \underset{(-4.25)}{-0.49} \text{ GFCE\%GDP } 60\text{–}67 \qquad R^2 = 0.58 \qquad (17.1)$$

$$\text{GRGDP } 70\text{–}81 = 4.95 \underset{(-1.82)}{-0.11} \text{ GFCE\%GDP } 70\text{–}77 \qquad R^2 = 0.16 \qquad (17.2)$$

$$\text{GRGDP } 60\text{–}81 = 7.67 \underset{(-3.80)}{-0.22} \text{ GFCE\%GDP } 60\text{–}81 \qquad R^2 = 0.46 \qquad (17.3)$$

Some economists have suggested that increased public expenditure takes place at the expense of investment (see Bacon and Eltis, 1976; Smith, 1975), and that affects growth rate. In our analysis we found this to have been conspicuously true in the 1970s, when the ratio of the growth rate of government expenditure to that of gross fixed capital formation, at constant prices (GRGFCE/GFCF), was clearly greater than 1 for all countries except Canada and the USA (during the 1960s this ratio was less than 1 for most countries). In a single regression this ratio is also significant in explaining 36% of the differences in GDP growth rate in 1970–1981.

$$\text{GRGDP } 70\text{–}81 = 4.33 \underset{(-3.08)}{-0.49} \text{ GRGFCE/GFCF } 70\text{–}80 \qquad R^2 = 0.36 \qquad (17.4)$$

For the other two periods (1960–1970 and 1960–1981) this ratio for respective periods was not statistically significant.

A problem also arises if public expenditure grows more rapidly than the GDP, in which case the government has two alternatives. The increase can be financed by adding to the borrowing requirement, leading to inflation, or it can be financed by increased taxation. In this latter case the wage earners respond by claiming higher wages, which has been an important cause of inflation in recent years. The ratio of growth rate of government expenditure to that of GDP, at constant prices (GRGFCE/GDP) provides an explanation for the GDP growth rate. Equation (17.5) gives the result of regression analysis estimating the average annual GDP growth rate in 1970–1981 (GRGDP 70–81) by this ratio of the same period:

$$\text{GRGDP } 70\text{–}81 = 4.49 \underset{(-1.99)}{-0.43} \text{ GRGFCE/GDP } 70\text{–}81 \qquad R^2 = 0.19 \qquad (17.5)$$

The result for 1970–1981 is much better than that for other periods.

Government expenditure on social security and welfare in the industrialized countries has had a number of adverse consequences. Social security reduces the rate of savings, it reduces labor mobility, distorts work incentives, and favors bureaucratic inefficiency (see Vaubel, 1981). Giersch and Wolter (1982) cite Maddison (1982, p. 13), who reports a rate of 10% absenteeism in the Netherlands where benefits are generous, but only 2.5% in the USA, where they are much smaller. This example can be seen to explain much about the negative influence of social security generosity on the economic growth of industrialized countries.

We have found that social security transfers, expressed as percentage of total government expenditure (SOC%EXP), is negatively correlated with the GDP growth rate in 1960–1970, 1970–1981, and 1960–1981. The correlation is strongest in 1970–1981:

$$\text{GRGDP } 70\text{–}81 = 5.34 - 0.06 \text{ SOC\%EXP } 73\text{–}77 \qquad R^2 = 0.25 \qquad (17.6)$$
$$(-2.35)$$

These results confirm the theoretical considerations about the adverse effect of high social security expenditures.

17.2.2. Megalomania

Many doubts have been expressed about the efficiency of large and complex organizations. As enterprises grow, there is likely to be a gradual change in their internal structures towards greater internal bureaucracy resulting in a decline in productivity or growth retardation. Leibenstein (1981) asserts that big firms enjoy monopoly privileges by having reduced pressure from competitors so that the translation of inputs into outputs occurs at a point further away from the minimum cost level.

Small is not only beautiful but also efficient. Olson (1983) shows that small organizations have fewer adverse affects on the GDP growth rate than large ones, while small groups make oligopolistic bargaining advantageous. Trade unions and large professional associations reduce growth rates by limiting entry into the industries and occupations they control. Olson adds that a society with greater barriers to entry will grow less rapidly due to innovation slowing and barriers in resource allocation needed to maintain Pareto-efficiency. On the concept of "institutional sclerosis", Millendorfer (1982) adds a new medical term – namely, "institutional elephantiasis". Large organizations can make non-optimal decisions and still survive; this explains their adverse effects on growth rates.

It is difficult to find a comparable summary indicator with which to measure the degree of concentration in industry as a whole; thus, for our purposes, we looked for feasible alternatives. Love (1979) lists the most important companies in Europe in 1976, based on "size and significance within the national economy in terms of turnover, exports, assets and labor force". The number of these companies per thousand population (IMPCOM/POP), when compared with GDP growth rates, gives significant results:

$$\text{GRGDP 70–81} = 4.15 - 0.08 \text{ IMPCOM/POP 76} \qquad R^2 = 0.52 \qquad (17.7)$$
$$(-3.74)$$

Assuming that the number of such companies does not change very quickly, we see that this indicator explains 52% of the difference in GDP growth rates in 15 Western countries (excluding Canada, Greece, Japan, and the USA) in 1970–1981.

We have constructed another measure for all the countries studied that reflects the average size of manufacturing establishments employing more than 10 persons ($M > 10$). These values explain the GDP growth rate in 1960–1970 with high significance:

$$\text{GRGDP 60–70} = 6.70 - 0.02\, M > 10 \qquad R^2 = 0.27 \qquad (17.8)$$
$$(-2.45)$$

In fact, there exists an optimal level of concentration (which naturally varies from branch to branch), and when this is exceeded (i.e., when firms become too large) they begin to act as barriers to further GDP growth. These results confirm the hypothesis that high concentration, in any field of society, leads to inefficiency and thereby slows down economic growth.

17.2.3. Isolation

Economic growth and a high level of industrialization in developed countries have unfortunately led to a number of adverse social consequences. The most important, and at the same time the source of several other social ills, is the deteriorating quality of family life leading to isolation in society. Families in today's industrialized countries are becoming weaker and more scattered, a tragic consequence of which is suicide (Durkheim, 1983; Fuchs *et al.*, 1977). It is therefore not a coincidence that, by and large, the richer the country, the higher is the suicide rate (Naroll, 1983). The most striking instance of this tendency is the high suicide rate among divorced people. As a proxy of measuring worsening of the quality of family life leading to isolation, we studied two indicators, namely illegitimate birth rate (ILLBRTH) and divorce rate (DIVORCE).

$$\text{GRGDP 60–70} = 6.72 - 0.23 \text{ ILLBRTH 63–68} \qquad R^2 = 0.25 \qquad (17.9)$$
$$(-2.39)$$

The average divorce rates for 1960–1970 and 1970–1980 have slightly weaker correlations with the corresponding GDP growth rates (–0.31 and –0.35), but if we take the whole period together then it increases:

$$\text{GRGDP } 60\text{–}81 = 4.89 - \underset{(-2.0)}{0.61} \text{ DIVORCE } 60\text{–}80 \qquad R^2 = 0.19 \qquad (17.10)$$

Suicide rates are also negatively correlated with growth rates for all of the periods analyzed here.

Hofstede (1978) has constructed four indicators to reflect individual behavior patterns in various societies. One of these, the "individualism index", opposes "a loosely knit social framework in society in which people are supposed to take care of themselves and their immediate families only, to one in which they can expect their relatives, class or organization to look after them" (p. 11). This index (HOFIND) has a significant effect on the growth rate:

$$\text{GRGDP } 70\text{–}81 = 8.53 - \underset{(-2.80)}{0.04} \text{ HOFIND } 77 \qquad R^2 = 0.32 \qquad (17.11)$$

In Section 17.4 we observe that in addition to the strong correlation between divorce and suicide, promiscuity also plays an important role as growth-retarding factor.

17.2.4. The process of leveling

One of the social developments associated with economic growth is the changing role of women in society. In analyses of the age–sex composition of the labor force, Kendrick (1981) and Kendrick and Grossman (1983) show that the increase in female labor force participation since the 1960s had a negative effect on the growth rate in this period. Kendrick (1981), however, shows that the effect of this shift was diminished in the period 1973–1975. The change in the share of females in the total labor force from 1961 to 1970 indeed had a negative effect ($R = -0.28$) on the GDP growth rate in the corresponding period, but in the next decade, there was no correlation.

As another measure of the increasing role of women, we analyzed the ratio of female/male death rates due to car accidents (F/M CARACC). Both for 1960–1970 and 1970–1981 there are high negative correlations between these indicators and corresponding GDP growth rates.

$$\text{GRGDP } 60\text{–}70 = 12.08 - \underset{(-3.64)}{0.22} \text{ F/M CARACC } 64\text{–}66 \qquad R^2 = 0.44 \qquad (17.12)$$

$$\text{GRGDP } 70\text{–}81 = 5.63 - \underset{(-2.19)}{6.71} \text{F/M CARACC } 75\text{–}78 \qquad R^2 = 0.22 \qquad (17.13)$$

Wage quotas, defined as compensation of employees as a percentage of national income (WAGEQUOTA), also reflects, in a cross-country analysis, the process of leveling. In a regression function it is significant:

$$\text{GRGDP 70–81} = 7.16 - \underset{(-2.43)}{0.07}\ \text{WAGEQUOTA 74} \qquad R^2 = 0.26 \tag{17.14}$$

The leveling process is of course connected with reducing inequalities in the distribution of income. Such equality in incomes (Jain, 1975) is negatively correlated with GDP growth rates for the 19 countries, but neither correlation coefficients nor t-values are statistically significant.

17.2.5. Multiple regression analysis

The power of the various growth-retarding factors to explain the slowdown in economic growth is relatively low. This leads to the question whether, instead of a monocausal approach, combinations of the various factors might show much better explanatory strength. We therefore combined all the above variables to obtain four sets of growth-retarding factors. Taking all variables into account, factors from each of the four groups were standardized and combined to form four synthetic variables: state, concentration, isolation, and leveling.

Table 17.1. Multiple regression analysis in explaining the GDP growth rate, 1970–1981 ($n = 15, F = 48.8, R^2 = 0.95$).

Independent variables	*Regression coefficient*	*t-value*
State 70–80	–1.04	–9.74
Isolation 70–80	–0.30	–2.40
Concentration	–0.26	–2.99
Leveling	–0.35	–2.78

In *Table 17.1* we present the results of estimates of the GDP growth rate for 1970–1981 using the four synthetic variables. High (R^2) values reflect the significance of the four sets of growth-retarding factors taken together. All t-values are significant at the 95% level, and F-statistics at the 99% level. Results for the 1960s are similar to those presented in *Table 17.1*. In *Figure 17.1* we present the relationships of the four growth-retarding factors separately as well as their combined effect on GDP growth rates.

17.3. Growth-Retarding Factors and Long Waves

All growth-retarding factors presented here are positively correlated with GDP growth. They increase in value together with GDP, and after a certain

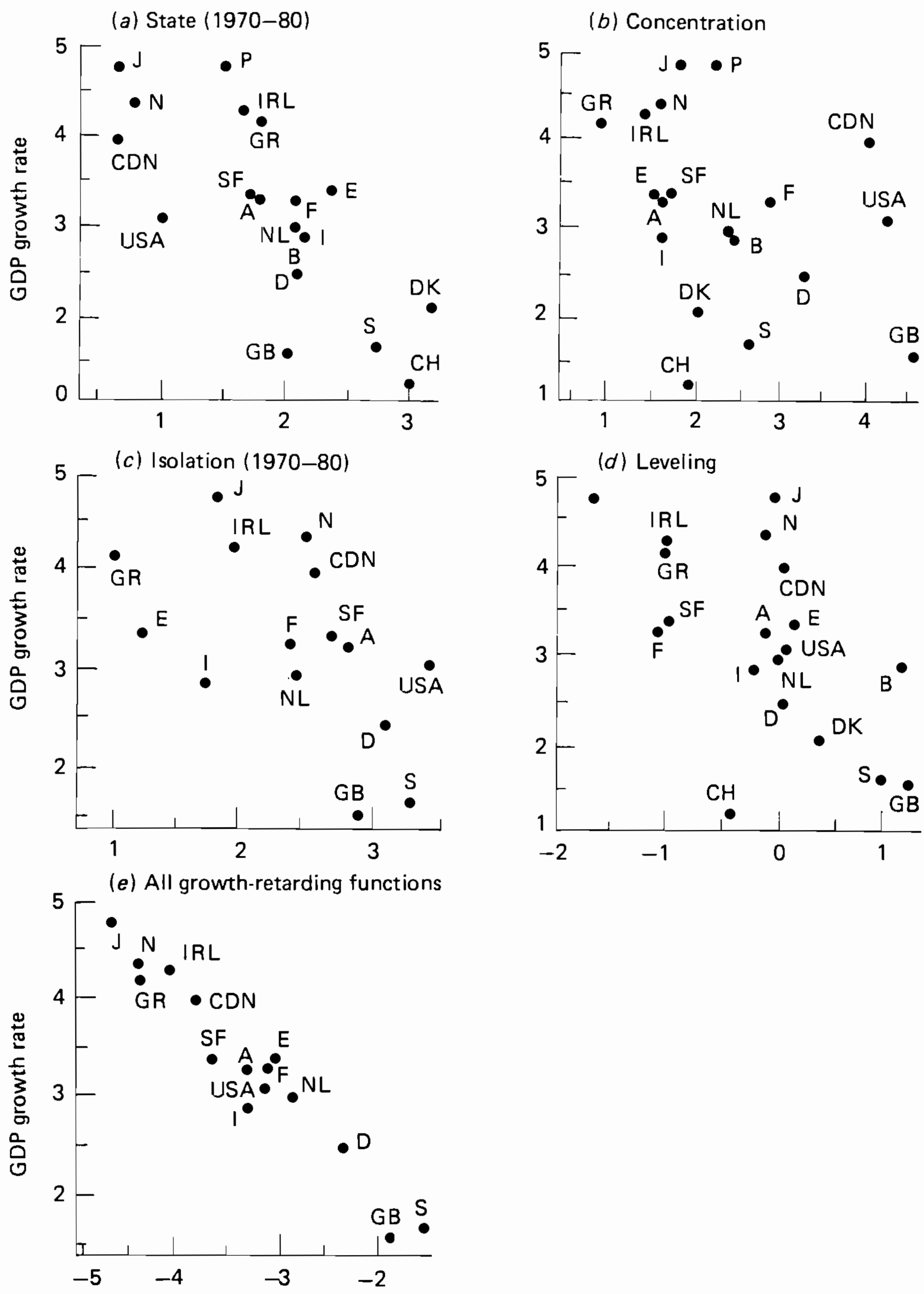

Figure 17.1. **Graphic representation of the relationship between growth-retarding factors and the GDP growth rate.**

period start acting as barriers to growth. How do these factors behave over a long period of time and what consequences do they have on GDP? In the following we try to determine some mechanisms that lead to long-term oscillations.

17.3.1. Long-term oscillations

Let y denote GDP, so that $(dy/dt)/y$ is the GDP growth rate. In Section 17.2 we estimated the following multiple regression function:

$$dy/dt/y = a_0 - a_1 z_1 - a_2 z_2 - a_3 z_3 - a_4 z_4 = a_0 - \Sigma a_i z_i \qquad (17.15)$$

where z_i is the ith growth-retarding factor. *Figure 17.1* illustrates this linear relationship, and the results of estimates of this function are presented in *Table 17.1*.

The growth-retarding factors (z_i) can depend on the GDP in various ways; in the following we present three possibilities:

(a) If the factors z_i depend linearly on the GDP, i.e., if

$$z_i = b_{0_i} + b_i y \qquad (17.16)$$

then equation (17.15) can be written

$$dy/dt/y = a_0 - \Sigma a_i (b_{0_i} + b_i y) = a_0 - \Sigma a_i b_{0_i} - \Sigma a_i b_i y \qquad (17.17)$$

Now putting a^* for $a_0 - \Sigma a_i b_{0_i}$ and b^* for $\Sigma a_i b_i$, we get

$$dy/dt = y\,(a^* - b^* y) \qquad (17.18)$$

This is a Bernoulli differential equation, the solution to which can be represented graphically by a logistic curve, the asymptote being the point $y = b^*/a^*$ [see *Figure 17.2(a)*].

(b) We have a different situation if the growth-retarding factors depend upon $\int \ln y$, i.e., upon accumulated wealth, i.e., if

$$z_i = c_{0_i} + c_i \int \ln y \, dt \qquad (17.19)$$

then $dz_i/dt = c_i \ln y$, and

$$dy/dt/y = \frac{d \ln y}{dt} \tag{17.20}$$

$$= a_o - \Sigma a_i z_i = a_0 - \Sigma a_i (c_{0_i} + c_i \int \ln y \, dt)$$

$$= a_o - \Sigma a_i c_{0_i} - \Sigma a_i c_i \int \ln y \, dt$$

Putting $k = \Sigma a_i c_i$ and $u = \ln y$, we get

$$d^2u/dt^2 = -ku \tag{17.21}$$

The solution to equation (17.21) is a sinusoidal function and it can be represented graphically by a sinusoidal oscillation [see *Figure 17.2(b)*].

(c) Perhaps the most probable dependency can be illustrated by combining (17.16) and (17.19):

$$z_i = b_{0_i} + b_i y + c_i \int \ln y \, dt \tag{17.22}$$

then

$$dz_i/dt = b_i + c_i \ln y = b_i + c_i u \tag{17.23}$$

Therefore

$$dz_i/dt = b_i + c_i u \quad a \quad du/dt = a_0 - \Sigma a_i z_i \tag{17.24}$$

Equation (17.24) represents a Lotka–Volterra differential equation, whose solution can be illustrated by predator–prey oscillations [*Figure 17.2(c)*]. *Figure 17.3* presents graphically the above relationships of growth-retarding factors with income and wealth and their long-term consequences.

In any case the political conclusions are similar. In the first Bernoulli case the asymptote of the logistic curve indicates the end of the fruitfulness of the old paradigms of the former period: a new upswing is only possible with new paradigms. In the other two cases the downswing of the oscillation occurs for the same reasons; only the anticipation of the new paradigm of the coming upswing can retard the downswing. In addition, in these cases the impact of the growth-retarding factors must be diminished by investments for this purpose. This new form of investment also leads to returns if the costs of diminishing the growth-retarding factors are smaller than the gains due to

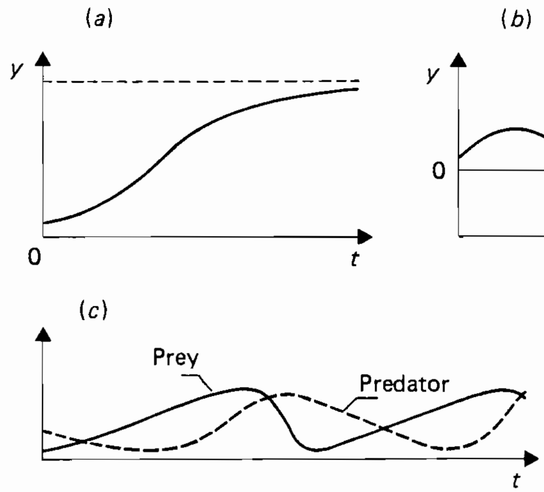

Figure 17.2. Long-term behavior of GDP growth rates: (*a*) Bernoulli logistic curve; (*b*) sinusoidal oscillations; (*c*) Lotka–Volterra differential equation.

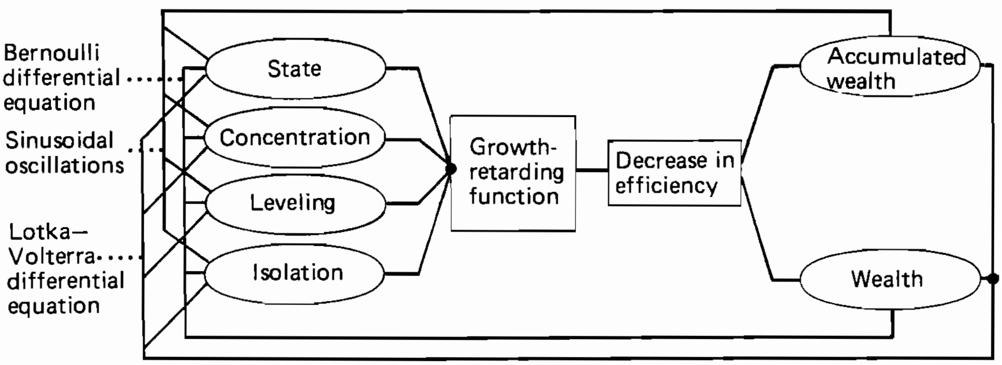

Figure 17.3. Feedback system of growth and growth-retarding factors.

improved efficiency. The question of long waves is, therefore, not so much a theoretical issue but rather a challenge in the form of the practical economic problems we have to cope with.

17.3.2. Sociopsychological feedback system

McClelland (1961) has constructed for a number of countries an "achievement motivation index" in which a high quality of family life is a precondition for high achievement motivation. Alternatively, Fuchs *et al.* (1977) show that high achievement motivation, 25–30 years later, leads to lower quality of family life. They argue that highly motivated people have less time for their families, particularly for their children, so that when the children grow up they normally cannot lead a good family life.

Thus we have a negative feedback and something like a control circuit with a delay of 25–30 years (see *Figure 17.4*). The feedback system works in the sequence: (high) quality of family → (high) achievement motivation → (high) performance of the system → dominance of the system over the human area → decreasing quality of family life → decreasing achievement motivation ... The delay of 25–30 years could be seen to be an anthropological constant caused by interrelationships between generations. This delay leads to cyclic oscillations with a period of 50–60 years, the existence of which was suggested by the negative correlation between the "achievement motivation index" of 1925 and that of 1950. *Figure 17.4* points out empirically observed relationships in the feedback system. *Figure 17.4*(*a*) shows a positive relationship between the motivation index for 1938 and per capita incomes 30 years later, *Figure 17.4*(*b*) shows a negative correlation between quality of family life and per capita incomes, while *Figure 17.4*(*c*) illustrates a negative relation between the motivation index for 1938 and the quality of family life in 1970.

Empirical support for the existence of such oscillations comes from Marchetti (1982), who observed cycles of suicides with a period of 54 years. As was mentioned above, suicides and divorces are correlated, and they also play major roles in determining the quality of family life; if one of these variables oscillates, the others should also do so. In this sense Marchetti's observations fit well in our framework of oscillations.

Schumpeter's description of long-wave upswings with new technologies does not explain why these innovation pushes occur at all and why the wave period is 50–60 years. We think that the above sociopsychological feedback system is connected with economic long waves, and that oscillations in creativity and motivation contribute to the innovation pushes of the same length, namely, around 60 years.

17.4. Principal Plane Analysis

In order to determine the relationships between growth, growth restraints, and other variables, data matrices are displayed in two projection planes called principal planes. In multivariate data analysis this is a useful technique (Lebart *et al.*, 1984; Gabriel *et al.*, 1976) derived from principal component analysis, singular value decomposition, biplot and cluster analysis.

In constructing the planes, some interpretation rules must be kept in mind. In each plane, variables and countries are represented simultaneously. A projection of a country point on the axis through the variable point and the origin always recreates the original data. The length of the variable vector shows the explanatory power of a plane as a percentage of explained variance

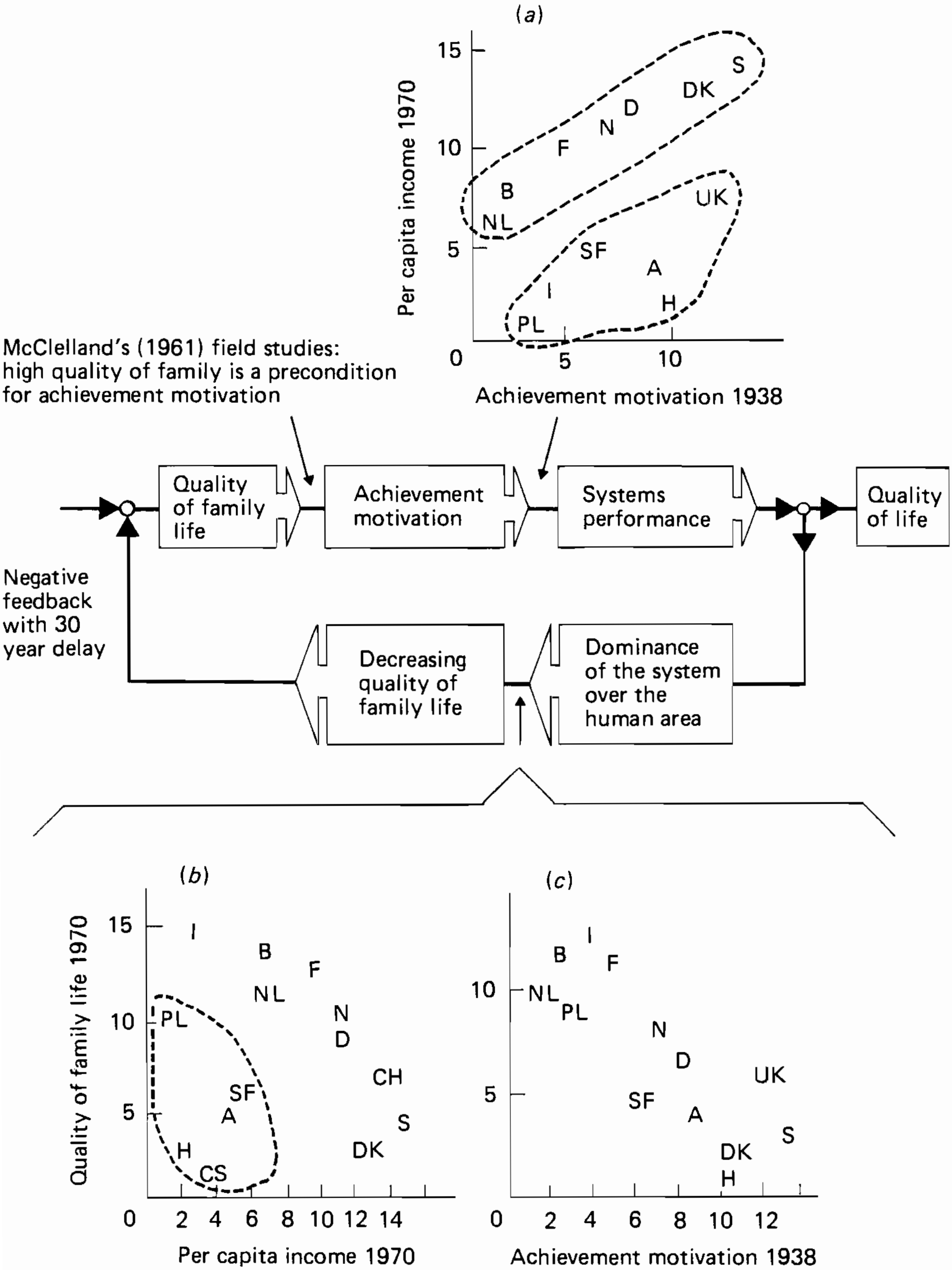

Figure 17.4. **A sociopsychological feedback system.**

of that variable. The cosine of the angle between two variable points is the correlation coefficient between these two variables. The better the fit, the better this relationship will be maintained in the projection of the map. Thus, nearly parallel variable vectors mean high positive or negative correlation, depending on the direction of the vector. Orthogonal variable vectors signify independent phenomena. Different principal planes are related to different issues: principal plane I is related to policy issues and social psychology, while plane II is related to economics and institutional structures (see *Figure 17.5*).

Principal plane I has been discussed in Millendorfer (1985) and Fuchs *et al.* (1977). Not all relationships of a principal plane can be interpreted in terms of causality, but we can legitimately compare the relative positions of two variables with respect to the entire set of countries (see *Figure 17.6*). We confine ourselves to the following conclusions:

(1) Divorce and suicide rates are interlinked and correspond to the isolation factor (see above).

(2) The roles of government expenditures and consumption have shifted in time. Government transfers paralleled the strengthening of family ties in the 1950s, but 25 years later the coincidence of state consumption and isolation in Europe reached its maximum. The state sector itself has become a growth-retarding factor, while at the same time it has led to weaker family ties and thus greater isolation.

(3) In the early 1980s a reverse movement of these two restraints was visible.

Principal plane II fits GDP growth and growth-retarding factors for 1970–1980 to a two-dimensional subspace by the classical least squares method. Norway and Japan show the highest, and Sweden and Britain the lowest growth rates. The growth retardants – leveling, isolation, and concentration – form a group and are clearly separated from state. It should be mentioned that high isolation and low state in the USA and Canada is responsible for the fact that the two vectors are non-parallel, as opposed to *Figure 17.5*, where the analysis is conducted for European countries only.

Supplementary variables such as market orientation, per capita income, and energy consumption are incorporated to illustrate the nature of growth-retarding factors. Thus the claim for more market orientation would certainly reduce the state restraints. Market orientation, therefore, is a necessary precondition of growth. However, alone, it seems to be insufficient. In fact, market orientation is quite highly correlated with Hofstede's individualism index, a growth restraint, as argued above. Large units resulting from a long industrialization period (measured by the time integral of energy consumption) contribute to Olson's institutional sclerosis, and now are restraining Sweden and Britain.

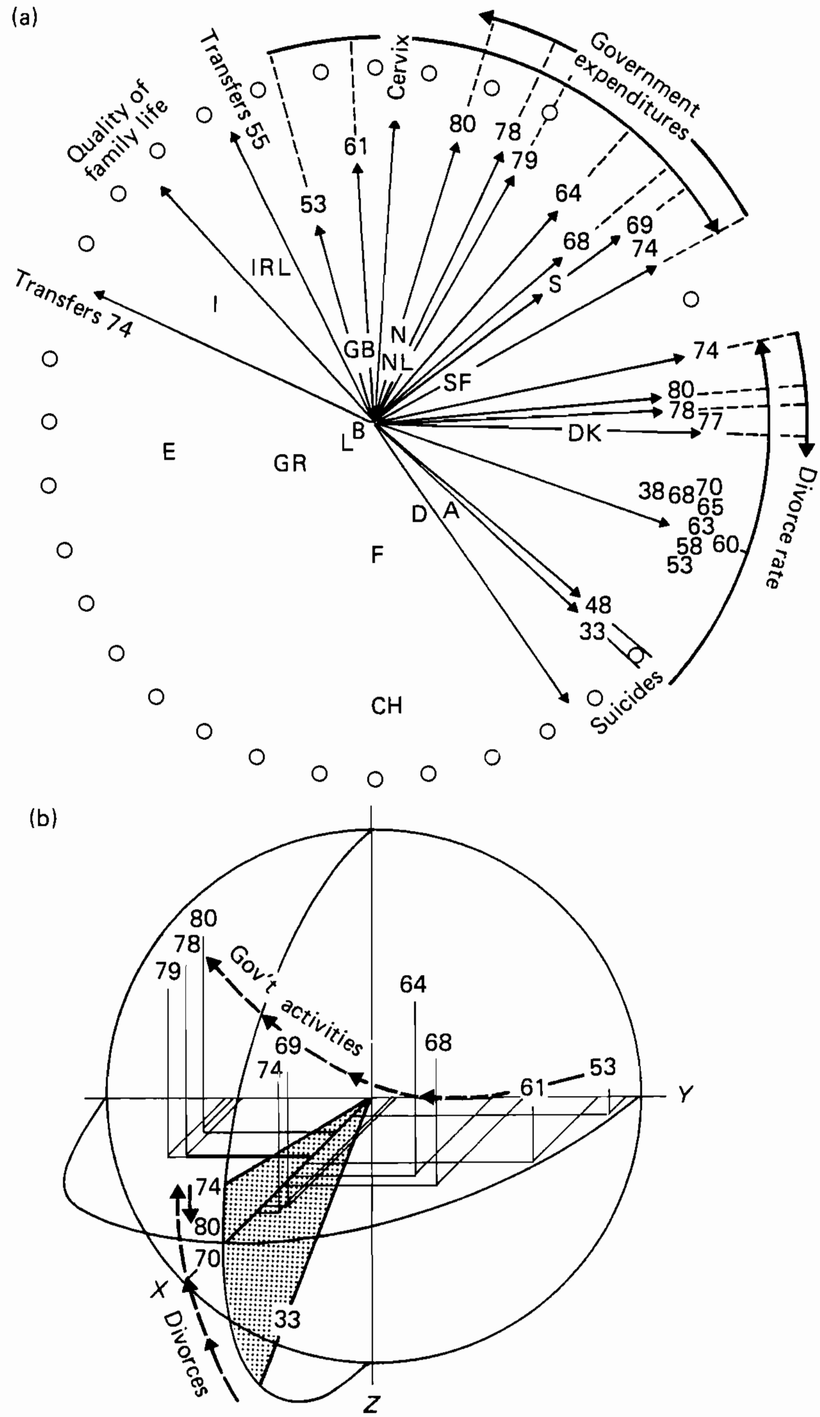

Figure 17.5. (*a*) Vectors in a principal plane, and (*b*) in a principal 3-D space.

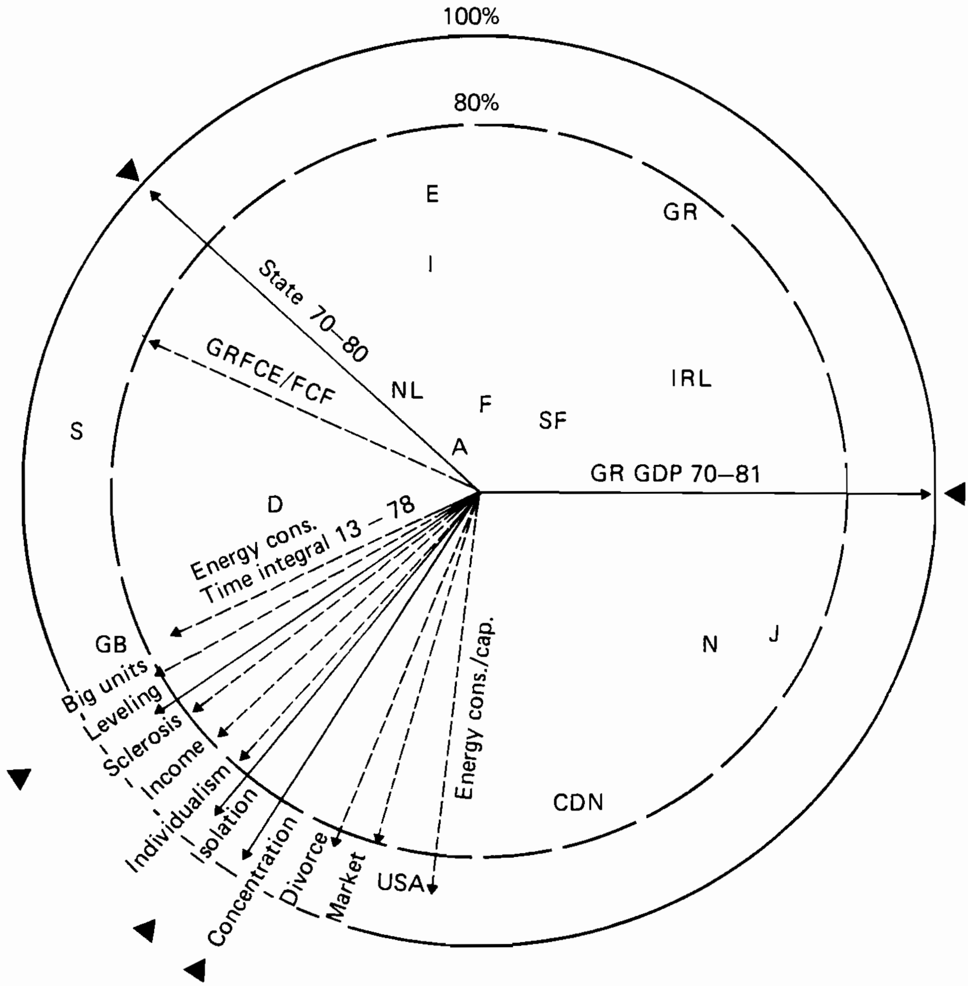

Figure 17.6. Growth-retarding factors and GDP growth in a principle plane.

17.5. Concluding Remarks

In this chapter we have tried to give, as far as possible, a complete account of the causes of slowdowns in growth in the hope that it will help to identify the real problems faced by modern industrial nations. The analysis of socio-psychological phenomena leads us to issues concerning long-term oscillations in a number of factors that have a direct or indirect influence on economic growth. We have seen that the length of such cycles is determined by an anthropological constant governing the dynamics of interrelations between generations. There may be neither instrumental variables nor political tools available to change the length of the cycle during a downswing, but what we can do is minimize the severity of the downswing by anticipating the new paradigm of the coming upswing. This upswing will be characterized by four principles that may be considered new paradigms of development (see Millendorfer, 1985): the human-economic principle; the priority of immaterial over material factors; finely structured formations rather than gigantomania; and context and totality.

The implementation of these paradigms can only minimize the severity of the present recession by constraining the growth-retarding factors described here. This will open the way for a new upswing of what may be another long wave.

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CHAPTER 18

Technoeconomic Succession and the Economic Long Wave

Erik Mosekilde, Steen Rasmussen, and Maciej Żebrowski

18.1. Introduction

Since the Industrial Revolution some 200 years ago, Western economic development appears to have been characterized by alternating phases of expansion and stagnation with a period of 50–60 years (van Duijn, 1983; Rostow, 1978; Freeman *et al.*, 1982; Maddison, 1982). This phenomenon, known as the Kondratieff wave (Kondratieff, 1935) or the economic long wave, can be approached from basically three different points of view:

(1) The *episodic viewpoint* maintains that there is no real periodicity, and that the variations that may be observed over long periods of time, particularly for certain price variables, can be explained in terms of wars and gold discoveries. Significant technological breakthroughs may also be implied as explanatory factors. These are all phenomena that to a large extend occur independently of economic development, and at least in the present context they should be considered as random exogenous events.

(2) The *structural change approach* admits the existence of a certain rhythmicity in economic development but does not subscribe to the idea of a well defined period. Instead, this approach emphasizes qualitative changes that occur from wave to wave. By replacing old technologies, transportation means, energy sources, organizational forms, etc., each upswing "restructures" society from the inside. It is also emphasized that the geographical location of the dominant politicoeconomic center often shifts from upswing to upswing.

(3) The *coherent wave approach* pictures the economic system as oscillating in a relatively well defined mode in which variations in consumption, employment, production capacity, investment, etc., repeat themselves regularly every 50–60 years. The oscillation is usually considered to originate in economic instabilities, but the wave is accompanied by social and political changes that feed back and affect the wave itself. The years of economic upswing are thus characterized not only by massive investments, rising stock prices, increasing employment and growing prosperity, but during this period of optimism society usually becomes more open and permissive, and liberal political and economic ideas are adopted. Conversely, during the years of economic recession, the society often becomes more conservative and introverted, while at the same time economic inequalities increase.

Through the development of the National Model (NM; see Forrester, 1976), the System Dynamics Group at MIT has elaborated the wave picture in considerable detail. It has been shown how bounded rationality in economic decision making, combined with physical lags (e.g., in the acquisition of capital) create the potential for oscillatory behavior. By virtue of a number of self-reinforcing processes, including the acceleration and multiplication processes of ordinary Keynesian business cycle theory, the oscillatory behavior is destabilized, and the macroeconomic system becomes capable of performing self-sustained oscillations with a period of 50–60 years.

Sterman (1984) has presented the basic dynamic hypothesis of Forrester's theory in simplified form. According to his treatment, an increase in demand for capital leads to further increases through capital self-ordering, i.e., by the fact that the capital sector depends on its own outputs to produce more capital. Once capital expansion gets under way, reinforcing processes sustain it until nonlinear effects finally restrain the growth and allow production to catch up with orders. By this time, a considerable amount of excess capital has been built up, and the loops now reverse: a reduction in orders reduces the demand for investments, leading to a contraction in the capital sector. Capital production must remain below the level required for replacement until the excess capital has been fully depreciated and room for new expansion created.

The strength of the wave picture is that it deals with systematic processes controlled by interactions that to a large extend are well documented in the economic literature. The National Model has thus been able to explain adequately observed changes in both nominal and real interest rates, in real wages, and in capital–labor substitution through the various phases of the wave. The model can therefore serve as a useful instrument for designing policies to cope with the present economic imbalances.

A purely cyclical picture neglects the significant qualitative changes that take place from upswing to upswing, however, and it fails to view the Kondratieff wave as an integral part of the evolution of society. In fact, the present society is quite different from that of the 1930s: material wealth has increased immensely, women's participation in the workforce is much higher, social security has improved, international trade relations have changed, and last but not least, most of the production methods, products, means of transportation and communication, etc., upon which we now depend so heavily have been introduced during the last 30–40 years.

For these reasons we consider the structural change description as the more basic approach, and have therefore attempted to construct a simple model in which the alternating phases of expansion and stagnation arise through a series of unstable transitions by which discoveries, inventions and innovations at the individual or company level explode into dissemination waves that spread throughout the industrialized world.

A preliminary version of our model was presented at the System Dynamics Conference in Oslo (Mosekilde and Rasmussen, 1984). In this chapter the model is reformulated to give a more transparent definition of the variables. At the same time, the model now interfaces directly with Sterman's model, so that in the future it will be possible to combine the two models and obtain a description that integrates the wave and the structural change approaches. Since our model treats scientific discoveries, new inventions, and basic innovations as random processes, it already includes certain elements of the episodic points of view.

18.2. A Theory of Technoeconomic Succession

Based partly on earlier work by Kuznets and others, Mensch (1979) has described how the development of the industrialized world can be pictured as a succession of technoeconomic cultures. In this account, the first Kondratieff upswing exploited the potential generated through the introduction of cotton textiles and steam power between 1783 and about 1803, and the wave is generally referred to as the "Industrial Revolution Kondratieff". The upswing of the subsequent wave, the "bourgeois Kondratieff" (1843–1857) represents the economic growth made possible through the introduction of wood-powered locomotives, telegraphy, Bessemer steel, and Portland cement. The upswing of the "neo-mercantilist Kondratieff" (1893–1913) is associated with the introduction of coal-powered railroads, steamships, automobiles, electricity, and tungsten filament lamps. Finally, the fourth upswing (1949–1967) is associated with motorization, air traffic, electric-arc steel production, computers, and a variety of domestic appliances such as TVs, refrigerators, and washing machines.

Graham and Senge (1980) suggest that each Kondratieff wave can be associated with a particular type of primary energy. The use of wood as a fuel appears to have peaked at the end of the first Kondratieff upswing. The significance of wind and water power reached saturation at the end of the second Kondratieff upswing, the use of coal reached a relative maximum in about 1910, and the significance of oil presumably peaked around 1970, or just at the end of the fourth Kondratieff upswing. In accordance with the National Model, Graham and Senge see the periodic shifts in technology and the associated wave-like variation in the rate of innovation as a consequence of the

50–60 year oscillation generated by self-ordering in the capital sector. Each burst of capital build-up allows a new set of technologies to be utilized, but as the build-up proceeds beyond its initial stages, opportunities for applying new inventions deteriorate rapidly. Society locks itself onto a particular mix of technologies: rapid expansion of the dominant industrial sectors reduces incentives for investments in new and less tried techniques, commitment to a particular type of infrastructure makes it difficult to apply other forms of transport or communication systems, engineers are taught to use the adopted technologies, and administrators learn to trust them. In this period, the society greatly favors improvements to existing technologies over the introduction of basically new technologies.

During the subsequent downturn, innovation opportunities gradually improve as existing capital becomes increasingly obsolete, and large and strong institutions are brought to fall. Near the bottom of the wave, where old capital is depreciated and the technologies of the previous expansion completely outdated, the possibilities for introducing basic new innovations reach a maximum.

We certainly subscribe to most of these ideas, but we would like to stress the qualitative changes associated with technological development, and we would like to see the potential of a given ensemble of techniques and the switch from basic to improvement innovations explicitly represented in the model. In addition, we do not see the existence of capital *per se* as a hindrance to the introduction of new techniques: if a completely new type of industry has to develop, it does not necessarily have to await the depreciation of old capital. If the geographic location of the dominant politicoeconomic center is going to shift (as it has done between some of the previous waves), we do not think that the next upswing has to await the depreciation of infrastructure in the existing center.

As an alternative and presumably more general approach, we have therefore turned to the metamorphosis model developed by Mensch (1979). *Figure 18.1* illustrates the main ideas of this model: Fundamental scientific discoveries are considered to reflect spontaneous processes, and basic new inventions are therefore assumed to be made randomly over time. For an invention to acquire economic significance, however, it must be turned into a basic innovation from which new industries can grow. This transformation, i.e., the introduction of basically new techniques, is conditioned by the state of the economy and particularly by the expectations of the techniques already adopted. The time must be right, which means that exploitation of the present ensemble of techniques must be approaching saturation.

Under such favorable conditions, many of the inventions accumulated since the last economic upswing may be turned into practical applications within a relatively short period of time, and together they lay the seeds for a coming upswing. Completely new industries develop, and the most viable of these start a rapid (exponential) growth. In the beginning, as long as the new industries are economically insignificant, the competition for capital, labor, and other production factors is weak, and the growth process is practically

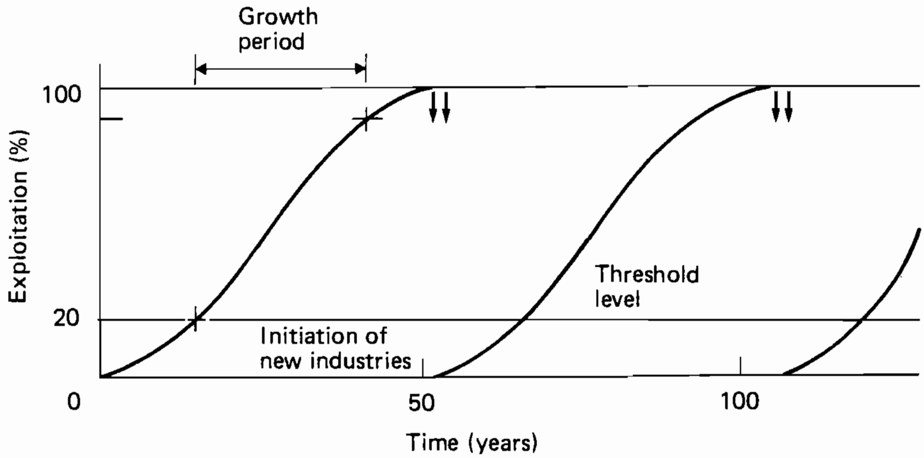

Figure 18.1. A graphic representation of Mensch's model of socioeconomic metamorphosis.

without constraints from the surroundings. However, as the new industries start to become significant, the competition increases, some of the less promising die out, and the incentives to introduce further new innovations fade away. In this way, the society locks itself onto a particular set of technologies, and the interest shifts to improvement innovations.

This phase of rapid initial growth of new industries after the saturation of the former complex of leading sectors is actually the phase of economic stagnation. The economically significant industries have stopped growing, and the new rapidly growing industries have not yet reached macroeconomic significance. In particular, the new industries cannot yet absorb the workforce laid off from the old industries.

Assuming the growth process to be exponential in its initial phases, the economic activity of the rising new industries can be expressed as

$$Q(t) = Q_{in} \exp\{\alpha t\} \tag{18.1}$$

where α is the (linear) growth constant for these industries, and Q_{in} is the economic activity associated with the ever-present attempts to apply new techniques. Q_{in} is a measure of the readiness of persons and companies to experiment with completely new products and methods, even in periods where such ventures seem unnecessary. From a physical point of view, Q_{in} represents a source term of random noise through which the stability of the technoeconomic system is continuously probed in much the same way as mutations continuously probe the stability of a biological system (Allen, 1975). In practice, Q_{in} can be determined as the economic activity associated with techniques of the next upswing at the end of a given upswing. We may think, for instance, of the total activity associated with upcoming information, bio, energy, transportation, etc. techniques in 1973.

By solving (18.1), we obtain for the period of economic stagnation (Meyer and Mosekilde, 1967)

$$T_{st} = \alpha^{-1} \ln\{Q_{th}/Q_{in}\} \tag{18.2}$$

where Q_{th} represents the threshold economic activity at which the new industries become macroeconomically significant. Assuming $Q_{th}/Q_{in} \cong 30$, corresponding to an expansion of the new industries by a factor of 30 before they acquire significance in the total economy, we obtain T_{st}= 23 years for α= 15%/year. Note, however, that because of the ln-function, the value of α that gives T_{st}= 23 years depends only slightly on the ratio Q_{th}/Q_{in}. For Q_{th}/Q_{in}= 100, for instance, one has α= 20%/year. We consider these estimates of corresponding values of Q_{th}/Q_{in} and α as reasonable and thus conclude that the proposed mechanism can in principle account for the length of the stagnation period.

The following years are the years of prosperity and economic growth. The new industries have attained their leading position and are still growing rapidly. As expansion proceeds, however, the industries gradually approach the point at which the potential of the adopted technologies is fully exploited. The exponential growth may then turn into logistic growth described by

$$dQ/dt = \kappa Q(Q_o - Q) \tag{18.3}$$

where Q_o is here the total potential of the adopted technologies, $Q = Q(t)$ is the exploited part of this potential, and $\kappa \sim \alpha/Q_o$ is a constant that characterizes the rate of exploitation.

Identifying the period of economic growth T_{gr} with the period it takes for the upcoming new industries to grow from the threshold of economic significance Q_1($\cong$ 20% of total potential) to near saturation Q_2 (say approximately 90% of total potential), we have

$$T_{gr} = \frac{1}{\alpha} \ln \frac{Q_2(Q_0 - Q_1)}{Q_1(Q_0 - Q_2)} \cong 24 \text{ years.} \tag{18.4}$$

The simple logistic growth curve may be somewhat oversimplified since, as we have indicated, improvement innovations during the growth process will expand the potential of the adopted technologies. As a first approach we may describe this process by

$$dQ_o/dt = \kappa_i\, Q(Q_o - Q) \tag{18.5}$$

As before, Q_0 denotes the total potential for economic activities associated with the currently adopted technologies, and Q is the exploited part of this potential. Due to improvements, Q_0 is now a function of time. The constant κ_i describes the rate at which improvement innovations are introduced.

The set of equations (18.3)–(18.5) has the characteristic feature of prolonging the growth period. If $\kappa_i > \kappa$, the saturation level recedes faster than exploitation develops, and a new downturn never occurs. For a more reasonable value of $\kappa_i \cong \kappa/3$, the length of the upswing in our model is extended from 24 years to about 32 years, and the total wave period thus becomes $T_\kappa \cong$ 55 years.

18.3. A System Dynamics Formulation

According to our assumptions, each Kondratieff wave is qualitatively different from previous and from subsequent waves. Each wave has its own characteristic infrastructure, leading industrial sectors, and typical production methods. Since qualitative differences can only be handled through disaggregation, each wave must be described in terms of its own flow and stock variables.

The System Dynamics flow diagram of *Figure 18.2* shows how a potential for innovations is generated through accumulation of inventions and basic discoveries. As basic discoveries we consider significant scientific breakthroughs such as Hertz's discovery of radio waves, Pasteur's discovery of micro-organisms, and the development of quantum mechanics. Discoveries of new primary energy sources, new types of raw materials, and new production methods are also included, and so is the appearance of ideas that can lead to fundamental social and political changes (e.g., land reforms and parliamentarianism). Examples of inventions are the steam engine, the internal combustion engine, telephones, airplanes, transistors, etc.).

In the model, inventions and basic discoveries are both generated through Poisson processes (Mosekilde and Rasmussen, 1983), i.e., we assume that they occur randomly distributed in time. For simplicity, we consider that all inventions generate the same innovation potential, which we arbitrarily choose to be 600. Similarly, all basic discoveries are assumed to generate an innovation potential of 4000. In the preliminary version of the model, inventions are assumed to occur at an average frequency of 0.3/year, while basic discoveries are assumed to occur at an average frequency of 0.03/year. Thus the total innovation potential accumulated during a wave period, in average, amounts to $(0.3 \times 600 + 0.03 \times 4000) \times 55 \cong 16000$.

Scientific discoveries are not usually applied at once but often precede their practical use by 20–80 years. The basic discovery behind the locomotive, for instance, was made by Watt in 1769, but it was not until 1824 that Stephenson built his first locomotive plant (Marchetti, 1980). Certain mathematical discoveries, such as Boolean algebra and some of Leibniz's theories, have remained practically idle for centuries until, with the inventions of the transistor, the integrated circuit, and the digital computer, they suddenly became of central importance. One can also point to a long series of

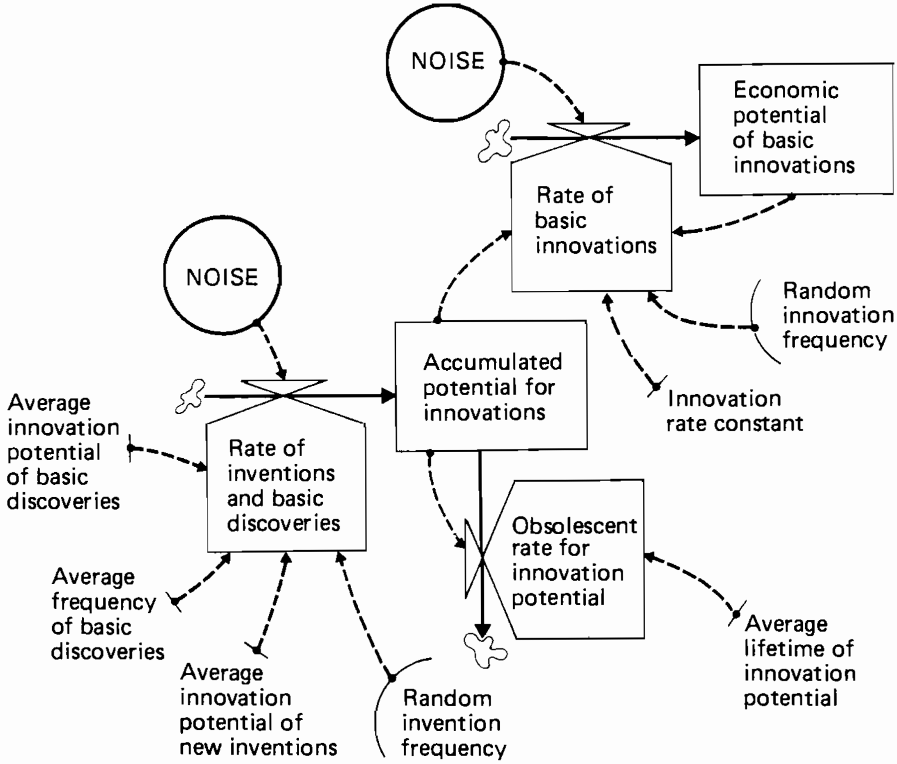

Figure 18.2. Accumulation of inventions and basic discoveries produce a potential for innovations.

inventions that have never been used in practice, such as Leonardo da Vinci's famous machines. In the model, inventions and discoveries therefore accumulate as ideas and basic knowledge from which new innovations can be generated. Some of the accumulated knowledge may become obsolete as time goes on, and we have therefore assumed an exponential decay for the innovation potential corresponding to an average lifetime of 80 years. It should be stressed, however, that this time constant has no direct significance for the periodicity of the long wave.

As basic new innovations we consider the first practical application of new techniques, the introduction of new agricultural production methods, the introduction of new types of consumer goods, the establishment of significant trade agreements, the first successful formation of labor unions, etc., recognizing that technological change in the present context must be given a very broad definition. Innovation and introduction of new techniques create a potential for economic activity. Exploitation of this potential involves the buildup of new industries and infrastructures, the cultivation of new land, the production of new types of consumer goods, etc. It is not until this stage that significant amounts of production factors (labor and capital) become involved, and it is therefore exploitation of the generated economic potential that controls overall economic development: periods in which the rate of exploitation is high are economic growth periods, and periods in which relatively few new possibilities are exploited are stagnation periods.

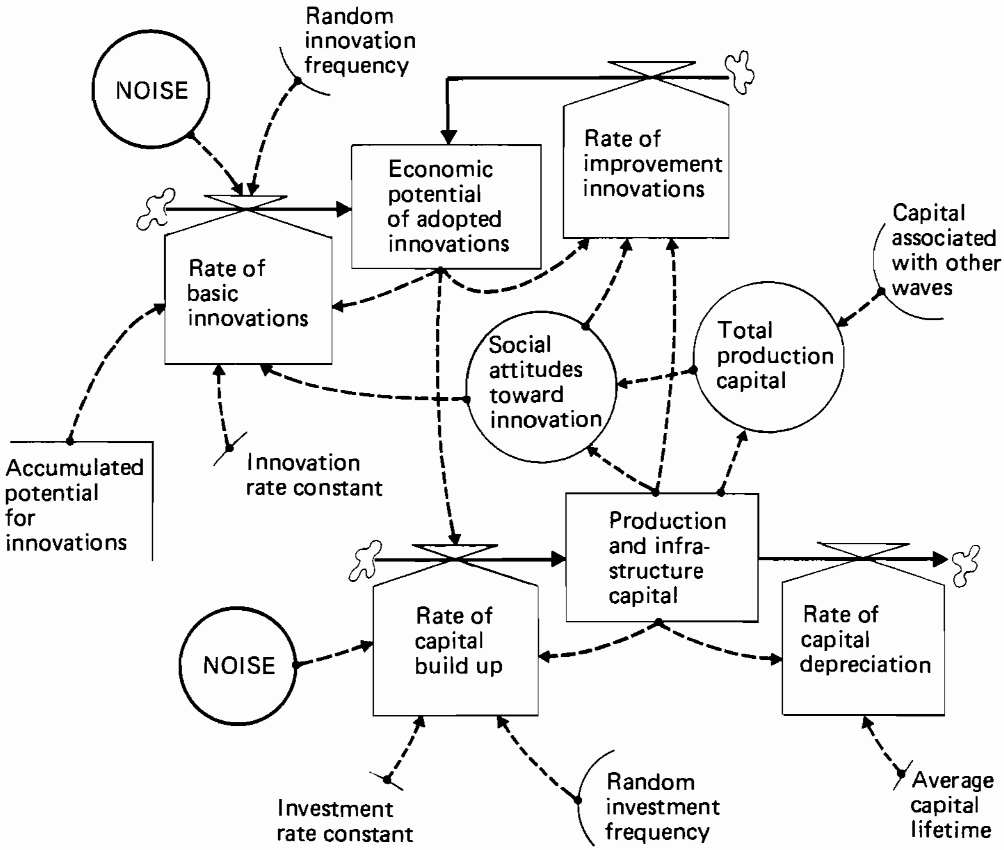

Figure 18.3. This module describes the adoption of new techniques and the buildup of production and infrastructure capital associated with one particular Kondratieff upswing. Similar modules are used to describe preceding and subsequent waves.

As shown in *Figure 18.3*, the adoption of new techniques through innovations, and the buildup of infrastructure and production capital through investments, are both modeled as logistic market penetration processes. The rate of innovations is thus taken to be proportional both to the number of innovations under present exploitation (economic potential of adopted innovations) and to the accumulated knowledge (potential for innovations). The first factor gives amplification as the exploitation of already adopted techniques requires additional innovations. The second factor provides a saturation mechanism if the available inventions and basic discoveries become fully exploited. Similarly, the rate of investments is proportional both to existing production capital and to the economic potential of adopted technologies.

Our model is more profound than usual market penetration models, in that it describes both how the logistic growth processes become possible as instabilities arise in shifting parts of the system, and how the growth processes initiate in the background noise of random attempts to adopt or exploit new techniques. There will always be attempts, for instance, to turn existing scientific knowledge into practical applications, and the rate of innovation therefore contains a random noise term proportional to the intensity or frequency of these attempts. Similarly, the rate of capital buildup contains a noise term that represents the always present random attempts to invest in the production of new types of goods and services.

Under normal circumstances, the economic system is fully occupied with exploiting already adopted techniques, and attempts to introduce basic new technologies seldom succeed. However, if an existing set of technologies approaches saturation, the suppressing forces weaken, the system becomes susceptible to new ideas, and through an unstable transition it yields to a wave of new innovations. This creates a potential for new economic possibilities in the face of which the economic system becomes unstable, and a wave of exploitation unfolds.

The flow diagram of *Figure 18.3* also shows how the economic potential during its exploitation can increase through improvements to existing technologies. This is modeled through the rate of improvement innovations, which, in accordance with our discussion above, is taken to depend both on the potential under exploitation (economic potential of adopted innovations) and on the already exploited potential (production and infrastructure capital).

Finally, *Figure 18.3* illustrates how society shifts its attention from basic new innovations to improvement innovations as the production and infrastructure capital of an upcoming wave becomes comparable to the total production capital in society. This is modeled through the auxiliary variable denoted "social attitudes toward innovation", a nonlinear function that reduces the rate of basic innovations and increases the rate of improvement innovations as the upcoming new industries mature, and society locks itself onto the already adopted technologies.

Figure 18.4 provides an overview of the model structure for one particular Kondratieff upswing. This figure also shows how the random invention, innovation, and investment frequencies can be made to depend upon the overall economic capacity of society through feedbacks from total production capital. Such feedbacks are required to produce secular economic growth in the model, but they have not been included in the simulations presented below.

Finally, *Figure 18.5* illustrates how the instabilities are directed through the system from one module to the next. The first module is unstable

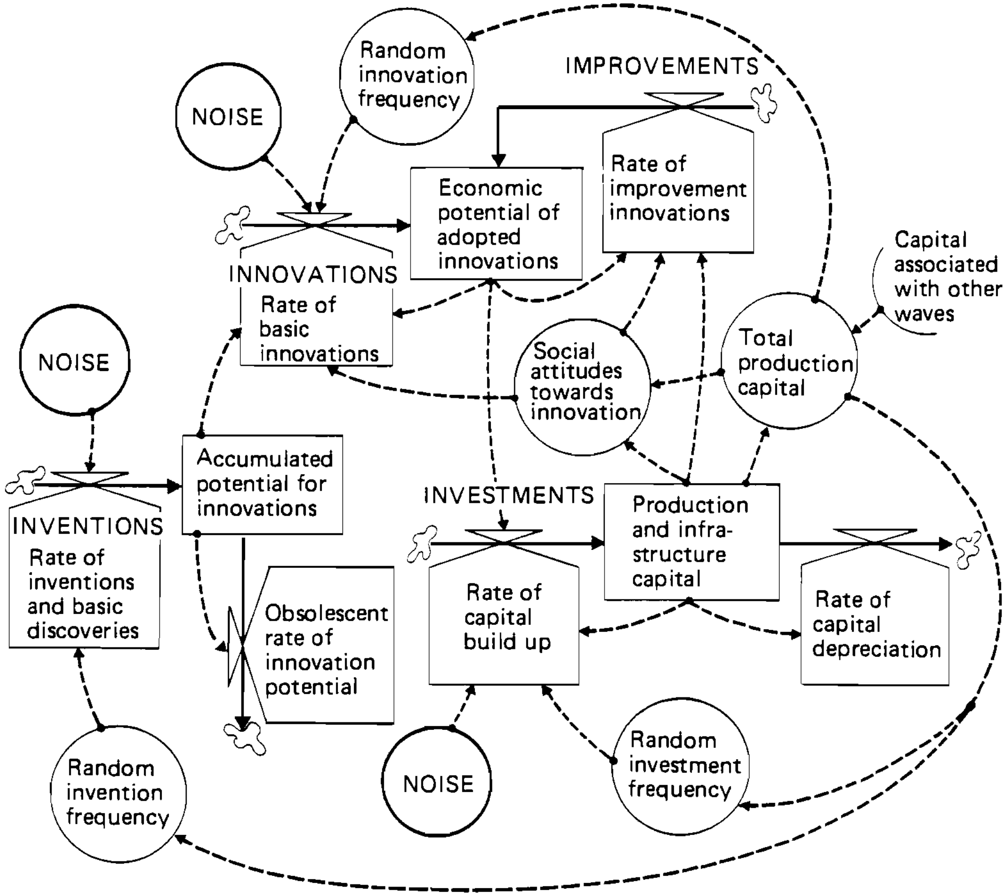

Figure 18.4. Overview of the model structure for one particular Kondratieff upswing. Similar modules are used to describe preceding and subsequent waves.

from the outset, since it is assumed that a number of unexploited scientific discoveries have accumulated, and since the model is initiated in a state where society is susceptible to new innovations. After an incubation time, the length of which depends both on the noise level (i.e., the intensity of random attempts to turn accumulated knowledge into new innovations), and on the gain factor (i.e., the innovation rate constant), a macroscopically significant potential for new economic activities develops. This innovation wave is assumed to last for about 10 years, or about 1/5 of the total wave period.

By creating a potential for economic activities, a new instability is generated, and an exponential growth in production capital is initiated. After a new incubation period, which again depends both on the random investment frequency and on the gain factor (the investment rate constant), the

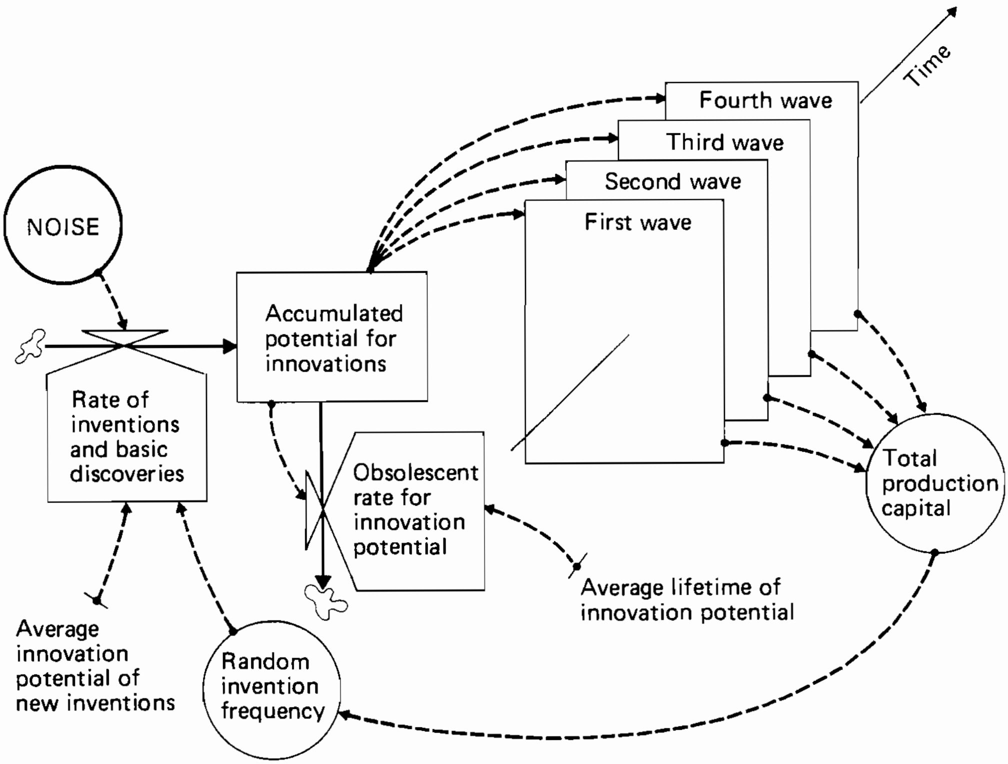

Figure 18.5. Overview of the coupling of subsequent modules.

production and infrastructure capital associated with the upcoming wave reach macroscopic significance. Society now engages itself fully in the exploitation of already adopted technologies, and the rate of basic innovations falls to zero.

As the exploitation of first-wave technologies continues, a point of saturation is approached. The economic growth rate then declines, and society gradually becomes ready to accept a new set of technologies based on scientific discoveries that have accumulated since the first innovation wave. Hereafter follows the exploitation of second-wave technologies, adoption of third-wave technologies, etc.

18.4. Simulation Results

Figure 18.6 shows a typical set of simulation results. For each of four subsequent waves we have here plotted the variation with time of the three state variables, the accumulated potential for innovations, the economic potential of adopted innovations, and the production and infrastructure capital. The figure shows how the curves for the economic potential of adopted technologies and for the installed capital all grow out of insignificant background noise.

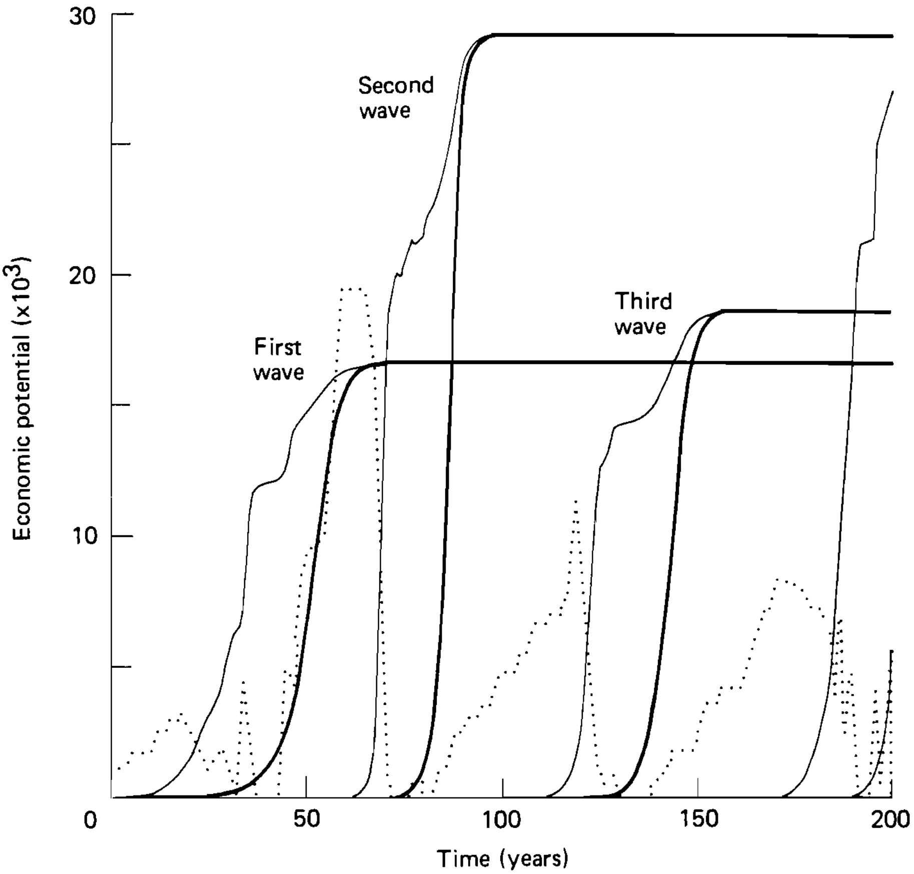

Figure 18.6. Variation of accumulated potential for innovations (dotted curve), economic potential of adopted technologies (fine curve), and production and infrastructure capital (heavy curve) in the base case run. The simulations were performed with a slightly simplified version of the model (Mosekilde and Rasmussen, 1984).

Note how the model produces a relatively regular succession of upswings with a 50-year period out of the external signals of random discoveries. Note also how the economic potentials of adopted innovations show a double logistic growth of which the first part is associated with basic new innovations during periods of economic stagnation, while the subsequent enhancement is associated with improvement innovations during periods of economic growth.

Figure 18.7 shows the rates of basic innovations and the investment rates associated with four subsequent Kondratieff waves. On this figure we have also plotted the randomly occurring inventions and basic discoveries. It can be seen, how basic innovations predominantly occur in periods with low investment rates.

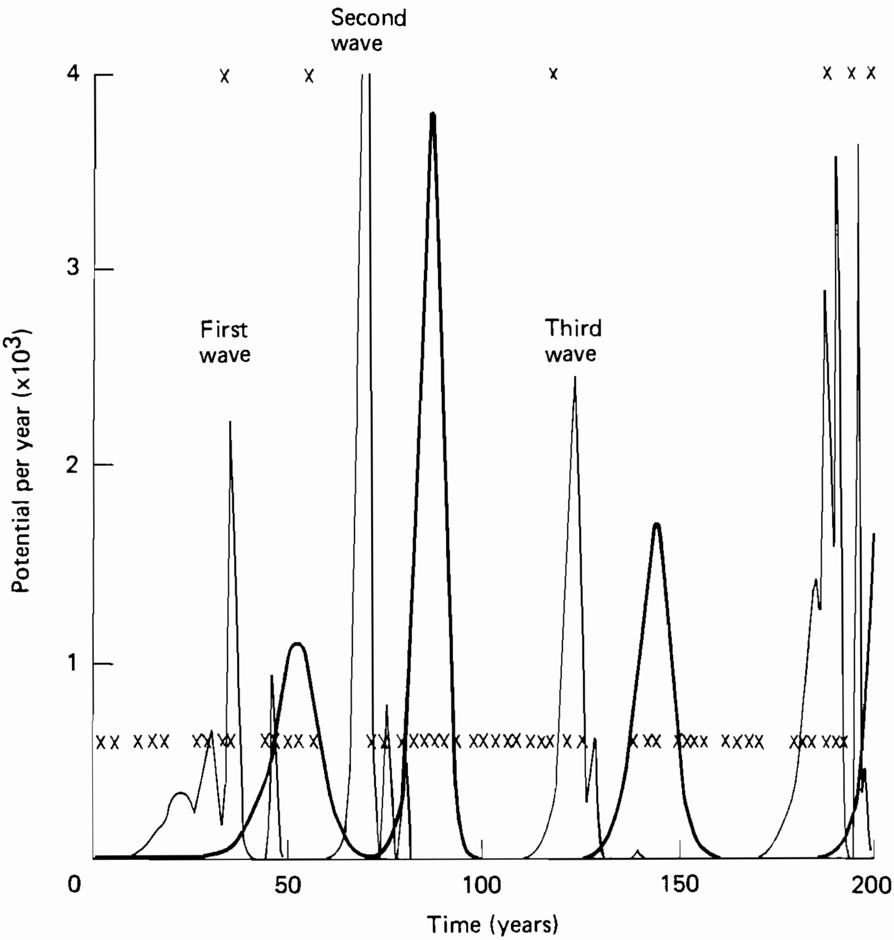

Figure 18.7. Rate of basic innovations (fine curve) and rate of investments (heavy curve) for four subsequent waves. The randomly distributed inventions and basic discoveries are indicated by crosses. Note how the model generates a relatively coherent investment wave out of random inventions and discoveries.

To illustrate the significance of the random element in our model, we have run a series of simulations with different initial values for Dynamo's NOISE-function (see *Figure 18.8*, which is directly comparable with *Figure 18.6*). As defined by the amplitudes of the individual waves and their precise time of occurrences, the behavior of the model strongly depends on the sequence of random discoveries. However, the tendency to generate 50–60-year waves out of these discoveries is maintained independently of the NOISE-sequence.

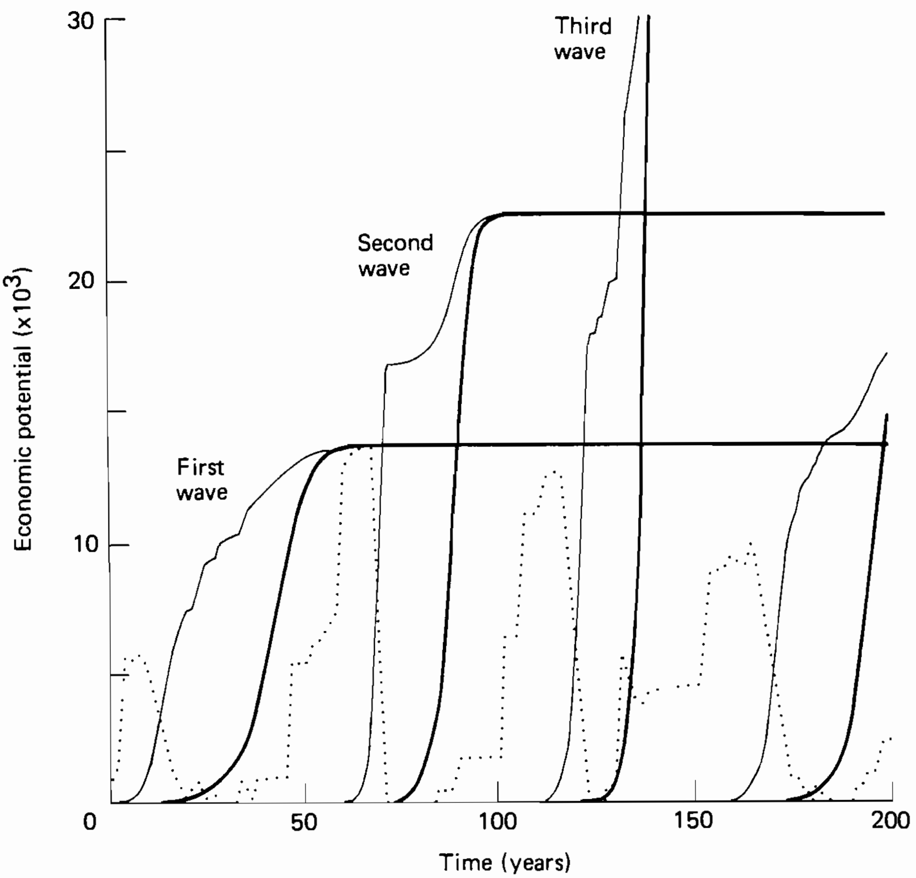

Figure 18.8. Accumulated potential for innovations (dotted curve), economic potential of adopted technologies (fine curve), and production and infrastructure capital (heavy curve) with a different initial value for Dynamo's NOISE-function (cf. *Figure 18.6*).

18.5. Discussion

Considering the dissemination of new techniques as a series of unstable transitions through which inventions, innovations, and random attempts to invest in new technologies at the individual or company level explode into waves that spread throughout the industrialized world, we have been able to develop a formal model of the economic long wave.

With this description, the qualitative changes in society from upswing to upswing are accounted for, at least in principle. There is no precise wave period since the amplitudes and accurate locations in time of the individual upswings are influenced by the random distribution of inventions and basic discoveries. Nonetheless, there is a tendency for the system to develop in a rhythmic manner with a typical period of 50–60 years.

This period is controlled by the rate constant for the buildup of production and infrastructure capital (assuming this to be the slower of the two dissemination processes), and by the number of decades over which the rising new industries must grow to attain macroeconomic significance. The more frequent the random attempts to adopt and exploit new techniques, the shorter will the wave period be, and the smaller is also the amplitude. According to the model, the intensity of the wave could thus be reduced if society were more open to experimentation with new energy sources, new transport and communication systems, etc., particularly during periods of high economic growth.

It is interesting to note that the value α = 15–20%/year, which we have to assume for the aggregated linear growth rate of upcoming new industries to obtain a period of 50-60 years for the rhythmic growth process, precisely corresponds to the value assumed in Sterman's (1983) model for the maximum investment rate. In our model an increase in α reduces the wave period, whereas an increase in the maximum investment rate prolongs the wave period in Sterman's model. The two models also differ widely in the significance they give to capital lifetimes. It will therefore be interesting to see the outcome of an integration of these approaches.

In their more detailed analyses, the MIT group has also discussed the shift in capital/labor mix during the phases of the long wave (see Sterman, 1984). We believe that this shift is affected not only by economic factors (such as aggregated factor prices), but that technological factors associated with e.g., the buildup of new industries, the adoption of new production methods, the introduction of new transport and communication systems, etc., are just as important. Also in this respect we would therefore like to see an integration of the two approaches.

With the adoption of the structural change approach, the Kondratieff wave becomes an integrated part of the long-term sociotechnoeconomic development of society. It will therefore also be of interest to investigate how determinants of long-term growth feed back and change the amplitude and period of the Kondratieff wave. Such determinants could be associated with the increasing complexity of society, with resource scarcity and pollution, or with the shift from material production to a service-oriented economy. In addition, there is no guarantee, of course, that basic scientific discoveries will continue to be made at more or less the same frequency.

Acknowledgments

Thanks are due to John Sterman and Peter Senge, the System Dynamics Group at MIT, and to Inge Ropke, The Institute of Social Sciences at the Technical University of Denmark, for a number of enlightening discussions. David Guistino, School of Humanities, Griffith University, Australia, has contributed significantly through his critical comments on a draft of this chapter.

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CHAPTER 19

New Technology and Regional Development

Peter Nijkamp

19.1. Introduction

In the history of economic thought technology has almost never been treated as an explicit subject, but has mainly been regarded as a datum for economic analysis (the so-called "data crown" hypothesis; see Eucken, 1950). In recent years, however, a profound interest in the causes and effects of technological changes – seen from an economic viewpoint – has emerged. The economics of technological change has come to the fore as an intriguing research issue (see Stoneman, 1983).

In the past, technological innovation has also been interpreted in the context of Schumpeter's view of technological revolutions as driving forces behind the Kondratieff cycles (see Kleinknecht, 1984). Clustered innovations have in the past exerted a profound impact on Western societies (railways, electricity, automobiles, etc.). The introduction of new technologies requires a "basic science" connected to "technical exploitation", followed by "imaginative laps" that precede all upswing phases in a Kondratieff long wave (see Rothwell and Zegveld, 1981). Much scientific discussion has also emerged on the question of whether new technologies are a result of a demand pull or a technology push. A great deal of confusion in this field has arisen because of a fuzzy use of the term "new technology", especially because the motives and impacts of process, product, institutional, and managerial innovations may be quite different.

Technology as the "society's pool of knowledge regarding the industrial arts" (Mansfield, 1968) is, however, not a homogeneous knowledge asset, but is marked by a wide variety of appearances ranging *inter alia* from small-scale to large-scale forms and from traditional to advanced activities. In the past, much attention has been focused on *new* technologies since it is widely believed that technological change may be one of the driving forces for new economic progress in an era of stagnation and structural change (cf. Nelson and Winter, 1982; Rosegger, 1980). However, the terms "new technology", "advanced technology", or "high technology" are not unambiguously defined and deserve closer attention. In this chapter an attempt will be made to demarcate more precisely the *meaning* of the concept "new technology".

A second aim of this chapter is to analyze the *locational* patterns of new technology. For instance, it has often been claimed that large metropolises are losing part of their innovative potential with regard to large firms in favor of medium-sized cities (see Malecki, 1983). In the light of the uneven geographical distribution of the new technology sector, it may be an important research objective to identify the economic motives for its locational behavior.

Finally, a case study of the Netherlands on the location pattern of new technology activities is described, in which it is concluded that the sector is not necessarily located in large cities, but may exhibit a more scattered spatial configuration although the sector is at least oriented toward the breeding ground function of large cities (the "urban climate" or "incubator" hypothesis).

19.2. New Technology in an Era of Change

Technology is not a datum in entrepreneurial behavior, but it may be one of the instruments that improves the relative economic position of a firm. Clearly, there must be a need for employing this instrument in a competitive system. In addition, the financial resources, capital, and entrepreneurship must provide the conditions for technological change. Other important prerequisites for technological innovation are the availability of an appropriate (external) *knowledge infrastructure* such as transfer centers, science parks, and knowledge centers (Mouwen and Nijkamp, 1985), and a sufficient level of (internal) *R&D investments* (Andersson and Johansson, 1984).

New technologies imply that inventions are successfully transformed into innovations that are technically feasible and commercially attractive. This implies a successful implementation of new products or production processes, and a successful introduction of related management and marketing changes (including the search for new markets or new market segments). Consequently, technological innovations also require the successful use of new information technology (NIT), since the information infrastructure is an essential ingredient in any (private or public) development strategy (Gillespie *et al.*, 1984).

Technological innovation is also closely linked to the product life cycle. The various (successful) stages of a new product require special technological changes and R&D efforts. First of all, the invention and introduction phases of a product require a close orientation toward both R&D divisions and sales markets. Next, during the expansion phase, more attention is needed to increase product standardization and labor productivity, given the competition with other entrepreneurs on the same market. In the third stage, an orientation toward more capital intensity and product export is necessary in order to prevent a stagnation in sales. Finally, in the mature stage, both domestic and foreign competition becomes so strong that – unless new market segments are created through increased product specialization, or cooperation with competitors is realized – a decline will commence.

Each phase of such technological innovations may have its own specific R&D and technology requirements, as well as its own specific locational requirements (Brotchie, *et al.*, 1985; Stöhr and Schubert, 1984). Consequently, regional development is codetermined by the life cycle phase of a new technology (see Section 19.3). The demarcation of *new technology* – in contrast with other technology – is not an easy task. In principle, two different approaches can be distinguished, i.e., the *cross-section* approach and the *selective sector* approach.

The *cross-section* approach examines all sectors of the economy and attempts to identify – on the basic of detailed surveys – the share of technological innovations (especially advanced technology) in each sector (for instance, by assessing the R&D input in each sector). This is a useful research strategy, although it is fairly time-consuming and does not always give accurate answers (Kleinknecht and Mouwen, 1985; Mouwen and Nijkamp, 1985).

The *selective sector* approach tries to identify those sectors in the economy that are characterized by a high degree of use of new technology activities. The main problem here, however, lies in drawing up a definition of new technological activities, in particular because a broad sectoral classification would be unsatisfactory.

In the literature, various definitions of new (advanced or high) technology have been given. Despite a certain vagueness or fuzziness in the terminology (Haustein, 1982), various general attributes of new technology can be identified:

(1) The use of highly skilled employees, many of whom are scientists or engineers (Doody and Munzer, 1981; Rogers and Larsen, 1984).
(2) A high proportion of R&D expenditures on sales (Doody and Munzer, 1981; Hall and Markusen, 1983; Premus, 1982; Rogers and Larsen, 1984).
(3) A nationwide or worldwide market for the products (Doody and Munzer, 1981; Rogers and Larsen, 1984).
(4) A fast rate of growth (Doody and Munzer, 1981; Hall and Markusen, 1983; Rogers and Larsen, 1984).
(5) A high degree of labor intensity in the production stage (Doody and Munzer, 1981; Premus, 1982).

In conclusion, the new technology sector can mainly be found in technically oriented industries based on scientific and technological practices that lead to a relatively high growth rate of value added. Examples of such industries are chemicals, electronics, aircraft, and precision instruments.

It is clear that a sharp definition and identification of the new technology is hard to give, because of rapid changes in many industrial sectors, incomparability of technological information, a firm's specific position in a product cycle, the lack of disaggregated empirical data on production processes at the micro level (even at the level of divisions or plants within one firm), and the lack of a sharp distinction between new technology products and processes (McQuaid and Langridge, 1984).

In this chapter the attention is focused on firms (or industrial sectors) producing new technology products and which are to a large extent marked by the above features. For practical reasons, in the empirical part the selective sector approach will be used, so that attention will be given to a selected set of (fairly detailed and disaggregated) industrial sectors that comply with the above mentioned features.

19.3. The Location of New Technology Firms

The locational analysis of new technology firms is still underdeveloped: a clear theoretical framework is lacking, while various case studies provide sometimes only anecdotal observations (Malecki and Varaiya, 1986). Nevertheless, some structural spatial development patterns do seem to be emerging. New technology firms are increasingly dividing their activities into routine (or standardized) and non-routine (or innovative) operations. The non-routine (mainly R&D-oriented) activities tend to concentrate in only a few locations marked by significant agglomeration advantages such as accessibility. For instance, Hekman (1980) indicates that computer firms in the USA tend to maintain their innovative activities in only a few regions (like California, Texas, or Massachusetts). Standardized production and assembly operations are either moving into small towns or peripheral areas or into low-wage Third World countries (Bluestone and Harrison, 1982).

Next, non-routine activities in the new technology sector rely heavily on skilled and professional labor inputs, so that the quality of the residential climate (including sociocultural amenities) also becomes a major locational motive (Brotchie *et al.*, 1985; Hall *et al.*, 1983). Similar results were found by Oakey (1981) in a study of the British instruments sector, who concluded that skilled workers largely determine the location of production. This result was supported by Malecki (1984) and Oakey (1983), who observed that locational preferences of technical personnel exert a large influence on the location decisions of R&D. Such personnel appear to attach a high priority to cultural, educational, and employment opportunities in urban areas.

With regard to routine activities, especially of multi-plant corporate organizations, it is evident that low-skill labor is still the main input. In as far as low-skill employment is abundantly present in various regions, it is mainly the wage level that determines the locational pattern of these standardized activities (Hansen, 1980). It should be added, however, that these activities are fairly capital intensive, so that aging and life cycle processes of capital stocks may also exert a significant long-term influence on industrial location patterns of new technology firms.

In addition, it has to be mentioned that a large concentration of new technology activities may lead to congestion phenomena, especially if innovative firms create spin-off effects that lead to an increase in routine activities. Premus (1982), for instance, observed that in recent years there has been a tendency for new technology firms in the USA to move from the Sunbelt states to the Midwest due to bottleneck factors (such as high wage rates, high land rents, insufficient area for industrial expansion, high local taxes, and traffic congestion). Clearly, this "crowding out" phenomenon may also be related to the firm's position in the product cycle. Similar results were found in Scotland (Cross, 1981), the Netherlands (Hoogteijling *et al.*, 1986; Wever, 1984), and in the FRG (Wettmann, 1983).

Another (important) locational determinant of the new technology sector is its orientation toward an accessible communications and information network, so that this sector is either located at nodal points in a physical communications infrastructure or in areas near research and educational institutes (Levy, 1983). This may also lead to job-hopping, as has occurred in California's Silicon Valley.

A final relevant component of an innovation infrastructure of the new technology sector is the availability of venture capital (Rothwell, 1982), especially in those countries that are marked by regional variations in the provision of venture capital. This may especially hold true for large countries (like the USA) with segmented markets for venture capital. In small countries, however, it is plausible to assume that regional differences in venture capital hardly exist, so that this is not a location-specific factor (though it may be generic determining factor for new technological innovations in the country as a whole).

The foregoing remarks lead to the following propositions, which will be further tested in an empirical study on the locational pattern of the new technology in the Netherlands:

(1) Non-routine (R&D-oriented) new technological activities are sensitive to communication, information, and accessibility, so that their location may be expected at nodal points in a spatial network.
(2) Routine (standardized) new technological activities and operations may exhibit a more scattered pattern due to crowding-out effects.
(3) New technological activities recruit highly skilled employees who attach a high priority to a favorable residential climate near major urban centers.
(4) The location of the new technology will not be influenced by the wage level and the presence of venture capital, insofar as in a small country significant regional differences in these locational factors do not exist.

These propositions will now be examined in the context of a Dutch case study on new technology.

19.4. Location of New Technology in the Netherlands: A Test

Following the above arguments, we consider first the operational demarcation of high technology sectors in the Netherlands and the operational definition of locational determinants of the new technology (Bouman *et al.*, 1985).

The conventional sectoral subdivision of *Business Week – Data Resources* is based on five categories: energy, agriculture, high technology, services, and old line industries. For our case study, based on the above selective sector approach, *Table 19.1* lists activities in the Dutch economy that are assumed to belong to the new technology sector by their four-digit standard industrial classification. This classification is mainly based on the *design* of new products; the *use* of high-tech products by other sectors is left out of consideration, since use is not regarded as a new technology activity *per se* (unless the use of such products is necessary for designing more advanced new technology products, as is the case in the medical sector, the robotics sector, and the optical industry).

Table 19.1. New technology sectors in the Dutch economy.

Standard industrial classification code	*Sector*
3581	office equipment
3593	weighing instruments and retail equipment
3693	electrical and electronic measurement and control equipment and electromedical equipment
3694	telecommunications and signal equipment
3695	radio, television, and electronic equipment
3771	aircraft
3811	medical, surgical, dental, and veterinarian instruments
3821	measurement and control instruments
3831	optical and phototechnical instruments
3841	clocks and watches

The spatial dispersion of new technology firms in the Netherlands has been analyzed on the basis of a sample of firms in the sectors included in *Table 19.1* (provided by the Dutch Chamber of Commerce). The location of all new technology firms could be derived from this sample, so that a detailed insight into the geographical pattern of the sector in the Netherlands could be obtained. Some results will briefly be presented here. *Table 19.2* presents a representation of the spatial dispersion at the provincial level in the Netherlands, based on the location quotient (the ratio of the provincial share of the new technology sector with respect to provincial share of the total industrial sector).

Table 19.2 clearly shows that the new technology sector is overrepresented in the three industrialized, urbanized provinces (the so-called Randstad or Rimcity), confirming the conventional wisdom that the new technology sector is very much oriented toward large-scale urban/industrial agglomerations.

Table 19.2. Location quotient for Dutch new technology firms.

	New technology firms		*Industrial establishments*		
Province	*No.*	*%*	*No.*	*%*	*Location quotient*
Groningen	36	2.8	1499	3.2	0.88
Friesland	26	2.0	1860	4.0	0.55
Drente	26	2.0	1005	2.2	0.90
Overijssel	76	5.0	3365	7.3	0.69
Gelderland	119	9.2	5748	12.4	0.74
Utrecht	129	10.0	2902	6.3	1.59
Noord-Holland	268	20.8	8405	18.1	1.15
Zuid-Holland	340	26.4	9220	19.9	1.33
Zeeland	22	1.7	1026	2.2	0.77
Noord-Brabant	159	12.4	7579	16.3	0.76
Limburg	73	5.7	3545	7.6	0.75
Zuid-Ysselmeer	13	1.0	253	0.5	2.00

However, it is interesting to study some results at a more spatially disaggregate level (the so-called COROP level marked by 40 nodal regions). These results are presented in *Figure 19.1*. This map demonstrates a slightly different pattern. It is still evident that various nodal regions are characterized by an overrepresentation of new technology firms. Furthermore, various regions outside the Randstad appear to have a fairly strong new technology orientation as well. Consequently, ecological fallacy may lead to a biased interpretation of the actual spatial distribution of new technology firms. The same pattern presented in *Figure 19.1* was obtained by examining the spatial dispersion of the new technology firms in terms of employment. A first look at *Figure 19.1* suggests that the locational pattern of new technology is closely related to the presence of an urban agglomeration marked by a high degree of accessibility and of R&D infrastructure. Similar results have been found for the USA by Premus (1982) and for France by Aydalot (1984), which also suggest that the diffusion of high technology firms does not exhibit a hierarchical distance-decay pattern from the center, but rather a multiple-nuclei pattern. This pattern can be further analyzed by examining the locational determinants of the new technology sector.

An operational definition of the locational determinants discussed in the previous section is far from easy. The following indicators based on available data from the Netherlands have been used:

(1) *Education*. The regional share of highly skilled employees in the total regional labor force.

(2) *R&D infrastructure*. The (weighted average) distance of each regional main centre with respect to all R&D centers (university institutes, public research institutes, technology and transfer centers, etc.).

(3) *Amenities*. A (weighted) sociocultural index constructed on the basis of the regional availability of recreational facilities, monuments, and cultural facilities (standardized for the number of inhabitants per region).

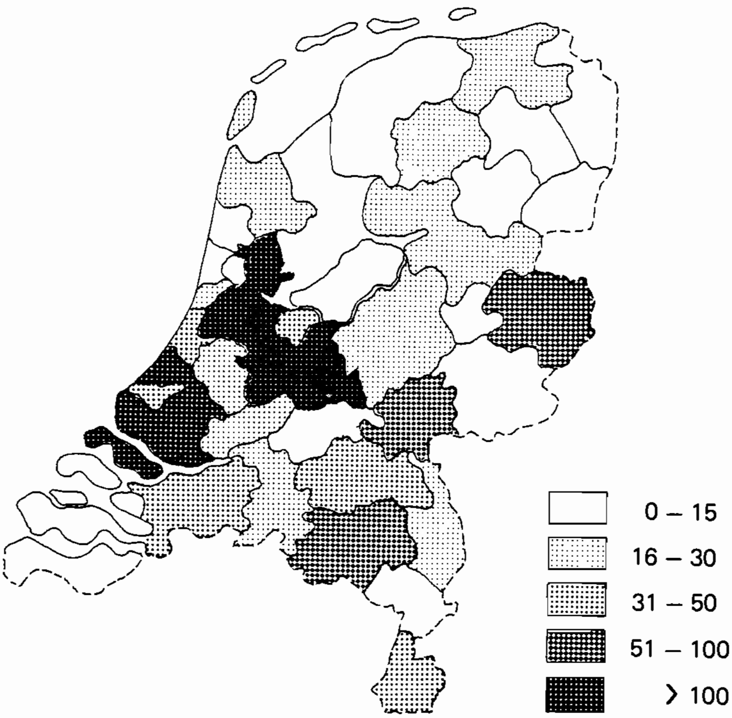

Figure 19.1. Number of regional technology establishments.

(4) *Venture capital.* The regional supply of venture capital provided by (publicly financed) regional development corporations.
(5) *Urbanization.* The share of the regional population living in large urban centers.

An econometric test of the validity of these locational determinants at the provincial level would lead to unreliable results in the light of the small number of provinces (12); an adjusted approach has thus been adopted here. From our literature survey it has become clear that at least a ranking of the order of importance of these locational determinants can be derived. In most cases, an orientation toward large agglomerations is regarded as an extremely important explanatory factor for the spatial pattern of the new technology sector (indicator 5), followed by high-skill educational facilities (indicator 1) and R&D infrastructure (indicator 2), while amenities (indicator 3) and venture capital (indicator 4) have usually a much lower ranking. Based on expert views and intuition, the following weight coefficients have been used in an explanatory model for the geographical distribution of the new technology firms (*Table 19.3*).

By next calculating using a linear model the expected geographical dispersion of new technology firms, based on weights in *Table 19.3* and the actual regional observations on the locational determinants (1–5), a fairly satisfactory result is obtained: 96% of the variance in the actual geographical pattern of new technology firms is explained by the weights in *Table 19.3*. A check by means of a regression model confirmed the results for the main indicators (1), (2) and (5), while for the remaining indicators insignificant results were obtained.

Table 19.3. Weights attached to locational determinants.

Location indicators	(1)	(2)	(3)	(4)	(5)
Weights	0.25	0.2	0.1	0.1	0.35

19.5. In Retrospect

The following conclusions can be inferred from the Dutch case study. Not all propositions mentioned in Section 19.3 could be tested due to the limited empirical data on the locational patterns and motives of new technology firms, but the available data support the hypothesis that new technology firms tend to locate at nodal points in an accessible network, with a strong orientation toward large urban centers. This bias against the urban milieu is once more favored due to the high-skill and R&D requirements of new technology firms. Crowding-out effects could be observed in two respects: (1) the trend toward a suburban location (with a favorable living climate) of new technology firms, and (2) the trend toward an urban location in intermediate and/or peripheral areas. Regional differentation of wage levels and of the supply of venture capital could hardly be observed in the Netherlands, so that these factors vanish as explanatory determinants of the geographical location pattern of the new technology sector. Finally, due to lack of data on routine versus non-routine data at the firm level, the spatial differentiation between routine and non-routine new technologies could not be examined. The overall conclusion is that the empirical evidence from the Netherlands supports most hypotheses offered by the present literature, while the differences that do occur are due mainly to the spatial scale of the country.

Our findings on the metropolitan orientation of the new technology sector have various policy implications: a regional development policy focusing on new technology should take the metropolitan area as its geographical base. In this area the conditions for new technology location have been favored by supporting the development of contract information flows, since this determines the comparative advantage of the area (Brotchie *et al.*, 1985). Such agglomeration advantages are of utmost importance for the creation of advanced knowledge and creativity (requiring *inter alia* advanced educational institutes and R&D centers). The economic potential of such agglomerations is thus strongly determined by public overhead capital inducing the development of the new technology sector.

Acknowledgments

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CHAPTER 20

Scientific and Technological Cycles: Program- and Aim-Oriented Planning

Yu. V. Yakovets

20.1. Introduction

The radical, worldwide changes in science, technology, and economics that have occurred since the mid-1970s have aroused the interest of researchers into their causes, which may be rooted in the regularities of scientific and technological progress. The literature on the subject is growing, and national and international conferences are frequently held. In the USSR intensive research is being conducted into these regular cycles of scientific and technological development (Gatovski, 1974; Kedrov, 1980; Rajkov, 1983; Sedov, 1977; Yakovets, 1984). This chapter deals with the theoretical background, content, and applied aspects of the utilization of these cycles of development that, in our view, are of paramount importance if we are to understand the changes occurring in the world and to adapt ourselves to them effectively.

20.2. Theory of Scientific and Technological Cycles

Technology and science do not develop in a straight line or exponentially. The pattern of development resembles a spiral where qualitative, revolutionary leaps are followed by periods of evolutionary expansion and the improvement of a new generation of machinery. In this spiral-like movement one can identify structural elements of various depths and duration and discover quantitative measures of their sequence and periodicity.

The primary and most frequently observed form of qualitative leap in technology is the *machine generation change* (Yakovets, 1984). At the core of such a leap lies the realization of a new, more effective technological idea or invention that enables goods of better quality to be produced at substantially lower costs. This machine generation change covers all fields of application of a particular technology, and occurs on average every 8–10 years; in new branches (such as electronics) such changes occur more frequently, whereas in traditional industries (e.g., textiles or mining) they appear over longer periods.

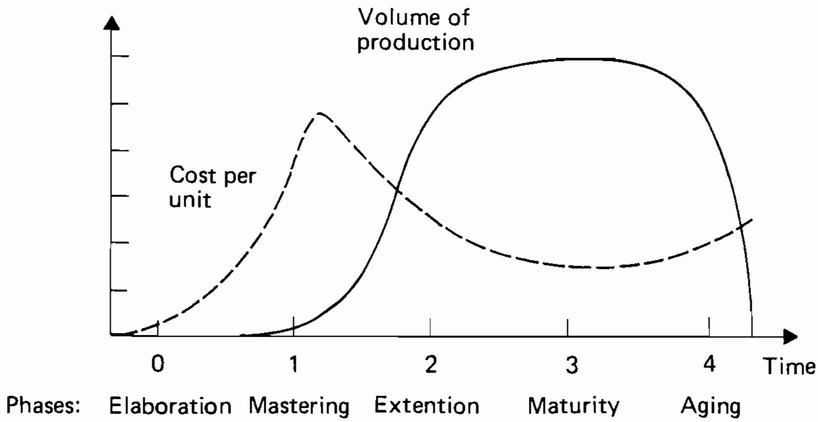

Figure 20.1. Phases of the scientific–technological cycle.

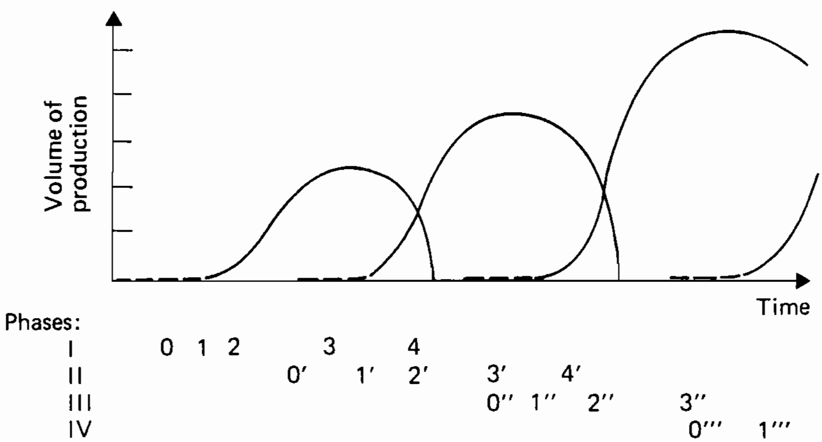

Figure 20.2. Changes in generations of technology.

In the life cycle of each machine generation five phases can be distinguished (*Figure 20.1*):

(1) A zero or pre-production phase 0, which includes the elaboration and testing of a new idea or invention and its translation into experimental prototypes.
(2) In phase 1 the new generation of machines is mastered. This is the most complex and difficult phase, since it is connected with the transformation of spheres of production, the application of the new technology, and its high production and utilization costs.
(3) In phase 2 production rapidly expands, new models are created to meet the requirements of various spheres of application, and prices fall rapidly. All this extends the effective use of a new machine generation.
(4) In phase 3 the scale of production, costs, and price levels do not change substantially, and effective growth rates become notably lower, but the extent of the economic effect is greatest.
(5) In phase 4 the moral and technological aging of the machines takes place, and further improvements and modification are no longer effective. It is necessary to replace the old machines with new ones as rapidly as possible, and their development and introduction are timed and coordinated with phases 3 and 4 of the previous generation (*Figure 20.2*). Only then is continuity and effectiveness of technological progress assured.

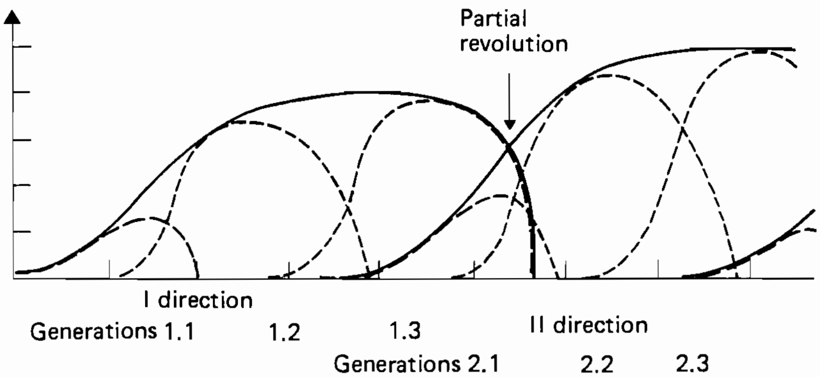

Figure 20.3. Changes in the directions of technology.

Marx first pointed out the cyclical nature of innovations in the production technological base. The periodic, massive renewal of fixed capital caused by a transition to a more effective technology in capitalist economies serves as the material foundation for periodic overproduction crises (Marx and Engels, 1961). Although the mechanism of capitalist cycles has recently been considerably modified, it continues to operate. In socialist economies the transition to a new generation of technology is planned and is thus devoid of crises.

More comprehensive and complex technological leaps are manifested in new *directions of technological development*, based on a qualitatively

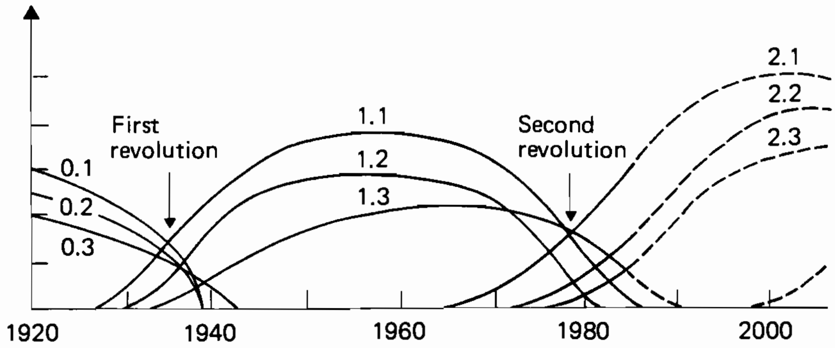

Figure 20.4 General technological (scientific-technological) revolutions.

different principle, through which major scientific discoveries can be utilized as basic innovations (e.g., robots, biotechnology, lasers, microelectronics, etc.). Several generations of machinery may be replaced (*Figure 20.3*), within various spheres of application; this may take several decades and is generally linked with the formation of new branches of industry. The development of this form of technological cycle has five phases, the duration of each of which is longer than that of the change in machine generations. The costs of mastering the machines of the new direction may be higher but their economic impacts are much greater. The onset of a new direction implies a partial technological revolution.

When several new technological directions converge over a relatively short period, enriching and enhancing each other, we can speak of the emergence of a *general technological revolution* (*Figure 20.4*). Initially, this occurs in a group of leading sectors in the developed countries, then in a wave-like manner it spreads rapidly from the epicenter, radically transforming the material and technological basis of society, accelerating the rates of economic growth, and increasing the efficiency of production processes. The occurrence of such a revolution is connected with a scientific revolution, qualitative transformations in the training of workers (education revolution), and in the organization of production (*Figure 20.5*).

On the whole, these radical changes express the main content of the next stage in the development of productive forces, and ultimately bring about – through complex and often contradictory interrelations – qualitative leaps in economic and social relationships. Hence, the scientific–technological cycle reveals the dialectical mechanism of the development of productive forces as the material base for social progress.

Several such upheavals in the history of technological development can be identified. In early human society the first of these were the development of agriculture and the use of metals (bronze and iron). In the eighth to tenth centuries AD the center of technological development was in the Far East, and the shift to Europe in the thirteenth and fourteenth centuries gave rise to

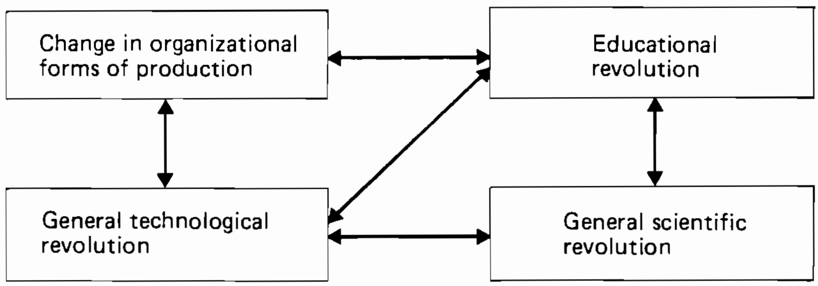

Figure 20.5. Structure of revolutions in productive forces.

the trade guilds. A revolution in manufacturing took place in the sixteenth and seventeenth centuries, and introduced a rigid division of labor. The Industrial Revolution of the late eighteenth and early nineteenth centuries laid the foundation for mechanized production as the material basis of capitalism. We can also observe technological changes of lesser importance in the mid-1900s, and the electrical (electrotechnical) revolution of the late 1900s. In the present century we have witnessed the greatest general technological revolution of the 1940s and 1950s, and most recently in the 1970s.

The development of science is also cyclical, although the boundaries of the phases and cycles are less distinct (Bernal, 1956; Kedrov, 1980; Rajkov, 1983; Yakovets, 1984). New theories periodically emerge, creating partial scientific revolutions in various branches of knowledge, as well as general scientific revolutions that radically change our views and signify new steps towards recognizing the laws of the world around us and offer new ways of applying them. Such revolutions began with the creation of the system of sciences in ancient Greece (600–400 BC). Subsequently, scientific revolutions occurred due to major discoveries in the Far East at the end of the first millenium AD; in the fifteenth and sixteenth centuries in Renaissance Europe; in the late seventeenth century preceding the Industrial Revolution; in the mid-1900s; in the natural sciences at the turn of the century (in particular, Einstein's theory of relativity and Planck's quantum theory); in the 1930s and 1940s; and finally the present general scientific revolution of the 1970s.

Technological and scientific cycles are closely interconnected: every major step in technological development puts new scientific ideas into practice, while at the same time creating the necessity and providing the technical means for the next step in the development of science. The twentieth century has witnessed a qualitatively new phenomenon in that revolutions in science and technology have become so closely interwoven that it is now possible to refer to them as scientific–technological revolutions. However, science and technology have each retained some independence in the general stream of scientific–technological progress.

As before, we can observe ever-shorter scientific–technological cycles and intervals between them. In the first scientific–technological revolution of the 1930s (Mensch, 1975; van Duijn, 1983) basic innovations were made, and these were implemented in the 1940s. The 1950s was a decade of rapid expansion and diffusion, and the 1960s was the period of maturity. By the mid-1970s the economic potential of the technology created in the 1930s had been mostly exhausted, and the final stage of the cycle began – the maturation and aging of old technologies, at the same time as the development and mastering of achievements of the new revolution, the effects of which are only gradually being recognized.

The foundations of theory of technological revolutions were laid by Marx in *Capital* and his other works. He studied the history of technology and its basic stages of development, content, historical significance, and socioeconomic implications using the example of the Industrial Revolution. Engels interpreted many of the technological and scientific revolutions of the past, and foresaw the implications of the electrotechnical revolution of the late nineteenth century (Marx and Engels, 1961). Lenin also contributed greatly to the assessment of technological revolutions, and described their spiral-like development.

In the 1920s a discussion of long waves took place in the USSR. As noted by Kondratieff and Oparin (1928), they are caused by the large-scale introduction of significant inventions, while Schumpeter (1939) studied the cyclical nature of technological and economic developments due to innovations. In 1956 Bernal published a study of the history of scientific and technological revolutions, but interest in the phenomena diminished noticeably until the mid-1970s, when a number of publications appeared (van Duijn, 1983; Mensch, 1975; Bianchi *et al.*, 1985).

20.3. The Second Scientific–Technological Revolution

That the latter half of the 1970s marked a period of profound technological change is now widely accepted, but there are several approaches to its evaluation. Some consider it to be simply a further stage in the development of the second scientific–technological revolution, without specifying its possible duration, while others believe it to be the beginning of a "third wave" (Toffler, 1980). Assessments of technological changes that have occurred in the second scientific–technological revolution are centered on the following fields (see *Figure 20.6*):

(1) Revolutionary developments in physics, biology (genetic engineering), and technical sciences have provided possibilities for major breakthroughs, particularly in microelectronics and biotechnology.
(2) Changes occurring in the means of production, materials, and energy sources (automated production using robots, flexible manufacturing systems, composite materials, energy-saving techniques, and new methods of processing substances with minimal waste).

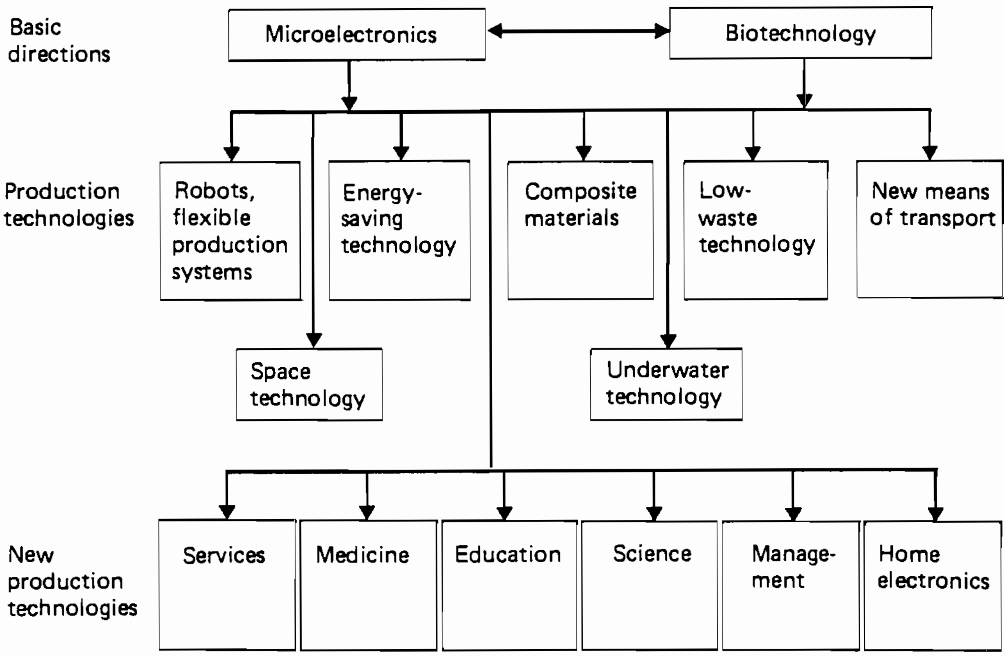

Figure 20.6. The structure of the second scientific–technological revolution.

(3) The developments in the service sector embrace many fields of application (service industries, medicine, education, management, domestic use, etc.).

(4) The periodicities of the waves of change are becoming shorter. At present, this trend is difficult to demonstrate mathematically, but the longer the period under investigation, the more clearly is this trend revealed. The major cycles in the past are believed to have been 50–60 years long, but have fallen to 40–50 years long in the present century. The third scientific–technological revolution is most likely to occur in the 2010s.

Technological change presents an opportunity for increasing economic growth rates through improved production efficiency. But considerable investment capital is required, not all of which may provide immediate returns. The restructuring of the education system, reorganization of production systems, reorientation of management to the use of new technology, overcoming psychological barriers, etc., are examples of problems that are being tackled in all countries.

Accelerated automation of production has caused increased levels of unemployment in many Western countries. In socialist countries the social implications of a new scientific–technological revolution are different in principle, although they also face the problem of adaptation of workers to new technology. These changes will affect all nations, including developing countries, even though they are not yet ready to cope with new technologies and expensive scientific–technological projects. All relevant assistance on the part of the developed countries, as well as the UN, will therefore be necessary.

20.4. Program-Oriented Planning

The solution to key problems in socioeconomic development, the acceleration of scientific–technological advance, depends on the rate at which the innovations of the scientific–technological revolution are adopted. The most effective method of achieving this is program-oriented planning, which was first introduced by the USSR. For example, the GOELRO plan (the state plan of Soviet electrification) introduced by Lenin was the first long-term program to utilize the achievements of the electrotechnical revolution. Thus within a very short time the USSR was able to overcome backwardness and reach the heights of the first scientific–technological revolution at the same time as the USA.

The advantages of program-oriented planning are that scientific–technological efforts and capital investments can be concentrated in crucial sections of the economy. Simultaneously, efforts can be made to restructure the technical base, to train or retrain personnel, to change production systems, and to educate management. It also facilitates increased international cooperation in order to develop collectively major scientific–technological directions where resources of an individual country may be inadequate. Finally, it enables technological change to occur efficiently and quickly.

In the USSR the current policy for science and technology is to introduce new technological systems that are capable of raising labor productivity, reducing consumption of raw materials, and increasing returns on investments (CPSU, 1985). Further fundamental research is needed and its results rapidly implemented, and the engineering industry needs to be expanded and oriented toward the production of more efficient machinery and equipment. All industrial branches of the national economy need to be re-equipped using the latest technology, and the economy needs to be more receptive to scientific developments. These are just some of the tasks formulated by the CPSU in facing the problems of accelerating scientific–technological progress (Gorbachev, 1985).

In the USSR, program-oriented methods are becoming important in the realization of a unified science and technology policy for the next 20 years, based on a complex program of scientific and technological progress that can be viewed as a series of long-term forecasts of scientific, technological, and economic development as solutions to environmental and social problems. In the future this is to be coordinated with a complex 15–20 year program of scientific and technological progress for CMEA countries, which envisages priority directions of cooperation in the fundamental and engineering sciences.

Scientific and technological programs are being elaborated at several levels: all-Union programs that are incorporated in national economic plans, branch programs that are included in ministerial and departmental plans, and programs for the republics and regions, which constitute an integral part of territorial planning. It is important that all these programs be in line with the general strategy to master the new scientific and technological revolution within a short period of time and to achieve the most rapid progress possible so that they might supplement and reinforce each other.

In the investigation of regularities in scientific and technological progress and methods of their application, many complicated problems have emerged. It would be useful if economists and historians of science and technology, as well as those who study patents, make joint efforts to determine the length and extent of previous technological and scientific revolutions, their structure, and their resultant economic and social effects. A study of past experiences may reveal regularities and characteristics of these processes, give appropriate assessments of the status of productive forces, and suggest reliable forecasts of future scientific–technological revolutions, both in general and in detail.

Similar investigations in the various branches of science and technology would be also of use in that they may enable us to guide future scientific and technological progress. It would be worthwhile to generalize experiences in program- and aim-oriented planning in various countries and in the field of international cooperation. Such investigations would be not only of cognitive but also of applied importance.

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CHAPTER 21

Technical Innovation, Diffusion, and Long Cycles of Economic Development

C. Freeman

21.1. Introduction

During the last postwar boom in the 1950s and 1960s, there was relatively little interest in the idea of long cycles of capitalist economic development. But in the last few years there has been a resurgence of discussion and debate among economists about this phenomenon, and an increasing amount of empirical research both on the historical evidence and on contemporary aspects of the worldwide slowdown in economic growth. This chapter discusses a neo-Schumpeterian interpretation of long cycles, which is based on a research project on "Technical Change and Employment" (TEMPO) carried out at the Science Policy Research Unit at the University of Sussex, England, from 1979 to 1984. In two books (Freeman *et al.*, 1982; Freeman and Soete, 1987), I and my colleagues have attempted to show the connection between long cycles and long-term trends in unemployment. This chapter deals with more general problems of long-wave theory.

In his review of the long-wave debate, Delbeke (1984, 1985) points to the variety of theoretical explanations of the long wave ("historical-institutional", "growth-theoretical", "macroeconomic" and "sociological"), but also to the need for an integrated theory. He points out that many long-wave theories belong to more than one category, and that any classification system oversimplifies the complexity of the debate. The same applies to a classification system based on more orthodox theoretical paradigms in economics – Keynesian, monetarist, neo-classical, Marxist, Schumpeterian, etc. – even though some of the participants are recognizably adherents of one of these schools.

Within the diversity of explanations of the long wave, an increasing emphasis on the role of technology is clearly discernible. Thus, for example, while most Marxist economists stress the importance of changes in the rate of profit and the process of capital accumulation (e.g., Mandel, 1975; Menshikov and Klimenko, 1985), there is growing recognition that technical innovations are one of the most decisive influences on the rate of profit. Kuczysnki (Ch. 5, this volume) not only demonstrates that Marx and Engels made some important observations about long-term swings in the growth process of capitalist countries, but also argues that major changes in technology are the type of events that bring about the big structural changes associated with the long wave. He emphasizes Marx's interesting distinction between minor fluctuations in the rate of profit characteristic of short business cycles, which are not usually sufficient to move capital out of old sectors, and the major changes that could bring about a major structural reallocation of capital.

The descripf this chapter as "neo-Schumpeterian" should not be taken therefore as a precise classification label; Schumpeter himself owed much to Marx, and so does the approach described here. It is rather intended to indicate the strong emphasis on the role of technical innovation, which is generally accepted as one of the main characteristics of Schumpeter's theory. The chapter attempts to take one step further the analysis introduced by my colleagues at Siena in 1983 (Bianchi *et al.*, 1985).

21.2. Schumpeter's Theory of Long Cycles

One part of Schumpeter's theory would probably be accepted by almost all economists: it would be difficult to disagree with his insistence that technical innovations appear and diffuse very unevenly between sectors, over time, and in space. However, the full implications of this uneven process of development have *not* been absorbed. The uneven sectoral distribution and occurrence of inventions and innovations is a commonplace for those working with R&D statistics, patent statistics, or histories of inventions and innovations. It is well known that industrial R&D in most countries is concentrated in half a dozen "high technology" industries. Between one-quarter and one-half of all industrial R&D and more recently of new investment in fixed assets, excluding buildings, is now concentrated in electronic and computer-related areas. Yet hardly any of these most active fields of innovative activity existed at all in the nineteenth century, and most of them did not even exist before World War II.

Schumpeter insisted on the explosive growth of new technologies in some sectors and relative stagnation in others. Once a major innovation had demonstrated profitability, this led to imitative "swarming" behavior as many firms rushed to get on the bandwagon of the new growth area. It was these spurts of innovation-related investment which he believed led to cyclical phenomena in the economy as a whole and to the changing location of technological and economic leadership, both within and between countries. Thus, for Schumpeter, economic growth was not a smooth development, but a succession of spurts and explosions; it was not merely accompanied by the introduction of new products and processes, but was driven by these innovations. Moreover, he did not make the distinction made by so many economists between "cyclical" and "technological" unemployment. He maintained (1939) that "basically, cyclical unemployment *is* technological unemployment ... linking up as it does with innovation ... (technological unemployment) is cyclical by nature". Schumpeter's "creative gale of destruction" necessarily involved the decline of "old" industries and occupations and an extremely uneven process of structural adaptation with substantial time lags.

Although historians have always found Schumpeter's view of capitalist dynamics rather plausible, it did not coexist easily with mainstream general equilibrium theory and the emphasis of neo-classical economics on marginalism and smooth processes of incremental adaptation. Schumpeter's own attempts to reconcile his theory of technological innovation with Walrasian equilibrium theory was rather an unsatisfactory compromise and led to a major weakness in his theory of long cycles: the explanation of depressions.

When Schumpeter first published *Business Cycles* (1939), Kuznets, the leading American economic historian, in a long and generally sympathetic review (1940) of his book, pointed to some fundamental problems in his explanation of Kondratieff cycles. First, he pointed out that for innovations to have the effects on the behavior of the economic system that Schumpeter predicted, they would have to be either very big innovations or "clusters" of many innovations. As an example of the kind of innovation that might indeed have the kind of long-wave effects that Schumpeter had suggested, Kuznets mentioned railways, but he pointed out that there were very few such innovations, whereas smaller innovations were occurring all the time in very large numbers. Some of these might cause minor perturbations, but they would not generate effects in the economy as a whole unless they were bunched. Second, Kuznets raised this question: even if such very large and important innovations could induce cyclical effects and could be identified and separated from the myriad of minor innovations occurring continuously, why should they have effects lasting several decades rather than years? Major innovations or clusters of innovations might indeed cause a spurt of investment associated with a short-term business cycle, but why a long wave?

Finally, even if major innovations could generate boom effects in the economy lasting several decades, why should depressions occur? Kuznets asked ironically whether Schumpeter's heroic entrepreneurs got tired every half century, but more seriously other critics have pointed out that he tended to look at the deep depressions as pathological symptoms and that he did not have a theory of depressions anything like so convincing as his theory of boom induced by the "swarming" behavior of firms endeavoring to jump on the bandwagon of new technologies.

These three questions highlight crucial problems, but the research and the debate associated with the revival of long-wave theory have in my view begun to provide some answers to all three.

Although he stressed the importance of "metamorphosis" rather than cyclical development, a major contribution to the first and second points has been made by Mensch (1975). He suggested that radical innovations did indeed cluster together and that they were bunched in periods of deep depression, i.e., the 1830s, the 1880s, the 1930s, and (he predicted) the 1980s. This bunching, according to Mensch, was brought about by the depressions themselves, when firms were compelled to accelerate the introduction of radical innovations because they could not continue to make a profit from their existing activities. Mensch's theory has found some support both in Western and Eastern Europe, for example from Mandel (1984), Kleinknecht (1981), and Kuczynski (Ch. 5, this volume). However, the debate around his pioneering book has given rise to theories of the timing and clustering of innovations, which are, in my view, more likely to survive the test of empirical research and theoretical debate than Mensch's first formulation.

In our view (Freeman *et al.*, 1982), the empirical evidence suggests that radical innovations occur more randomly over time than Mensch (1975) and Kleinknecht (1981) maintained. Thus, although there was certainly a cluster of radical innovations in synthetic materials and electronics in the depression of the 1930s, there were also clusters of radical innovations in drugs, semiconductors and integrated circuits, and scientific instruments in the 1950s and 1960s, and in biotechnology in the 1970s. Some empirical studies also suggest that the carrot (strong demand stimulating higher profit expectations) may be a more important inducement mechanism for radical innovations than the stick (deep depression inducing radical innovations). Moreover, Mensch's theory suggests that big booms are built on the radical innovations that are made in the preceding depression. But this is not necessarily the case, because the impetus to "swarming" and to major surges of investment often takes longer than a few years after the *first* arrival of a radical innovation. The technical problems and false starts associated with the first arrival of radical innovations are well known and often take many years to resolve.

In understanding the relationship between innovation and growth cycles, it is not the date of the *first* arrival that matters so much, but the ***diffusion*** process. The major spurts of investment and market growth that characterized the great booms of the 1850s and 1860s, in the ***belle epoque*** (before World War I), and the 1950s and 1960s, were all based on clusters of radical innovations, some of which were made ***before*** as well as during the depressions – railways in the 1820s, or even earlier; electrical innovations in the 1860s and 1870s; consumer durables and mass-produced passenger cars in the first decades of the century. It is unlikely that the biotechnology innovations of the 1970s and 1980s will have any substantial effects on world economic growth before the next century, but they could well have a major influence then. If we are hoping for a major upswing of the world economy in the late 1980s and 1990s, then it cannot be based primarily on biotechnology, but it could conceivably be based on a cluster of radical innovations, such as those made in the 1940s, 1950s, and 1960s – computers, robots, integrated circuits, and optical fibers.

This already begins to answer the second point made by Kuznets as well as the first – empirical research on diffusion of innovation does indeed suggest that diffusion processes, especially for radical innovations, do often take decades, rather than months and years. This is particularly true if one takes into account not only individual products but also technological *systems*, i.e., clusters of technically and economically interrelated innovations. This points to the need for a taxonomy of innovations that goes beyond Mensch's distinction between incremental and radical (basic) innovations and includes a third category of technological revolutions, or changes in technological paradigm. We may thus define the three categories as follows (Freeman and Soete, 1985):

(1) *Incremental innovations.* These occur more or less continuously, although at differing rates in different industries, but they are concerned only with improvements in the existing array of products and production processes. They are reflected in the official measures of economic growth simply by changes in the coefficients in the existing input–output matrix. Although their combined effects are extremely important in the growth of productivity, no single one has dramatic effects.

(2) *Radical innovations.* These are discontinuous events, and their *diffusion* may often take a cyclical form. New materials, such as nylon or polyethylene, or new products and services, such as TV, are examples of such radical or "basic" innovations (Mensch, 1975).

(3) *Technological revolutions.* These "creative gales of destruction" are at the heart of Schumpeter's long-wave theory. The introduction of electric power or steam power are examples of such deep-going transformations. A change of this kind carries with it many clusters of radical and incremental innovations, as for example in electric power generation and transmission, as well as in electric motors and domestic appliances. A vital characteristic of this third type of technical change is that it must have *pervasive* effects throughout the economy, i.e., it must lead not only to the emergence of a new range of products and services in its own right, but it must also affect every other branch of the economy by changing the input cost structure and conditions of production and distribution throughout the system. It is the extension of the effects of a new technological system beyond the confines of a few branches to the economy as a whole, which constitutes one basis for major upswings of the world economy and which justifies the expression "change of paradigm" or "change of technological regime". This type of change involves new rows and new columns in an input–output table, as well as changes in the coefficients. Information technology clearly belongs to this class.

We may thus define the characteristics of a technological revolution as follows:

(1) *A drastic reduction in costs and improved productivity potential of many products and services.* In some areas this will be an order of magnitude reduction; in others, much less. But it provides the essential condition for Schumpeterian "swarming", i.e., widespread perceived opportunities for new profitable investment.

(2) *Scope for an entirely new range of products and services and for a dramatic improvement in the technical characteristics of many other products and processes.* This affects improved reliability, accuracy, speed, and other performance characteristics, and leads to the design and redesign of numerous products and processes.
(3) *Social and political acceptability.* Although economists and technologists tend to think narrowly in terms of the first two characteristics, this third criterion is extremely important. Whereas the first two advantages are fairly quickly perceived, there may be long delays in *social* acceptance of revolutionary new technologies, especially in areas of application far removed from the initial introduction. Legislative, educational, and regulatory changes may be involved, as well as fundamental changes in management and labor attitudes and procedures. For this reason the expression "change of paradigm" perhaps best conveys the full flavor of this type of technical change. The interplay between technoeconomic characteristics and the socioinstitutional framework is a major consideration in assessing the time lags involved in the adjustment of the system.

A technological revolution therefore represents a major change of paradigm, affecting almost all major managerial decisions in many branches of the economy. Several authors have used the expression "technological paradigm", but probably the most thorough and systematic exposition of the idea is in the work of Perez (1983, 1985). She defines a "technoeconomic paradigm" as a new set of guiding principles, which become the managerial and engineering "common sense" for each major new phase of development.

Criticizing Schumpeter's narrow economic theory of depression, Perez suggests that depressions represent periods of "mismatch" between an emerging new technoeconomic paradigm (already quite well advanced in a few branches of the economy) and the institutional framework. The widespread profitable generalization of the new technoeconomic paradigm throughout the system is possible only after a period of change and adaptation of many social institutions to the potentialities of the new technology. The big boom periods of economic expansion occur when such a good "match" between the new technoeconomic paradigm and the socioinstitutional framework have been made.

These ideas of paradigm change and of "mismatch" during depression and good match during boom go a long way towards answering the criticisms voiced by Kuznets and others of Schumpeter's original theory. However, some problems certainly still remain. For example, a number of critics have argued that there is no clear-cut evidence that new technological paradigms *do* increase productivity or profitability in the economy as a whole, and specifically that since a general fall in productivity and profitability occurred in the OECD countries in the 1970s, precisely during a period of rapid diffusion of computer-based technology, other factors must be more important. One weakness in this argument is already apparent from what has been said about lags in institutional readjustment, but to deal with this more thoroughly it is necessary to move to a more disaggregated level of analysis.

21.3. Productivity and Profitability in the Long Wave

A great deal of empirical research needs to be carried out to demonstrate in detail the variations in profitability and productivity growth associated with the introduction and diffusion of new products, processes, systems, and industries. In this section it is possible only to present a general theoretical argument and to give a number of examples based mainly on UK experience from the TEMPO project.

Following Marx, Schumpeter argued that the introduction of new products or processes enables the innovating firms (if they succeed in overcoming early teething problems) to reap exceptionally high profits, based on a temporary monopoly. However, because of the swarming and bandwagon effects, these abnormally high profits would ultimately be eroded or "competed away". Examples of exceptionally high innovative profits can be found among railway companies in Britain and the USA in the 1850s and 1860s, among electrical equipment companies at the turn of the century, and among chemical companies producing synthetic materials (nylon and polyethylene) in the 1950s. At one time ICI derived more than half of its corporate profits from polyethylene.

A particularly good example is given by Klein (1977): the introduction of the assembly line by Ford to produce the Model T. The price of the model fell from $850 in 1908 to $360 in 1916, while profits were sometimes as high as 300%/year, and the market share increased from 10% in 1909 to 60% in 1921. The basic innovation was an organizational one, but this was related to a whole cluster of interrelated technical innovations:

> Once the organizational change was made, the automobile firms found many opportunities for developing more efficient machines by making them more automatic ... literally dozens of cases can be found in which better machines permitted output per worker to increase by a factor of between two and ten.

A similar example is that of IBM with the 650, 1401, and 360 series of computers in the 1950s and 1960s. These made IBM one of the most profitable and fastest-growing large corporations in the world, even though the firm was not the first to introduce electronic computers or integrated circuits.

However, both in the case of the automobile industry and the computer industry, not all those who jumped on the bandwagon made giant profits. Some made losses and, as the industries matured, many were driven out of business. The Schumpeterian swarming argument does not require that all firms embarking on a new type of production make exceptionally high profits, only that *some* of then perform so well in the period of high growth that there are clear profitability and productivity signals to encourage imitators. It is generally agreed that the advances in microprocessor technology have made possible performance characteristics that are superior by orders of magnitude from earlier generations of electronic equipment. Why is it then that in a period of rapid diffusion of microprocessor technology, overall productivity growth in the economy of most countries has been slower than it was in the 1950s and 1960s, and the average rate of profit has tended to fall?

It was argued in Section 21.2 that technical change is extremely uneven among firms, industries, and countries. Furthermore, we are arguing that a long-wave upswing occurs *not* as the result of technical innovations in one or a few industries, *nor* indeed as the result of the rapid growth of a single industry, such as the US automobile industry in the 1920s, or the US computer industry in the 1970s, but rather as the result of the diffusion of a new technoeconomic paradigm (or "style") from a few leading sectors to the rest of the economy, and especially to the capital goods industries and related services.

This brings out a fundamental difference between our approach and that of Mensch, and also of Schumpeter himself. Schumpeter discussed the internal combustion engine *and* electricity as both important "engines of growth" in the *third* Kondratieff upswing without making much distinction between them. For us, there is a fundamental difference. The technoeconomic paradigm that characterized the third Kondratieff wave was, in our view, based on *electrification* and the diffusion of electric power throughout the economy, including both industrial and widespread domestic applications. The "Fordist" mass production paradigm, on the other hand, although it certainly *emerged* during the third Kondratieff cycle, and was an important *auxiliary* source of growth in the 1920s in the USA, did not become the prevailing *dominant* paradigm until after the major structural crisis of adaptation in the 1930s, and the emergence of Keynesian techniques of regulating the system's behavior. The automobile industry, consumer durables, petrochemicals, oil refining, plastic mass-produced articles, etc., and all the related infrastructure and services, were in our view the "engines of growth" of the *fourth* Kondratieff upswing, *not* the third, even though many of the innovations were, of course, first introduced during the third. But their worldwide diffusion was possible only on the basis of many social and institutional changes that permitted the generalization of an energy-intensive mass production and consumption paradigm.

By the same token, the extremely rapid growth of the computer, semiconductor, and TV industries in the 1950s and 1960s certainly did *not* mean that information technology was the *dominant* technological regime or paradigm in the economic system as a whole. Far from it; the newly emerging technological paradigm created acute problems of structural adaptation for the system as a whole, including the (now) older mass production industries and services. Information technology can only become the dominant technoeconomic paradigm as a result of a successful process of social and institutional change, which is costly and difficult to accomplish.

It is only in this perception that it is possible to address the question of the labor productivity slowdown in the 1970s and 1980s, the decline in capital productivity (in our view a much neglected but extremely important phenomenon), and the associated decline in the rate of profit, which was perceptible already in the late 1960s. In order to understand these phenomena it is absolutely essential to move to a disaggregated level of analysis, since what we are discussing is the extremely uneven diffusion of a new technological paradigm from a few leading sectors to the economy as a whole.

In our TEMPO project we attempted to study the long-term changes in labor and capital productivity in the principal sectors of the British economy (the 40 industries distinguished in the Cambridge growth model) from 1948 to 1984. The following account is based on the five-volume report of that analysis (Soete, 1985; Clark, 1985; Guy, 1984; Freeman, 1985; Smith, 1985) and the full summary (Freeman and Soete, 1987). In our view, although there are important national variations, the broad picture described below is characteristic of all the major OECD industrial economies.

When we analyze changes in labor productivity and in capital productivity over the past 20 years at a sufficiently disaggregated level, then we find the following picture:

(a) The sectors with the highest growth rates in labor productivity are the electronics industries, and especially the computer and the electronic components industries. These industries also make the greatest use of their own technology for design, production, stock control, marketing, and management. They are the only industrial sectors that show a substantial rise in *capital* productivity and have demonstrated the advantages of the new paradigm for everyone else.

(b) In those sectors that have been heavily penetrated by microelectronics, both in their product and process technology, there is also evidence of a considerable rise in labor productivity, and even some advance in capital productivity in the most recent period. This applies, for example, to the scientific instruments, telecommunications, and watch industries, which have now virtually become a part of the electronics industry.

(c) In sectors where microelectronics has been used on an increasing scale over the past ten years, but older technologies still predominate in product and process technology, there is a very uneven picture. Some firms have achieved very high productivity increases, some have stagnated, while others have actually shown a decline in productivity. This is the case, for example, in the printing, machine-building, and vehicles industries. This uneven picture is completely consistent with Solter's (1966) vision of the spread of new technologies within established industries through new capital investment. In many cases information technology is introduced in a piecemeal fashion and not as part of an integrated system. First, one or a few CNC machine tools are introduced or a few robots or word processors in one department; these are small "islands" of automation. This is not yet computer-integrated manufacturing or office systems and does not yet achieve anything approaching the full *potential* productivity gains. There may even be a temporary fall in productivity, because of the lack of the necessary skills in design, in software, in production engineering, in maintenance, and in management generally. Problems of institutional and social adaptation are extremely important, and flexibility in this social response varies greatly between countries, as well as between enterprises. Among OECD countries, Japan and Sweden appear to have been particularly successful in making progress in this area of "mechatronics", but the USA, which has been successful in achieving productivity gains in the first two sectors above (although much less so than Japan), has been rather unsuccessful in the mechatronics area, with the partial exception of defense-based industries such as aircraft.

(d) Sectors producing standardized homogeneous commodities on a flow production basis in rather large plants have made considerable use of information technology in their process control systems and in various management applications. They were indeed among the earliest users of minicomputers for these purposes. This applies, for example, to the petrochemical, oil, steel, and cement industries. This has helped them to achieve considerable improvements in their use of energy and materials, but the gains in labor productivity have often been less than in the 1950s and 1960s, while capital productivity usually has shown a marked decline. To understand this phenomenon it is essential to recognize that these industries are amongst those most heavily affected by the shift from an energy-intensive and materials-intensive mass production technological paradigm to an information-intensive paradigm. At the height of the consumer durables and vehicle consumption boom of the 1950s and 1960s, they were achieving strong labor productivity gains based on big plant economies of scale. But with the change in technological paradigm, the slowdown in the world economy, and the rise in energy prices in the 1970s, they now often face problems of surplus capacity and high unit costs based on below-capacity production levels [but see (h) below for those cases in which surplus capacity has been eliminated].

(e) Service sectors that are completely based on information technology (software services, data banks, computerized information services, design services, etc.) are among the fastest growing and (for individual firms), most profitable activities in the leading industrial countries. But although their growth potential is enormous, they so far account for only a small proportion of total service output and employment. Productivity statistics are extremely difficult to generate, but inferential evidence suggests high rates of growth.

(f) Service sectors that have been considerably affected by information technology (banking, insurance, and distribution), although the diffusion of new technology is extremely uneven, both by firm and by country, show evidence of significant gains in labor productivity. This phenomenon is important because hitherto it has often been observed that the service sector of the economy was not capable of achieving the type of labor productivity gains achieved in manufacturing. Information technology now offers the *potential* (and in some cases already the reality), of achieving such gains outside manufacturing. However, the progress of technology depends heavily on institutional and structural changes.

(g) In most service sectors, information technology still has diffused only to a small extent, and these areas are still characterized by very low labor productivity gains, or none at all. The stagnation in labor productivity in these sectors may be attributed to the *lack* of information technology, but it certainly cannot be attributed to the impact of information technology. These account for by far the larger part of the tertiary sector.

(h) Finally, in many industrialized economies some sectors have shown labor productivity gains over the past ten years, which are due far more to structural rationalization than to the direct impact of new technology. Examples are in the textile and food industries and also some of those sectors discussed in (d) above, where plant closures and rationalization have been implemented. Since in any industry there is always a "tail" of low-productivity plants, a significant rise in *average* labor productivity can always be achieved simply as a result of scrapping the older generations of plant, even without any further technical improvements in the more recent plants, which can now work closer to full capacity.

Summing up this discussion, it is not difficult to see that the slowdown in *average* labor productivity gains over the 1970s and 1980s, which has been a worldwide phenomenon by comparison with the 1950s and 1960s (see Maier, Ch. 6, this volume), is precisely the aggregate outcome of a structural crisis of adaptation or change of technoeconomic paradigm, which has accentuated the uneven development in different sectors of the economy. On the one hand, the previously dominant energy-intensive mass production paradigm or "technological regime" was reaching limits of productivity and profitability gains, due to a combination of exhaustion of economies of scale, erosion of profit margins through "swarming", market saturation in some sectors, diminishing returns to technical activities (Wolff's law) and cost pressures on input prices. On the other hand, the new paradigm, which offers the *possibility* of renewal of productivity gains and increased profitability, has so far deeply affected only a few leading-edge industries and services.

The full realization of the productivity gains that can be achieved as a result of information technology depends on the diffusion of the new paradigm throughout the economy. This in turn will be possible only as a result of many social and institutional changes, which will involve interrelated organizational and technical innovations, as well as a large increase in new skills and a transformation of the existing capital stock.

Schumpeter already emphasized the importance both of *organizational* innovations and of *technical* innovations, and of their interdependence. This combination is the major characteristic of a change of technological paradigm, such as the introduction of information technology, and leads to changes in management structure as well as process technology. Schumpeter, however, did not develop the notion of a "paradigm" change, and it is here that Perez (1983, 1985) has made an important original contribution.

An interesting historical analogy to the case of information technology is provided by the experience of electric power. Although Mensch (1975) was correct in drawing attention to a cluster of radical innovations in the 1880s, the major *economic* effects of electrification came much later with the growth in the share of electricity in mechanical drive for industry from 5% in 1900 to 53% in 1920. This was possible only after the acceptance of a major change in factory organization from the old system based on one large steam engine driving a large number of shafts through a complex system of belts and pulleys, to a system based first of all on electric group drive and later on unit drive (i.e., one electric motor for each machine). Under the old system all the shafts and countershafts rotated continuously no matter how many machines were actually in use. A breakdown affected the whole factory. Devine (1983) has documented this change in some detail. He points out that:

> Replacing a steam engine with one or more electric motors, leaving the power distribution system unchanged, appears to have been the usual juxtaposition of the new technology upon the framework of an old one ... Shaft and belt power distribution systems were in place, and manufacturers were familiar with their problems. Turning line shafts with motors was an improvement that required modifying only the front end of the system ... As long as the electric motors were simply used in place of steam engines to turn long line shafts the shortcomings of mechanical power distribution systems remained (p. 357).

It was not until after 1900 that manufacturers generally began to realize that indirect benefits of using unit electric drives were far greater than the direct energy-saving benefits. Unit drive gave far greater flexibility in factory layout since machines were no longer placed in line with shafts, making possible big capital savings in floor space. Unit drive meant that trolleys and overhead cranes could be used on a large scale unobstructed by shafts, countershafts, and belts. Portable power tools increased even further the flexibility and adaptability of production systems. Factories could be made much cleaner and lighter, which was very important in industries such as textiles and printing, both for working conditions and for product quality and process efficiency. Production capacity could be expanded much more easily.

21.4. Conclusions

These examples of structural changes and policy changes associated with the widespread introduction of new technology are relatively straightforward compared with the fundamental problem of restructuring the world economy and especially of putting North–South relationships on a new basis. It is here that the uneven development of the world economy is most evident and raises the most intractable problems.

The establishment of the IMF and the World Bank and the general adoption of expansionary Keynesian policies after World War II created a fairly stable framework for the growth of the world economy. Large-scale public and private investment in Third World countries also encouraged the efforts of many of these countries to catch up with leading OECD countries. However, in the 1980s, these rather favorable conditions for the poorer countries to improve their situation no longer exist. The burden of debt repayment has now become so great that it constitutes a major source of economic and political instability, especially in Latin America and Africa. There is now a net *outflow* of funds from many Third World countries, and a net *inflow* into one of the richest countries, the USA, which finances the enormous deficit in US foreign trade. This deficit is also related to the relative failure of the US economy to adapt to the new paradigm outside the military area, by comparison with the much more successful adaptation by Japan, resulting in the high Japanese surplus. This situation cannot be sustained and points to the need for fundamental structural change in the international machinery for adjusting international payments and capital transfers as well as to major policy changes with OECD countries. The real resources available to the IMF and the World Bank are now grossly inadequate compared with the vastly increased volume of international trade and investment.

A recent report of the Inter-American Development Bank (September 1985) has highlighted these critical problems confronting the world economy and has warned that IMF measures to deal with the crisis have been short-term palliatives, not long-term solutions. Albert Fishlow points out that Latin America faces a burden of debt service repayments double the level of reparations that Germany found impossible after World War I. It will be remembered that Keynes made a devastating critique of the German reparations arrangements and pointed out that they would result in world economic collapse and would probably lead to a second world war. Only a recovery of productive investment and technical innovation in Latin America could sustain the growth needed to finance even a much lower level of debt repayment.

The Third World countries are also experiencing difficulties in developing the new information technology industries to sustain their competitive power. However, as Perez (1985) has pointed out, the new technologies do actually offer some major advantages to Third World countries, provided they modify their trade, industrial, and technology policies. In sectors such as software engineering and telecommunications equipment, there are big new opportunities for developing countries, both in local applications of information technology and in world markets. But these "catching up" efforts of Third World countries require some resolution of the basic structural problem confronting the entire world economy. This implies new measures to facilitate the international transfer of technology, as well as a resolution of the debt problem.

But as in the 1880s and 1930s, in confronting a major structural crisis of adaptation, there are many alternative courses, and the outcome will depend on the balance of social and political forces. There are strong pressures to restore the general rate of profit, not so much through technical change and imaginative social improvements, but by a combination of military expenditures, increased protectionism, and reduction in the power of trade unions. This creates an urgent need for all those in the world who wish to avert such dangerous nationalistic and militarist solutions, to develop imaginative programs for the growth of the world economy, involving the widespread use of the new paradigm, for improvement in the living and working conditions for the majority of the world's population.

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PART III

The Role of Financial and Monetary Variables in the Long-Wave Context

CHAPTER 22

Long-Term Trends in the Belgian Money Supply, 1877–1984

Jos Delbeke

22.1. Introduction

This chapter is an interim report on a research project that aims to analyze long-term fluctuations in prices, money and credit, and the incidence of these variables on and from the real sector. We present here some historical time series data on the money supply M1 of Belgium and, starting from an inspection of the data, our aim is to provide scope for model construction and simulation.

We follow a two-fold strategy that is unusual in current long-wave research. First, we have explicitly chosen not to undertake sophisticated statistical manipulation; indeed, we are convinced that this way always presents difficulties, namely, a too-small sample, filtering, detrending, and so on. We prefer to be as careful as possible not to construct waves, and have thus opted for a cycle-oriented research. Second, we have tried to make explicit the most important variable behind the general price level – the money supply. We have actualized the basic inspiration of Dupriez (1947) and applied the money base framework of Brunner and Meltzer to the series we could reconstruct from 1877 up to 1983.

22.2. The Money Base Framework

To analyze the quantity of money and credit available in an economy, Brunner and Meltzer developed an interesting framework by reconciling the traditional demand and supply hypothesis. They treat the money base by the authorities as dominant, but they take explicitly into account the allocation behavior of the banks and the public by analyzing the multiplier (Verheirstraeten, 1977).

We use the M1 definition of the quantity of money, since enlarged definitions do not necessarily seem to be superior. Moreover, in our data, the role of time deposits is only important after World War II. The money base or high-power money is defined as the net monetary liabilities of the government in the hands of the public and the banks. The reason for the name "base" is that this government money is used as a basis for multiple deposit creation by the banks.

The basic equation of Brunner and Meltzer can be summarized as follows (Verheirstraeten, 1977, pp. 94–95):

$$\mathrm{M1} = B.m1 = B \frac{k + p + 1}{k + p + r(1 - t)} \tag{22.1}$$

Equation (22.1) shows that the money supply can be interpreted as the product of the base money B and the multiplier m, which is dependent on the currency ratio k, the postal deposits ratio p, the reserve ratio r, and the time deposit ratio t. For our analysis this equation can be rewritten in growth rates; thus:

$$\log \mathrm{M1} = \log B + \log m1$$

$$\frac{\mathrm{dM1}}{\mathrm{M1}} = \frac{\mathrm{d}B}{B} + \frac{\mathrm{d}m1}{m1} + e \tag{22.2}$$

Equation (22.2) shows that the growth rate of M1 can be divided into the growth rates of the base money and the multiplier, and an error variable. This enables us to analyze which variable is the cause of a change in M1.

The growth rates of the base money and the multiplier can be analyzed in the same way. The sources of the base can be written as follows:

$$B = IR + S_G^{CB} + AD + O \tag{22.3}$$

where IR = international reserves, S_G^{CB} = government securities in the central bank portfolio, AD = rediscounting of bills of exchange by the central bank, and O = is a rest variable. After some manipulations we get:

$$\frac{\mathrm{d}B}{B} = \frac{\mathrm{d}IR}{IR} \cdot \frac{IR}{B} + \frac{\mathrm{d}S_G^{CB}}{S_G^{CB}} \cdot \frac{S_G^{CB}}{B} + \frac{\mathrm{d}AD}{AD} \cdot \frac{AD}{B} + \frac{\mathrm{d}O}{O} \cdot \frac{O}{B} \tag{22.4}$$

In other words, equation (22.4) shows that the money base growth rate can be divided according to the part of each source. The same can be done for the multiplier, as follows:

$$\frac{dm1}{m1} = \varepsilon(m1, k) \cdot \frac{\delta k}{k} + \varepsilon(m1, p) \cdot \frac{\delta p}{p} + \varepsilon(m1, r) \cdot \frac{\delta r}{r} + \varepsilon(m1, t) \cdot \frac{\delta t}{t} + e \quad (22.5)$$

where ε = the multiplier elasticity of a particular ratio. For the development of the elasticities; see Verheirstraeten (1977, p. 142).

In conclusion, we can state that the growth of the money supply can be analyzed according to its sources, i.e., foreign influences, central bank action, or the behavior of the banks and the public.

22.3. The Evolution of the M1 Money Supply

We have reconstructed a homogeneous series of the M1 money supply since 1877, and we applied the Brunner–Meltzer model to it. Unfortunately, we were unable to go back to at least 1873, which is considered an important turning point (Dupriez, 1977).

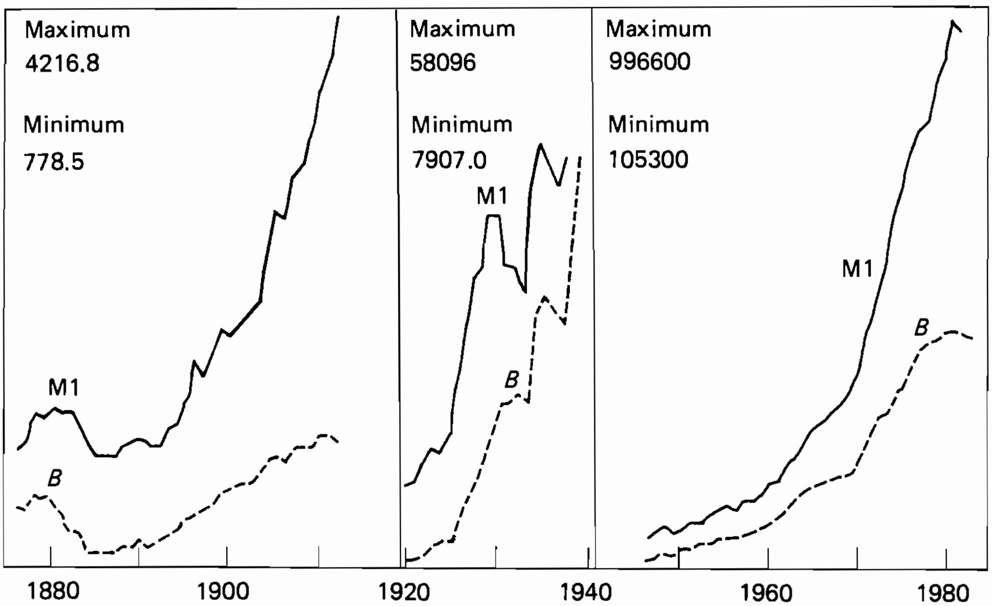

Figure 22.1. The money supply M1 and base money *B*, 1877–1983.

In *Figure 22.1* the data for M1 and *B* are shown for the three subperiods: prewar (before 1914), interwar (1920–1939), postwar (1950–1983). From 1877 to the mid-1890s, M1 and *B* fluctuate around a horizontal trend. Thereafter, the trends of both have positive slopes, which is larger for M1 than for B, indicating the growing role of the multiplier. Moreover, M1 seems to have a time lag on B. During the interwar period, the constant increase in M1 until 1931 is followed by a significant contraction in 1931–1934 and a recovery of the money supply in 1934–1936. The base has the same pattern, although with one important exception: instead of a contraction in 1931–1934, we observe only a stagnation. The postwar figures show continuous and stable growth patterns, and illustrate the uniqueness of the period. Only in the 1980s does the M1 figure stagnate, preceded by the base. The distance between the curves is again increasing, indicating a growing multiplier.

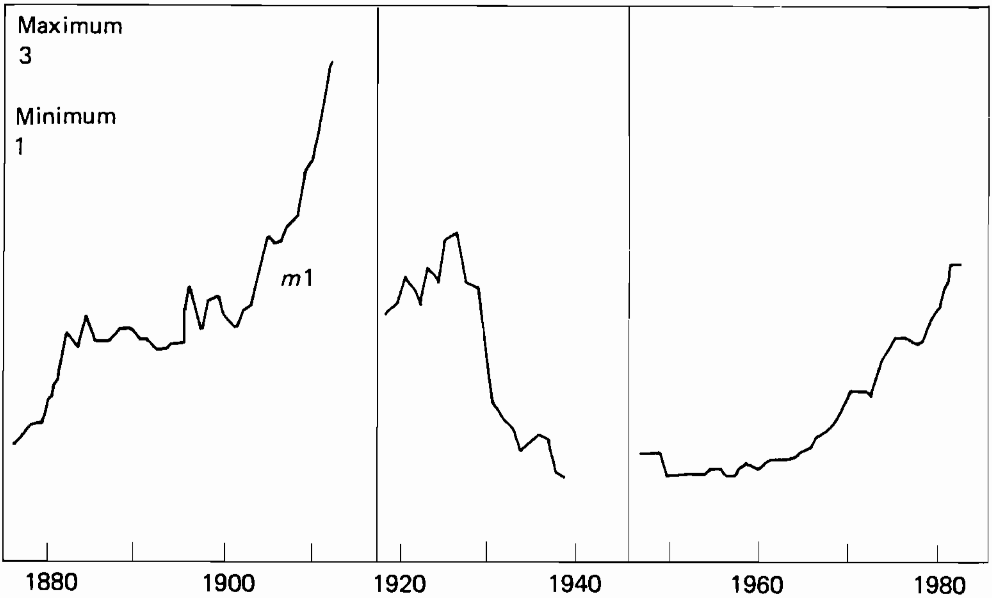

Figure 22.2. The $m1$ multiplier, 1877–1983.

In *Figure 22.2* we can observe very clear, long-term fluctuations in the multiplier. In the prewar period, $m1$ increases from 1.39 to 2.8, but with a remarkable stagnation between 1883 and 1896. This rise has to be attributed to the substitution of gold and silver for uniform bank notes, a policy concomitant with the development of central banking. However, this trend was temporarily interrupted, presumably because of a lack of confidence during the stagnation of the 1880s. After World War I, this trend continues to rise until 1928, when a remarkable and persistent decline begins. In the postwar period, the multiplier shows the opposite trend: a slow but continued increase from 1.3 in 1950 to 2.1 in 1982, with two minor decreases in 1971–1973 and 1978.

In conclusion, we can state that a clear long wave emerges between the maxima of 1928 and 1982. If we take into account the historical particularities of the nineteenth century, we can observe an analogous tendency from 1877 onward. It is important to note that this movement comes through without any statistical manipulation.

Inspection of the absolute data of M1, *B* and *m*1 over the last century shows that clear movements can be discerned. However, for analyzing them further, a more operational unit of time is needed. Various authors (in our view rightly) argue that the cycle has to be the medium for studying longer movements (Dupriez, 1947). We follow this suggestion also for empirical reasons: it is crucial not to compare lower and upper turning points of business cycles in order to avoid manipulated long-wave construction. We do not have a generally accepted dating of business cycles for our period, such as the US dating by the National Bureau of Economic Research, so we have to construct them. We have chosen the troughs for dating, since they can be deducted from the annual growth figures of the M1 money supply (*Table 22.1*).

Table 22.1. Juglars in the M1 money supply (according to troughs).

Prewar	*Interwar*	*Postwar*
1878	1921	1950
1880	1924	1954
1882	1929	1957
1885	1932	1960
1892	1934	1967
1898	1937	1969
1901		1973
1907		1979
1909		1983
1912		

We then analyzed for each cycle which part of M1 growth is caused by the growth of the money base and the multiplier, respectively. These results are summarized in *Figure 22.3*. From this figure, it can be seen that the growth figures of M1, *B*, and *m*1 do not follow constant trends. Long periods of absolute and relative increases and decreases are observable. Although no absolute contraction happened after 1945, the growth rates have been declining since the late 1970s. The money base analysis seems to be fruitful in showing the origins of M1 fluctuations. An important hypothesis of this method, namely, that the base is the dominant source of M1 change, is generally correct but has to be modified. Indeed, the multiplier growth is not unimportant and can even dominate the evolution of M1.

Between the long-term fluctuations in the growth of *m*1 and *B*, there are important time lags resulting in compensating and amplifying effects on M1 growth. During the mid-1880s, the recovery of the base preceded that of the multiplier, and both work in the same sense thereafter. However, after 1900, the base growth starts to decline, while the multiplier change kept rising

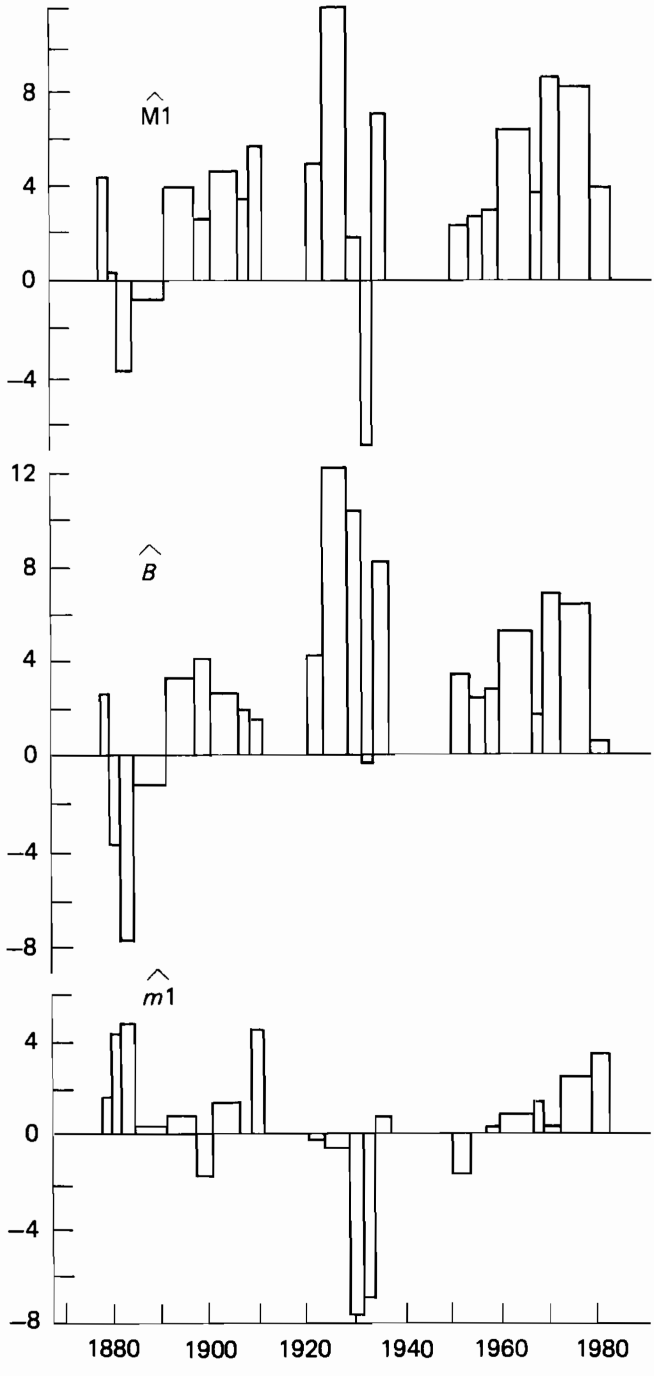

Figure 22.3. Contribution of base money *B* and multiplier *m*1 to the growth rate of the money supply M1, 1878–1983 (cyclical averages).

until it achieved a share of 79% of M1 growth in 1909–1912. Presumably the base stimulates the M1 recovery, but once a reasonable growth is realized, the multiplier becomes the major source of continued M1 expansion.

During the interwar period, the most extreme M1 growth figures can be noted, namely, +12.2% in 1924–1929 and –7% in 1932–1936. The high base growth is remarkable; it compensates for the neutral (1920s) and negative (1930s) role of the multiplier. When the base growth fails to continue this task, as in 1929–1932 and especially in 1932–1934, the effect on M1 growth is disastrous.

After 1945 (and also after 1935), the base again induces M1 growth, while the multiplier slowly becomes more important. After this recovery they work in the same sense, although the base influence is dominant. However, after 1973, the slower base growth is partly neutralized by the increasing role of the multiplier, which becomes dominant in 1979–1983, with a share in M1 growth of more than 80%. In fact, this is the basic pattern of the periods 1878–1885 and 1909–1912, where a low or even negative M1 growth can be temporarily avoided.

As a preliminary conclusion we can state that a serious decline or a too-slow expansion of the base money is temporarily corrected by the multiplier. In other words, the time lag in the behavior of the public and the banks acts as a buffer, so that the evolution of the base generally precedes that of the money supply. The crucial question to be asked, then, is which are the determinants of these evolutions in the base and the multiplier.

22.4. The Sources of *B* and *m*1 Growth

22.4.1. Determinants of money base change

The major source of long-term fluctuations in the growth of the money base are the international reserves and the central bank, which finance the private sector; government financing is clearly a more recent phenomenon and has grown to unprecedented levels in the last decade, dominating the growth of the base. Nevertheless, over the whole period, it shows a certain anti-business cycle behavior (*Figure 22.4*).

The influence of international reserves seems to be particularly strong during the contraction and recovery cycles of the money base. Empirically, it is very difficult to analyze the sources of this evolution, since we only have rough balance of payments for the interwar period and, of course, complete information for the postwar period. From qualitative historical sources, however, we can presume that before 1914 these international reserves were dominated by capital earnings (Chlepner, 1930), during the interwar period by hot capital (Van der Wee and Tavernier, 1975), and since 1945 by the trade balance.

The rediscounting of bills of exchange by the central bank shows a procyclical behavior, with the exception of the 1930s. In the cycles 1901–1912

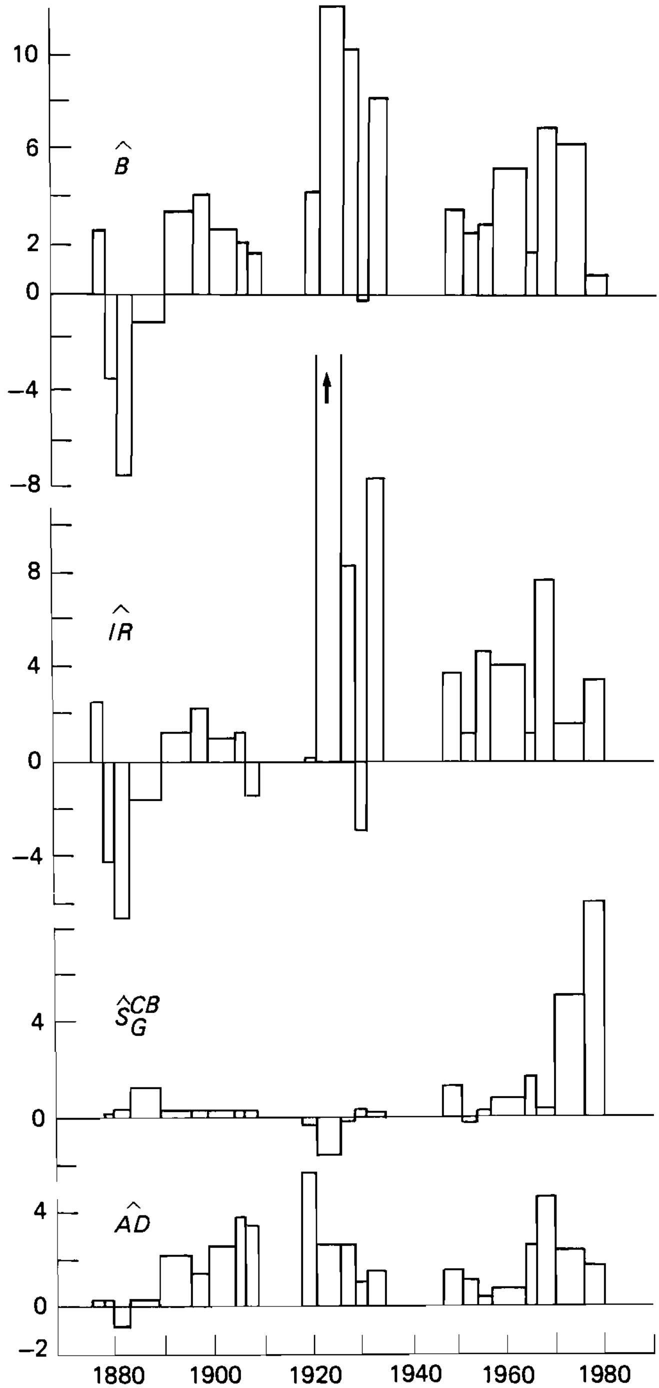

Figure 22.4. Sources of the base money growth rate, 1878–1983 (cyclical averages).

and 1967–1969, it becomes the dominant source of base money, compensating for the declining role of international reserves. Moreover, the contribution of this rediscounting to the base money creation shows a clear long-wave pattern. This behavior of private banks, approved by the monetary authorities, is a strong amplifier of the long-wave pattern in the growth of the money base and of the money supply. For Dupriez, therefore, this financing of private banks by the central bank plays a crucial role in his explanation of long waves. It stimulates the credit supply during the expansion and therefore helps to create this expansion, while the opposite is true in times of contraction.

22.4.2. Determinants of the multiplier change

This analysis can be conducted two ways. Here we look for the influence of the intermediate determinants of the multiplier, i.e., currency, postal deposits, reserves, and the time and savings deposits ratio. In the future, the analysis will be enlarged to include the so-called ultimate determinants of the multiplier, i.e., income, wealth, and interest rates. The influence of the immediate determinants is shown in *Figure 22.5*.

Over the whole period, the influence of the currency ratio is very important and shows regular, long-term fluctuations. In other words, the behavior of the public in choosing more or less currency *vis-à-vis* demand deposits, is a strong determinant of the multiplier as well as of the growth of the money supply. The postal deposits ratio follows the currency ratio passively, and its influence on the multiplier is marginal. The same can be said of the time and savings deposits ratio, although it should be noted that it has a distinct influence on the M2 money supply, particularly during the postwar period. In conclusion, we may state that in the long term, public confidence in the soundness of the banking system, most of all via the currency ratio, should not be neglected.

In the twentieth century, the role of the reserve ratio of the private banks becomes more important. In particular, it is the dominant factor in the 1920s and 1930s. Even if we add the postal and time deposits ratios to the currency ratio in order to know the "global" influence of the public, the dominance of the reserve ratio is not always threatened. Since it has a distinct negative function from 1924 to 1934, we can say that the private banks lose their confidence earlier than the public; when the latter also becomes more pessimistic, the negative multiplier change dominates the contraction of the money supply. From 1934 on, the confidence of the banks is restored before that of the public. During the postwar period, the bank behavior is rather neutral, when the Korean crisis is taken into account. However, in 1969–1973 international monetary events alarm the banks before the public is aware that something is happening. At the end of the 1970s, both regain their confidence.

Thus, by comparing the most important contributions to the multiplier change, namely the reserve and currency ratios, we can observe a distinct

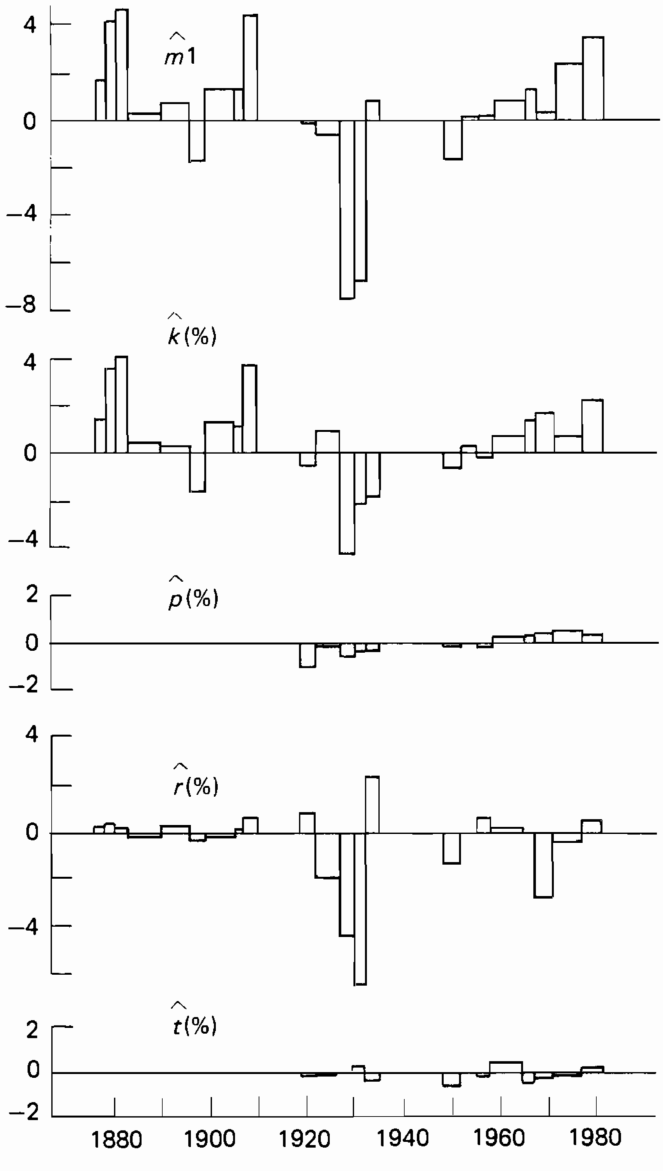

Figure 22.5. Sources of the growth rate of multiplier *m*1, 1878–1983 (cyclical averages).

time lag of ± 5 years between the two. As a result, compensating and amplifying effects emerge. However, the experience of the 1970s is not exactly the same as that of the 1930s. Indeed, the cycle of 1979–1983 shows a restoration of confidence, i.e., it seems to be more analogous to the cycle of 1909–1912. This "early" recovery could then be attributed to the trust created by the government, which avoids massive failures by offering subsidies, and by the monetary authorities, who give signals of being ready to play their role of lender of last resort.

Another hypothesis could be that the experience of the 1970s and 1980s resembles more the period 1878–1885. Then, the banks and the public seemed to work together in order to compensate for the sudden contraction of the base. This explanation is compatible with the development of new forms of money recently stimulated by technological development, e.g., electronic money. The implication of this latter hypothesis could then be that a monetary crisis is still to come, but on the conditional hypothesis that the observed long-term fluctuations continue into the future. Nevertheless, in our view, it remains crucial to know which of these hypotheses is the most likely.

22.5. Conclusion: Toward a Typology

The recovery of the money supply growth rate is caused by an increase in base money, and this is determined by an influx of international reserves. In a small, open economy such as Belgium, the crucial variable is the competitive position. This restoration of international reserves, however, can be realized by a trade balance surplus (as in the postwar period) or by net imports of capital earnings (as in the prewar period). In other words, the core of the recovery phase is the restoration of competitiveness of Belgian investments, either at home or abroad, or both.

Once the growth of the money is under way, all other determinants follow and stimulate the growth of the money supply. The growth of the money base is, apart from international reserves, enhanced by the development of the internal sources, i.e., the financing by the central bank of private banks (via rediscounting) and later of the government (via open market operations or money financing of the budget deficit). The significance of the latter, however, has only recently been recognized. Once the base growth recovers, the confidence of the private banking system is restored, and credit expansion becomes a growing source of money. This optimism spreads to the public, which becomes convinced of the solidity of the recovery. In other words, the expansion of money growth finds its origin in a "virtuous circle", a spiral of optimism.

After some time, the growth of international reserves falls, and the basis of the "virtuous circle" begins to shrink. But the growth of the money base is only stagnating or undergoing a slight decline because internal sources substitute for the diminishing international reserves: the central bank increases its financing of the banks and the government until they become dominant sources of base money creation. However, the slower growth of the base and its origin do not escape the attention of the banks. They increase their reserves, which have a negative effect on their money creation possibilities.

Finally, the "virtuous" circle becomes a "vicious" one, when the public realizes that the basis for their optimism has disappeared. This realization becomes more widespread when the growth of the money base slows down or even becomes negative: the central bank is no longer able to compensate for the declining role of international reserves with internal sources, or even tries to diminish them with the aim of coping with inflation. The public loses its confidence in the soundness of the banking system, and the private banks increase their reserves to reassure the public. The multiplier, being the major source of money, shrinks by the combined negative action of the currency and reserve ratio. The growth of the money supply declines sharply or even becomes negative. This deflationary spiral, whose ultimate cause lies in the loss of international competitiveness, works as a boomerang on the real sector as a credit squeeze accompanies the monetary contraction of the money base, and the money supply can start again.

In this scheme, the present situation is difficult to interpret: either we are still in a prolonged recession, which will be followed by a depression, or we will be witnesses to a crucial institutional change. The external sources are substituted for internal ones, not so much by financing the banks, but the state. Until now, this high base growth has been able to avoid a monetary contraction; although the base growth rate has recently fallen, the confidence of the banks and the public has not been shaken, but has even been restored after the turbulence of the early 1970s. This same policy has also been successful in avoiding a credit squeeze.

The cost of this successful operation seems to have been twofold. The overbuilt internal sources of money base have created inflation. Since the multiplier remains high, credit is widely available; but too much is used to finance the high debt position of firms, including marginal ones, and the government. Thus, a rapid recovery of competitive positions by market forces is postponed. We believe that a credit crisis has the advantage (although it is the only one) of discriminating between solid and marginal firms within a short time. On the other hand, a stagflationary solution requires a long time, as the need for a restructuring policy is felt later, and only then can design and implementation be started. That could be why a long wave could again be a long one .

Whether a depression is still to come, or institutional change, will in our view depend on the further ability of governments to avoid a crisis of confidence in the banks and the public. A too-tight and sudden deflationary policy to control budget deficits and inflation could cause a negative multiplier change, which, in addition to a smaller money base, could result in a violent monetary crisis.

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CHAPTER 23

Relative Prices and Technical Change: A Suggested Approach to Long Waves

Massimo Di Matteo

Over the last decade there has been an increasingly widespread feeling that conventional static economic theory is unable to offer a convincing analysis of the evolution of economic systems and reliable proposals for remedies to the situation of stagflation. As a consequence, in the last five or six years there has been renewed interest in the analysis of long waves described by Kondratieff (1926, 1928), which were consigned to oblivion after World War II. As early as 1913 Pareto wrote a paper, taking France as an example, which sketched very clearly the argument that the world economy was characterized by long-term oscillations. The idea was that a study of long-term tendencies, or the forces and mechanisms that shape and govern them, would help in answering in a more satisfactory way the questions posed by the real world.

Before suggesting a framework for analyzing long waves, I discuss the existence of Kondratieff cycles themselves, since many economists question them both on statistical and more general grounds. The latter claim that long waves are nothing more than historical episodes that correspond to different stages in the evolution of capitalism as a result of external forces rather than internal mechanisms. It is interesting to note that this argument was put forward at the same time as the pioneering contributions by Kondratieff were published (see Day, 1976). This is certainly a serious objection, and it is difficult to make the case for one position or the other. I think that there is no need (even if it were possible) to settle the matter on *a priori* grounds because we can adopt the Kondratieff intuition as a temporary working hypothesis, leaving it to researchers to judge whether or not simple mechanisms can be found that are consistent with long waves. Meanwhile, it is worth exploring the consequences of adopting the hypothesis in terms of the light that may be shed on the workings of the capitalist system. This procedure has the advantage of helping to establish a dialogue between historians and economists on a topic that certainly needs a joint effort in order to be dealt with satisfactorily. It is clear that the longer the period under examination, the more difficult it is to find (or extract) a set of general laws that apply to different nations at different stages of development; but on the other hand some regularities and similarities can be detected and should be studied carefully. In this case what is left unexplained could well be the peculiar elements that can be understood and clarified with the help of a detailed historical analysis.

There is also the statistical debate (see Soper, 1975). The main reason for the lack of agreement among scholars is that, in comparison with the length of the cycle to be detected, the available times series are too short to apply spectral analysis, and the elimination of the trend is often a doubtful procedure. My position is as follows. I distinguish (following Kondratieff himself) between long waves in prices and in physical production. Whereas the existence of the latter is much in doubt, the former is widely recognized. It is often stated that, unless it can be proved that the economic system does oscillate in real quantities as well, the long-wave hypothesis must be totally rejected. I do not share this view. First, long waves in output can be detected at least for some countries and for world production (Bieshaar and Kleinknecht, 1984). Second, something more can be said about price movements. As Rostow (1978) has forcefully argued, oscillations in the terms of trade between manufactured goods and raw materials can be detected in the evolution of the capitalist economy. More precisely, he showed the existence of alternations in the value of the ratio between the price of commodities produced in the industrial sector and the prices of raw materials and foodstuffs. Accordingly, one can distinguish in world history roughly five periods in which foodstuffs and raw materials prices increased with respect to those of manufactured commodities (A-periods), and four periods where the opposite held true (B-periods). The periodization chosen by Rostow is as follows (A-periods only): I, 1790–1815; II, 1848–1873; III, 1896–1920; IV, 1936–1951; and V, 1973– ... If Rostow's chronology is accepted (and I think it should because it is statistically sound) one is in search of a set of elements that account for such a pattern and the corresponding movements in production (see Rostow 1960, 1979, 1980).

Thus it is clear that of the various scholars, I have some sympathy for Rostow's approach. This is not to deny validity of the analyses of Schumpeter (1939, and his followers), Mandel, Forrester, Freeman, etc. I have simply chosen a general view common to the one shared by Rostow and at the same time offer some considerations on a mechanism that could be important in shaping economic evolution. I do not want to discuss and criticize Rostow's arguments since my purpose is to offer something which, building on Rostow's intuition, is (I hope) less unconvincing. The model put forward by Rostow and Kennedy (1979) omits many interesting elements like unemployment, oligopolistic markets, and endogenous technical progress. It would be highly desirable to construct a model that captures all the important elements, but that task is beyond my ability. I therefore outline a set of elements that could make up a picture, drawing partly on previous work by Di Matteo and Ruiz (1986).

For the sake of clarity let me split the analysis into several parts. It has been observed that the various phases of a cycle may be due to different causes, so that my procedure will not be considered totally unsound. As a first step, I introduce the Harrodian warranted and actual growth paths. According to Harrod (1973) it is possible under suitable assumptions that warranted and actual growth paths tend to coincide without having necessarily wildly unstable behavior in the economic system. The equality between the two growth rates can be trough cycles and, for positive or negative growth rates, it constitutes a very simple description of the behavior of the system in a first phase where we leave the natural rate of growth out of account and concentrate instead on natural resources. (In the following I assume two composite goods – natural resources and manufactures.)

It is important to start from an observation regarding the neoclassical theory of exhaustible resources. The latter is centered on the Hotelling rule, which states that under perfect competition the price of an exhaustible resource must grow steadily at a rate that is dictated by the rate of interest. Whatever the merits of this approach, it takes for granted that the definition of an exhaustible resource as something whose amount is fixed is sufficient for the analysis. Though logically impeccable, this line of argument does not apply easily to the real world where we witness situations that are far from being as clear-cut as the application of the theory requires. Gordon (1967) noted that for the theory to be adequate the owner of the resource has to be sure that the resource will actually be exhausted in a period of time near enough to affect his behavior. In other words, user costs may be considered negligible under proper circumstances, and therefore the owner of the resource will follow different optimal decision rules. In this case it could be perfectly legitimate to treat the resource as any other produced commodity.

The above argument is correct, I believe: the introduction of natural resources will then not alter the Harrodian story in any significant respect. Along the growth path, prices can be fairly constant with wages growing *pari passu* with productivity. We abstract from complications arising from the changing structure of demand and different rates of productivity. The story does not have a happy ending, however, as soon as the situation described above ceases to hold. When would one expect this change to occur? One could imagine that as a result of cumulative growth the economic system would come near to the natural resource ceiling, at which point the attitude of the owner of the resource may change since he now feels that the time when exhaustion will occur is not too far away. To describe what would happen following this switch, we need another piece of theory. One is tempted to employ any one of the economic growth models with an exhaustible resource that proliferated after the first oil crisis. Although models like those developed by Stiglitz (1974) have given some interesting results (a long-term appreciation of the resource price with respect to the produced commodity price), I nevertheless do not regard them as suitable for my purpose since they overlook the macrolevel and the importance of technical progress. Moreover, the nonexistence of perfect competition in industrial and resource markets forces me to introduce different hypotheses.

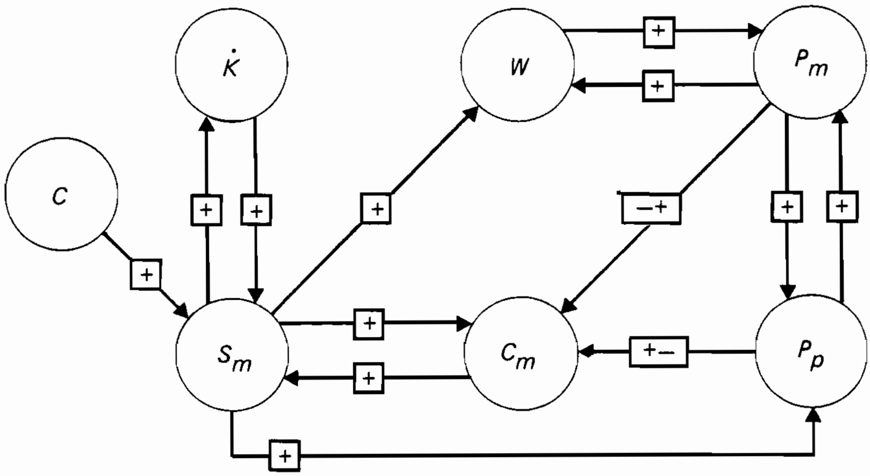

Figure 23.1. Model relations (Di Matteo and Ruiz, 1986). $\dot{K}$ = investments, C = autonomous expenditure, S_m = output of manufactured goods, C_m = consumption of manufactured goods, W = wage rate, P_m = price of manufactured goods, P_p = price of oil.

With respect to oil, Di Matteo and Ruiz (1986) elaborated a medium-term model that attempts to capture some aspects of the recent past [1]. The model is a simple integrated macromodel, i.e., a dynamic aggregative model where the prices of oil and manufactured goods are endogenous in a context of market imperfections. Relative prices do affect aggregate demand. *Figure 23.1* summarizes the relations of the model (the monetary sector is not taken into account). We have a stock adjustment equation where desired capital is a function of expected demand (which in turn depends on current demand) via an expectation function based on adaptive expectations. Then we have a Phillips' curve where wage changes are explained by the level of output and changes in the price of the manufactured good. The latter is based on a mark-up equation where both oil and labor inputs are linked to outputs via fixed coefficients. The demand for the manufactured good depends directly on income and also on the price ratio in a way that I summarize below. Finally, the price of oil is determined by the willingness of the owner to supply more oil in the unit period (and therefore to exhaust his resource earlier). At the same time the price charged by the owner reflects changes in the price of the manufactured good so that the owner's revenue is in "real" terms.

From the theory of consumer behavior in a two-good economy, we know that the price coefficients of the demand function are opposite in sign. If the share of oil in the consumers' income is high (low) then an increase in the price of oil will lower (raise) the demand for the manufactured good. In our model we chose the second alternative, since oil is a small share of the consumers' budget. If we wish to adapt our model to the more general problem of resources (in the spirit of Rostow), then the opposite holds.

The specification of the sign has important implications for the stability conditions of the model. In the oil case, it is easy to find a set of economically meaningful sufficient conditions for stability, whereas in the Rostow case the situation is unclear: stability cannot be completely excluded but the economic interpretation is not so easy. In the latter case the working of the model can be outlined briefly. Suppose that for some reason the price of the natural resource is higher than its equilibrium value. Then the demand for consumer goods falls and sets in the multiplier accelerator mechanism. Next, cost effects have to be taken into account. An increase in the resource price raises the price of the manufactured good, which raises consumer demand and this increases wages, and thus prices. This in turn reinforces the rise in the natural resource price owing to the indexation effect, so that the price of the latter can continue to move away from the equilibrium level unless the previous rise in consumer demand reverses the whole process.

At this point one could argue that models showing a high probability of exhibiting unstable behavior should be discarded altogether since in reality we do (or could) not observe such explosive movements. However, even unstable models can serve a useful purpose; indeed, any model gives a one-sided representation of the economic system. It would be the end of economic science the day when we had a complete dynamic model of the way any economy works. It would be a mistake to assume that parameters do not change with time. If we approximate a nonlinear phenomenon by means of connected linear pieces, it is clear that the approximation ceases to be valid after a while, so we could interpret instability as a signal that the model is a partial one and that it overlooks some important elements.

Returning to our framework, we could expect two things to happen. First, there should be a movement towards a particular form of technical progress. Hicks (1932) conjectured that a rise in the price of a factor of production would be itself "a spur to invention and to an invention of a particular kind – directed to economizing the use of a factor which has become relatively expensive" (p. 124). Following that hint [2], many tests have been conducted and, by and large, Hicks' approach has been found not to be inconsistent with observed facts (see Binswanger and Ruttan, 1978). Thus there is a strong presumption that after a while innovations that lower the input coefficient of natural resources in commodity production will occur. Although this modification is not made in the formal model (because of the mathematical awkwardness), this might lead to a reversal in the tendency of natural resource prices to rise. On the other hand, the latter event could be reinforced by the lifting of the natural resource barrier due to the previous price rise, which presumably has the effect of encouraging investment, e.g., in the discovery of new oil fields.

In the following the convenient but restrictive assumption of a single natural resource is abandoned in order to bridge the gap between economic theory and historical analysis. During the unfolding of the process described above, another parallel process has to be considered, although it is treated separately since it can not be accommodated in a formal model but should not be overlooked. Rosenberg (1976, 1983) stressed the existence of a form of endogenous technical progress that I will relabel endogenous qualitative technical progress. It is endogenous since it is largely determined by socioeconomic factors rather than by autonomous scientific research and inventions. Drawing on extensive historical data he provides many instances where threats of factor limitations tend to stimulate innovative efforts towards either economizing on that factor or finding a substitute. He does openly reject Hicks' analysis of the cause of the technical change, but I do not think the two explanations necessarily conflict. I share Rosenberg's view that technical innovation is one of the ways an economic system has to adapt itself to changing patterns of resource availability over time. The latter fact is not reflected in price changes by necessity (so that even if the model outlined above were not unstable, induced technical progress is still possible).

Thus the existence of a shortage (or the belief in its existence) could not only produce the change in behavior discussed by Gordon (1967), but also could set in a process of technical change. In particular, Rosenberg (1976) imagines a situation where a qualitatively different input (e.g., a new energy source) starts being used in the production process of the manufactured good. In this way one could mark the specificity of each cycle where just one resource (or a few) will be substituted, thus fulfilling the condition for the realization of a new phase in the evolution of the economic system. It has been observed (Robertson, 1915) that each cycle is characterized by a particular industry or group of industries that leads the cycle itself. Also, the development of a particular industry or group of industries in each cycle is correlated quite often and intimately with the availability of certain kinds of raw materials and particular sources of energy. It therefore may be possible, via a structural analysis of the economic system, to single out those crucial types of raw materials and sources of energy that can have the effects described, although of course they will differ from cycle to cycle. The process above would look like stripping the petals of a daisy, one after another!

In this chapter a discussion of lags and time patterns has been carefully avoided, not because I am unaware of their importance, but because a serious discussion would necessitate a good deal of further research. In particular, it is clear that the process of technical change takes a considerable amount of time to start and to be completed, according to Rosenberg. On the question of periodicity I have nothing to say, but I feel less guilty since my approach shares the same difficulty as other approaches to the long-wave phenomenon, as noted by Rosenberg and Frischtak (1984).

Notes

[1] In our model variables move around a trendless equilibrium, but the model can be reframed so that variables move around a steady state path.

[2] Hicks' intuition was confirmed with the proof by Binswanger (1974) that under reasonable assumptions (essentially decreasing marginal returns to research) a rise, say, in the price of labor will lead to the adoption of a new technique with a labor-saving bias. This approach can be compared with that of Marx (see *Capital*, Vol. 1, ch. 23).

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CHAPTER 24

A Monetary Model of Long Cycles

Pekka Korpinen

24.1. Introduction

The reasons for the slow growth in the world economy since 1973 are not yet fully understood. In search of possible explanations, the long-cycle hypothesis has attracted renewed interest.

Long-term fluctuations were first observed in price levels and other monetary variables (Tooke and Newmarch, 1928; Jevons, 1887; Wicksell, 1936; Cassel, 1932), but Kondratieff (1935) was one of the first to integrate monetary and real factors into a general long-cycle hypothesis. His preliminary theoretical efforts concentrated around long-term fluctuations in prices and interest rates, loanable funds, and long-term investments (Garvy, 1943, pp. 207–208). In contrast to Kondratieff, Schumpeter (1939) laid the foundation for the theory of long cycles based on innovations and technical change, allotting monetary factors as secondary. The majority of the contemporary long-cycle/wave researchers (e.g., Mensch, 1975; Mandel, 1975; Forrester, 1976; Rostow, 1978; Freeman, 1981; van Duijn, 1983) follow Schumpeter in the sense that key explanatory factors lie outside the monetary field.

In this chapter (see also Korpinen, 1981) reasons for long-term fluctuations in economic activity and employment are sought first from changes in price levels, monetary policy, and interest rates. A model is specified in which, through the introduction of monetary variables, a Harrod-type balanced growth path can be turned into long-term oscillations around a moving equilibrium.

The motivation for concentrating on monetary factors arises from the following observations. In the 1970s there was a shift towards a less accommodative monetary policy stance in several major industrial countries, especially in the USA. Subsequent increases in nominal and real interest rates led to distortions in debt–equity ratios and consequently to debt crises for nations, governments, important sectors such as agriculture and energy, and large firms of "old industries". For the most part, the adjustment took the form of reduced investment expenditure. High interest rates and unemployment have also led to rapid disinflation and in some cases (e.g., in commodity prices) to a straight deflation.

From the historic point of view, real interest rates can remain high for a considerable time. In fact, over the last 200 years real interest rates have followed the pattern of long cycles amazingly well (see Shiller and Siegel, 1977), so it is not unreasonable to have real interest rates among the key explanatory variables.

24.2. The Model

Following Harrod (1939) we assume that the equilibrium output Y grows $\dot{Y}$ a constant fraction $1/k$ of incremental capital I. It is further assumed that wages W are consumed, and profits x are invested. If the labor force is constant and productivity (Y/N) grows at a constant rate $\hat{y}$, steady growth is warranteed when $x = k\hat{y}$. So what would happen, say, if the Harrod-type growth process gets out of balance? In order to answer that question we need a set of equations to describe basic behavioral relationships outside the equilibrium path.

We start with the demand and supply of money. We assume that the velocity of money is inversely proportional to the interest rate:

$$M_d = \frac{\alpha YP}{1 + \beta(R - \hat{y})} \tag{24.1}$$

where M_d is the demand for money, Y is national income in real terms, P is the price level, R is the interest rate, $\hat{y}$ is the productivity growth rate (a constant, equal to the "natural rate of interest"), and α (inverse of the technological velocity of money) and β are positive coefficients. The rate of accommodation of the money supply depends on the wage inflation.

$$M_s = \frac{\alpha YP}{1 + \gamma(\hat{W} - \hat{y})} \tag{24.2}$$

where $\hat{W}$ is the relative increase in money wages $(\dot{W}/W)$, and γ is a positive coefficient.

The supply of and demand for money determine the interest rate:

$$R = A + B\hat{W} \tag{24.3}$$

where $A = (1 - \gamma/\beta)\hat{y}$ and $B = \gamma/\beta$. The equilibrium condition for the market for goods and services is

$$Y = C + I \tag{24.4}$$

where C is the volume of consumption and I is the volume of investment. The consumption function is based on the notion (*à la* Kalecki) that "workers spend what they get and capitalists get what they spend".

$$C = wN \tag{24.5}$$

where w is real wages and N is employment as well as the employment rate, because the labor force is assumed to be constant and the measurement of labor force is normalized at unity.

The investment volume is assumed to depend on the growth of output, profits, and interest rate.

$$I = k\dot{Y} + \delta(\pi - k\hat{y}Y) - \zeta(R - \hat{y})Y \tag{24.6}$$

where k is the capital–output ratio, π is real profits ($= I$), $k\hat{y}Y$ is "natural" real profits, and δ and ζ are positive coefficients.

The growth rate of nominal wages depends on productivity growth, the share of profits (or wages), and the change in employment.

$$\hat{W} = \hat{y} + \eta(x - k\hat{y}) + v\hat{N} \tag{24.7}$$

where x is the share of profits, $k\hat{y}$ is the "natural" share of profits, and η and v are positive coefficients.

The rate of inflation is determined by unit labor costs and the change in the mark-up factor, which depends on the capacity utilization ratio described by the employment rate.

$$\hat{p} = \hat{W} - \hat{y} + \kappa(N - \tilde{N}) \tag{24.8}$$

where κ and $\tilde{N}$ are positive coefficients. From equation (24.8) we get (remembering that $\hat{w} = \hat{W} - \hat{p}$ and $\hat{z} = \hat{w} - \hat{y}$)

$$\hat{z} = \kappa(\tilde{N} - N) \tag{24.9}$$

where $\hat{z}$ is the relative change in the share of wages ($x = 1 - z$).

Equations (24.3)–(24.7) lead to

$$\hat{N} = D\,(k\hat{y} - 1 + z) \quad D = \frac{\delta - 1 - \zeta B \eta}{k - \zeta B v} \tag{24.10}$$

Equations (24.9) and (24.10) form a nonlinear Lotka–Volterra system, which has an equilibrium point $(\hat{N}, 1 - k\hat{y})$. If the system is in equilibrium, both the capital stock and output grow along the Harrod's warranted growth path. In this case capital, output, and productivity all have the same growth rate $(\hat{y})$.

24.3. Properties of the Model

In order to analyze the properties of the model we first solve the equations of the trajectories of the system (24.9) – (24.10). Eliminating time and integrating, we get

$$\kappa \tilde{N} \log N - \kappa N + (D - Dk\hat{y}) \log z - Dz = \log c \tag{24.11}$$

where c is an integration constant. Equation (24.11) can also be written

$$\frac{z^D\,(1 - k\hat{y})}{e^{Dz}} \cdot \frac{N^{\kappa\tilde{N}}}{e^{\kappa N}} = c \tag{24.12}$$

Equation (24.12) describes the trajectories (given the initial condition), that form a closed curve, if $D > 0$. N and z reach their maximum and minimum values on the trajectories when $z = 1 - k\hat{y}$ and $N = \hat{N}$. The movement along the trajectories is counterclockwise. If $D < 0$, then the equilibrium point is not a center, but on "the knife edge": disturbances lead either to cumulative inflation and full employment, or deflation and increasing unemployment.

The numerator of D is always negative, since δ has to be smaller than 1. Therefore, the sign of D depends on whether $k \geq$ or $\leq \zeta B v$. One could assume that the capital–output ratio (k) is somewhere around 4. Since the values of ζ and v are probably somewhere around 1, the value of B has to be quite high in order to turn a unstable growth process into a cyclic one. The value of B depends on how sensitive the money supply is to wage inflation, as well as on how inelastic the velocity of money is in relation to interest rates. It is only through a "sadistic" monetary policy, which allows interest rates to skyrocket, that the cumulatively inflationary long upswing phase is turned in the model to disinflation and finally a deflationary long downswing.

The next property of the model to be analyzed is the length of the cycle. Even though there also exists an explicit solution (Frame, 1974) to the length of the cycle in the Lotka–Volterra system, there is an easy way to obtain an approximate solution using a linearized version of the model. We can transfer the equilibrium point of the system

$$\dot{N} = D\ (k\hat{y}\ - 1 + z)N \quad \dot{z} = \kappa\ (\tilde{N}\ - N)z \tag{24.13}$$

to the origin by letting $n = N - \tilde{N}$ and $v = z - 1 + k\hat{y}$,

$$\dot{n} = D\tilde{N}v + Dvn \quad \dot{v} = -\kappa(1 - k\hat{y})n - \kappa nv \tag{24.14}$$

When only the linear terms of (24.14) are taken into account, the solution of the system is

$$n = c_1 \cos \sqrt{DN\kappa(1 - k\hat{y})}\ t + c_2 \sin\sqrt{DN\kappa(1 - k\hat{y})}t \tag{24.15}$$

$$v = c_3 \cos \sqrt{DN\kappa(1 - k\hat{y})}\ t + c_4 \sin\sqrt{DN\kappa(1 - k\hat{y})}t$$

The length of the cycle (T) can be calculated from the formula

$$T = 2\pi/\sqrt{DN\kappa(1 - k\hat{y})}$$

It is difficult to say *a priori* anything specific about the quantitative values of some of the parameters. In order to reach the range of 40–60 years, acceleration of inflation has to be slow, i.e., both η and κ should be very small. In practice this means that workers increase wage demands only gradually when the share of profits increases, and that capitalists are cautious to increase their mark-up over unit costs when demand is strong. As the length of an inflationary phase, 20–30 years is not necessarily in contradiction with empirical observations before and after the two world wars. By assuming that prices react slowly, one is in a sense eliminating short cycles and describing only long-term fluctuations in the price level. It is possible that a similar model structure with different parameter values could also be used to describe the so-called stop–go cycle.

24.4. A Further Development

The initial conditions of the model affect the amplitude of the cycle, but not the average values over time of employment (N) and distribution of income (z). On empirical grounds one can question the fact that the cycle is symmetric to the axis in the sense that the two values of employment assigned to each value of the share of wages always have the same average, i.e., the equilibrium value (see Korpinen, 1981, p. 152). One would perhaps want to see a trade-off between employment and a share of wages (profits). If wages are pushed to their maximum, where there are no profits, one would expect employment to be below average. In the following we achieve this result, but at the cost of complicating the model.

By using real a interest rate $(R - \hat{P})$ instead of nominal interest rate in the investment function (24.6), the model can be described as follows:

$$\hat{z} = \kappa(\tilde{N} - N) \tag{24.9}$$

$$\hat{N} = F + Gz + HN \tag{24.10}$$

where

$$F = \frac{[1 + (B - 1)\zeta\eta - \delta](1 - k\hat{y}) + \zeta\kappa\tilde{N}}{k + (1 - B)\zeta v}$$

$$G = \frac{-[1 + (B - 1)\zeta\eta - \delta]}{k + (1 - B)\zeta v} \qquad H = \frac{-\zeta\kappa}{k + (1 - B)\zeta v}$$

Equations (24.9) and (24.10) form a dynamic, almost linear system (for a proof see Korpinen, 1981, p. 148) that has an equilibrium point $(\tilde{N}, 1 - k\hat{y})$, i.e., as in the model (24.9)–(24.10). Using the same reasoning about the magnitude of the parameters as in the previous model, the system can be proved, using Liapunov's first method (Boyce and Di Prima, 1969, pp. 394–395), to be an explosive spiral (*Figure 24.1*).

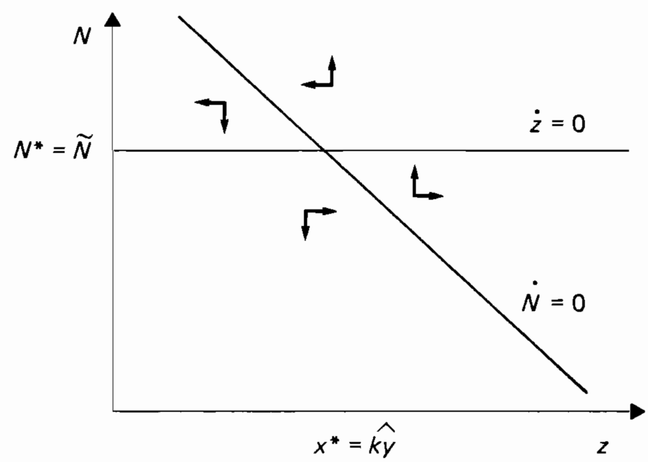

Figure 24.1.

24.5. Concluding Remarks

Even though monetary variables play a key role in the model, it is not correct to call it monetarist. It is even difficult to speak of the effects of monetary policy since the money supply is totally endogenous in the model.

In order to try to give a causal interpretation, let us call a period with high interest rates a "monetarist" regime and a period with low interest rates a "Keynesian" regime. The monetary squeeze under a monetarist regime works its effect on price levels through investment, employment, and income distribution. Disinflation or deflation is gained only by substantial and long-lasting losses in production. A Keynesian era is characterized by low interest rates, increasing employment, and a rising share of profits, which lead to militancy and greater demands by workers. The ongoing class struggle has a cumulative momentum of its own. Inflation accelerates, and the tone of monetary "policy" starts to change.

The price and wage mechanism described by the model refers to a closed economy, i.e., to the world as a whole. If world market prices are given, as in the case of a small open economy with fixed exchange rates, then higher nominal wages should lead to higher real wages (as postulated in Goodwin's 1967 model, which in a sense is the opposite case of our model). Without "given" outside markets, prices are basically determined by costs, of which wages are the most important part.

The distribution assumption in the foregoing analysis is similar to Kaldor's (1955) growth model, in which the relation between prices and money wages depends on the total demand (investment). The idea here is that perpetually high employment increases the degree of monopoly (prices in relation to price costs; see Kalecki, 1943). In the normal business cycle recession, the degree of monopoly might continue to increase temporarily since overhead costs are relatively higher; but during the long depression phase unused capacity will eventually bring a halt to the monopolistic pricing process, culminating in cut-throat competition.

Moving outside the model, it is plausible that economic policy has a tendency always to be late and therefore "wrong". If the reality determines consciousness and consciousness determines action, there is an unavoidable lag. The writings of Smith (1776) and Ricardo (1817) were made during an inflationary long upswing, but their recommendations (hard currency, *laissez-faire)* were still applied during a deflationary period. Tooke (1926-57) and Keynes (1936) made their contributions during a deflationary long downswing, but their policy recommendations were mainly followed in an inflationary environment. This leads to the theory of long cycles in its simplest form: the same mistakes are repeated by every second generation. The economic policies of the 1970s and the 1980s resemble surprisingly those of the 1920s and the 1930s, as well as those of the 1870s and 1880s or, even further back, of the 1820s and 1830s.

The emphasis on monetary factors in this chapter does not imply that innovations and other technological factors are unimportant: it is simply too difficult to analyze all the relevant variables simultaneously. It may very well be that monetary factors are relatively more important in explaining the turning point from a long upswing to a long downswing, whereas the accumulation of unused technological possibilities might have comparative advantages in explaining the resumption of growth.

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PART IV

Modeling the Long-Wave Phenomenon

CHAPTER 25

Catastrophe Theory Applied to the Analysis of Long Waves

L. Klimenko and S. Menshikov

Menshikov and Klimenko (1985) suggested a model of long waves using the US economy as an example. The model has four variables: labor productivity, capital intensity of labor (capital–labor ratio), profit rate, and profit per unit of labor time. The model deals with growth rates of these variables, functional relationships are described by linear differential equations, and parameters are estimated by ordinary least squares (OLS) using time series for 1889–1982. The model (model 1) generates long-term fluctuations of approximately 50 years. Variables describing the velocity and direction of technical progress – labor productivity and the capital intensity of labor (see *Figure 25.1*) – play a decisive role in determining the turning points in the cycle. Changes in the relationships between these variables, i.e., in the capital–output ratio, determine (with a certain lag) the turning points in the profit rate and gross national product (GNP). Through capital intensity the profit rate also determines changes in the output–capital ratio. The shortcomings of model 1 are due to its linearity, which accounts for smooth and dampened oscillations. Proximity to actual dynamics is achieved only when additional exogenous variables and stochastic shocks are introduced.

In this chapter the same statistical series are used in a nonlinear analysis of economic fluctuations by means of the catastrophe theory (Poston and Stewart, 1978). It is known from catastrophe theory that any smooth dynamic process may be locally approximated by polynominals whose order depends on the number of parameters, and represents n-dimensional surfaces that have specific features such as folds, pleats, etc. Movement along such surfaces, in spite of smooth parameters changes, may lead to sudden transformations from one regime to another, i.e., to bifurcations or "catastrophes".

In a capitalist economy fluctuations in output exhibit various periodicities that can be explained by various primary factors: fluctuations in general

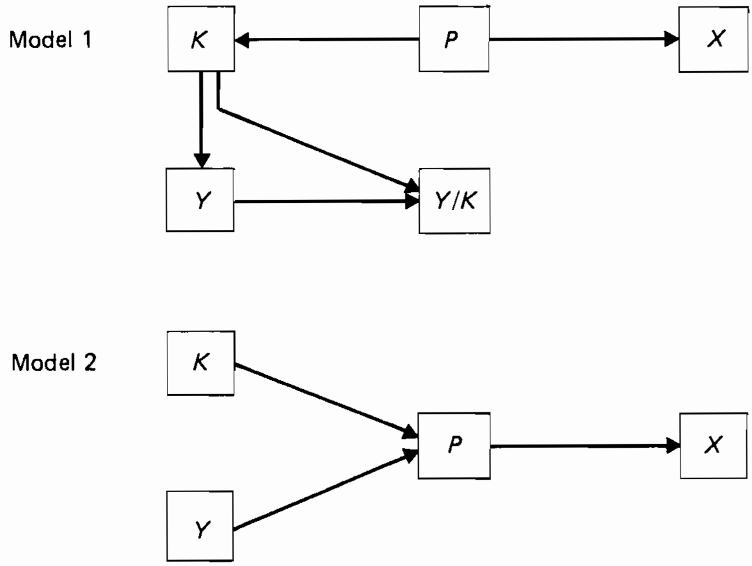

Figure 25.1. Causal relationships in models 1 and 2.

inventories and stocks of consumer durables (3–4 years), renovation of fixed capital invested in production equipment (8–10 years), waves in the construction of production buildings and structures (18–20 years), and general revolutions in the technological basis of production (50–60 years). The amplitudes of these fluctuations vary, and the waves of different periodicities are superposed on one another, such that they either increase or reduce the overall intensity of changes in output. The deepest crisis in the history of the capitalist economy occurred in 1929–1933, but none of the empirical models known to us has been able to simulate this crisis with adequate accuracy. The steep decline in production during this crisis has been largely simulated by introducing stochastic (unexplained) influences that could themselves be manifestations of the crisis.

What new elements can catastrophe theory add to the analysis of fluctuations in a capitalist economy? Catastrophe theory makes it possible to find such values of the control variables of the system, which determine either a smooth or a bifurcational reaction of the internal variable to smooth changes in control variables. The area of change in control factors, which accounts for bifurcational change in the internal variable, is called the critical or catastrophe area.

The first attempt at such analysis was made by Mensch (1979, 1983), who used US statistical series for 1900–1934 to construct synthetic variables expressing extensive and intensive directions in technical progress. He assumed that the potential production function is described by a polynominal of a certain concrete type. From his analysis Mensch found that around 1918 the US economy experienced a qualitative transition to a new economic optimum. Mensch's theoretical curve followed fairly closely deviations from the trend of the actual industrial production index (coefficient of determination = 0.78).

Unlike Mensch, we have used time series for 1889–1982 to estimate directly coefficients of a fourth-order polynominal, which expresses the functional dependence of the GNP on profit rate, labor productivity, and capital intensity, i.e., on indicators of the rate and the direction of technical progress (see *Figure 25.1*). The most strongly fluctuating of these variables is the profit rate, and this was chosen as the internal variable to follow the bifurcations in economic performance. It is assumed that the actual movement of GNP is close to optimal points corresponding to changes in the profit rate. Labor productivity and capital intensity are control factors.

It is known from catastrophe theory that a dynamic system that depends on two control variables contains the specific feature of a pleat, and the typical family of functions describing it has the form:

$$f(u, t_1, t_2) = \pm(u^4 + t_2 u^2 + t_1 u) \tag{25.1}$$

where u are the internal variables and t_1 and t_2 are the control parameters. Thus, it is reasonable to approximate the movement of GNP by equations of the type:

$$X_1 = a_1 P^4 + a_2 P^3 + a_3 P^2 Y + a_4 PK + a_5 L + a_6 \tag{25.2}$$

or

$$X_2 = a_1 P^4 + a_2 P^3 + a_3 P^2 K + a_4 PY + a_5 L + a_6 \tag{25.3}$$

where X = output, or GNP, or gross private domestic product (GPDP), P = profit rate, Y = labor productivity, K = capital intensity, and L = employment. Let us assume that employment L enters the equation linearly and does not introduce additional specifics in GNP movements other than a long-term growth trend. We now check a hypothesis according to which the GNP moves along a path that is close to the optimal points of functions (25.2) and (25.3) relative to the profit rate. The form of these functions allows the possibility of one, two, or three optimal points (within ranges that actually exist in an economy). The area where this possibility exists is determined by the relation between intensive (labor productivity) and extensive (capital intensity) factors of technical progress. Drastic changes in the profit rate, and thus rifts in the transition from one level of output to another, are explained in the model by changes in the relation between optimal output and profit rate caused by the general economic situation.

The totality of all values of P, Y, and K, corresponding to optimal values of X, constitute surfaces of two types:

$$\frac{dX_1}{dP} = 4a_1P^3 + 3a_2P^2 + 2a_3PY + a_4K = 0 \tag{25.4}$$

$$\frac{dX_2}{dP} = 4a_1P^3 + 3a_2P^2 + 2a_3PK + a_4Y = 0 \tag{25.5}$$

For any given values of Y and K, equations (25.4) and (25.5) have three solutions. If there are no complex roots, then there are three optima (two maxima and one minimum, two minima and one maximum, and one or two flexion points) of X by the profit rate, which are the object of our analysis. We are concerned only with positive roots, since only they correspond to actual conditions. We now determine which of the optimal points corresponds with which of the calculated roots; how close are the observed profit rate values to the roots. We thus determine which of the theoretical optimal points is closest to the actual condition of the economy. It will also become clear when (i.e., at which values of factors Y, K, and P) a bifurcational transformation occurs in the actual economy to the alternative optimal point, what is its direction (upward or downward), and extent (i.e., how large a fall or increase in output). If the solutions contain complex roots, then there exists only one optimal point. If the corresponding profit rates are far from their observed values, then we must conclude that our hypothesis of closeness to optimal points is not upheld for the period in question.

Rewriting equation (25.4) as functions for K [or (25.5) for Y] and differentiating by P, we obtain critical profit rate values P_{cr} under which, given various values of Y (or K), the possibility exists of bifurcational changes in the profit rate, and a sudden transformation from one optimal point of the profit rate can be calculated from

$$P^1_{cr} = \left\{ \frac{-6a_2}{a_4} \pm \left[\frac{6a_2}{a_4} \right]^2 - \frac{96a_1a_3}{a_4^2} Y \right\}^{\frac{1}{2}} \Big/ \left[24\frac{a_1}{a_4} \right] \tag{25.6}$$

$$P^2_{cr} = \left\{ \frac{-6a_2}{a_4} \pm \left[\frac{6a_2}{a_4} \right]^2 - \frac{96a_1a_3}{a_4^2} K \right\}^{\frac{1}{2}} \Big/ \left[24\frac{a_1}{a_4} \right] \tag{25.7}$$

The corresponding critical areas of change, or catastrophe areas, are found from

$$\{K_{cr}\} = \left\{ -\left[\frac{4a_1}{a_4}(P^1_{cr})^3 + \frac{3a_2}{a_4}(P^1_{cr})^2 + \frac{2a_3}{a_4}P^1_{cr}\,Y \right] \right\} \tag{25.8}$$

$$\{Y_{cr}\} = \left\{-\left[\frac{4a_1}{a_4}(p^2_{cr})^3 + \frac{3a_2}{a_4}(P^2_{cr})^2 + \frac{2a_3}{a_4}P^2_{cr}\,K\right]\right\} \tag{25.9}$$

where P^1_{cr} and P^2_{cr} have two values. Using observed values of Y (or K), we can obtain the areas $\{K_{cr}, Y, P^1_{cr}\}$ and $\{K, Y_{cr}, P^2_{cr}\}$ whose borders determine possible values of Y, K, and P, leading to sudden changes in output. This method was used to analyze relations of the type (25.2) and (25.3) at different times.

The estimated equation for the entire period 1889–1982 is:

$$\underset{(4.2)}{X = 1.664P^4} \; \underset{(7.5)}{-\,50.234P^3} \; \underset{(6)}{+\,0.636P^2K} \; \underset{(17.8)}{+\,74.95PY} \; \underset{(12.3)}{+\,0.701L} \; \underset{(7.8)}{-\,34702} \tag{25.10}$$

where $R^2 = 0.999$, $S = 0.5 \times 10^4$, $F = 7668$, and $DW = 0.53$. The figures in parentheses are t-statistics; R^2 = coefficient of determination; S = standard error; F = Fisher statistics; DW = Durbin–Watson statistics.

The solution to equation (25.5) for observed values of Y and K in 1889–1982 gives three real roots for the first 42 points (i.e., before 1930), and one real negative root for almost all other points. Two of the three real roots are positive and one is negative. Since the coefficient at P^4 is positive, it follows that X has two minima and one maximum. From their alteration it follows that the negative root corresponds to one of the minima X, the smaller positive root to the maximum, and the larger positive root to the second minimum. As the relationship between Y and K changes in time, the two positive roots approach each other. After they converge at a point close to 1931, there remains one real negative root that corresponds to the first minimum in the previous period.

Assuming theoretical profit rate values in 1889–1930 to equal one of the positive roots closest to the observed values of P, we obtain theoretical GNP values for every year in question (see *Figure 25.2*). This theoretical time series follows the observed series extremely well, and the direction of change in both series coincides for each year. Thus our hypothesis that actual economic development followed paths close to the local maximum of function (25.10) is confirmed for the period 1889–1930. After 1930 the economy apparently underwent a qualitative change, and its path may have lain close to other local optima that are not described by function (25.10).

The critical profit rate values corresponding to function (25.10) and to observed values of K are within gradually decreasing intervals (0.8; 14.3) and (4.6; 10.6) (see *Figure 25.3*). Observed profit rate values lie within the critical area until 1939, after which they leave.

A similar situation occurs in the sub-period 1889–1930. GNP dynamics are approximated by the polynomial

$$\underset{(7.2)}{X = 5.09P^4} \; \underset{(11.6)}{-\,101.21P^3} \; \underset{(8.4)}{+\,5.96P^2Y} \; \underset{(6.1)}{+\,15.91PK} \; \underset{(13.9)}{+\,0.47\,L} \; \underset{(3.4)}{-\,12552} \tag{25.11}$$

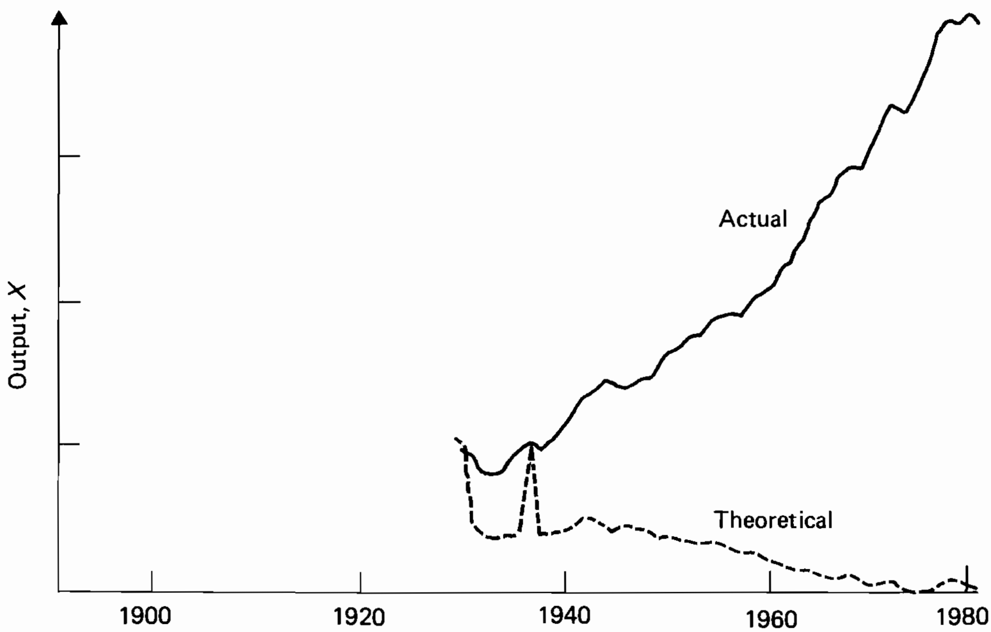

Figure 25.2. Actual and theoretical output, 1889–1982.

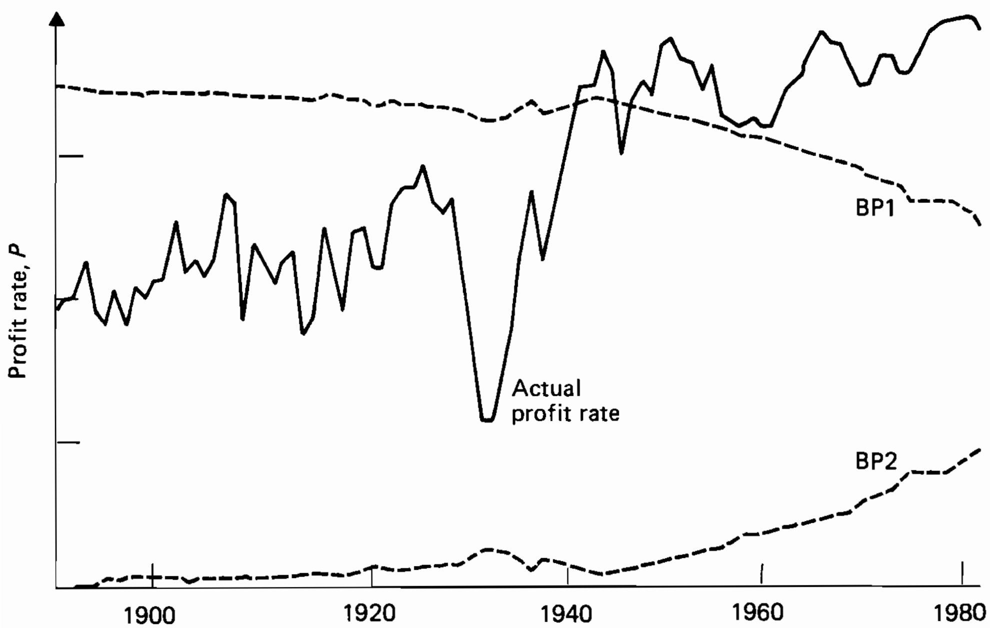

Figure 25.3. Critical and observed values of the profit rate, 1889–1982 (BP1 and BP2 are boundaries of the critical area).

where $R^2 = 0.999$, $S = 0.2 \times 10^4$, $F = 804$, and $DW = 1.4$. Unlike the polynomial used for the full period in function (25.11), Y is a parameter at P^2 and K at P.

Solving equation (25.4) for function (25.11) and using observed values of Y and K, we obtain three real roots for the first 30 points (i.e., before 1918) and only one real negative root for the rest of the period. The three roots, as in the equation for the full period, correspond to two minima and one maximum. However, unlike the full period where the actual movement of the economy was close to the theoretical maximum throughout 1889–1930, model (25.11) produces a different movement: (a) a qualitative change in output occurs as early as 1916 (instead of 1930); and (b) the actual movement before 1916 follows two optimal paths: a maximal in 1889–1898 and a minimal in 1899–1916.

Critical profit rate values are within decreasing intervals from (0.7; 9.2) to (2.4; 7.6), and observed profit rate values are close to the critical values throughout the entire period before 1916. The observed values of capital intensity reached their upper critical levels around 1916. A similar result occurred in the overall period around 1930 when actual labor productivity values coincided with the maximum critical values.

The equation estimated for 1939–1982 is of type (25.3):

$$X = \underset{(2.4)}{1.94P^4} - \underset{(3.7)}{62.63P^3} + \underset{(3.6)}{0.47P^2K} + \underset{(14.2)}{66.61PY} + \underset{(19)}{2.09L} - \underset{(18)}{147573} \qquad (25.12)$$

where $R^2 = 0.999$, $S = 0.3 \times 10^4$, $F = 856$, and $DW = 1.17$. The solution to equation (25.5) for function (25.11) produces three real roots in 1939–1956 and one real negative root in the remaining period. The movement of the economy in 1939–1949 is close to the maximum corresponding to the smaller positive root, and both roots merge by 1956. However, around 1950 [similar to 1899 in model (25.11)] the economy changes to the minimum optimum and later (around 1956) moves away from paths described by optimal points.

Critical profit rate values are determined by decreasing intervals (0.8; 15.2) and (2.2; 13.8). Throughout the period, excluding only 1939 and 1940, observed values are close to critical ones, but the actual values of capital intensity reach maximum critical values around 1956.

For further clarification of the dynamics of the GNP and deeper analysis of turning points, the sub-periods 1889–1939 and 1939–1982 were further subdivided: 1889–1939 into the intervals 1889–1916 and 1916–1939; and 1939–1982 was extended slightly back in time and divided into the intervals 1933–1957 and 1958–1982. For estimating the equation for 1933–1957 the war years 1939–1945 were excluded.

The model for 1889–1916 is:

$$X = \underset{(3.5)}{2.19P^4} - \underset{(4.2)}{41.62P^3} + \underset{(2)}{0.56P^2K} + \underset{(4.2)}{109.08PY} + \underset{(7)}{0.45L} - \underset{(8.2)}{18107} \qquad (25.13)$$

where $R^2 = 0.999$, $S = 0.5 \times 10^4$, $F = 2542$, and $DW = 0.83$. For the entire period the roots of equation (25.5) in this case are real. The choice of one of them served to closely approximate the actual GNP movement, and thus to uphold the hypothesis of closeness to optimal points (see *Figure 25.4*(*a*). Before 1900 the economy is close to the maximum point *vis-à* the profit rate; in 1901 1906, 1907, and 1916 it is close to the minimum; and in other years it returns to the minimum. This result correspondences well with conclusions made for the whole period 1889–1939.

The critical area of changes in the profit rate, unlike the result for 1889–1939, widens from (–0.8; 10.3) to (–1; 10.5). However, as in the previous case, around 1916 actual productivity is equal to its maximum critical value.

The estimated model for 1916–1939 is:

$$X = \underset{(11.9)}{5.88\,P^4} - \underset{(13.8)}{109.29P^3} + \underset{(2.5)}{0.58P^2K} + \underset{(14.7)}{86.19PY} + \underset{(11.7)}{0.63\,L} - \underset{(9.1)}{20455.9} \quad (25.14)$$

where $R^2 = 0.999$, $S = 0.1 \times 10^4$, $F = 340$, and $DW = 1.98$. Three real roots are obtained from the solution to equation (25.5) for this model. As in other cases, the smaller positive root corresponds to the maximal optimal point, the larger positive root to the minimum. In the early part of the period (1916–1929), the economy moves close to minimum GNP *vis-à-vis* the profit rate, whereas in the crisis of 1930–1933 the economy moves to the local maximum [see *Figure 25.4*(*b*)].

The critical area of changes in the profit rate is between the intervals (0.4; 8.8) and (0.6; 8.6). As in other cases, the transfer to an alternative trajectory occurs when the higher boundaries of the critical area are reached.

In 1936 the economy returns to optimal points corresponding to the local GNP minimum in relation to the profit rate. Stable movement in the vicinity of this optimum continues until 1956–1958, as can be seen from the following model for 1933–1958:

$$X = \underset{(3)}{1.47P^4} - \underset{(8.7)}{52.56P^3} + \underset{(5.2)}{3.93P^2Y} + \underset{(2.6)}{9.975PK} + \underset{(11.2)}{1.96\,L} - \underset{(6.5)}{124528.9} \quad (25.15)$$

where $R^2 = 0.999$, $S = 0.1 \times 10^4$, $F = 4321$, and $DW = 2.05$. In this case there are three optimal points throughout the period. The only positive real root corresponds to minimum GNP in relation to the profit rate, which is the and $DW = 2.05$. In this case there are three optimal points throughout the period. The only positive real root corresponds to minimum GNP in relation to the profit rate, which is the continuation of the optimal regime started in 1935.

The theoretical profit rate values are very close to observed values. Correlation between theoretical and actual GNP is high [see *Figure 25.4*(*c*)]. The critical area of changes in the profit rates lies between the narrowing intervals (17.4; 1.8) to (14.4; 4.8). Real profit rate values approach the critical area, starting in 1942. Unlike the turning points of 1916 and 1930, the actual value of capital intensity in 1956 is far from its critical value.

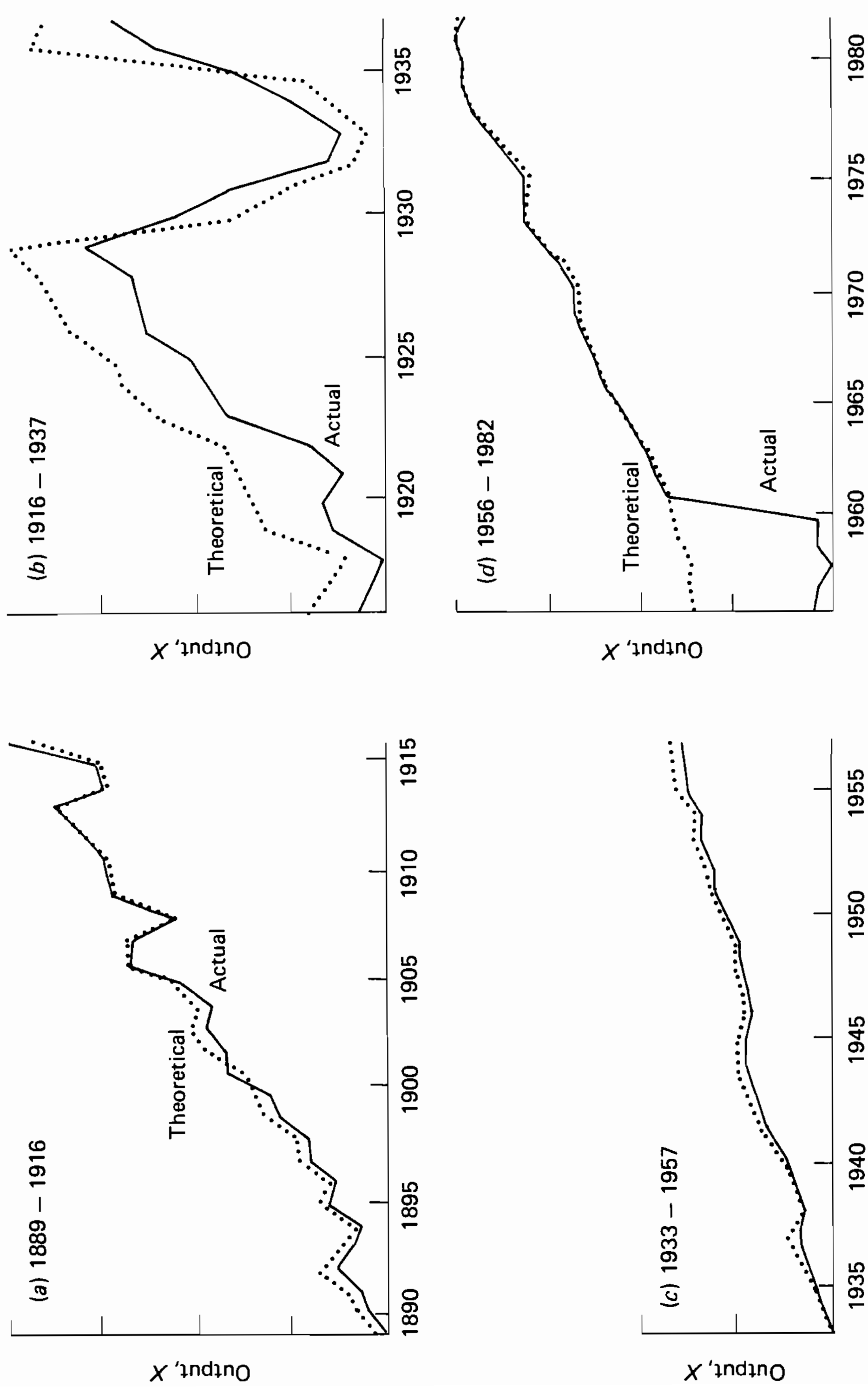

Figure 25.4. Actual and theoretical output in (*a*) 1889–1916; (*b*) 1916–1937; (*c*) 1933–1957; (*d*) 1956–1982.

The estimated model for 1956–1982 is:

$$X = -5.03P^4 + 53\,P^3 + 4.67\,P^2Y + 6.53PK + 2.31\,L - 219103 \qquad (25.16)$$
$$\quad (4.7) \qquad (2.5) \qquad (13.5) \qquad (3.5) \qquad (22.0) \qquad (9.0)$$

where $R^2 = 0.999$, $S = 0.18 \times 10^4$, $F = 9173$, and $DW = 1.8$. Unlike all the other models considered above, this one has two maxima and one minimum. Out of the three real roots two are negative, starting in 1960 (while in 1956–59 two roots are complex). The only positive root represents maximum GNP in relation to the profit rate [see *Figure 25.4(d)*]. The results are summarized in *Table 25.1*.

Table 25.1. Results of model simulations.

Period of estimation	*No. of real positive roots*	*Period of real positive roots*	X_{min} *period*	X_{max} *period*
1889–1982 (94 years)	2	1889–1930	–	1889–1930
1889–1930 (42 years)	2	1889–1916	1898–1916	1889–1898
1939–1982 (44 years)	2	1939–1956	1950–1956	1939–1949
1889–1916 (28 years)	2	1889–1916	1901–1901	1889–1900
				1902–1905
			1906–7, 1916	1908–1915
1916–1939 (24 years)	2	1916–1939	1916–1929	1918
			1936–1939	1930–1935
1933–1958 (26 years)	1	1933–1958	1933–1958	–
1956–1982 (27 years)	1	1960–1982	–	1960–1982

What substantive conclusions follow from this analysis?

(1) When long periods (40–90 years) are considered, the models enable fairly accurate simulations of real dynamics of output to be made only for approximately half of the period. However, it is logical to assume that when these models cease to describe actual GNP behavior close to one of the optimal points, serious changes occur in long-term economic conditions. For example, the models for 1889–1982 and 1889–1930 show that around 1916 and 1930 long-term turning points are observed in the relative dynamics of labor productivity (Y) and capital intensity (K). In both cases the output–capital ratio (Y/K) reached its local minimum. Such conditions are characteristic of a transition to the opening phase of a new technical revolution in production.

(2) During approximately half of the long periods, the real output dynamics stray far from trajectories indicated by theoretical optimal points, so that the analysis must be supplemented by observing shorter periods of 25–30 years. In this case the real movement, as a rule, is closely simulated by theoretical trajectories during the whole period under consideration.

(3) The most interesting cases are when there is a bifurcation in output from a local minimum (in relation to the profit rate) to a local maximum, and back. These appear three times in the period 1889–1916; in two of the three cases (1889–1901 and 1906–1907), the bifurcations coincided with actual recessions in the economy. In period 1916-1939 output was mostly close to the minimum as related to the profit rate, but in the crisis years 1930–1935 it changed to the maximum optimal point. This can be explained in the following way.

The capitalist economy is a combination of monopolistic and non-monopolistic sectors and components. When business conditions are favorable, a new economic structure is created and aggregate demand, on the whole, leads supply, the tendency to use monopoly advantages is extremely strong, and situations prevail in which it is possible for monopolies to achieve higher profits by limiting output. On the contrary, under unfavorable business conditions, when the old economic structure is undergoing a crisis and new technologies start to emerge in clusters, the monopoly situations associated with the old structure may be destroyed by objective market forces, and highly competitive situations tend to prevail even in some highly monopolized sectors. This occurred in 1930–1935 and evidently also in some previous recessions.

Consider *Figure 25.5(a)*, which shows the typical situation occurring in the models, as described above. For every observed combination of K and Y there exist two different optimal output points that are consistent with two levels of P. The maximum optimal point in GNP is achieved when P is at its local minimum, and the minimum optimal point in output corresponds to the local maximum. *Figure 25.5(b)* is a reminder of the simple example of relative conditions of monopoly and free competition. Under free competition output X_1 is determined by the intersection of the curves of supply and demand. But this is not the point of maximum profit, which, under a monopoly, is assured by smaller output X_2 and higher price. Under prevailing monopoly conditions actual output tends to be closer to the local minimum (X_2), whereas in a prevailing competitive situation it tends to be closer the local maximum (X_1).

These diagrams show only the possibility of bifurcation, since they apply only at a given moment of time. Actual changes from one optimal point to another occur from one point in time to another. Therefore, what is a change from minimum to maximum GNP in a crisis is really a fall in the actual level of output (and profit).

Consider *Figure 25.6(a)* which shows actual and theoretical profit rates in the period 1889–1916. The prevailing mode of operation of the economy here is competitive, particularly in the 1890s, when cartels and trusts were still in their formative period and when the long recession of 1873-1895 was giving way to a new long recovery. Then, on two occasions (1901 and 1906–1907) there were bifurcations from a predominantly competitive to a predominantly monopolistic mode. In both cases, however, the latter did not last and was broken by cyclical crises (belonging to short and medium waves).

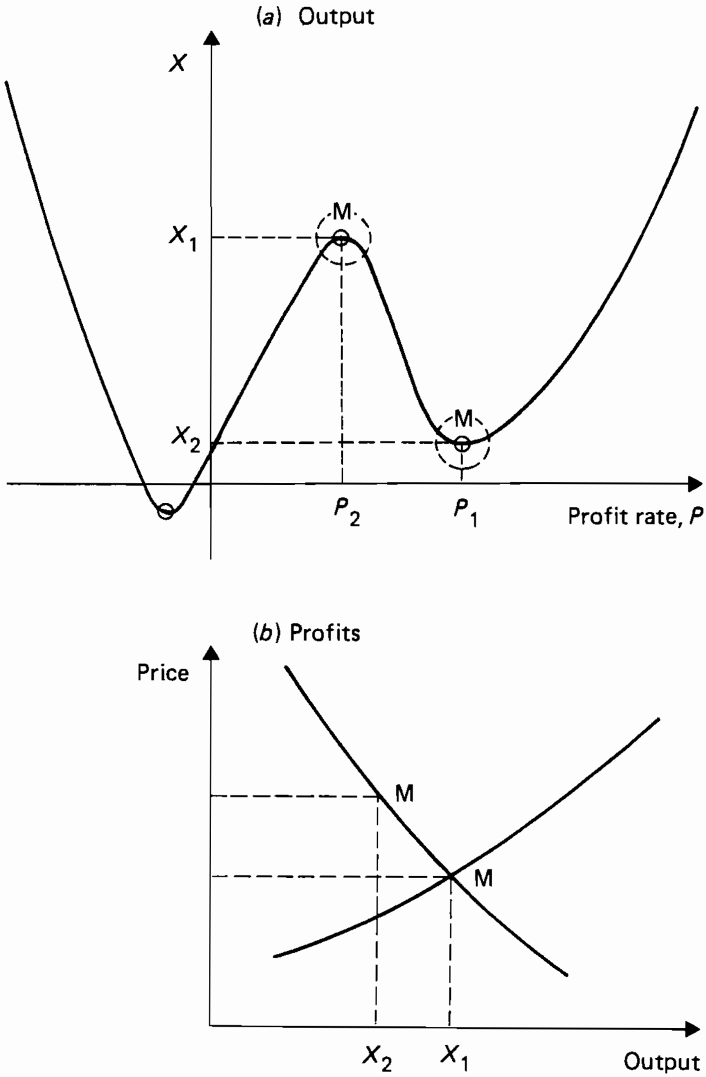

Figure 25.5. **Maximum and minimum optimal points in (*a*) output and (*b*) profits.**

These crises, although they coincided with long upturns, were fairly strong by historical standards. It is of this period that Lenin (1964), writing in 1916, indicated that cartels aggravated economic crises instead of making them less vigorous. Note that the theoretical values, even those representing one of the two real positive roots, follow year-by-year changes in the actual movement; only the big leaps are better described by a change to the other root.

Figure 25.6(*b*) extends this analysis to 1916–1937. It is apparent that at some time during World War I the prevailing competitive mode changed to a predominantly monopolistic one, which was seriously broken only by the crisis

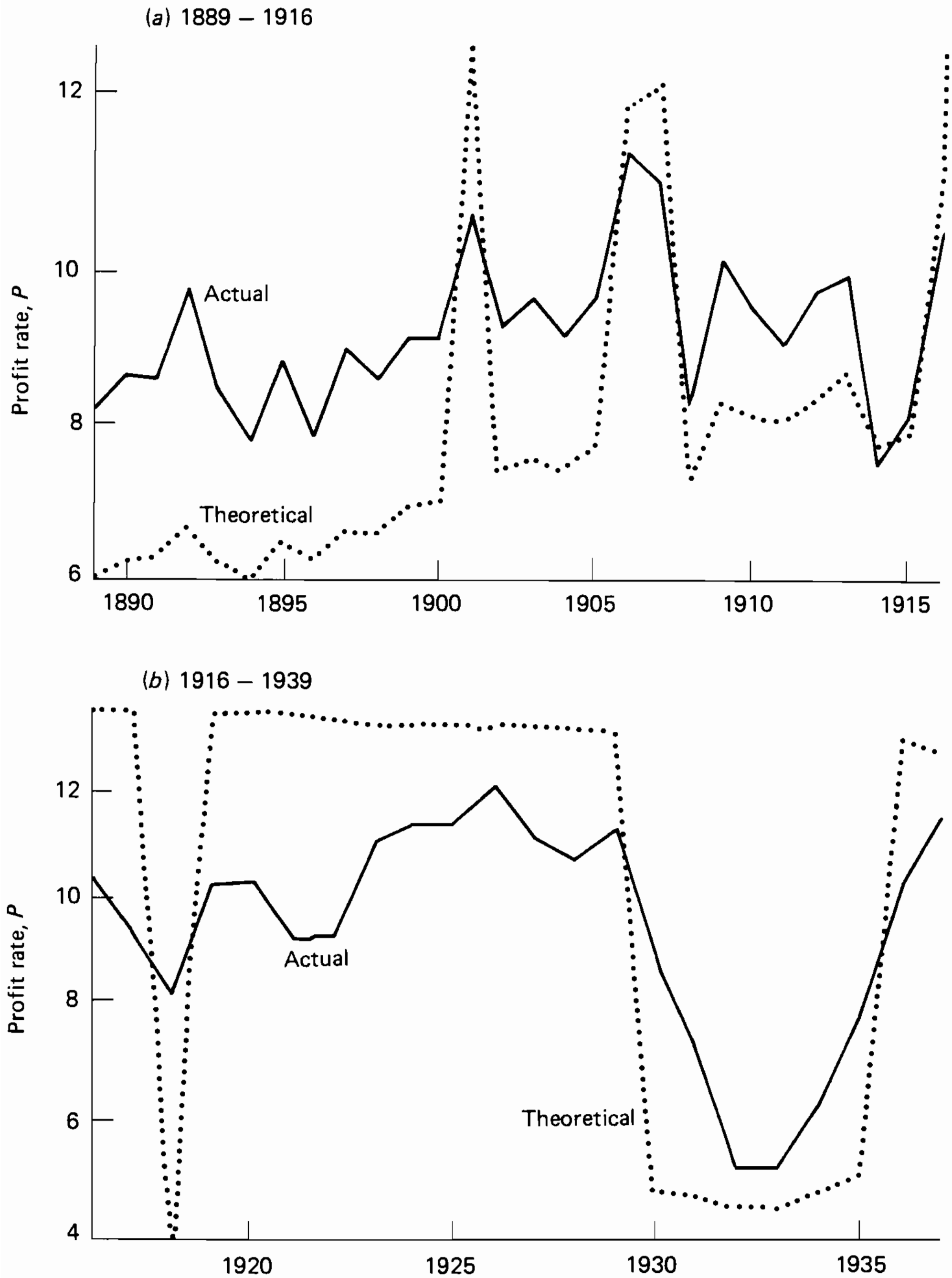

Figure 25.6. **Actual and theoretical profit rates in (*a*) 1889–1916 and (*b*) 1916–1939.**

of 1929–1933. The movement of the theoretical values, at least, for the larger real root, becomes rigid and replicates changes in the actual profit rate less accurately. This is also true of later periods. After World War II all models have only one root corresponding to real paths of the economy, and thus the possibility of a leap in the mathematical sense is absent. This may reflect a new situation, when monopolistic tendencies in the economy are actively supported by the state (conditions of state-monopoly capitalism).

However, it should be noted that for the postwar, as for earlier periods, there were both movements close to minimum output in relation to profits, reflecting relatively more favorable long-term business conditions (1939–1956), and movements close to maximum output in relation to profits, when long-term business conditions were becoming relatively less favorable (1960–1982). This apparent change in the mode of operation of the economy coincided with actual changes from the phase of upturn to downturn in the long wave.

But although the optimal regimes in the two models that are used to approximate the postwar period (1933–1958 and 1956–1982) are definitely different, the transfer from one to the other is not directly registered in the overall model for the postwar period (1939–1982); the latter refuses to support the general hypothesis only after 1956. It is worth noting that the model for 1956–1982 starts its operation in the maximum regime only after 1960, but again refuses to support the existence of a different regime before 1960. Apparently the transition from one regime to another does occur in 1956–1960, but we have not yet been able to model it.

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CHAPTER 26

Structural Change and Long-Term Fluctuations in Economic Growth

W. Krelle, R. Dobrinsky, J. Gajda, H. Ross, I. Székely, and H. Welsch

26.1. Introduction

The last decade was and the next decades will be periods of substantial structural economic change: newly industrialized nations emerged, East Asia became a leading economic center, new products and production technologies were developed, energy and environmental problems were recognized, and unemployment and short- and long-term cycles were much in evidence. Thus IIASA decided to look into the problems of structural change and long-term economic fluctuations. In February 1985 a joint Bonn–IIASA research group was established at Bonn University, in collaboration with research groups in several industrialized countries, to analyze and forecast economic structural change at the world level. This chapter outlines the theoretical background and approach of the project, shows how long-term fluctuations may arise, and presents some preliminary results of the project.

26.2. A Theory of Long-Term Fluctuations

26.2.1. Theoretical background: A two-country growth model

We begin with a two-country growth model and analyze the equilibrium growth path. Changes in the determinants of this growth path give us the main reasons for structural change, and cyclical changes in these determinants help explain long-term fluctuations in economic growth.

Consider two countries *vis-à-vis* the rest of the world, each of which produces goods under a neoclassical production function. The gross domestic product (GDP) Y_i of country i is produced by labor L_i with efficiency π_i, and with capital K_{ii} produced within the country and capital K_{ji} imported from the other country. Domestic secondary inputs are netted out; imported secondary inputs may be subsumed under imported capital. Thus we assume

$$Y_i = F_i(L_i \pi_i, K_{ii}, K_{ji}) \quad i,j = 1,2 \quad i \neq j \tag{26.1a}$$

where F_i has the usual neoclassical properties (quasiconcave, non-negative, homogeneous of degree one). Because of the homogeneity property, we may rewrite equation (26.1a) as

$$y_i = \pi_i g_i(\kappa_{ii}, \kappa_{ji}) \quad y_i := \frac{Y_i}{L_i} \quad \kappa_{ji} := \frac{K_{ji}}{L_i \pi_i} \tag{26.1b}$$

The product of each country may be used for consumption as well as for investment in both countries. The products are assumed to be different. Labor and capital are assumed to remain within each country, but commodities move freely across the border. The exchange rate floats freely and is determined by the equality of foreign currency demand and supply on the exchange market. Firms minimize cost and households maximize utility, which determines the demand functions for primary factors and commodities. The exogenous variables are the savings (or investment) ratios:

$$s_1 := \frac{I_{11}}{Y_1} + \frac{p}{e} \cdot \frac{I_{21}}{Y_1} \tag{26.2a}$$

$$s_2 := \frac{I_{22}}{Y_2} + \frac{e}{p} \cdot \frac{I_{12}}{Y_2}$$

where I_{ij} := investment goods produced in country i and invested in country j, $p := p_2/p_1$ = ratio of price levels of countries 2 and 1, e := exchange rate = price of the currency of country 1 in terms of the currency of country 2 (country 2 = the country considered, country 1 = the rest of the world).

$$w_{Li} := \dot{L}_i / L_i = \text{rate of growth of labor supply in country } i \tag{26.2b}$$

$$w_{\pi i} := \dot{\pi}_i / \pi_i = \text{rate of technical progress in country } i \tag{26.2c}$$

$$w_{pi} := \dot{p}_i / p_i = \text{rate of inflation in country } i \tag{26.2d}$$

and, of course, the initial conditions L_0, π_0, and p_0. If we want an equilibrium growth path at the global level, we also have to assume that

$$w_{L1} + w_{\pi 1} = w_{L2} + w_{\pi 2} \tag{26.2e}$$

which is not unreasonable in the very long term. Details of the model may be found in Krelle (1985a) and Krelle *et al.* (1985). It can be shown that this model determines the equilibrium growth path of all endogenous variables as functions of the exogenous variables and that the model is stable in the relevant region [see Krelle (1985a)]. The main features of the solution are:

(1) The equilibrium growth rates of both countries are equal.
(2) Real wage rates, interest rates, capital labor ratios, wage–profit ratios, capital coefficients, GDP and GDP per capita are and remain different, in general. There is no tendency for the standards of living in both countries to become equal.
(3) The global-level GDP is higher with foreign trade than without it, and this also applies for each country separately. In exceptional cases consumption per capita may nevertheless decline in one country (see Krelle, 1985a).
(4) The relative purchasing power parity theory (PPPT) of the exchange rate is valid.

If capital movements are considered, the real interest rates will be equal in both countries, all other results remain unchanged. Free mobility of labor is required to equalize real wage rates on the equilibrium path, in general. The Bonn–IIASA world model is a 23-country (or country group) model constructed along these lines. The real part of it is described briefly below.

26.2.2. The real part of the Bonn–IIASA world model: An overview

The basic tool is a Cobb–Douglas-type production function for each country i. Thus, equation (26.1a) is specified and modified as:

$$Y_{i,t} = \pi_i(t) \cdot L_{i,t}^{\alpha_1} \cdot K_{i,t}^{\alpha_2} \cdot IM_{Ri,t}^{\alpha_3} \tag{26.3}$$

where IM_{Ri} = real imports of secondary inputs (raw materials, energy, etc.). The exogenous variables are the same as in (26.2). The GDP Y_i of country i is subdivided into ***sectoral products*** y_{ij}, such that $Y_i = \sum_j y_{ij}$. Sectoral production y_{ij} is a function of total production Y_i, labor productivity Y_i / L_i, consumption per capita C_i / L_i, capital–labor ratio K_i / L_i, export ratio EX_i / Y_i, import ratio IM_i / Y_i, and similar variables:

$$y_{ij} = \beta_{ij}\,[(Y_i / L_i), (C_i / L_i), (K_i / L_i), (EX_i / Y_i), (IM_i / Y_i), \ldots]\,Y_i \tag{26.4}$$

such that $\sum_j \beta_{ij} = 1$.

Several types of functions β_{ij} have been tried (linear, exponential, etc.). The sectors considered include agriculture, mining, manufacturing, electricity and gas, construction, and services. Similarly, the commodity structure of exports and imports are estimated by functions explaining this structure.

26.2.3. The monetary part of the Bonn–IIASA world model: An overview

For market economies the price level in each country is explained by the money supply (exogenous), the real GDP (as determined above), and the velocity of money, which in turn is explained by the rate of inflation, the capital coefficient, the purchasing power, interest rate disparities, and other variables. The exchange rate index $\bar{e}_2$ of the currency of country 2 with respect to all other currencies is explained by:

$$\bar{e}_2 = \frac{p_2}{p_1}(a_0 + a_1\pi + a_2\rho + a_3\rho_{-1} + a_4\rho_{-1}\pi + a_5\Delta w_Y + a_6\lambda + a_7 e_{-1}) \tag{26.5}$$

where $\pi = w_{p1} + w_e - w_{p2}$ = the purchasing power disparity, $w_e := \dot{e}/e$; $\rho = r_1 + w_e - r_2$ = the interest rate disparity, r_i = interest rate in country i; $\Delta w_Y = w_{Y1} - w_{Y2}$ = the growth rate differential, $w_{Yi} := \dot{Y}_i / Y_i$; and λ = the net creditor or debtor position of country 2 (= the net assets or the debts of country 2 divided by the GDP of country 2). The individual exchange rates e_{ij} of each currency with respect to each other currency can be obtained from the time series of $\bar{e}_i$ for each country i. If the arbitrage conditions

$$e_{ij} = \frac{e_{ik}}{e_{jk}} \quad i,j,k = 1,\ldots,n \quad e_{ii} = 1 \tag{26.6}$$

are fulfilled, and if the exchange rate index $\bar{e}_i$ of currency i is a weighted average of all exchange rates with respect to currency i,

$$\bar{e}_i = \sum_{j \neq i} \alpha_{ij} e_{ij} \quad i = 2,\ldots,n \quad \alpha_{ij} \geq 0 \tag{26.7}$$

$$\sum_{j \neq i} \alpha_{ij} = 1$$

the exchange rate e_{i1} for each country $i = 2,\ldots,n$ with respect to currency 1 is determined by

$$1/e = A^{-1}\alpha \tag{26.8}$$

where

$$\frac{1}{e} = \begin{bmatrix} 1/e_{21} \\ \cdot \\ \cdot \\ \cdot \\ 1/e_{n1} \end{bmatrix} \quad \alpha = \begin{bmatrix} \alpha_{21} \\ \cdot \\ \cdot \\ \cdot \\ \alpha_{n1} \end{bmatrix} \quad A = \begin{bmatrix} \bar{e}_2 & -\alpha_{23} & \dots & \alpha_{2n} \\ -\alpha_{32} & \bar{e}_3 & \dots & -\alpha_{3n} \\ \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot \\ -\alpha_{n2} & -\alpha_{n3} & \cdots & \bar{e}_n \end{bmatrix}$$

Unfortunately, the determinant A is sometimes very small. Therefore, in a newer version of the model we use a behavior equation instead of the identity (26.8) to recover the exchange rates e_{i1} from the exchange rate indices $\bar{e}_i$. This behavior equation explains e_{i1} by the ratio $\bar{e}_i/\bar{e}_1$ of exchange rate indices and a weight adjustment factor, which reflects the importance of the trade relations between country i and country 1.

For the CMEA countries other methods are used to determine exchange rates and the price levels. For OECD countries capital flows and interest rates are also determined endogenously (see Krelle, 1985b; Krelle and Welsch, 1985).

26.2.4. Determinants of long-term economic growth and structural change

Long-term fluctuations in economic growth are considered to be fluctuations in the equilibrium growth path of an economy. We have outlined above a global model where the equilibrium growth paths of all economic variables, aggregated (such as GDP, exports, imports) as well as disaggregated variables (such as agriculture, manufacturing), are determined by four exogenous variables (or time series): the savings or investment ratio, labor supply growth rate, the rate of technical progress, and the rate of growth of money supply (or the rate of inflation) of each country. We now consider 23 countries (or groups of countries) which together make up the whole world. Thus there are 23 × 4 = 92 time series (or in this simple case, constants) that must be predetermined in order to solve the system in the forecasting period. If all exogenous variables are constant, the system should settle down to an equilibrium growth path. If they show long-term fluctuations, the system should produce long-term fluctuations for the aggregates as well as for all sectors. We now show that long-term fluctuations in the savings ratio and in the rate of technical progress are likely to occur.

26.2.5. Long-term fluctuations in economic growth

The investment ratio and the rate of technical progress depend on the "degree of activity" within the society, which (following Schumpeter) may also be called the "degree of entrepreneurship" (see Schumpeter, 1914, 1926, 1939). It is highly correlated with a preference for work and risk, with a spirit of optimism and a small discount rate for the future, as opposed to a preference for leisure and safety, a spirit of pessimism and a high discount rate for the future. We measure this degree of activity by an index α, which might be considered as the reciprocal of the average disutility of work in the society. The rate of technical progress $w_\pi := \dot{\pi}/\pi$, as well as the investment ratio s, depend on α:

$$s = s(\alpha) \quad s' > 0 \quad w_\pi = w_\pi(\alpha) \quad w_\pi'(\alpha) > 0$$

The dependence of s on α may be derived from a Ramsey-type model of optimal capital accumulation (see Ramsey, 1928; Krelle, 1984, 1985a). The rate of technical progress also depends on α, since the rate of introducing new technologies depends on the degree of risk that the society is willing to take, and on investment in research and development (Krelle, 1984).

Thus if α fluctuates in the society, the equilibrium growth paths change with respect to the level as well as to the rate of growth. Since growth is stable on the equilibrium path, the system will slowly converge to a new equilibrium path, as shown in *Figure 26.1* (dotted curve).

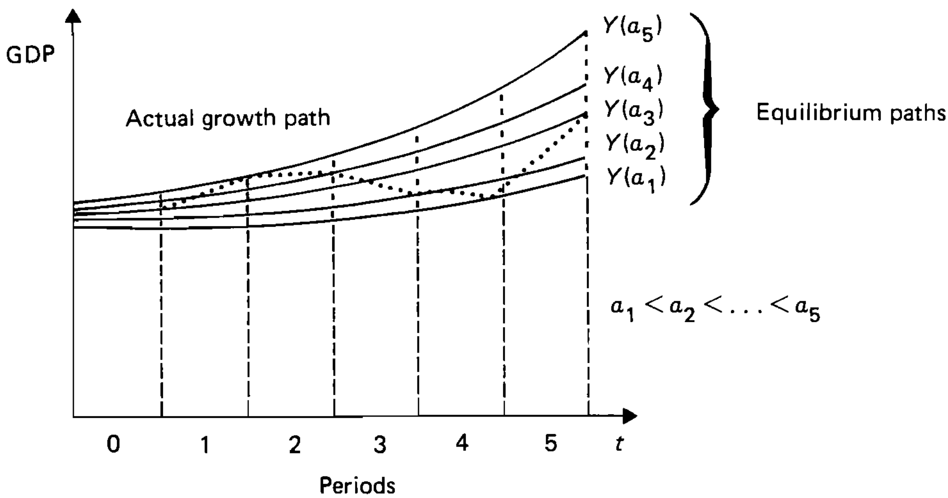

Figure 26.1. Equilibrium growth paths.

Fluctuations in α are due to the process of transfer of knowledge and values within the society. We assume that knowledge is created by people mostly working in research and development institutions, and it is transmitted to others by the communication system. Similarly and connected with knowledge, valuations are "invented" and transmitted to other people who adapt their own valuations and convey them again to other people. This process may be described by an interdependent system of linear difference equations and, in general, the solution will be cyclical. For society as a whole this process may be approximated by a simple linear second-order difference equation:

$$\alpha_t = b_1 \alpha_{t-1} - b_2 \alpha_{t-2}$$

where $b_i > 0$, $i = 1,2$, and $b_2 > b_1^2/4$. The characteristic roots are

$$s_{1,2} = \frac{b_1}{2} \pm \sqrt{b_1^2/4 - b_2} \quad \text{conjugate complex}$$

The solution is $\alpha_t = r^t [A \cdot \cos\varphi t + B \cdot \sin\varphi t]$, where

$$r = \sqrt{b_2} \qquad \varphi = \arccos \sqrt{(b_1^2/4)/b_2}$$

and A and B depend on the initial conditions. If $b_2 = 1$ we get pure sinusoidal fluctuations; if $b_2 < 1$ the system requires external shocks in order to show steady fluctuations. For $b_1 = 1.9$, $b_2 = 0.925$ the frequency of the fluctuations is about 40 years, if the period is one year. This seems to be a reasonable order of magnitude for long-term cycles.

26.3. Status of the Bonn–IIASA Research Project

Of course a theory as suggested above should be tested, and the Bonn–IIASA project provides the preconditions. In this section the preliminary results obtained so far are presented.

26.3.1. Empirical results: The real part of the Bonn–IIASA world model

The parameters of the production function (26.3) have been estimated for all 23 countries and country groups under consideration. For the socialist countries net material product (NMP) was used instead of GDP. In all cases in a first step imported raw material IM_{Ri} has been approximated by total imports IM_i. The assumption of a constant growth rate $w_{\pi i}$ of technical progress requires a specification $\pi_i(t) = \alpha_{0i} \cdot \exp(w_{\pi i} \cdot t)$. In equation (26.3) technical progress is written in the form of Hicks' neutral technical progress. Since we are using a Cobb–Douglas production function, this is also a Harrod neutral progress, and the classification of $\pi_t(t)$ as labor efficiency is justified. But note that the growth rate of the labor augmenting technical progress $\tilde{\pi}_t(t)$ from the specification $Y_t = f_t[(\tilde{\pi}_t \cdot L_t), K_t, IM_t]$ is normally higher than the growth rate of Hicks' neutral progress π_t from $Y_t = \pi_t \cdot f_t(L_t, K_t, IM_t)$. In the case of Cobb–Douglas functions $w_{\tilde{\pi}t} = (1/\alpha_1) \cdot w_{\pi t}$ where $\alpha_1 < 1$ is the production elasticity with respect to labor; $w_{\pi t}$ is always given as a percentage.

An assessment of the estimates was made with respect to different statistical criteria and economic plausibility:

(1) Standard error of estimation (SEE) or R^2, where the latter is normally very high because of the tendency of all time series to grow.
(2) Durbin–Watson (DW) statistics and sometimes plots of the residuals to decide whether autocorrelation might be due to some economic cycles that are not explained by the equation.
(3) t-statistics for the coefficients.
(4) Positive elasticities and reasonable parameters sizes: for market economies a "reasonable" size of the production elasticities is that of the factor cost shares. Both coincide if the marginal productivity theory holds.

When multicollinearity prevented a joint estimate of all parameters, values of $w_{\pi t}$ were fixed exogenously and the estimate with the best fit was selected. In general, the approach can be deemed successful because at least one satisfying equation was obtained for each country or country group. Two examples are presented in *Table 26.1*.

Table 26.1.

GDR (1960–1982)	$w_\pi = 1.0$	$\alpha_2 = 0.399$ (13.37)	$\alpha_3 = 0.188$ (8.68)	$\alpha_1 = 1 - \alpha_2 - \alpha_3 = 0.413$
	$R_c^2 = 1.0$	$DW = 1.32$		
Other Mid-East and North African developing countries (1962–1981)	$w_\pi = 1.5$	$\alpha_2 = 0.431$ (4.84)	$\alpha_3 = 0.196$ (3.1)	$\alpha_1 = 1 - \alpha_2 - \alpha_3 = 0.373$
	$R_c^2 = 0.98$	$DW = 1.21$		

Further research showed that the assumed constant growth rate of technical progress is somewhat restrictive when explaining historical trends. Many facts indicate that technical progress was higher in the 1960s than in the 1970s. Two approaches were made to deal with this in the production function: (i) the estimation period was split up into two shorter ones to which different growth rates were fitted; and (ii) the growth rate was specified to be a linear function of time: $w_{\pi i}(t) = \bar{w}_{\pi i} + \delta \cdot t$. The first approach resulted in considerably lower growth rates for the period 1973–1982 compared with those for 1960–1972. The statistical results improved in most cases. The second approach always led to a negative value of δ, implying a decrease in the growth rate. The results are shown in *Table 26.2* by some typical examples.

Table 26.2.

UK	$w_\pi = 1.38$	$\delta =$	-0.044		
(1960–1982)	(2.32)		(2.59)		
		$\alpha_1 =$	0.614	$\alpha_2 = 0.238$	$\alpha_3 = 0.147$
			(6.7)	(2.53)	(3.29)
	$R_c^2 = 1.0$	$DW =$	2.17		
Hungary	$w_\pi = 0.75$	$\delta =$	-0.011	$\alpha_1 = 1 - \alpha_2 - \alpha_3 = 0.282$	
(1960–1982)	$\alpha_2 = 0.357$	$\alpha_3 =$	0.361		
	(6.78)		(10.08)		
	$R_c^2 = 0.99$	$DW =$	1.26		
Developing	$w_{60-78} = 2.50$	$w_{79-81} =$	1.0		
Asian countries	$\alpha_2 = 0.462$	$\alpha_3 =$	0.135	$\alpha_1 = 1 - \alpha_2 - \alpha_3 = 0.403$	
excluding	(4.92)		(2.40)		
India (1960–81)	$R_c^2 = 1.0$	$DW =$	1.5		

The production structure is modeled by the production sector functions β_{ij} (26.4), which present the shares of GDP (NMP) produced in the different sectors of the economy. Production sector functions have also been estimated for all 23 countries and country groups.

Since the production sector functions explain sector *shares*, they should be estimated according to certain requirements, the most important of which are:

$$0 \le \beta_{ij} \le 1 \quad \text{and} \quad \sum_j \beta_{ij} = 1$$

These requirements have been used where necessary to impose restrictions on the parameters of the estimated equations.

Three types of functional relationships have been tested for the production sector functions: linear, exponential, and Cobb–Douglas type; the outcomes of these tests can be summarized as follows. The linear functions can be estimated with parameter restrictions that guarantee that the summing up requirement is always met, but the non-negativity checks showed that these functions very often yield negative values for combinations of values of the explanatory variables that may occur in the forecast period. The exponential type of β_{ij} functions did not meet the $\beta_{ij} \le 1$ condition in quite a few cases. In general, the functions specified in Cobb–Douglas form best met the main requirements, and this specification seems most appropriate for the production sector functions of the countries and groups of countries.

Table 26.3. Estimates of production sector functions for agriculture and manufacturing, using the estimated equation (26.8).

Sector/Area	a_1	a_3	a_4	a_5	R^2	*DW*
Agriculture						
USA	−1.354	–	–	−0.261	0.96	1.39
	(27.11)	–	–	(2.05)		
GDR	−0.625	–	−0.486	0.696	0.92	1.16
	(3.24)	–	(1.33)	(2.1)		
Developed Latin America	−0.670	–	–	−0.139	0.97	1.77
	(13.18)	–	–	(1.1)		
Manufacturing (industry total for CMEA)						
USA	0.579	−0.085	−0.191	0.51	0.77	1.69
	(4.84)	(1.84)	(3.03)	(5.53)		
GDR	0.137	–	0.076	−0.166	0.02	1.04
	(4.0)	–	(1.05)	(2.51)		
Developed Latin America	0.128	–	−0.170	0.387	0.84	1.21
	(3.76)	–	(3.08)	(3.86)		

Within each estimated production sector function, different combinations of explanatory variables have been tested, and the selection has been made according to the common statistical criteria as in the case of the production functions (see above). In some cases it was necessary to omit some explanatory variables due to multicollinearity or low statistical reliability of the estimated parameters. As an example, *Table 26.3* presents the estimation results using equation (26.8):

$$\beta_j = a_0 (Y/L)^{a_1} \cdot (K/L)^{a_2} \cdot (EX/Y)^{a_3} \cdot (IM/Y)^{a_4} \cdot (I/Y)^{a_5} + u \quad (26.8)$$

for the production sector functions for two of the most important economic sectors: agriculture and manufacturing (industry total, in the case of the CMEA countries) for three of the countries and country groups.

26.3.2. Empirical results: Exchange rates and capital flows for OECD countries

At present, *exchange rates* have been modeled for the OECD countries represented separately in the model, i.e., the USA, FRG, Japan, France, UK, Italy, Netherlands, Belgium/Luxemburg, and Canada.

The theoretical basis for exchange rate determination is a two-country model, where each country produces a specific good and has its specific money and an interest-bearing asset (see Krelle and Welsch, 1985). For each of these items, demand functions are derived from utility or portfolio optimization. Their arguments are available income, the exchange rate, the price ratio, and the relative creditor or debtor position. The exchange rate equation is derived by substituting the appropriate demand functions into the balance of payments equation and solving for the exchange rate. After some approximations and linearizations, this procedure yields the estimation equation (26.5), which states that in long-term equilibrium growth (with constant π, ρ, Δw_y, λ), the exchange rate is determined by relative purchasing power parity. Deviations from purchasing power parity are due to monetary disequilibria, differences in growth rates, and foreign debts.

Table 26.4. Exchange rate index parameters for the FRG. (The estimation method was in all cases OLS, the estimation period 1970–1982; figures in parentheses are t-values).

a_0	a_1	a_2	a_3	a_4	a_5	a_6	a_7	*DW*	R^2C	*MAPE*[a]
1.321	−0.013	0.025	0.010	–	–	−1.308	–	1.53	0.969	2.34
(22.72)	(2.58)	(4.14)	(3.69)			(4.10)				

[a]MAPE = mean absolute percentage error.

Table 26.5. Exchange rate index parameters for other countries.

	Japan	*France*	*UK*	*Italy*	*Netherlands*	*Belgium*	*Canada*
DW	1.19	1.51	1.12	1.16	1.94	1.53	0.96
R^2C	0.893	0.944	0.978	0.993	0.923	0.880	0.892
MAPE	14.13	1.34	2.57	2.09	1.55	1.39	2.52

In order to implement this approach in the multi-country case, we estimate the exchange rate index of each country with respect to all other countries. The index is defined as a weighted average of the individual exchange rates, where the weights are averages of export and import shares. This index formula can in turn be used to determine the individual exchange rates from the estimated exchange rate indices. Parameter estimates for the exchange rate index of the FRG according to equation (26.5) are given in *Table 26.4*, and for other countries in summary form in *Table 26.5*.

In general, the fit is quite good. All parameters have the right sign. The *DW*-figures for all estimates lie in the indifference region; thus we cannot reject the hypothesis that there is no first-order autocorrelation in the residuals. (The region for acceptance of this hypothesis is empty for some countries, due to lack of degrees of freedom.) Except for Japan, all estimated parameters are significant according to the t-values. Since the t-test is only valid in the case of normally distributed residuals, we also applied the χ^2-test on normal distribution. The normal distribution hypothesis could in no case be rejected at the 0.95 significance level. Variations of the estimation period showed that the estimates are also sufficiently stable. In recovering the individual exchange rates, i.e., the price of the US dollar in terms of the various other currencies, we obtained the mean absolute percentage errors in *Table 26.6*.

Table 26.6.

	FRG	*Japan*	*France*	*UK*	*Italy*	*Netherlands*	*Belgium*	*Canada*
MAPE	5.74	7.05	5.67	6.17	4.87	5.30	5.93	3.99

Since they are influenced by the errors in all estimated equations, they are larger than the MAPE for the exchange rate indices.

Capital flows are treated in the model in the form of balances since we do not have data on the inflows and outflows separately. The estimation equation is (see Krelle and Sarrazin, 1983):

$$B'C = a_1 \rho Y + a_2 \pi Y + a_3 \delta Y + a_4 \rho_{-1} \Delta Y + a_5 \pi_{-1} \Delta Y + a_6 \delta_{-1} \Delta Y + a_7 (EX - IM) \quad (26.9)$$

where $B'C$ is the balance of capital flows (inflows minus outflows), Y, EX and IM denote nominal GDP (of all countries considered), nominal exports and imports, respectively, δ is the ratio of the change in foreign reserves to nominal GDP, and the other notations are as above. The equation was estimated with good results for the FRG, and for others the preliminary results are quite promising.

26.3.3. Empirical results for CMEA exchange rates

The definition of exchange rates in East European CMEA countries poses special problems. The values of exports and imports are published basically in units of "valuta currencies" (except for Hungary since 1976, and Poland since 1982), which are not related to the units of domestic currencies. Imported goods with the same dollar (valuta) prices can have different domestic prices. This is roughly equivalent to variable subsidies and taxes associated with different commodities. The exchange rates of CMEA countries remained unchanged until 1971 and since then have moved in a similar, although non-identical fashion. It is important to find an explanation for their behavior; our behavior function links the exchange rate of the Soviet valuta rouble (= FXDA16) to the dollar position on the international market (= FXSE01, which is the exchange rate of the US dollar with respect to special drawing rights) and to the US price level (= P'GDP01):

$$FXDA16 = (a_0 + a_1 \cdot FXSE01 + a_2 \cdot P'GDP01) \cdot \frac{P'GDP16}{P'GDP01}$$

which is a linearized version of the purchasing power parity hypothesis. The exchange rates of the other East European CMEA countries are linked to that of the valuta rouble FXDA16 in the same manner (see *Table 26.7*).

Table 26.7. Exchange rates of the CMEA countries.[a]

Country	*CONST*	*FXDA16*[b]	*P'GDP01*[c]	*DW*	R^2C	*MAPE*
USSR[d]	−0.976	0.889	1.096	1.55	0.93	1.684
	(11.7)	(8.8)	(37.3)			
Bulgaria	−0.839	0.805	1.068	1.62	0.95	1.205
	(14.6)	(10.3)	(38.1)			
Czecho-	−0.902	1.015	0.881	1.00	0.94	1.479
slovakia	(14.3)	(11.8)	(28.6)			
GDR	−0.554	0.517	1.037	1.38	0.80	1.949
	(6.4)	(4.4)	(24.4)			
Hungary	−1.101	0.650	1.463	1.41	0.94	2.258
	(8.8)	(3.8)	(24.0)			
Poland	−0.802	0.919	0.907	1.95	0.90	1.598
	(11.2)	(9.4)	(25.8)			
Romania	−0.688	0.483	1.228	1.72	0.96	1.417
	(11.4)	(5.9)	(41.7)			

[a] t-ratios are shown in parentheses.
[b] The exchange rates FX... were expressed as indices, with the basis year 1975.
[c] Related price levels ($P'GDP_i$, i = 16,71,72,73,74,75,76) of CMEA countries were set equal to 1.
[d] For the USSR, FXSE01 was used instead of FXDA16.

Although they are still preliminary, these results support the hypothesis that the dollar and rouble exchange rates are the leading causes of adjustments in the value of East European valuta currencies. The estimates seem acceptable from the point of view of their fit, signs of coefficients, and of the test statistics of the estimates. They clearly indicate the possibility of deriving values of the CMEA valuta currencies from the real value of the purchasing power of the US dollar. Of course the problem of linking these rates to the domestic market remains. Directions for further improvements (introduction of domestic prices, net foreign assets, debts) can be found in Krelle, 1985b).

26.4. Concluding Remarks

It has been shown that a world model may be constructed that is capable of producing equilibrium growth paths for all countries. These paths depend on the savings (or investment) ratios, rates of technical progress, rates of growth of labor supply, and the rates of inflation of all countries. These differ from country to country, in general, and therefore GDP per capita, real wage rates, interest rates, and other economic variables are and will remain different, in spite of the free flow of commodities between countries. Kondratieff cycles are explained as long-term fluctuations in equilibrium growth paths due to cyclical movements of exogenous variables, especially the savings ratio and the rate of technical progress. These cycles arise from the transfer of knowledge and valuations within the society. The theory can be tested by a world model of the kind envisaged in the Bonn–IIASA project.

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CHAPTER 27

Outline of a Formal Theory of Long-Term Economic Cycles

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27.1. Introduction

As unemployment persists in many regions and industries in the developed world, the Kondratieff-wave model has returned into favor with those who wish to say why unemployment crept in and persists. The trouble is that the gradualism built into the long-wave concept overshadows the true causality: The underlying change in industry structure, and the swiftness of possible reversal to full employment if investors are not discouraged by wrong notions of gradualism. The main objective, thus, of this chapter is to bring back hope. There exist faster ways to full employment than suggested by the wave model.

Schumpeter's fundamental insights into the dynamics of economics is that the economic nonequilibrium process may be viewed as a superposition of long- and short-term cycles. This is a mechanistic concept. The micro-economic reasons for the appearance of these cycles are very different. Their formal treatment thus necessitates both micro-economic and macro-economic concepts.

Short-term economic cycles, with periods of only a few years, may be viewed as arising within a quasi-stationary phase of a long-term cycle. In such a phase the total structure of the economy remains quasi-stable. The development in that phase is viewed as driven by an ensemble of products, and market growth is promoted by competing entrepreneurs who are capitalizing on the driving forces of technological progress and are checked by market constraints. Therefore an appropriate description of these short-term processes consists in a mathematical theory about the decision framework of interacting entrepreneurs. Most important are their decisions on expansionary or rationalizing investments undertaken because of the pressure in the markets. Such a theory has been implemented by the authors, in several papers in recent years.

Long term economic cycles, if they exist, are expected to arise for other, deep-lying structural reasons. The main "phases" of long-term cycles (recovery, prosperity, recession, and depression) have been analyzed in detail by Kondratieff, Schumpeter, and many others.

With respect to the definition and sequence of these phases, Mensch (1975) came to differing conclusions. His metamorphosis model built upon the well known observation of leading industrial economists that each product in its individual life cycle passes through several stages from technological progeneration to technological maturity. He related the organic growth model of technological change on market levels with microeconomic notions of investment (including investment in innovation, product development, technology transfer, basic research, etc.). Distinguishing "basic innovations" (which give birth to new industries), "improvement innovations" (in established industries), and "pseudo innovation" (when markets mature), Mensch (1971, 1972) developed a longitudinal model of industrial evolution. The idea is that at any time, within any economy, there is a manifold of competing commodities on the market, and these can be ordered according to their level of immaturity. There can be found a distribution of products ranging from young, developing, and prospering, to mature, aging, and obsolete products. In a nutshell, the concept of immaturity (= 1 - maturity) operationalizes innovations by tying it in with the notion of imperfect markets.

This approach we shall employ here. The main insight is that each phase of the long-term cycle can be characterized by the maturity distribution of the product manifold *typical for this phase*. For instance, in an era of general economic prosperity one finds that a majority of products are also in the prospering phase of their life-cycles, while in a recession the majority of relevant products are in an aging phase, implying pseudo innovation, market congestion, stagnation, decline.

The main idea on the generation of long-term macroeconomic cycles with the above sequence of phases can now be identified. Within an economy there must exist dynamic principles of metamorphosis, leading to interdependencies between "generations" of products in *similar* stages of their inherent development. In passing through their life cycles, these products may even cluster, and then more or less simultaneously traverse the stages of innovation, prosperity, and aging. Mensch's metamorphosis model suggested: basic innovations tend to occur in clusters, triggering subsequent sequences of improvement and, later, pseudo innovations. In the aggregate, this timing and synchronization creates the observed phases in the long-term cycle.

At this point it is important to stress that one seemingly simple explanation of product clusters must be rejected: inputs of new basic ideas, namely, basic inventions, which later give rise to basic innovations and a series of new products, do not generally appear in clusters. Available data show (Mensch, 1975) that the flow of newly arising basic laws and ideas is relatively smooth and stationary. Not a science push, but an entrainment into the economic process leads to the formation of product clusters and corresponding phases of the long-term cycle; at least in the past that was the causal direction in most cases observed.

27.2. Construction Principles for Models of Long-Term Cycles

The above description of industrial transformation suggests several elements that could be used to build a mathematical model of long-term cycles. Since the life cycles of products (a "meso-economic", semi-aggregate concept between micro- and macro-economics) play a fundamental role in the understanding of long-term economic processes, it seems appropriate to choose them as the central concept of a model. The main contribution in this chapter is to separate the causal dynamics of product development into two forces: (a) the *intrinsic dynamics* describing the "natural metamorphosis" of a product over its technological maturation process and evolution of its market share; and (b) the *interaction dynamics* describing how the product's life cycle is influenced by its technological and market interaction with the manifold of competing commodities at different stages of maturity. Hence we distinguish between intraindustrial (branch-specific) and interindustrial (cross-sectional) interaction dynamics between product life cycles.

Our long-term-cycle model architecture combines longitudinal elements of "innovation potential" and "technical constraints" with cross-sectional "market opportunities" for selling to buyers in other industries, and "cost constraints" on purchases from supply industries. The core of the proposed model consists of a set of coupled differential equations for the life cycles of interacting commodities. The interaction terms are chosen in a manner to describe the mutual promotion or suppression of interacting products at different stages of maturity. This mutual influence may lead to either acceleration or retardation of the development of certain groups of products. In this way, notions of economies and diseconomies to scale combine with notions of speed of change and substltition. The hypothesis is that the intensity of interaction will also lead to a *synchronization effect* so that bundles of products adapt their development stage and finally form clusters of innovations.

We hope that our model will be able to explain the self-organization of temporal structures – in terms of groups of products of synchronized maturity – and hence the generation of economic pulses that establish the phases of long-term cycles and on several levels of aggregation.

27.2.1. Intraindustrial dynamics

The mathematical formulation of these ideas can be outlined as follows. The starting point is an appropriately standardized description of the intrinsic dynamics of a single product life cycle. In this first step only the "selfaction" of the product's technological development and of the development of its market share is taken into account, regardless of the influences of its specific interactions with competing products. The typical form of such an idealized and isolated branch cycle of a product i is described by the function

$$m_i(t) = \tanh[\nu_i (t - t_i)] \tag{27.1}$$

which satisfies the differential equation

$$\frac{dm_i(t)}{dt} \equiv \dot{m}_i(t) = \nu_i (1 - m_i^2) \tag{27.2}$$

where ν_i is a diffusion or development rate parameter, and $m_i(t)$ is a normalized measure of the degree of maturity of product i, whose domain of definition is

$$-1 \leq m_i \leq +1 \tag{27.3}$$

The meaning of these definitions becomes clear if we plot the function (27.1) and identify its parts with the evolutionary stages of the product's life cycle (see *Figure 27.1*).

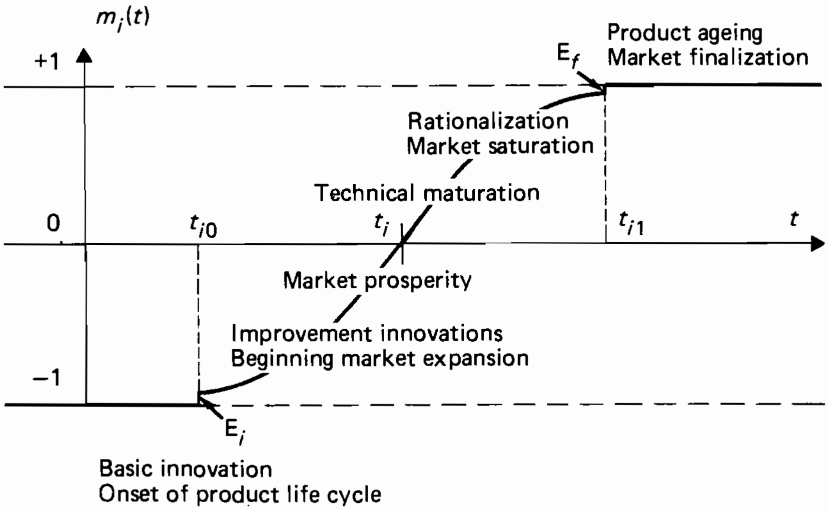


Figure 27.1. Stages of an isolated standard product life cycle.

Obviously the rate of development of very young and very old products is slow, while the maximum rate $\dot{m}(t = t_i) = \nu_i$ is reached at time t_i in the period of rapid technical maturation and maximal market expansion. Other equations of motion have also been proposed to describe "natural" or "standardized" product life cycles. All of them have the typical S-shaped form of a development function. Consider, for example, the well-known logistic equation for $n(t)$, which can be viewed as a measure of the market share of the product:

$$\frac{dn}{dt} \equiv \dot{n} = 2\nu n \left(1 - n/K\right) \tag{27.4}$$

with the standard solution

$$n(t) = K\left[1 + \frac{K - n_o}{n_o} e^{-2\nu t}\right]^{-1} \tag{27.5}$$

where $n(-\infty) = 0$; $n(0) = n_o$; and $n(\infty) = K$.

It turns out that equation (27.4) is equivalent to equation (27.2) after the transformation:

$$n = \frac{K}{2}(m + 1) \qquad m = \left[\frac{2n}{K} - 1\right] \tag{27.6}$$

Equation (27.2) will be used hereafter because it is more amenable to our purposes.

Before proceeding further, equation (27.2) has to be modified to take into account the fact that the lifetime of a product does not extend from $(-\infty)$ to $(+\infty)$, as does the solution (27.1) of (27.2), but that there is a well defined onset time t_{io} of the product cycle, namely the time of the basic invention. In many cases a more or less well defined finalization time t_{i1} also exists, when the product reaches a steady state in the market and a constant share in the economic process. Both effects can be included by adding an initiation term ε_i and a finalization term ε_f to equation (27.2)

$$\frac{dm_i}{dt} = \nu_i(1 - m_i^2) + \varepsilon_i\,\delta(t - t_{io}) + \varepsilon_f\,\delta(t - t_{i1}) \tag{27.7}$$

where $\varepsilon_i = m_i(t_{io}) \ll 1$ and $\varepsilon_f = [1 - m_i(t_{i1})] \ll 1$, and where the initial condition chosen is

$$m_i(-\infty) = -1 \tag{27.8}$$

A basic innovation occurs at t_{io}. That event triggers the branch cycle. The δ-function terms in (27.7) give rise to the step in m_i from $m(t < t_{io}) = -1$ to $m_i(t_{io}) = (-1 + \varepsilon_1)$, the beginning of the cycle, and to the step in m_i from $m(t_{i1}) = (1 - \varepsilon_f)$ to $m(t > t_{i1}) = 1$, the finalization of the cycle. The solution to the modified equation (27.7) is now exactly as shown in *Figure 27.1*, namely,

$$\begin{aligned} m_i(t) &= -1 && \text{for} \quad -\infty < t < t_{io} \\ m_i(t) &= \tanh[\nu_i(t - t_i)] && \text{for} \quad t_{io} \le t \le t_{i1} \\ m_i(t) &= +1 && \text{for} \quad t_{i1} < t < +\infty \end{aligned} \tag{27.9}$$

In concrete models the onset time t_{io} and the finalization time t_{i1}, as well as the development rate ν_i and the time of maximal prosperity t_i are chosen for each product according to economic data (for abstract normative models, however, one may make simplifying assumptions). The step constants ε_1 and ε_f are then determined by

$$\begin{aligned} m_i(t_{io}) &= (-1 + \varepsilon_1) = \tanh[\nu_i(t_{io} - t_i)] \\ wm_i(t_{i1}) &= (1 - \varepsilon_f) = \tanh[\nu_i(t_{i1} - t_i)] \end{aligned} \tag{27.10}$$

We are now describing groups of branch cycles. To obtain a first impression of the situation in an economy in terms of its product composition, let us make the customary, simplified assumption that the life cycles $m_i(t)$ of products i are noninteracting and hence obey equation (27.7) with solution (27.9). Furthermore, we assume equal rates $\nu_i = \nu$ and equidistant distribution of product onset times t_{io} (an alternative assumption would be a random distribution of onset times with constant mean density per time interval). We thus obtain *Figure 27.2(a)*, which depicts birth and growth of new industries as a succession of branch cycles. That is the longitudinal pattern under these simplified assumptions. Of great interest now is the cross-sectional pattern. At any time τ, $\tilde{\rho}(m;\tau)\,dm$ describes the number of products in the interval $(m, m + dm)$; then $\tilde{\rho}(m;\tau)$ is the density distribution function. It has some remarkable properties. First, the number of products in the interval dm is proportional to the time dt, that a product spends in dm, i.e., to $dt = dm/\dot{m}$. Hence, $\tilde{\rho}(m;\tau)$ must be proportional to $1/\dot{m}$. Inserting (27.7), one finds that

$$\tilde{\rho}(m;\tau) \sim \frac{1}{(1 - m^2)} \tag{27.11}$$

except for the fringe domain $|m| \gtrsim 1$, where the initiation and finalization steps occur. Second, equation (27.11) shows that products in very early or late development phases are more common than those in the prosperity phase, simply because each product stays longer in the early innovation or late

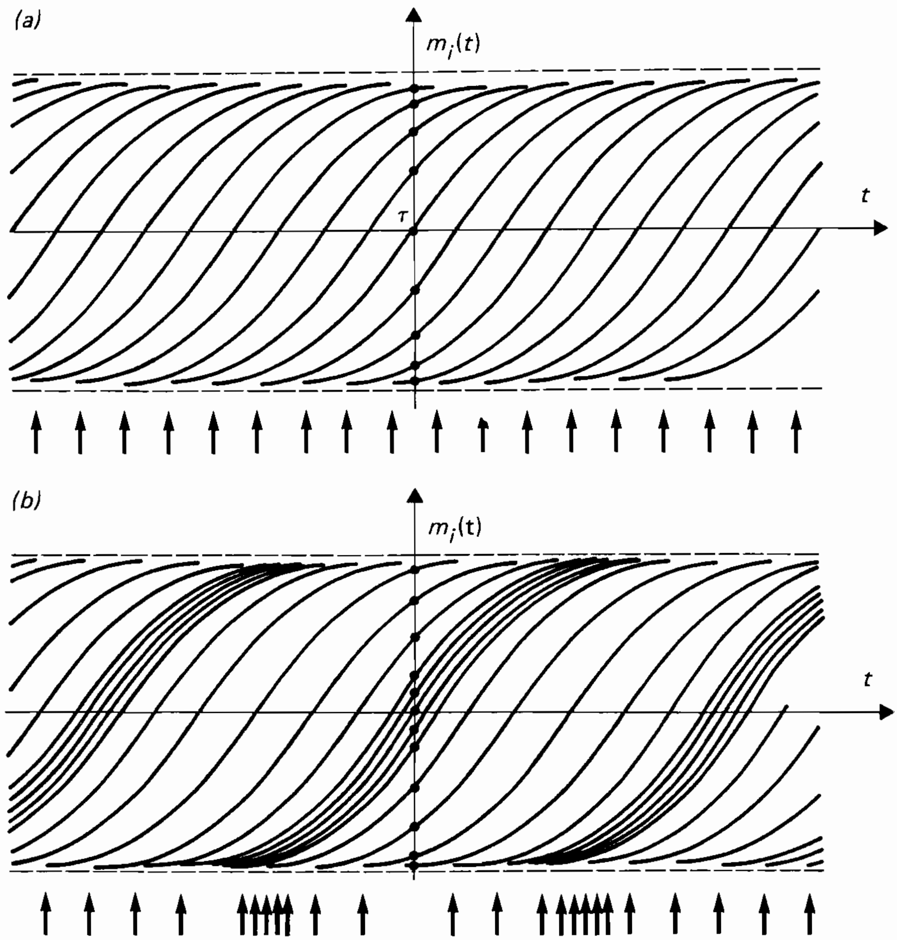


Figure 27.2. Ensembles of (*a*) noninteracting and (*b*) interacting product life cycles.

stagnation phases. This can be seen from the product distribution at time τ in *Figure 27.2(a)*. Third, the density distribution is the same at all times t.

Products in different phases have different weights for the economic process. Products in their prosperity phase provide a much higher volume of business than those in the early innovation phase, when market shares are small, or in the late stagnation phase, when supply per unit of output is smaller in highly rationalized production. Therefore, instead of $\tilde{\rho}(m;\tau)$, a "renormalized" density function $\rho(m;\tau)$ is introduced. It incorporates the weights of products in different phases. Then $\rho(m;\tau)$ gives a more realistic picture of the branches' relative importance for the state of the economy. The simplest choice for weighting is to multiply $\tilde{\rho}(m;\tau)$ by $(1-m^2)$, because it puts the weights in the "middle". Then one obtains the renormalized density function

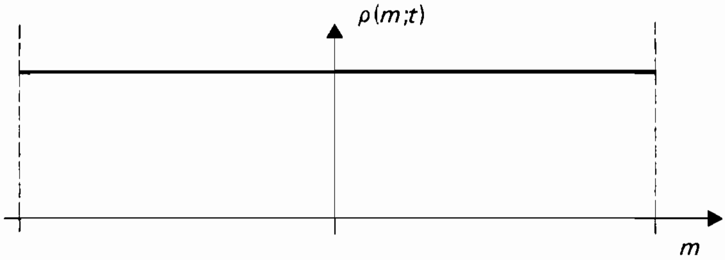


Figure 27.3. Weighted product density function $\rho(m;\tau)$ for noninteracting product cycles.

$$\rho(m;\tau) = (1 - m^2)\,\tilde{\rho}(m;\tau) = \text{const} \tag{27.12}$$

which has been depicted in *Figure 27.3.*

This constancy and time-invariance of the cross-sectional density pattern is a very important property, because it flies in the face of any experience. Hence, it must be based on highly implausible assumptions. The function (27.12) is valid only in the limiting case of noninteracting and equidistant entry of new product cycles. Nearly the entire literature on product life cycles implies these conditions, as does mainstream economics if it does not specify a better set of entry assumptions.

27.2.2. Interindustrial interaction dynamics

We now give up the assumption of *isolated* product life cycles. As suggested above, the oscillatory long-term dynamics of an economy is generated by the *interaction* between life cycles. Therefore, in a second and important step, equation (27.7) will now be extended by including interaction terms between product life cycles. The general form of the equation of motion for interdependent life cycles $m_j(t)$ then reads:

$$\frac{dm_j}{dt} = \left[\frac{\partial m_j}{\partial t}\right]_{\text{intra}} + \left[\frac{\partial m_j}{\partial t}\right]_{\text{inter}} \tag{27.13}$$

where the first term

$$\left[\frac{\partial m_j}{\partial t}\right]_{\text{intra}} = \nu_j\,(1 - m_j^2) + \varepsilon_1\,\delta(t - t_{jo}) + \varepsilon_f\,\delta(t - t_{j1}) \tag{27.14}$$

describes the self-formation of the product life cycle by its internal dynamics according to equation (27.7), while the second term $\left(\partial m_j / \partial t\right)_{\text{inter}}$ contains the interaction of $m_j(t)$ with all other product cycles at time t. There exist, of course, numerous ways of specifying this term. As a first approach we propose the following form for the interaction term:

$$\left(\frac{\partial m_j}{\partial t}\right)_{\text{inter}} = \sum_i^{m_i > m_j} F_{ji}^{+} + \sum_i^{m_i < m_j} F_{ji}^{-} \tag{27.15}$$

where supporting and detracting forces are defined as

$$\begin{aligned} F_{ji}^{+} &= C^{+}(m_i)E^{+}(m_j)D^{+}(m_{ij})\ \Theta\,(m_{ij}) \\ F_{ji}^{-} &= C^{-}(m_i)E^{-}(m_j)D^{-}(m_{ji})\ \Theta\,(m_{ji}) \end{aligned} \tag{27.16}$$

The key interaction variables m_{ij} are

$$m_{ij} = \frac{m_i - m_j}{2}; \quad -1 \le m_{ij} \le +1 \tag{27.17}$$

They will now be explained in connection with the first and second terms on the right-hand side of (27.15). These two terms express the accelerating or retarding total action forces exerted on m_j by all product cycles m_i at more mature ($m_i > m_j$) or at younger ($m_i < m_j$) stages than m_j.

First, there is the individual force $F_{ji}^{\pm}$ that cycle m_i exerts on m_j, according to (27.16). It is assumed to factorize into influence parameters having different functional dependencies on m_i and m_j.

Second, there are the terms $\Theta(m_{ij})$ and $\Theta(m_{ji})$, where $\Theta(x)$ is the step function,

$$\Theta\,(x) = 1 \ \text{ for } \ x > 0 \qquad \Theta\,(x) = 0 \ \text{ for } \ x < 0 \tag{27.18}$$

They set the boundary conditions, as they automatically ensure that $F_{ji}^{+} \neq 0$ only for $m_i > m_j$, and $F_{ji}^{-} \neq 0$ only for $m_i < m_j$.

Third, the factors $E^{\pm}(m_j)$ describe how the sensitivity of product j to the influence of others depends on the degree of maturity m_j itself. These factors express the "cross-elasticities".

Fourth, the factors $C^{\pm}(m_i)$ incorporate the dependence of force $F_{ji}^{\pm}$ on the degree of maturity m_i of product i interacting with product j. More generally, $C^{\pm}(m_{i,\ldots})$ could also depend on $\dot{m}_i \equiv \mathrm{d}m / \mathrm{d}t$ and $\ddot{m}_i \equiv \mathrm{d}^2 m / \mathrm{d}t^2$, since the influence of i on j will depend strongly on the "dynamics" of product i as expressed by its maturation rate $\dot{m}_i$ and acceleration $\ddot{m}_i$. However, as soon as one neglects the interaction terms $[\partial m_j / \partial t]_{\text{inter}}$ in (27.13), $\dot{m}_i$ and $\ddot{m}_i$ can be readily expressed by m_i using equation (27.7) for isolated life cycles:

$$\dot{m}_i \cong \nu_i (1 - m_i^2); \quad \ddot{m}_i \cong -2\nu_i m_i (1 - m_i^2) \ . \tag{27.19}$$

If the self-dynamic terms $[\partial m / \partial t]_{\text{intra}}$ in (27.13) dominate, while the interaction terms $[\partial m / \partial t]_{\text{inter}}$ play the role of perturbations, equation (27.19) remains approximately valid also in the case of the full set of equations (27.13). Hence, one may consider $C^{\pm}(m_i ; \dot{m}_i , \ddot{m}_i)$ as a function of m_i only after substituting (27.19) for $\dot{m}_i$ and $\ddot{m}_i$.

Finally, the terms $D^{\pm}(m_{ij})$ take into account that the influence of i on j may strongly depend on the "maturity distance" m_{ij} between products i and j. For instance, the aging of obsolete products will have a stimulating and accelerating influence on the development of younger products, and *vice versa*. These factors thus express the "generations gap" and conflict.

Detailed models built on the basis of equations (27.13)–(27.17) will, of course, require explicit assumptions about the form of coefficients $C^{\pm}(m_i)$, $E^{\pm}(m_j)$ and $D^{\pm}(m_{ij})$ in accordance with observations about the interactions between product cycles. Results of computer calculations with such explicit models, however, are beyond the scope of this chapter and will be published elsewhere.

Instead, we now deduce the effects of interactions between product cycles – as introduced in (27.13) – on the renormalized product density functions $\rho(m ; \tau)$ introduced in (27.12). We have seen that this distribution function is a constant for noninteracting and equidistantly introduced product cycles, as shown in *Figure 27.3*. What happens if we modify these assumptions?

A seemingly minor change in the sequence of entry of new branches dramatically changes the overall pattern of industrial metamorphosis. If we assume clustered entry of new industries, we get bundled growth in the new industries. This self-organization of branches has been depicted in *Figure 27.2(b)*. Now the cross-sectional density functions vary with time. In fact, a cluster of basic innovations creates pulse and ripple effects in improvement innovations, which spread through the economy's industrial base, causing growth and transformation. Hence, long swings and industrial metamorphosis can be explained: Long swings result from propagating long-term pulses of the density function $\rho(m ; t)$. *Figure 27.4* shows these pulses for a sequence of the four characteristic phases t_1 (prosperity), t_2 (recession), t_3 (depression), and t_4 (recovery).

This completes the delineation of our formal theory of long-term cycles. The density function $\rho(m ; t)$ for the (renormalized) maturity distribution is a central quantity. Many other macroeconomic variables are functions of it. It is, therefore, to be expected that the understanding of the long-term dynamics of $\rho(m ; t)$ in terms of interacting product life cycles as indicated above will promote a comprehensive and quantitative understanding of the dynamics

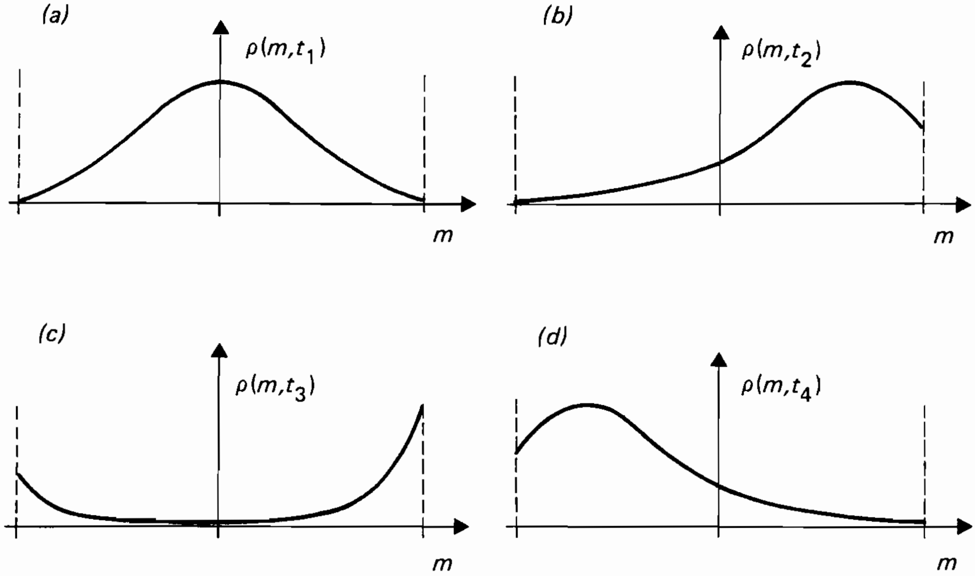


Figure 27.4. Density function pulses. (*a*) t_1 (prosperity): a prevalence of prospering products. (*b*) t_2 (recession): a prevalence of aging products and lack of innovations. (*c*) t_3 (depression): aging products becoming obsolete and the onset of innovations. (*d*) t_4 (recovery): development of an innovation cluster toward prospering products.

of relevant processes within long-term economic cycles. The linkage is strongest via investment theory.

27.3. Relations Between Maturity and Strategic Investment

New business develops in imperfect markets (immature industries) when firms undertake innovations. Then they invest. They invest if they face a threat or an opportunity. The concept of the maturity variable $m_i(t)$ connects to the notion of expectations. Expectations are not static. They are dynamic pictures of the future, and they should thus be related to variables that are particularly sensitive to changes in the degree of maturity of products.

In order to make the connection between innovation and investment, the notion of "strategic" investment is important here. In neo-classical and Keynesian economics, the notion of "induced" investment prevails: Total investment is viewed as a multiple (fraction) of desired total output or total capacity (flow and stock models). We define "strategic" investment as "microeconomically induced" by recognized imperfections in the market segments served by companies.

Viewed as such, two aspects matter concerning the total volume of expenditures for investment purposes, on the one end, and the net effect of all investment efforts after competition has cancelled some of the benefits of rivaling investments in contested markets. As is well known from the discussion of the investment multiplier, expenditures may be additive, the net effects are non-additive.

If competition is a two-frontier battle at the demand side and at the supply side of a contested market, then perceived sales opportunities may trigger expansionary investments E, and expected cost competition will trigger rationalizing investments R. These we denote "strategic" and postulate: the sum total of strategic investment I is $I = E + R$, whereas the net effect of that composition of investment is proportional to $E:R$ (Mensch, 1979).

The basic proposition here is that the rate and direction of innovative investment activity (E, R) change over time. This has been suggested before by economists in the Harrod, Domar, Robinson school of thought, as well as by managerial economists such as Abernathy and Utterback. In a nutshell, an E-bias drives branch growth via demand pull, whereas an R-bias in interrelated branches slows down growth in some supplying industries (factor squeeze) but accelerates growth in others (such as those who supply office automation, new manufacturing systems, robots, etc.). For an empirical validation of this view, see Chapter 29 in this volume.

We have thus set the stage for linking demand-induced product innovations and cost-induced process innovations to the level I and composition (E, R) of investment. We model long-term motions of industry by proposing that the evolution of branch i is an advancement in the maturity variable $m_i(t)$ caused by strategic investment, notably by the long-term components of the expansionary and rationalizing investment, $E_{io}(t)$ and $R_{io}(t)$, respectively. $E_{io}(t)$ and $R_{io}(t)$ do not contain short-term oscillations of branch i.

The (long-term) total strategic investment I_{io} in branch i is defined as above as

$$I_{io}(t) = E_{io}(t) + R_{io}(t) \tag{27.20}$$

and the expansionary (e) and rationalizing (r) shares of these quantities are defined as

$$e_i(t) = \frac{E_{io}(t)}{I_{io}(t)} \qquad r_i(t) = \frac{R_{io}(t)}{I_{io}(t)} \tag{27.21}$$

with $e_i(t) + r_i(t) = 1$. The basic proposition now means that we expect, at early stages in the life of product i, $e_i(t)$ to be rather large (near 1), and at aging stages it will be small (near 0). The converse holds for $r_i(t)$. For example, see *Figure 29.4(b)* in this volume. In a normative economy these variables can be linked to the level of maturity. In this way we begin by defining $m_i(t)$. Hence,

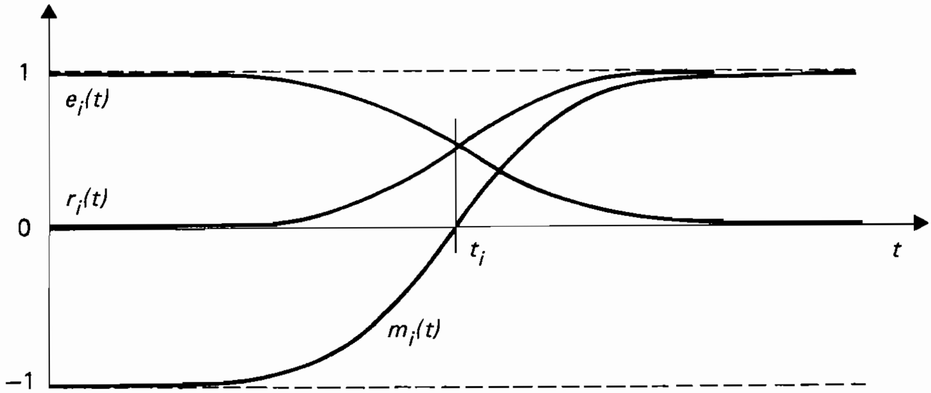


Figure 27.5. Expansionary and rationalizing investment shares and the maturity parameters in the ideal product life cycle.

$$m_i(t) = r_i(t) - e_i(t)$$

$$e_i(t) = \frac{1 - m_i(t)}{2} \quad r_i(t) = \frac{1 + m_i(t)}{2} \tag{27.22}$$

These quantities are depicted in *Figure 27.5*, where we have inserted (27.22) into form (27.1) of $m_i(t)$, and have neglected the interaction of $m_i(t)$ with other products for the moment.

For the evolution over time of total strategic investment, we assume that "strategic" expenditures for creating new demand and containing cost in the ith branch is proportional to the increment of change in maturity (= "program"):

$$I_{io}(t) = F_{io}\,\dot{m}_i(t), \quad F_{io} = \text{const} \tag{27.23}$$

as is depicted in *Figure 27.6*. The time of maximal prosperity of a product line comes when approximately $e_i \approx r_i$, or when $m_i(t) = 0$. This occurs at time t_i, when total strategic investment in branch i reaches its maximum. Of course a distorted maturity function $m_i(t)$ will also distort the symmetry of $I_{io}(t)$.

The evolution of $E_{io}(t)\ R_{io}(t)$ over time now follows from (27.21), with (27.22 and 27.23):

$$E_{io}(t) = I_{io}(t)\,e_i(t) = \frac{1}{2}F_{io}\,\dot{m}_i\,(1 - m_i)$$

$$R_{io}(t) = I_{io}(t)\,r_i(t) = \frac{1}{2}F_{io}\,\dot{m}_i\,(1 + m_i) \tag{27.24}$$

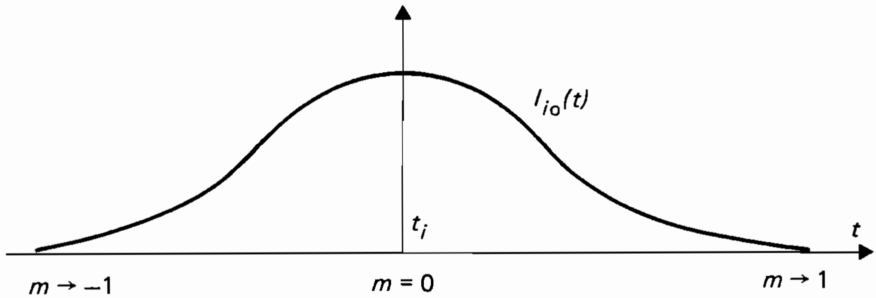


Figure 27.6. Total strategic investments as a function of time in the ideal product life cycle.

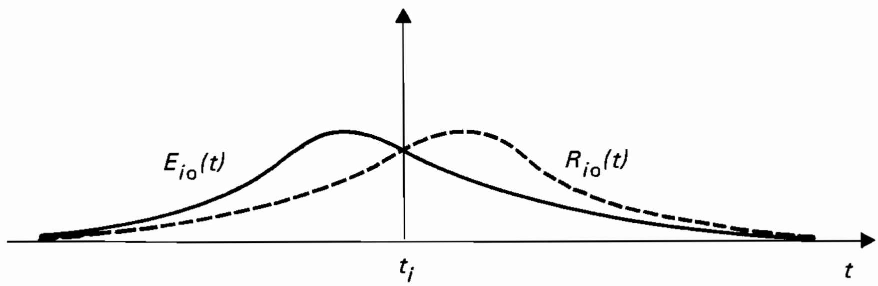


Figure 27.7. Expansionary and rationalizing investments for the ideal product li*f*e cycle.

as is depicted in *Figure 27.7*. This completes the deduction of the investment dynamics that underlie long-term swings.

Often, instead of the total strategic investment $I_{io}(t)$ of branch i, only the total investment $I_i(t)$ is known, where

$$I_i(t) = I_{io}(t) + I_{ia}(t) \tag{27.25}$$

$I_{ia}(t)$ is additional, tactical investment. If this is seen to be partially proportional to $E_{io}(t)$ and partially to $R_{io}(t)$, one can write

$$I_{ia}(t) = \alpha_i E_{oi}(t) + \beta_i R_{oi}(t) \tag{27.26}$$

where the positive coefficients α_i and β_i may be specified for each branch i. Inserting (27.26) and (27.24) into (27.25), one obtains

$$I_i(t) = I_{io}(t) \{1 + \alpha_i e_i(t) + \beta_i r_i(t)\} \tag{27.27}$$

which means that the shape of $I_i(t)$ is modified against that of $I_{io}(t)$ by the influence of $e_i(t)$ and $r_i(t)$.

In general, $I_i(t)$ is not symmetrical around t_i, even if $I_{io}(t)$ was so. Inserting (27.27) into (27.24), $E_{io}(t)$ and $R_{io}(t)$ can also be expressed as

$$E_{io}(t) = \frac{I_i(t)\, e_i(t)}{[1 + \alpha_i e_i(t) + \beta_i r_i(t)]}$$
$$R_{io}(t) = \frac{I_i(t)\, r_i(t)}{[1 + \alpha_i e_i(t) + \beta_i r_i(t)]} \qquad (27.28)$$

27.4 Application

In our post-Schumpeterian econometric work on employment, investment, innovation, and transformation, $E_{io}(t)$ and $R_{io}(t)$ are considered to be central causative variables for the whole economic process in branch i. It is also to be expected that $A_{io}(t)$, the trend in labor force working in branch i, depends on E_{io} and R_{io}, as does production $P_{io}(t)$.

A linear employment function,

$$A_{io}(t) = \tilde{u}_i E_{io}(t) - v_i R_{io}(t) + C_i \quad \tilde{u}_i > O \quad v_i > 0 \quad C_i > 0 \qquad (27.29)$$

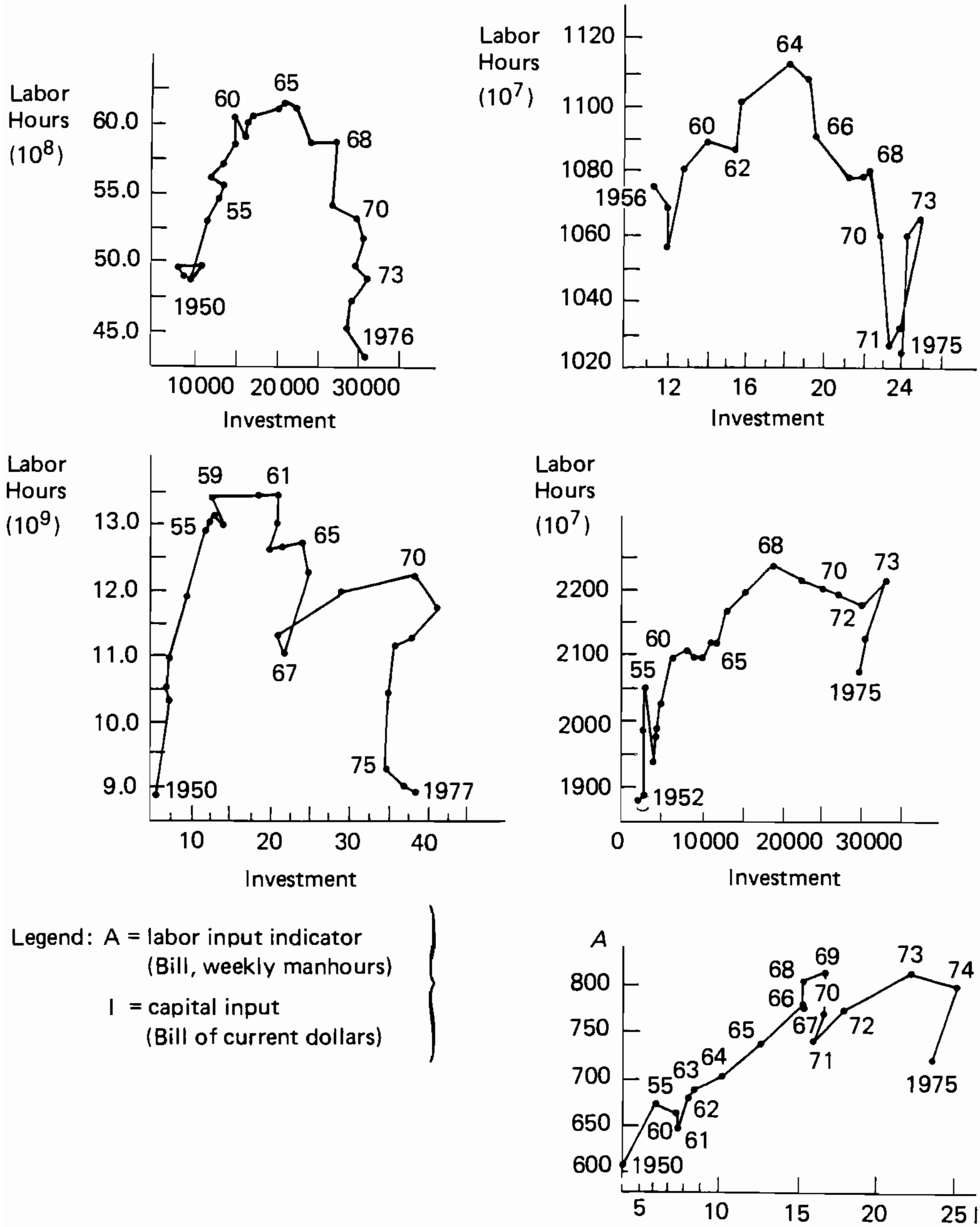
which incorporates that expansion, tends to increase and rationalization tends to reduce the total labor requirements. If, under ideal circumstances, time series for $A_{io}(t)$, $E_{io}(t)$, $R_{io}(t)$, $t = 1,2,\ldots,N$, were available, u_i, v_i, and C_i might be optically fitted by requiring:

$$\sum_{t=1}^{N} \{A_{io}(t) - [\tilde{u}_i E_{io}(t) - v_i R_{io}(t) + C_i]\}^2 = \min \qquad (27.30)$$

Finally, we wish to clarify the employment multiplier malaise that troubles mainstream economics (see ***Figure 27.8***). Equation (27.29), together with $I_{io}(t) = E_{io}(t) + R_{io}(t)$ [equation (27.20)], can be inverted for E_{io} and R_{io}, yielding

$$E_{io} = \frac{v_i I_{io} + A_{io} - C_i}{(\tilde{u}_i + v_i)} \qquad R_{io} = \frac{\tilde{u} I_{io} - A_{io} + C_i}{(\tilde{u}_i + v_i)} \qquad (27.31)$$

so that instead of $\{E_{io}, R_{io}\}$, the variables $\{A_{io}, I_{io}\}$ can be used to describe the evolution of branch i. Evidently any time path in the (I_{io}/A_{io}) plane is



Data source: Stat. Abstracts of the USA, 1976, Series 1303;
ILO yearbooks, 58er, 66er, 76er.

Figure 27.8. Moving proportions of employment and investment in five countries: (*a*) (*b*) (*c*) (*d*) (*e*). Data sources: Mensch (1979, pp. 233–235); *Statistical Abstracts of the USA, 1976* (Series 1303); and *ILO Yearbooks*, 58er, 66er, and 76er.

transformed into a time path in the (E_{io}/R_{io}) plane, and *vice versa*, by the transformation of coordinates (27.31). Hence, we have provided here a formal theory of long-term transformation that explains the mind-boggling picture of (I, A) trends in several Western countries first published by Mensch (1979).

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CHAPTER 28

Kondratieff and the Theory of Linear Filters

Rainer Metz

The discussion of long waves began with the publication of Kondratieff's essay in 1926, in which he examined 22 economic time series for Germany, France, England, and the USA with regard to the existence of long cyclical fluctuations. He noted that the movement of the elements examined showed great cycles from the end of the eighteenth to the beginning of the twentieth century. The movement is cyclical in nature, which means that it clearly differs from long-term changes in the series, which Kondratieff called the general tendency or secular trend. The essential feature of this long wave is that the different periods alternate in a cyclical way and thus seems to be law-governed. In contrast, the trend, whose course is also subject to certain changes, is not cyclical, i.e., it does not show a set pattern of upswings and downswings. Using his statistical analyses Kondratieff gave a fairly detailed description of the nature of these cycles.

(1) The length of the cycles fluctuates between 48 and 60 years.
(2) The cycles for the different series are highly synchronous, i.e., the upswing and downswing phases of the various indicators largely run parallel to each other.
(3) Long waves are an international phenomenon: the periods of these cycles are almost identical for all European capitalist countries.

Although Kondratieff admitted that the method he used to analyze the statistical data allowed an error of 5–7 years in determining the exact time of the turning point, he was convinced that the cycles were not the casual result of that method. Kondratieff's statistical procedure in particular was subject to severe criticism soon after the publication of his essay, and in the following these problems will be discussed in more detail. To this end, Kondratieff's methodology is briefly described here.

The basic tendency of all series that develop in a certain direction is eliminated. Kondratieff determined this tendency with the method of least squares by adjusting first- to third-degree polynomials to the corresponding series. Unfortunately, he did not adequately explain his choice of different trend equations adjusted to the various series, an omission that has drawn much criticism. Moreover, in his price series he eliminated neither the trend nor the short-term fluctuations. Since he based his analysis of long-term price cycles on original price data he has often been reproached for working arbitrarily.

After the trend has been determined, the purely cyclical movement can be produced by subtracting the trend value from the original values. The time series obtained in such a way, however, show not only long waves but also short-term cycles and random fluctuations. Kondratieff attempted to eliminate these by smoothing the trend-free series using a nine-year moving average; the long waves in pure form are the result of this statistical process.

Critics have pointed to both the arbitrary use of the procedures and their weaknesses; for example, Anderson (see Weinstock, 1964) highlighted the completely arbitrary choice of polynomials for trend approximation. In addition, Heiler (1981) pointed out that in most cases it has not been possible to substantiate the choice of a specific trend function statistically. In his work on Kondratieff cycles, Weinstock (1964) concluded that Kondratieff's results are too dependent on the applied procedures of trend elimination, so that it cannot be proved that Kondratieff's long waves are not just the result of statistical manipulation. The main problem in this context lies in finding a method of trend elimination that is particularly appropriate for the representation of long waves. In Weinstock's opinion, such a method has not been found, and so the problem remains unresolved (see below).

Apart from the problem of adequately determining the trend, criticism of Kondratieff's statistical procedure has also centered on the question of whether the long waves were artificially produced by multiple smoothing procedures. The danger that artificial cycles can be produced through these (transformation) procedures has been discussed as the "Slutzky-effect" (see Slutzky, 1937). For example, Nullau (1976) tried to prove that Kondratieff had produced the cycle artifically by continued smoothing. Garvy (1943) also criticized Kondratieff's methodological procedure in detail, particularly the arbitrary way in which Kondratieff determined the turning points of the long waves. These turning points were calculated from the original series and not from the smoothed trend-free series, giving the impression that the results were intentionally manipulated in order to make the different cycle phases nearly identical. Three essential points of criticism are discussed here:

(1) The problem of an adequate trend determination.
(2) The examination of statistical procedures with regard to a possible "Slutzky effect".
(3) The problem of determining the upper and lower turning points and, consequently, the upswing and downswing phases of the cycles.

After it was recognized that the once highly praised spectral analysis was completely useless in analyzing empirical evidence for long waves (see, e.g., van Duijn, 1983), the discussion on adequate trend determination has become more important in recent years. The most serious objection to the use of spectral analysis is that it can achieve reasonable results only if the time series being analyzed is stationary, i.e., trend-free. Since almost all economic time series show a more or less strong trend, they cannot be analyzed by means of spectral analysis. Those scientists who nevertheless utilize this method somehow try to eliminate trends from the series beforehand, but results achieved in this way vary considerably, and are sometimes even contradictory. As far as this procedure is concerned, its results are completely dependent on the way in which the trend is eliminated. As in all classical procedures of time series analysis, the problems of spectral analysis concentrate on the question of the adequate determination of the trend.

Intensive occupation with the characteristics of statistical procedures of time series analysis has shown that traditional methods are completely inappropriate in analyzing the phenomenon of long waves. This has led to the development of new techniques in which time series analysis is mainly considered to be a filter design problem (Stier, 1978, 1980). These considerations resulted from the fact that the current methods of time series analysis can also be regarded as filters; e.g., moving averages, polynomial trend approximations, and the calculation of first differences. Thus we can define a filter as a mathematical procedure that is used to change a given time series: each value of the time series is replaced by a new, transformed value. The various procedures have different characteristics, i.e., depending on the procedure applied, the transformed time series will take a different course. The filter theory deals with these (filter) characteristics in more detail.

The term *frequency* is the key to understanding this theory. In the simplest case, frequency means nothing other than the reciprocal of the duration of an oscillation; e.g., the frequency of a cycle with a periodic duration of 60 years is exactly 1/60 or 0.01667. The longer the duration of the oscillation, the smaller is the corresponding frequency. The shortest measurable duration of an oscillation of a series is always 2 time units and consequently has a frequency of 0.5 (the frequency can obviously have values ranging from zero to 0.5). A frequency of zero indicates that the corresponding oscillation is theoretically infinite. Frequency values can be calculated for long waves in a similar way. According to Kondratieff, the frequency of the long wave ranges from 0.0166 (= 1/60) to 0.0208 (= 1/48). If these frequencies are plotted, the frequency band corresponding to the long waves turns out to be extremely small compared with the many possible oscillation components of a time series. For the representation of the historical course of a long wave, time series oscillations are sought whose frequencies are in this domain. The duration of the oscillations on the left of this frequency band is longer than that of the long wave. These oscillation components are called a "trend". The filter theory aims to develop a technique that enables the representation of only those frequencies as a trend whose values are on the left of the frequency band of the long wave. Such a procedure can also be called a trend or low-pass filter. An important methodological advantage of filter analysis is that one can prove which frequency components are represented as a trend and which are eliminated or filtered out by the various methods. This characteristic of filter procedures can be examined by means of the so-called transfer function, which can be calculated for many procedures; its course indicates which oscillations are transmitted into the filtered series and which are not. Investigations of current procedures have shown that they do not achieve a clear separation between the trend and the long waves (see Schulte, 1981). As far as these procedures are concerned, the trend always contains at the same time potential long waves; thus it is impossible to prove the existence of long-term cycles in trend-free values even if they existed in the original series.

A further disadvantage of many procedures is that special oscillation components are amplified when the time series is transformed. If a filter procedure has such characteristics, there is always a danger that cycles will turn up that did not exist or were indistinct in the original series. It can be proved that the filters applied by Kuznets and Hoffmann to verify "long swings" have such Slutzky effects, especially in the frequency band of the "long swings" (see König and Wolters, 1972). According to these considerations, an adequate trend filter must meet the following requirements:

(1) It should only eliminate those oscillations as a trend whose period is longer than that of the long wave.
(2) It should not amplify any oscillations.
(3) All potential long-term cycles should be transferred unchanged, i.e., they must be represented as time series.

In other words, the transfer function of the procedure we are looking for must take the value 1 from the frequency 1/60 and must be zero for all frequencies from zero to less than 1/60. If the value of the transfer function is 1, the corresponding frequencies are exactly transformed in the filter output; if it is zero, the frequencies are completely eliminated. Schulte (1981) introduced a procedure of trend elimination that clearly shows these characteristics, and achieved for the first time an exact separation between the trend and the long waves.

Metz (1983) analyzed several economic time series with regard to the existence of long waves with this procedure. Even though the effect of this filter is impressive, it is difficult to interpret the trend eliminated by the filter in a reasonable way. Surprisingly, the trend calculated from the series has again a more or less wavy course. At that time it was not possible to explain this strange trend course, but since then the reasons for it have been explained. The filter causes a temporal shift in the different oscillations (see Schmidt, 1984). In concrete terms, this means the following: Let us assume that the delay of a cycle with a period of 52 years is 26 years. The peaks and troughs are delayed through the filter each time for about 26 years, so that whenever the original series has a peak, the filtered series has a trough; and *vice versa*. This characteristic of the trend filter is responsible for the wavy course of the trend, but it is obvious that such a procedure is completely inadequate in representing and analyzing long waves.

Schmidt (1984) has developed a technique that not only achieves an exact separation between trend and long waves as does the Schulte filter, but which also guarantees that the transformed oscillation components are not temporally shifted. In several papers I have discussed the effect and possibilities of this procedure for the analysis of long waves in industrial times (Metz, 1984b; Irsigler and Metz, 1984) and preindustrial times (Metz, 1984a; van Cauwenberghe *et al.*, 1984). In these articles I have also shown its advantages compared with the classical component model. Determination of the trend turned out to be the main problem in analyzing long-term cycles, in that it should be guaranteed that (1) the trend course can be interpreted in a reasonable way from both an economic and an historical view, and (2) the long waves are not enclosed in the trend.

With this filter, we have a procedure at our disposal whose lack was, in Weinstock's (1964) opinion, the reason why the problem of representing long waves empirically has so far been left unresolved. In the following I attempt to determine the trends for some of the time series analyzed by Kondratieff using this procedure, in order to show whether the long-term cycles identified by Kondratieff were actually the result of statistical manipulation. To this end, I first of all determined the trends for some of the series Kondratieff had analyzed: commodity prices (1780–1922), price of Consols [*Konsolidierte Staatsanleihen*] (1816–1922), and pig iron production (1840–1914) in England; price of the Rente [from the *Annuaire Statistique*] (1814–1922), total foreign trade (1827–1913), and coal consumption (1827–1913) in France. The trends were determined with the aid of a trend or low-pass filter in such a way that they only contained oscillations with a duration of more than 65 years. Consequently, potential long-term cycles have to be proved in the trend-free series.

The trend-free values can be represented by means of a trend elimination procedure or high-pass filter. Analogous to the trend definition, the high-pass filter eliminates all oscillations with a duration of more than 65 years. The long-term cycles can be represented as oscillations with periods ranging from about 60 to 12 years; this is done with the aid of a band-pass filter. The lower limit of 12 years was chosen according to Kondratieff's procedure, who achieved a similar effect with the use of a nine-year moving average. A comparison of the transfer functions of the applied filters with the frequency band of the long waves shows that the long-term cycles we are looking for are left untouched and not eliminated either by the procedure of trend representation or trend elimination. Since the technique applied here does not delay the filter output, the filter can be considered an ideal procedure for representing long waves.

[In the following figures, trends are estimated with a low-pass filter, and long-term cycles with the aid of a band-pass filter (BP). The amplitude characteristics (in years) of the filters used are denoted BP, beginning of passband; BS, beginning of stopband; EP, end of passband; and ES, end of stopband.]

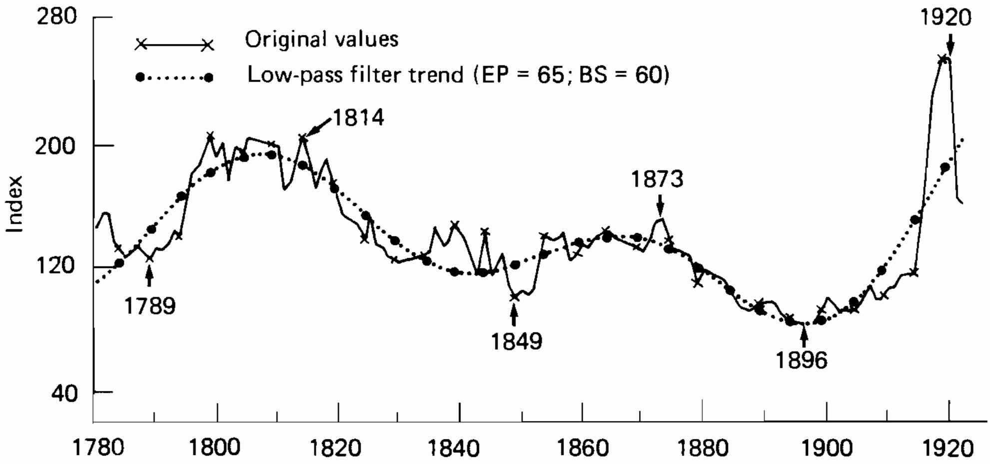

Figure 28.1. Trend in commodity prices in England, 1780–1922.

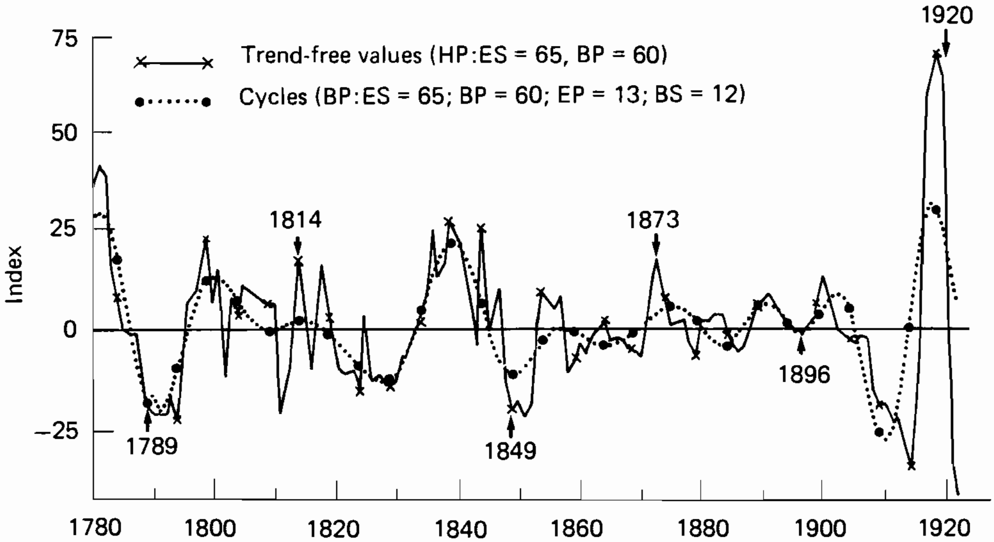

Figure 28.2. Long-term cycles in commodity prices in England, 1780–1922.

The results of the calculations were as follows. The trend in commodity prices in England is marked by clear trend phases that tend to fall until about 1900 (*Figure 28.1*), but these trend phases cannot be described as cyclical movements because the corresponding oscillations fluctuate between 65 years and infinity. Leaving aside Kondratieff's dating of the turning points, a trend upswing from 1780–1807 becomes visible, whereas Kondratieff dates the upswing of the first long wave to the period between 1789 and 1814. The following downswing lasts until about 1842. It is succeeded by a new faint

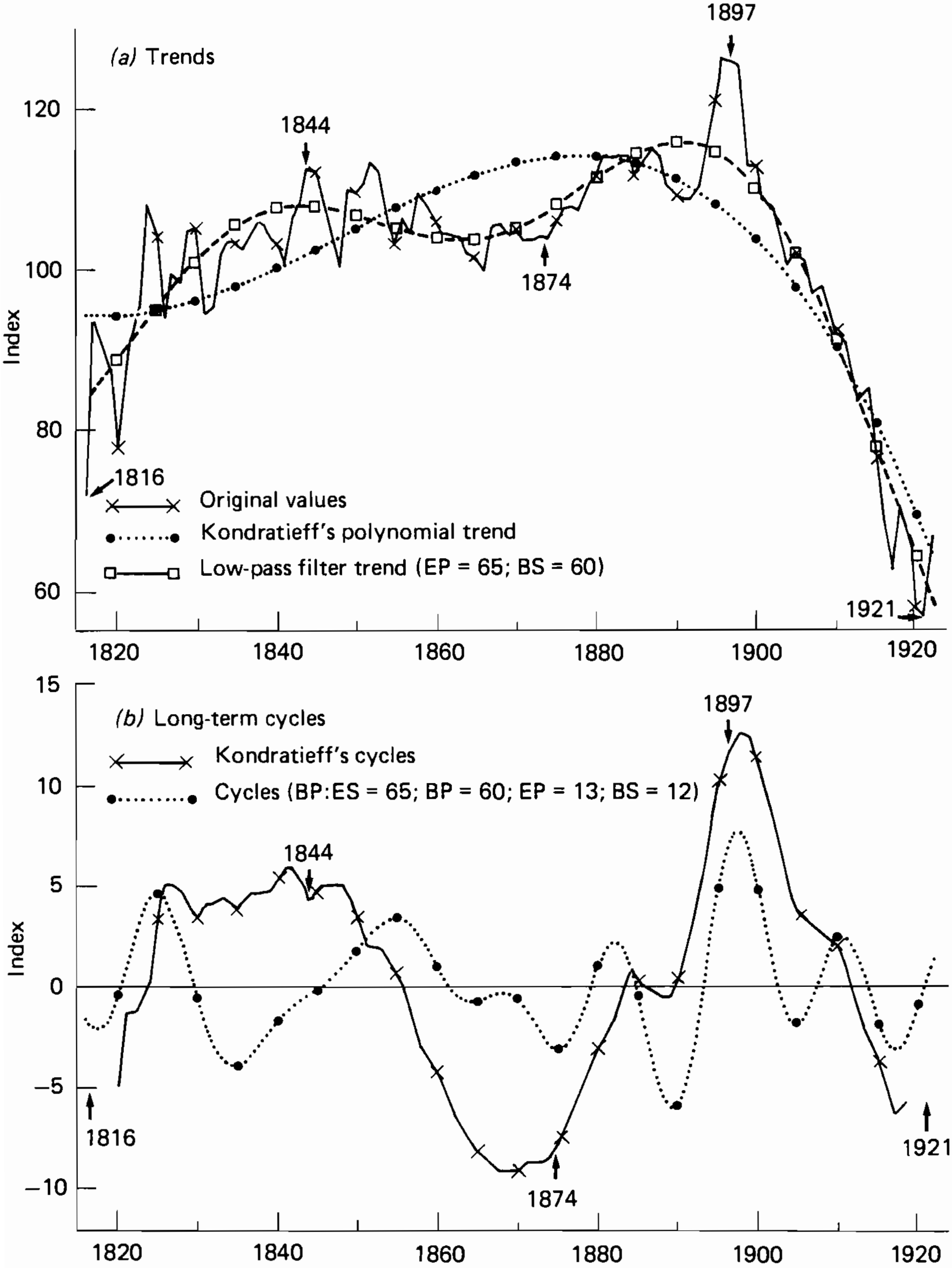

Figure 28.3. (*a*) Trends and (*b*) long-term cycles in consol prices in England, 1816–1922.

upswing ending in 1865, another downswing, and a new upswing that begins in about 1896. If these results are compared with Kondratieff's dating of long waves, it is evident that the long waves in commodity prices are trend phases that cannot be interpreted as cyclical movements; our cyclical movements follow a somewhat different course (*Figure 28.2*). The following long-term cycles can be ascertained (trough = T; peak = P): A first cycle extends from 1791 to 1800 (P) to 1825 (T). A clearly marked cycle follows until 1848 with its peak in 1839. The cyclical movement of the next period does not indicate clearly the existence of long-term cycles, but the level of the shorter cycles rises slightly until about 1902.

If the prices of the Rente in France and Consols in England are compared with the trends calculated by Kondratieff, the results shown in *Figure 28.3(a)* are obtained. The trend calculated by Kondratieff fits the course of the English consols much less closely than the trend according to our definition. Consequently, an exact separation of the trend from the long-term cycle is not guaranteed by Kondratieff's trend approximation; the result is that trend fluctuations are once more falsely interpreted as cyclical movements.

We calculate that the trend of the Consols rises to the year 1843, tends to fall until 1863, rises again until 1891, and falls steeply thereafter. Once again, these changes in the trend course cannot be interpreted as cyclical movements from a statistical point of view. Comparing our results with Kondratieff's cycles reveals clear differences [*Figure 28.3(b)*]. We calculate that a first cycle can be dated to the period 1817–1818 to 1834–1835, followed by a long upswing to 1855. The succeeding upswing lasts until the year 1889 and shows, especially after 1875, a distinct 14-year cycle that peaks in 1882. A 10-year upswing follows, which breaks off in 1897 and turns into a 21 year downswing lasting until 1917.

Similar strong differences between our and Kondratieff's results can also be found in the Rente price series in France. Kondratieff represents this series trend as a straight line. As *Figure 28.4(a)* clearly shows, this trend already anticipates the result – proof of the existence of long waves – that he could have achieved if he had dated the long waves according to the course of the original series. However, if the trend is calculated according to our definition, the long waves clearly prove to be trend phases. The trend shows two distinct upswing and downswing phases that cannot be measured as cyclical movements. Regarding the cyclical movements, the completely different trends may lead to different interpretations [(*Figure 28.4(b)*]. The two big cycles dated by Kondratieff dissolve into several shorter ones. The longest ascertainable cycle has a duration of 25 years, starting in 1848 and ending in 1873, and is succeeded by a further cycle whose trough is deeper than that of 1873, so that the end of this long cycle could be dated to 1888. The fact that the shorter cycles influence the trend-free movements more than the long waves is obvious. For this reason Kondratieff succeeds in verifying long waves in the three series investigated here, only because the chosen trend obviously cannot represent the existing trend phases adequately.

These trend phases therefore remain in the trend-free series and are erroneously described as cyclical fluctuations. According to our trend

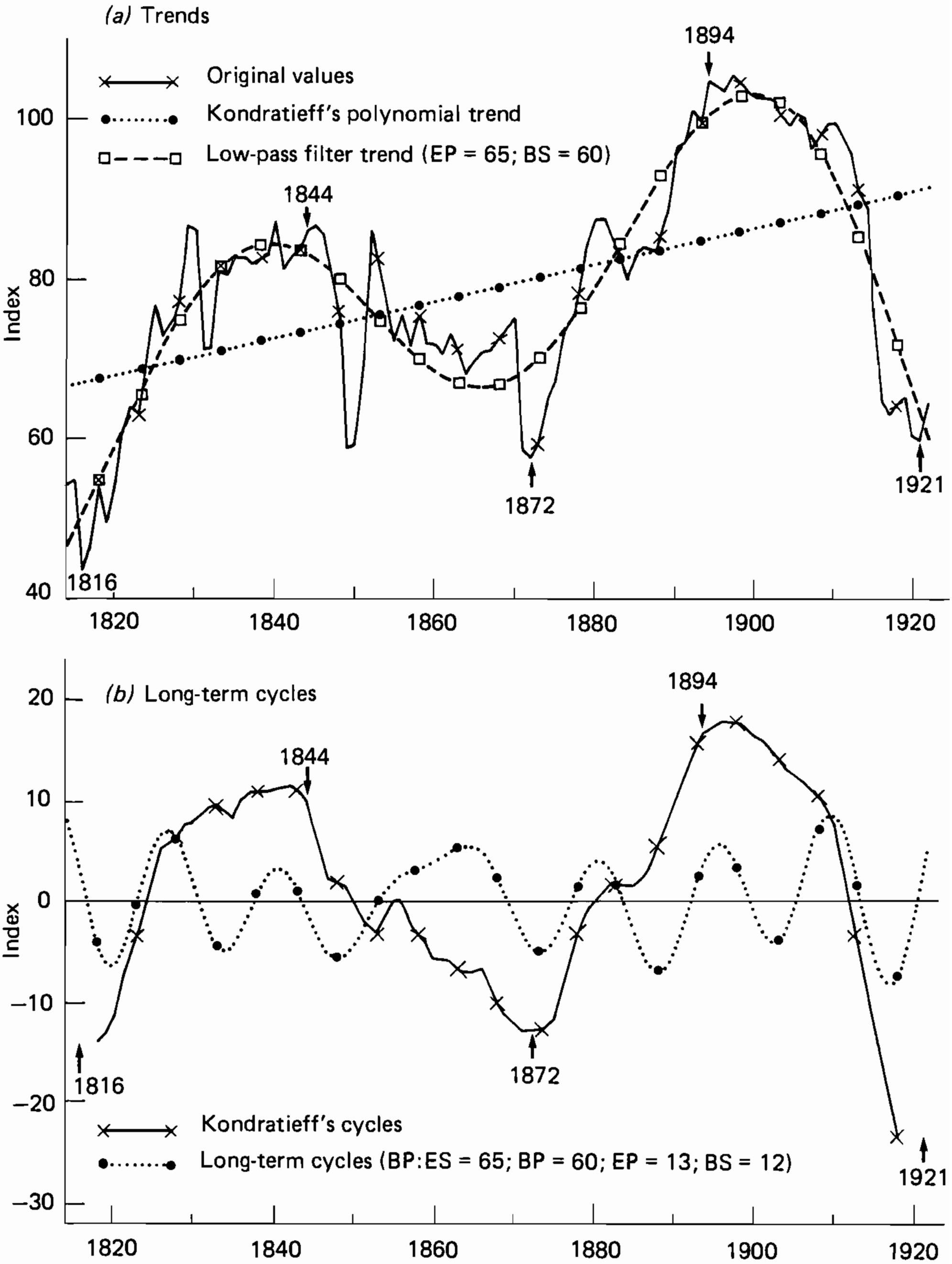

Figure 28.4. (*a*) Trends and (*b*) long-term cycles in Rente prices in France, 1814–1922.

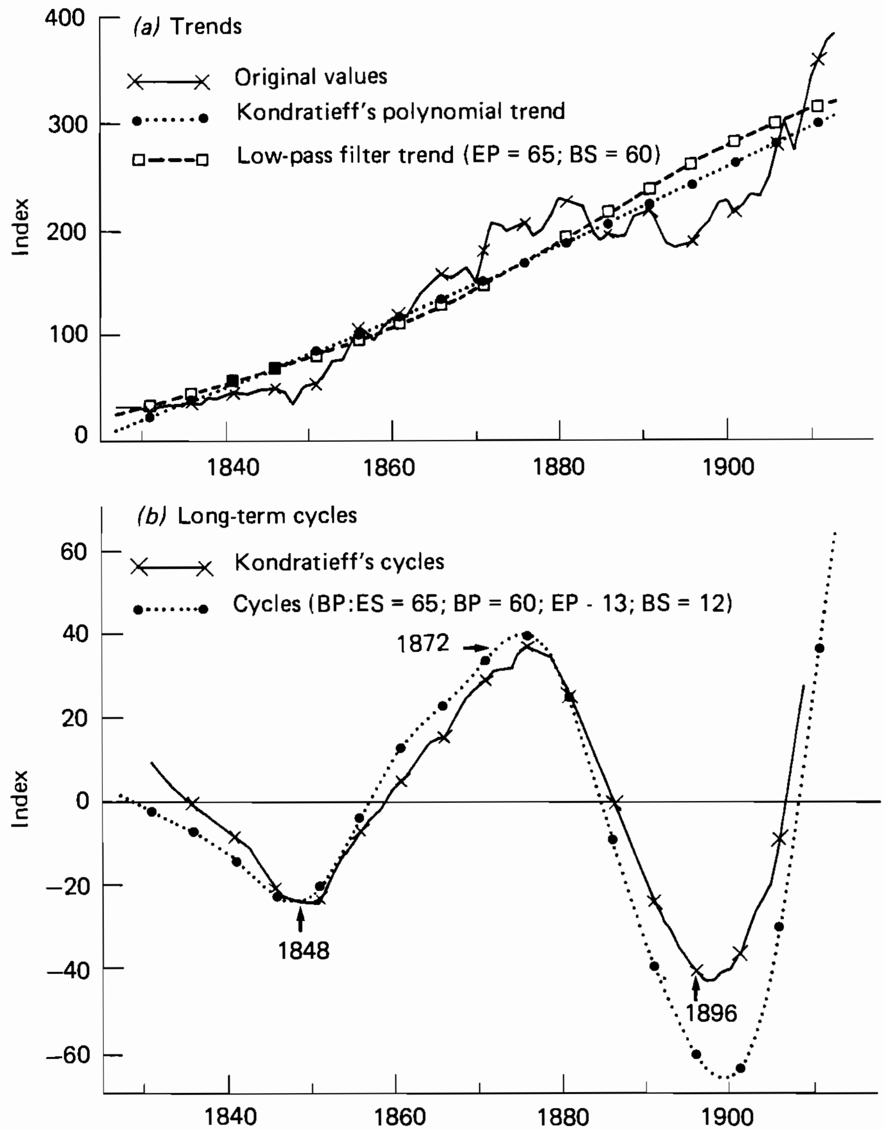

Figure 28.5. (*a*) Trends and (*b*) long-term cycles in total foreign trade in France, 1827–1913.

definition and the filter method, long-term fluctuations can be clearly determined as trend phases that cannot be definitely measured as cyclical fluctuations for the period analyzed.

An examination of the series for French foreign trade, French coal consumption, and English pig iron production yields completely different results. Apart from slight divergences, the trend estimated by Kondratieff is

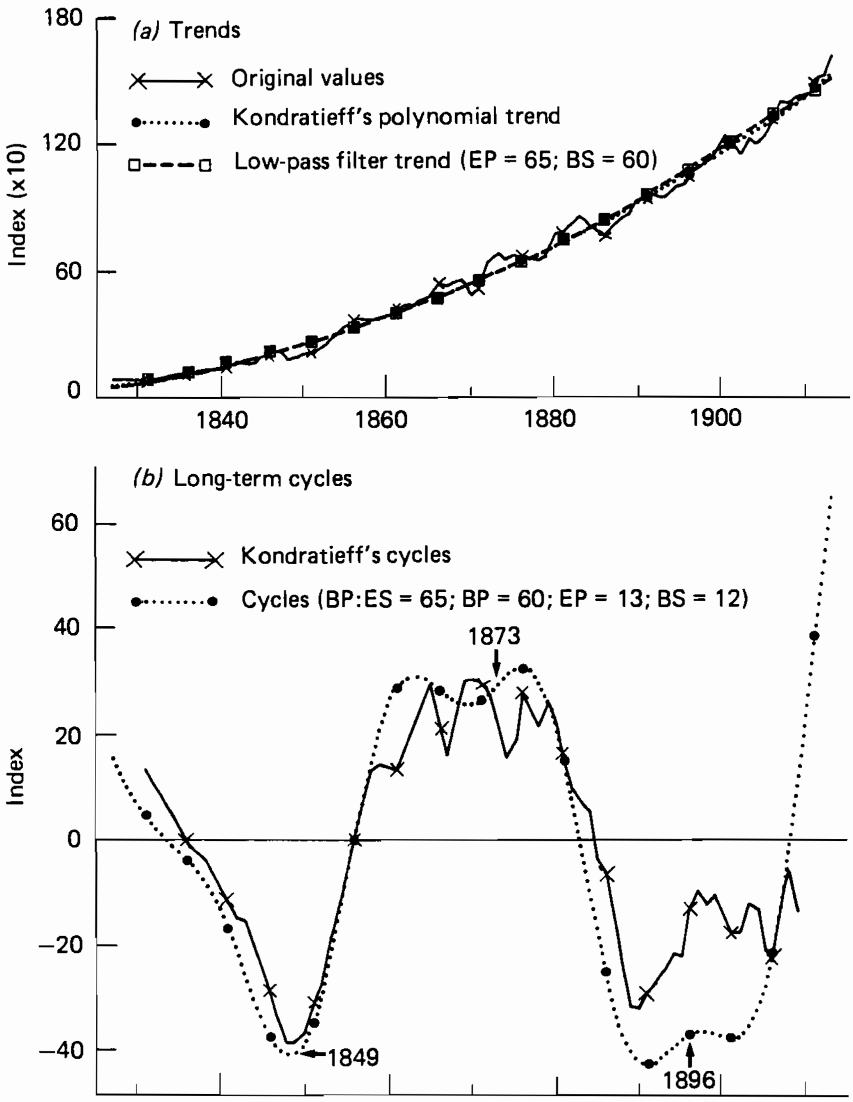

Figure 28.6. (a) Trends and (b) long-term cycles in coal consumption in France, 1827–1913.

confirmed by our calculations (see *Figures 28.5–28.7*). In contrast with the value series, these series show a distinct growth that determines the trend course. Except for English pig iron production since 1870, the trend shows a nearly linear course. Kondratieff's dating of the long waves is confirmed by our calculations, at least regarding French foreign trade and coal consumption [*Figures 28.5*(*b*) and *28.6*(*b*)]. Since these series are extremely short, we have

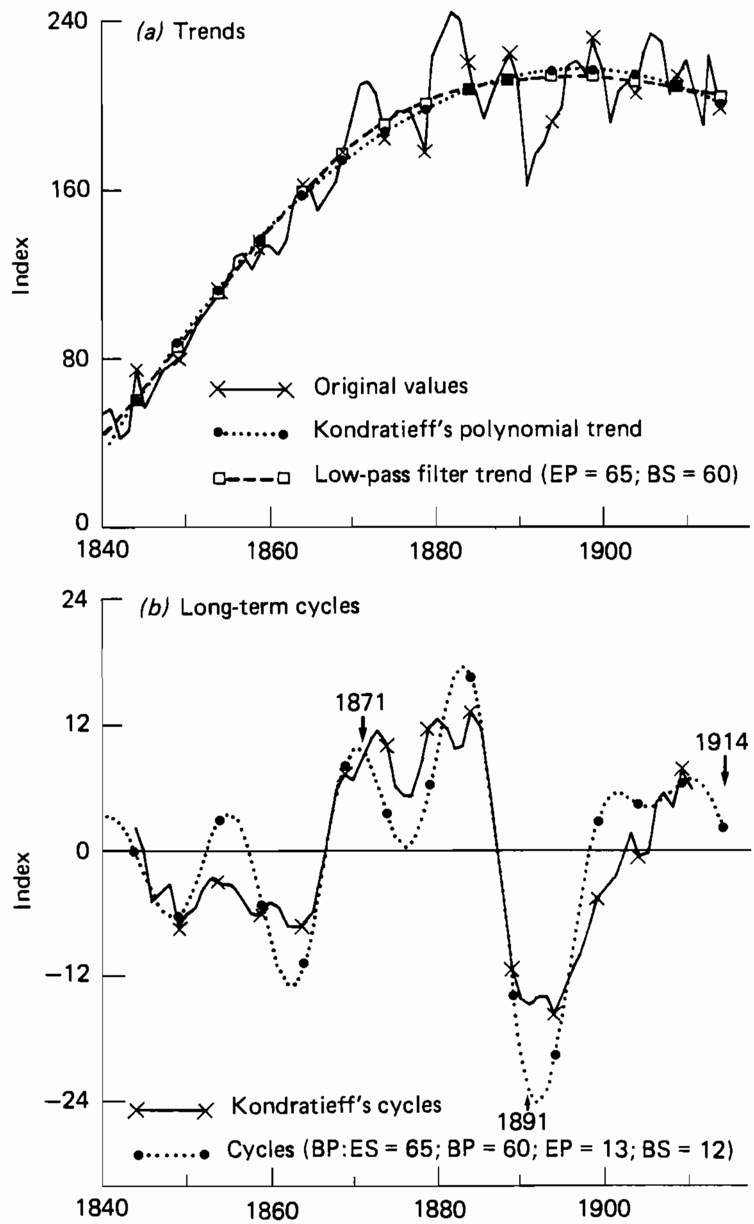

Figure 28.7. **(*a*) Trends and (*b*)long-term cycles in pig iron production in England, 1840–1914.**

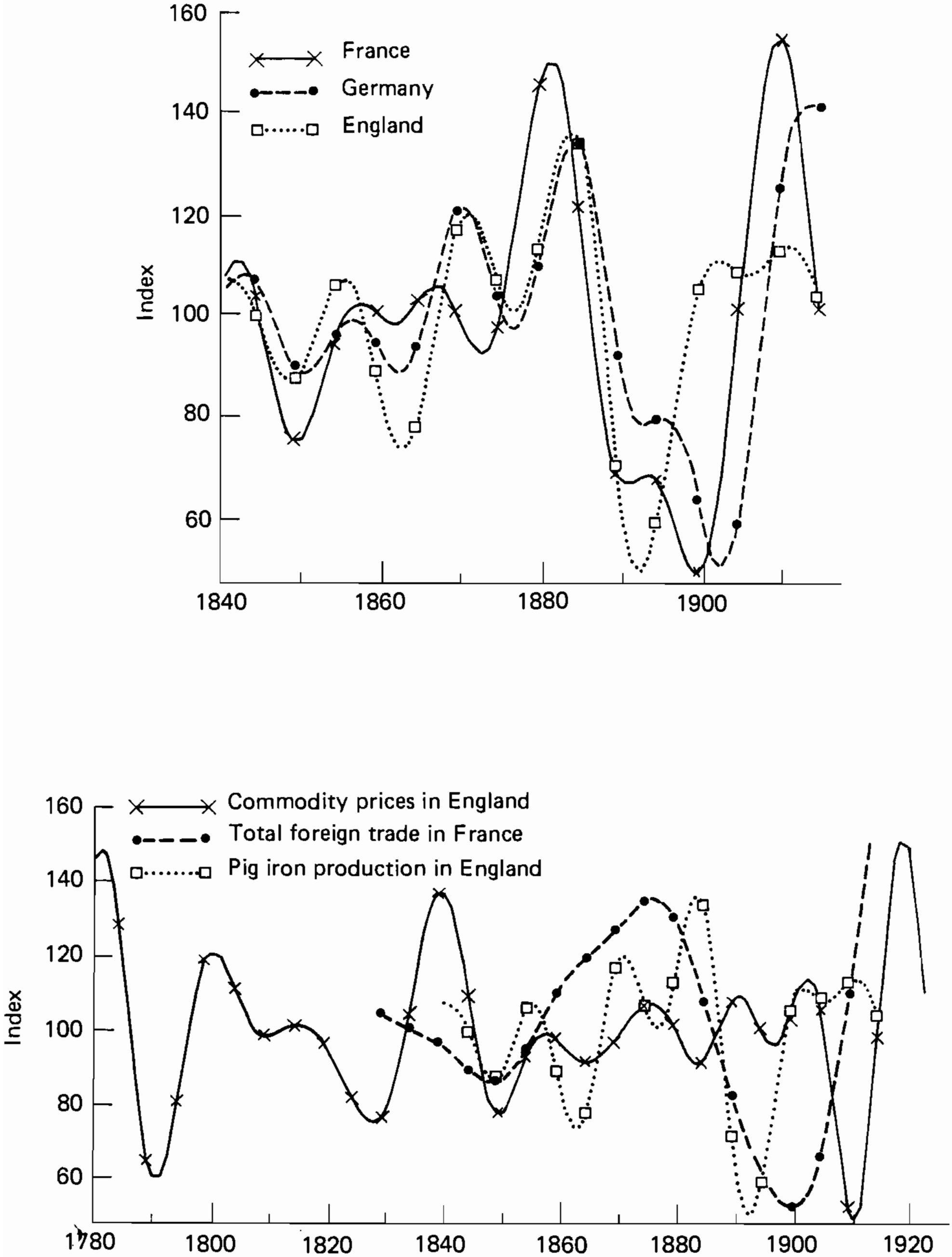

Figure 28.9. Long-term cycles in three series, 1780–1922.

to differentiate. The foreign trade series (1848–1875) and coal consumption (1844–1877) reveal only one long-term upswing and one long-term downswing between 1875–1899 and 1877–1893, respectively. These three series therefore confirm the existence of long-term upswing and downswing phases that can be clearly distinguished from the trend for the period 1848–1890.

The essential feature of these upswing and downswing phases extending over several short-term cycles is the predominance of short-term cycles, as examplified in the series for pig iron production in England [*Figure 28.7(b)*].

Finally, we wish to check Kondratieff's hypothesis about long waves with the aid of the series analyzed here. The maximum cycle length, which Kondratieff fixed to 60 years, cannot be confirmed by our calculations. Such a long oscillation can only be ascertained if the peaks and troughs of the trend phases discernible if the value series are considered.

In addition, Kondratieff thought that the cycles dated in the different series were highly synchronous; we could not examine this hypothesis in detail, but *Figure 28.8* confirms that international business cycles develop in a synchronous way. In this figure, which shows the long-term cycles in pig iron production in England, France, and Germany from 1840 to 1914 (Metz, 1984b), the synchronous character of the cycles is obvious, especially in England and Germany; the intensities of the amplitudes are also very similar. If the peaks and troughs are dated, the "cycle leaders" can be determined exactly; this is most obvious for the 1890s – the turning point for England was in 1892, France in 1899, and Germany in 1902.

If, however, the courses of the cycles of various indicators are compared, this parallelism is dissolved; *Figure 28.9* illustrates the long-term cycles in commodity prices in England, French foreign trade, and pig iron production in England. Kondratieff's assertion that the upswing and downswing phases of various economic indicators run to a great extent parallel to each other must therefore be modified. The empirical results indicate only that there is an international connection between the same production sectors.

As our calculations have clearly shown, Kondratieff's hypothesis of long waves must be modified considerably. We do not know, however, how Kondratieff would have interpreted the empirical results achieved with the filter, but it is certain that it would have been more difficult for him to regard the long waves in the way he did – as intersectoral and international cycles with highly synchronous courses and uniform duration of about 48–60 years.

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CHAPTER 29

Transfers Between Industrial Branches in the Course of Schumpeter–Mensch Long Swings

Herman Wold and Klaus Kaasch
(with comments by Gerhard O. Mensch)

29.1. Introduction

Schumpeter's transformation theory (1912, 1954) is an analysis of industrial development: economic innovations come in fits and spurts, which generate long waves and short-term business cycles. The first phase of a long wave is expansive: industrial production, employment, and capital investment increase under "competitive destruction". But as the pattern of demand stabilizes, production is more and more rationalized by increased capital investment; the price per unit product falls; demand increases; output rises. Later the increasing level of employment is first retarded, and then diminishes as rationalization proceeds. In the course of the change from increasing to decreasing employment per unit of output, there are shifts in the relative levels of activity in different industrial branches. The supply side undergoes transformation. Schumpeter's vision of development was greatly admired by many economists, but a common feeling was that it was a tragedy that he was unable to formalize it as a general theory.

Mensch's (1975) historical studies of economic evolution give evidence of Schumpeterian fits and spurts. They show that the social inventions and scientific discoveries that underlie basic innovations flow in a more or less continuous stream, whereas the basic innovations themselves cluster in relatively short "windows in time". There is gradual (continuous) emergence of possibilities for innovation, going hand in hand with speed-up and slow-down (discontinuity) in the rate and direction of basic innovation. Mensch's long-swing model, which thus is an alternative to the Kondratieff-wave model, incorporates a bi-equilibrium system (Mensch, 1980, 1986). The two equilibria of Mensch's bi-equilibrium (BIEQ) model are the expansive phase of increasing production and increasing employment, and the capital-intensive phase of increasing production per worker and decreasing employment per unit of output. The main contribution is that during a stalemate in technology, progress turns into a bifurcation. Then, the series of rationalization innovations tend to yield diminishing utility and inferior returns as firms and plants in established industries mature and become more inflexible. If inflexibility manifests itself in too many branches of industry (structural encrustation), the economy becomes structurally ready for the breakthrough of a new cluster of innovations.

These notions of rapid transitions from high to low levels of employment and capital utilization, and changes in the level and composition of production and investment, have been formalized in our BIEQ-PLS model (Wold and Mensch, 1983). It uses data on industrial branches, or groups of branches, and performs simultaneous analyses of several groups of branches, combining BIEQ and a nonlinear generalization of the basic PLS (partial least squares) algorithm of W. Wold (1973, 1985). Total industrial activity in the USA is modeled as weighted aggregates of branch data on employment, investment, and production. Shifts in the weights in the course of Schumpeter–Mensch long swings indicate shifts in and across branch activity, and slow versus swift transformations. The BIEQ-PLS model is unique in being able to provide quantitative information on shifts in branch activity in the course of the Schumpeterian wave. This research aim was spelled out by Wold and Mensch (1983), but was not carried through operationally. This chapter pursues this objective and provides experiments with somewhat disaggregated US data.

29.2. The BIEQ Model: A Briefing

The PLS model of H. Wold is the original method of theorizing with both observed and latent (computed) variables. The BIEQ-PLS model uses data on industrial production P_t, labor A_t, and investments I_t observed over time $t = 1,\ldots,T$ and standardized to zero and unit variance over t. Denoting estimated production by X_t, the BIEQ model obtains latent variables X_t by solving the third-degree equation

$$X_t^3 = R_t X_t + E_t \tag{29.1}$$

where expansive investment E_t and rationalization investment R_t are other latent variables obtained by the oblique rotation of observed labor A_t and investment inputs I_t:

$$\begin{bmatrix} A_t \\ I_t \end{bmatrix} = \begin{bmatrix} \cos\gamma & \sin\delta \\ \sin\gamma & \cos\delta \end{bmatrix} \begin{bmatrix} E_t \\ R_t \end{bmatrix} : \begin{bmatrix} E_t \\ R_t \end{bmatrix}$$

$$= \frac{1}{\cos(\gamma - \delta)} \begin{bmatrix} \cos\gamma & -\sin\delta \\ -\sin\gamma & \cos\delta \end{bmatrix} \begin{bmatrix} A_t \\ I_t \end{bmatrix} \tag{29.2a,b}$$

Note that E_t and R_t denote the "extensifying" and "intensifying" (Ricardo) effects of the investment mix. The basic idea of Mensch's approach is that they have to be inferred from related observations. The composition of investment (E_t, R_t) is used for causal analysis.

For an estimation of the goodness of fit, the BIEQ-PLS algorithm uses R^2, defined by

$$R^2 = 1 - \frac{1}{T} \Sigma_t (P_t - X_t)^2 \tag{29.3}$$

R^2 serves as a provisional criterion in the evaluation of the model. As will be seen, the fit is excellent. The actual evaluation involves two intricate steps. First, equation (29.1) is solved for each t, giving either one or three solutions X_t. In the expansive phase there is one solution X_t, which increases with t. In the rationalization (capital-intensive) phase there is again one solution X_t, which increases with t. When there are three alternative solutions X_t, i.e., when the economy is structurally unstable and given to rapid transitions, back and forth, from full employment equilibrium to underemployment equilibrium, one must be chosen. In making those choices in bifurcation situations, we have incorporated "hysteresis": that solution is chosen which, by continuity, extends the prevailing trend (lower or higher trend level).

Applying this model [(29.1), (29.2a,b)] to US data between 1947 and 1982, we can ask when and why X_t is at times unique, and at other times two- or three-valued. *Figure 29.1* illustrates the "cusp" of a BIEQ. In the (E, R) diagram, the time path (E_t, R_t) is plotted. A passage from one to three solutions X_t occurs when the curve enters the cusp. A phase transition (passage) from one equilibrium to the other occurs when the curve leaves the cusp over the South rim. In other words, for the solution X_t to have a discontinuity, it is necessary that the (E, R) curve pass through and drop out of the cusp. The discontinuity occurs when the curve leaves the cusp in a critical way – when the $E: R$ ratio falls below a threshold level. In Mensch's terms: when the rationalization bias dominates innovative activity, the economy slips into an underemployment equilibrium. In Mensch *et al.* (1980), we showed that West Germany underwent such a slip. Furthermore, our US analyses indicate that while US industry on the whole did not slip into underemployment equilibrium, some branches of industry did; and some regions did, where there was a high incidence of "declining" industries. On the other hand, some West German

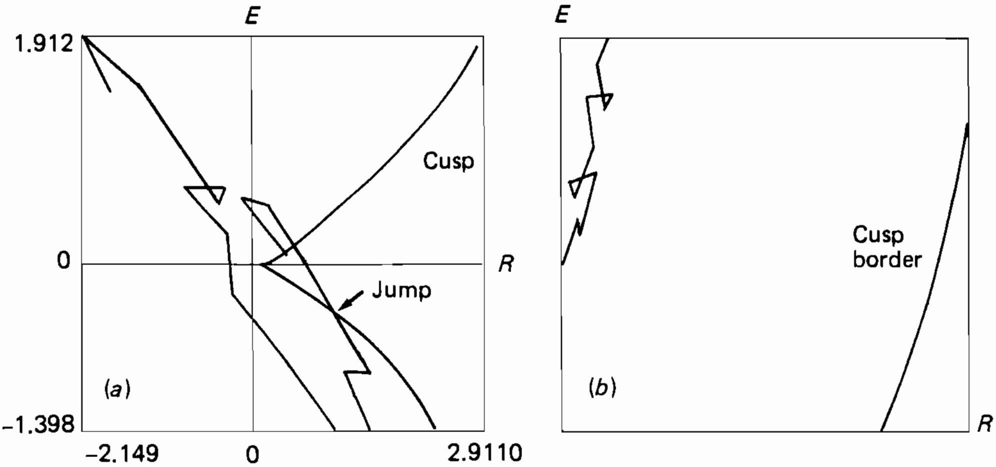

Figure 29.1. Illustrations of the (E, R) time path and the "cusp". (*a*) The path penetrates the cusp, giving rise to a jump in X_t. (*b*) The curve runs outside the cusp, and there is no jump in X_t.

industries enjoyed full employment, while total industry settled into an underemployment equilibrium.

If we regress X_t linearly on P_t over $t = 1,\ldots,T$, we obtain

$$X_t = a + b\ P_t + e_t \tag{29.4}$$

giving

$$R^2 = 1 - \mathrm{var}(e) \tag{29.5}$$

Since the R^2-criterion is vulnerable to discontinuities in highly nonlinear models, we employ the well known Stone–Geisser cross-validation test. The SG test assesses Q^2 for predictive relevance [see equation (29.7)]. Allowing the angular variables γ and δ to vary, a search procedure determines γ and δ so as to give Q^2 maximum value.

The rotation in equation (29.2b) can be performed by regression, i.e.,

$$E_t = c_{11}\ A_t + c_{12}\ I_t \quad R_t = c_{21}\ A_t + c_{22}\ I_t \tag{29.6a,b}$$

If we use oblique rotation as a first approximation, the four coefficients are restricted by two identities,

$$\sin^2\gamma + \cos^2\gamma = 1 \quad \sin^2\delta + \cos^2\delta = 1 \tag{29.7a,b}$$

This reduces the need for information, because in first approximation we need to assess only two free parameters (see Wold and Mensch, 1983).

29.3. Partial Least Squares (PLS)

Linear models with latent variables (LVP models) were first introduced by Wold (1973, 1982, 1985). The basic PLS algorithm for estimating linear LVP models is an iterative sequence of OLS (ordinary least squares) regressions, linear operations, and square root extractions. The predictive relations of the LVP model are subject to Wold's *predictor specification*. In contrast with the stringent assumptions of ML (maximum likelihood) estimation, the PLS assumptions are very general, so that PLS modeling has a wide scope in theory and practice.

For model evaluation PLS has adapted Tukey's (1958) jackknife assessment of standard errors and the cross-validatory test for predictive relevance introduced by Stone (1974) and Geisser (1974). The PLS adaptation of the Stone–Geisser (SG) test for predictive relevance is given by

$$Q^2 = \frac{\Sigma\,(y_t - \hat{y}_t)^2}{\Sigma\,(y_t - \tilde{y}_t)^2} \tag{29.8}$$

where $\tilde{y}_t$ is a trivial estimate of y_t; for example, $\tilde{y}_t = \bar{y}$. Tukey jackknife standard errors for model parameter estimates are obtained as a by-product of the SG test criterion, Q^2.

In maximum-likelihood (ML) model evaluations, the null hypothesis is that the model is true. Models are never exactly true, hence the null hypothesis is rejected sooner or later as the sample size increases indefinitely. This factor limits ML models. In contrast, the SG test applied to PLS asks whether the model has predictive relevance; if $Q^2 \leq 0$, the answer is no; if $Q^2 > 0$, the affirmative answer is a matter of degree. PLS models leave the door open for further improvement of the model.

There is a large literature that develops the jackknife and the SG test on the stringent ML assumptions, but in fact the jackknife and the SG test are much more general (see Bergström and Wold, 1983). Hence, PLS modeling is general in scope, not only with reference to estimation, but also to model evaluation.

Outside the realm of controlled experiments, the ML assumption of independent observations is often unrealistic, bringing an underestimation bias into the classical ML formula for standard errors. Bergström and Wold (1983) report an econometric model with 34 parameters where the classical ML formula underestimates the standard errors by some 10.3%.

ML modeling is an errors-in-variables approach; LS (least squares) and, in particular, PLS modeling is an errors-in-equations approach. In the PLS approach to an LVP model, each latent variable is indirectly observed by a block of manifest variables called indicators; each variable is estimated as a weighted aggregate of its indicators. Hence, if the model is highly nonlinear [example: equation (29.1)], PLS provides information on "goodness of the model", whereas ML fails if a latent variable is ambivalent [example: X_t is tri-valued in equation (29.1)].

The maximum-likelihood inference from the estimated model is sensitive to the realism of the hypothetical model (specified, multivariate distribution and independent observations). In contrast, the jackknife and the SG test refer to the computer output of the model as it comes, as a *fait accompli;* i.e., the tests are informative and valid whether or not the estimation method is consistent. When the method is inconsistent, as is the case with PLS estimation, this is expected to bring an automatic reduction in the Q^2 value of the SG test. Hence, our quantitative analyses give clues as to how better to model reality.

The ML methods of model evaluation are asymptotic and are valid for indefinitely large samples. The jackknife and the SG test are valid for any sample size, and even for quite small samples. An extreme case in point is the PLS model, which has $N = 10$ observations, 27 manifest variables, two latent variables, and the SG test shows the model to be predictive, $Q^2 = 0.42$ (Wold, 1985).

Scientific model building emerged in econometrics in the 1930s and 1940s. Lorentz (1984) reviews how activities in weather forecasting during and after World War II were thoroughly influenced by the advent of model building:

> It took me some time to recognize that rigor, while essential in pure mathematics, can be stifling in some applications. ... The conflict between mathematical and meteorological procedures has been at least partly resolved in the ensuing decades, in a manner which might not have been anticipated. The new element is the widespread use of *models*. ... To a considerable extent the adoption of models in meteorology represents only a change in attitude. What was once regarded as an approximation to the system of equations governing the atmosphere is now considered to be the exact system for a *model* of the atmosphere. The mathematically minded investigator often finds this arrangement more satisfying, since, once he has settled upon a model, he can retain *full mathematical rigor* in studying its behavior [emphasis added].

Scientific model building proceeds in four stages: (i) model specification; (ii) model estimation; (iii) model evaluation; and (iv) applications. PLS modeling aims at full rigor in the context of stages (i)–(iii). The BIEQ–PLS modeling effort includes (iv).

29.4. BIEQ–PLS: Generalizing Mensch's Bi-equilibrium Model

The above gives a formal exposition of the BIEQ–PLS approach. *Figure 29.2* illustrates an application to US data for 1947–1982. The discontinuous jumps

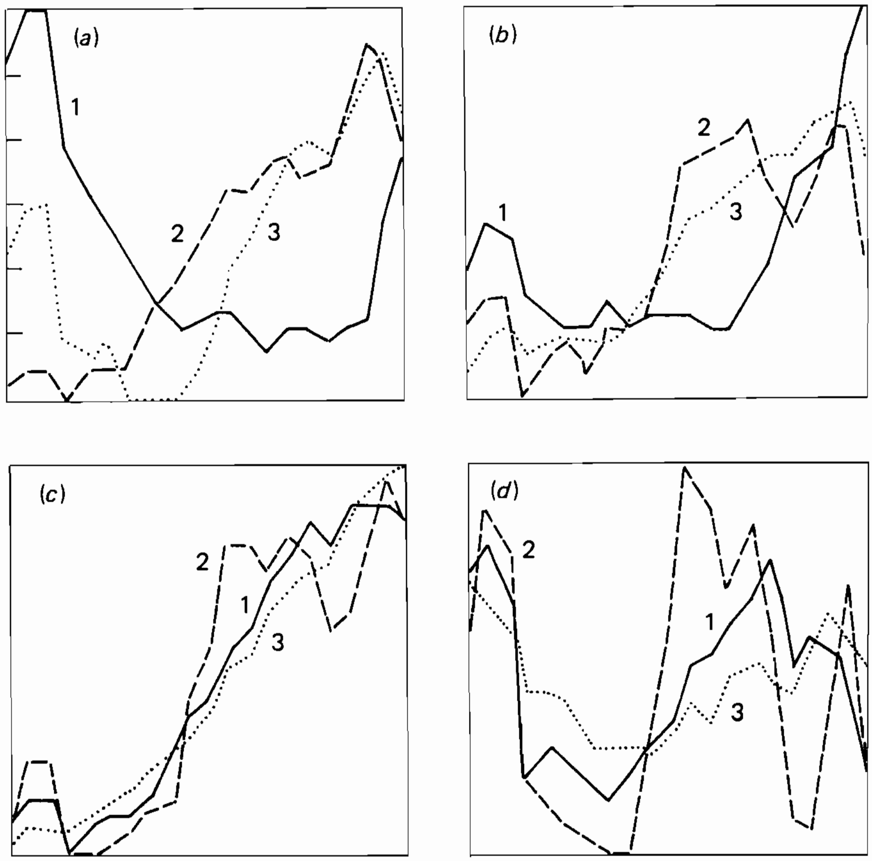

Figure 29.2. J3 data for manufacturing, mining, and transportation, standardized to zero mean and unit variance over time: (*a*) labor, A_{Bt}; (*b*) investment, I_{Bt}; (*c*) production, P_{Bt}; (*d*) detrended data.

in BIEQ–PLS are not in line with the gradual long-wave model of Kondratieff, Schumpeter, and many disciples. In order to include phase transitions and rapid swings in economic activities, an improvement in the long-wave approach is required. One improvement involves bi-equilibrium dynamics; another one, disaggregation.

Data for all industry are broken down into B branches:

$$\begin{array}{lll} \text{production} & P_t = P_{1t} + \cdots + P_{Bt} & t = 1, \ldots, T \\ \text{labor} & A_t = A_{1t} + \cdots + A_{Bt} & \\ \text{investment} & I_t = I_{1t} + \cdots + I_{Bt} & \end{array} \tag{29.9}$$

Figure 29.2 shows US data on labor input, investment expenditures, and production, for 1955–1975, for three branches: mining, manufacturing, and transportation. In order to test the effect of aggregation of sub-industries

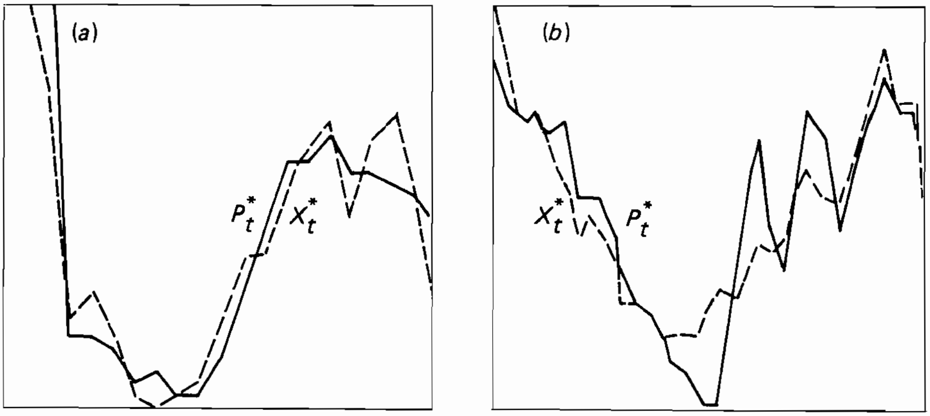

Figure 29.3. Observed (weighted) production P_t^* and estimated production X_t^* for (*a*) J3 data, and (*b*) J4 data.

(disaggregation), we distinguished "J3 data" [= all three branches separated; see *Figure 29.2* (*a*)–(*d*)] from "J4 data" (= two branches: manufacturing and mining combined, and transportation). *Figure 29.3* shows how, as a result of the different disaggregations J3 and J4, our production estimates differ. Note that our J3 and J4 data cover only three branches, whereas our formal model breaks all industry into B branches, opening up an avenue toward structural change analyses on more disaggregated levels.

The BIEQ–PLS estimation is an iterative procedure, with steps $s = 1,2,...,$ each with forward and backward substeps.

In the *forward* substep, total industrial labor is defined as a latent variable A_t, which is estimated by a weighted aggregate:

$$A_t^* = w_{a1} A_{1t} + \cdots + w_{ab} A_{Bt} \qquad t = 1, ..., T \tag{29.10a}$$

where modified weights w_{ab} are used in the next forward substep. Similarly, for total industrial investment,

$$I_t^* = w_{i1} I_{1t} + \cdots + w_{iB} I_{Bt}^* \tag{29.10b}$$

To paraphrase, the BIEQ–PLS algorithm regards total labor A_t and total investment I_t as unobserved latent variables, which are estimated by manifest branch data. The forward substep proceeds as shown above using A_t^*, I_t^* instead of A_t, I_t, and obtaining estimated production X_t for each $t = 1, ..., T$. In the first forward substep, all weights are made equal to unity,

$$w_{ab} = 1 \quad w_{ib} = 1 \quad b = 1, ..., B \tag{29.11}$$

In the *backward* substep, the X_t obtained in the forward substep is regressed over t on the branch products:

$$X_t = w_{p1} P_{1t} + \cdots + w_{pB} P_{Bt} + e_{pt} \tag{29.12}$$

where the systematic part gives the estimate of the (latent) total production:

$$P_t^* = w_{p1} P_{1t} + \cdots + w_{pB} P_{Bt} \tag{29.13}$$

Next, using the proxies E_t, and R_t obtained in the forward substep, we transform equation (29.1) into a multiple regression over t:

$$(P_t^*)^3 = s_0 + s_1 P_t^* R_t + s_2 E_t + e_t^* \tag{29.14}$$

The resulting regression coefficients s_1 and s_2 transform the forward proxies E_t and R_t into their backward counterparts:

$$R_t^* = s_1 R_t \quad E_t^* = s_2 E_t \quad t = 1, \ldots, T \tag{29.15}$$

Next, the inverse rotation equation (29.3) gives the backward proxies A_t'' and I_t'':

$$\begin{bmatrix} A_t'' \\ I_t'' \end{bmatrix} = \boldsymbol{M}^{-1} \begin{bmatrix} E_t^* \\ R_t^* \end{bmatrix} \tag{29.16}$$

where $\boldsymbol{M}$ is the oblique rotation matrix of the forward substep.

Finally, computing the multiple regression

$$A_t'' = w_{a1}'' A_{1t} + \cdots + w_{aB}'' A_{Bt} + e_{at}'' \tag{29.17}$$

and similarly for I_t'', the regression coefficients w_{ab}'' and w_{ib}'' give the weights for the next forward substep.

The iterations $s = 1,2,\ldots$ continue until they are stopped by a conventional convergence criterion, say,

$$\left| \left[X_t^{(s+1)} - X^{(s)}\right] / X_t^{(s)} \right| < 10^{-4} \quad t = 1,2, \ldots, T \tag{29.18}$$

Once the BIEQ-PLS model has been estimated, many relevant pieces of information can be recorded, including

(1) Graphs: A_t, I_t, E_t, R_t P_t, X_t, A_t^*, I_t^*, with $t = 1, ..., T$.
(2) Plots: (E_t, R_t), (P_t, X_t), (A_t^*, A_t), etc.
(3) Stone–Geisser test Q^2 in equation (29.6) for the comparison P_t versus X_t.
(4) Optimizing angles γ and δ (cf. Section 29.2).

For $t = 1, ..., T$:

A_t^* = estimated industrial labor [equation (29.10a)].
I_t^* = estimated industrial investment [equation (29.10b)].
X_t = solution tó equation (29.1).
P_t^* = estimated industrial production [equation (29.13)].

Correlations over $t = 1,..., T$:

$r(A^*, A)$, $r(I^*, I)$, $r(P_t^*, P)$.
correlations over $b = 1, ..., B$: $r(w_{a.}, w_{i.})$, $r(w_{a.}, w_{p.})$, $r(w_{i.}, w_{p.})$.
Rank ordering over $b = 1, ..., B$: w_{ab}, w_{ib}, w_{pb}.

29.5. Empirical Results I: Validity

In reporting our applications of the BIEQ–PLS model, we focus on typical results and emphasize the comparison with Schumpeter's theory. First, we turn to the question of how to modify the BIEQ–PLS model in order to extend the tendency of built-in gradual change that is part of the Kondratieff-wave model. In Mensch's model, Schumpeter's "process of creative destruction" is usually in disequilibrium ("expansionary bias": E >> R; or "rationalization bias": R >> E), and the bias may swiftly change over from one to the other (phase transition – cyclical and/or structural change). The concept is very rich in possible patterns of change. The most notable difference from the "gradual" long-wave model is that the Schumpeter–Mensch swings may occur rather suddenly. In light of the present unemployment levels in many regions and countries, a rather sudden boost E >> R is, indeed, what people hope for.

We now evaluate (1) convergence and (2) goodness of fit. *Convergence* of the BIEQ–PLS algorithm is satisfactory in our data. In our experiments we studied the entire period and five subperiods. The convergence is more rapid when we include only four, three, and two subperiods, respectively. For both J3 and J4 data, the Q^2 test is stable to two decimal places after ten iterations. In short: PLS works efficiently.

For the *comparison* of P_t versus X_t, and observed versus estimated total production, the correlation is typically high in our data, $R^2 > 0.90$. There is some reduction, as expected, when evaluating the comparison by the Q^2 test. Using data for 1947–1982, J3 and J4 give $Q^2 = 0.79$. In short: BIEQ–PLS works well.

The close agreement between actually observed and PLS-estimated production in US manufacturing, mining, and transportation, 1947–1982, is shown in *Figure 29.3*, for both the J3 and the J4 disaggregation methods. Therefore, the postulated causality should be regarded as empirically validated theory.

29.6. Empirical Results II: Causal Inferences

Mainstream economic theory of both Keynesian (macroeconomic) and neo-classical (microeconomic) leaning suggests that more investment creates more employment through the multiplier effect, alias Okun's Law. As is well known, this may be true for industry including all services, but false for specific industries. *Figure 29.4* shows that it is false for manufacturing, mining and transportation combined. The Schumpeter–Mensch theory, on the other hand, suggests that in the expansive phase new labor ΔA_t and expansive investment E_t increase, while total investment $\dot{I}_t$ and rationalizing investment R_t grow slowly or even stagnate; whereas in the rationalization phase ΔA_t and E_t decrease while I_t and R_t increase. The plots in *Figure 29.4* agree with these implications of the Schumpeter–Mensch long-swing theory. The swing in (E_t, R_t) as depicted in *Figures 29.4(b)* and *29.1* causes the change in input proportions and output levels depicted in *Figures 29.3* and *29.4(a)*.

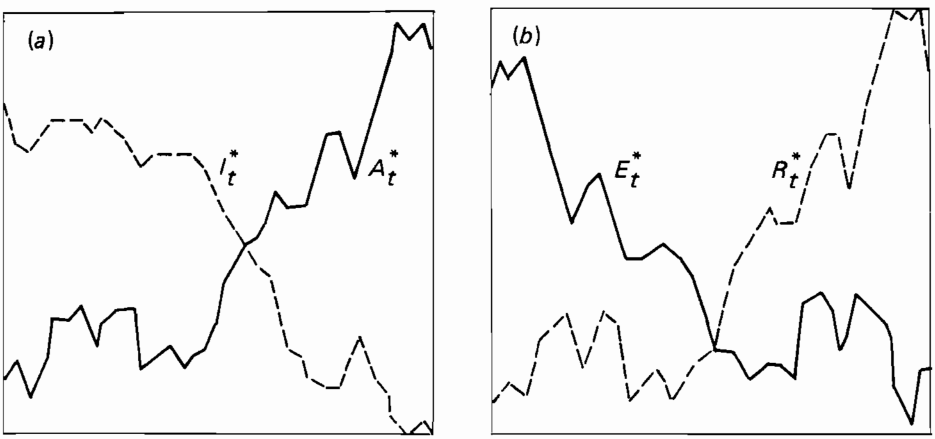

Figure 29.4. (*a*) Labor $A_t^{\bullet}$ and investment $I_t^{\bullet}$; (*b*) expansive $E_t^{\bullet}$ and rationalizing $R_t^{\bullet}$ investment.

We now turn to changes in branch activity in the course of the Schumpeter–Mensch wave. *Figure 29.2* gives some evidence of such changes: mining shows decreasing levels of labor A_{1t}, whereas labor levels rise in manufacturing A_{2t} and transport A_{3t}; similarly, mining investment I_{1t} rises sharply. Unfortunately, as will be discussed in the light of *Figure 29.5*, such changes are not brought to the fore by the BIEQ–PLS model as it stands.

Underlying equation (29.1) is the assumption that profits (sales − costs) as a function of production X take the form

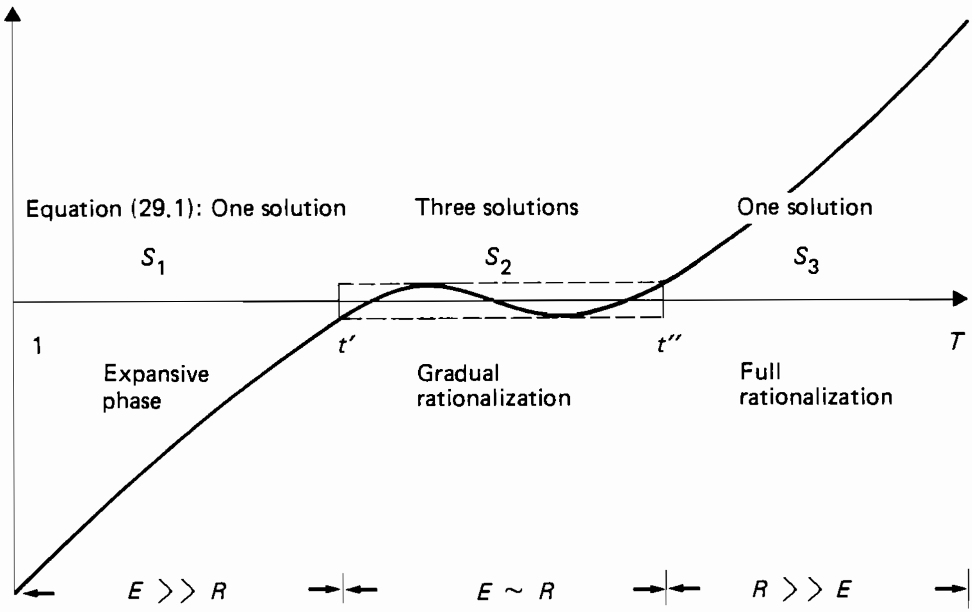

Figure 29.5. The third-degree curve for estimated production $X = X(R, E)$, and the three phases $(1, t')$, (t'', T) and (t', t''), where equation (29.1) has one or three solutions $X(R, E)$, respectively.

$$C = \frac{1}{4} X^4 - \frac{1}{2} R X^2 - EX \tag{29.19}$$

Profits are close to a competitive equilibrium (minimum) when $X = X(R, E)$ is a solution to equation (29.1): there are either one or three solutions. Typically, there is one solution in the expansive phase, when all revenue is reinvested, and one solution in the phase of full rationalization, when profits are squeezed out. These are the two equilibria of the BIEQ model. In theory, labor-saving rationalization is a gradual process, but this is not always so. In the BIEQ model, the expansive stage may end with a discontinuous jump (see *Figure 29.1*), namely, if the E:R-proportion falls below a threshold level. Then the economy may fall into "slumpflation" (M. Friedman). In Mensch's terms: "the supply side shrinks."

Let S_1, S_2, and S_3 denote branch activity in the three phases of *Figure 29.5*, defined by E versus R. Then if we adopt the proxy assumption that there is no rationalization in the first phase where $E \gg R$, and that gradual and full rationalization proceed with the same speed in the second and third phases, then

$$I_{ws} = \frac{-2S_1 + S_2 + S_3}{|S_1| + |S_2| + |S_3|} \tag{29.20}$$

provides an unpretentious index for "intrawave shifts" in branch activity. The index can be computed for labor, investment, or production.

Table 29.1 shows the index I_{ws} obtained from our J3 and J4 data. A negative I_{ws} indicates that the branch activity is relatively high in the expansive phase and diminishes in the course of the rationalization phases. In the J3 data, I_{ws} is negative for A_1, indicating that in the course of rationalization mining activity (as measured by labor A) decreases relative to manufacturing and transport. For mining activity (measured by investment I_1) the same tendency is apparent, although less pronounced. For production P, the J3 data indicate that the activity changes are parallel in the three branches.

Table 29.1. J3 and J4 data. Branch activity in phases S_1, S_2, and S_3 of the Schumpeter–Mensch wave, and index I_{ws} of shifts in branch activity.

	Data J3				*Data J4*			
	S_1	S_2	S_3	I_{ws}		S_1	S_2	S_3
A_1	1.092	−0.698	−0.393	−1.500	−1.075	−0.430	−0.107	1.000
A_2	−1.151	0.041	1.110	1.500	−0.718	1.182	1.147	1.236
A_3	−0.498	−0.656	1.154	0.647				
I_1	−0.338	−0.719	1.057	0.480	−0.927	−1.005	−0.025	0.421
I_2	−1.015	0.111	0.904	1.500	−0.191	0.952	1.196	1.082
I_3	−1.045	−0.163	1.208	1.297				
P_1	−1.098	−0.106	1.204	1.368	0.379	0.490	−0.421	−0.535
P_2	−1.063	0.081	0.982	1.500	−1.016	0.042	0.526	1.641
P_3	−1.072	−0.154	1.225	1.312				

The J4 data are the same as J3, with mining and manufacturing combined. For investment I, the J3 and J4 data indicate much the same branch activity changes in the course of the long wave, but not so for labor A and production P. I_{ws} indicates that branch activity (measured by labor A) is much more stable in J4 than in J3 data. For production P, in contrast with the J3 data, the rationalization process brings a marked shift in the transportation sector as compared to mining and manufacturing.

In fact, in expansionary phases of the economy, the supply side unfolds differently than in recessive periods. Recessive structural change is not just "slumping" or "shrinking" but "breaking". The implications for the theory of capital (both theory of stock and value) seem obvious, and they obviously are in need of further study.

29.7. Concluding Remarks

Of course, the results of this pilot study of the BIEQ–PLS model reported here are no more than trifling examples of the type of information provided by this approach. The analysis yields insights into questions such as these:

(A) Why do some regions or countries prosper while others decline?

(B) Which industries, and what innovation strategies in these industries, will carry another phase transition that promises full employment?

The next round of analysis will be extended to more comprehensive US data, and to data for West Germany and Sweden. Some points that require further investigation include the following technicalities:

(1) The oblique rotation, equation (29.2b), is too rigid. There are several ways to improve the model, which should further improve the good R^2 and Q^2 achieved with equation (29.2b).
(2) As often happens in econometric model building, the variables have very different scales, so that in linear models it is customary and appropriate to standardize the variables to zero mean and unit variance. The BIEQ and BIEQ–PLS models are nonlinear and the estimation is influenced by the standardization, so that some attention to scale effects is required in further studies.
(3) Schumpeterian theory raises the question of whether rapid reversals affect all the variables in play, or whether a subset of the variables remains unaffected by the swing. This question is part of the scaling problem mentioned in (2) above, and is part of the policy and strategy problems implied.

This chapter showed that the bi-equilibrium/partial least square approach passed the acid tests of (i) model specification, (ii) model estimation, and (iii) model evaluation. It is ready for (iv) applications to said policy and strategy problems.

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CHAPTER 30

Dynamic Programming of Socioeconomics and War: A Computer Experiment

Paul P. Craig and Kenneth E.F. Watt

30.1. Introduction

The world armaments industry is operating at record output. At enormous expense, the Soviet Union and the United States have through joint effort designed and constructed a device proposed many years ago by Herman Kahn – a ***doomsday machine***. The machine is now in place; it could go off at any instant. Yet arms expenditures continue to rise. In the United States we now spend annually about $6000 per family of four. More than half of our federal budget is spent paying for past and present military expenses. The situation is similar in the Soviet Union. Despite these massive and growing outlays, our future – all of our futures – are less secure now than just a few years ago.

There are relationships between economic activities of nations and armaments. The goal of our work is to explore some very simple models that will (we hope) provide some new insight into these connections. Wolfgang Pauli, the physicist who developed the theory of spin in atomic systems, once observed (so it is reported) that "it is very hard to make predictions, especially about the future". Our goal is *not* to make predictions. We seek insight.

Several scholars have particularly influenced our work. Richard Bellman explored the application of dynamic programming to human systems (Wilkinson *et al.*, 1973). The strengths and weaknesses of large-scale modeling are well described in work done for IIASA (Meadows *et al.*, 1982). The MIT group under Jay Forrester has illustrated both the problems of complexity and the promise of simplification of large-scale models.

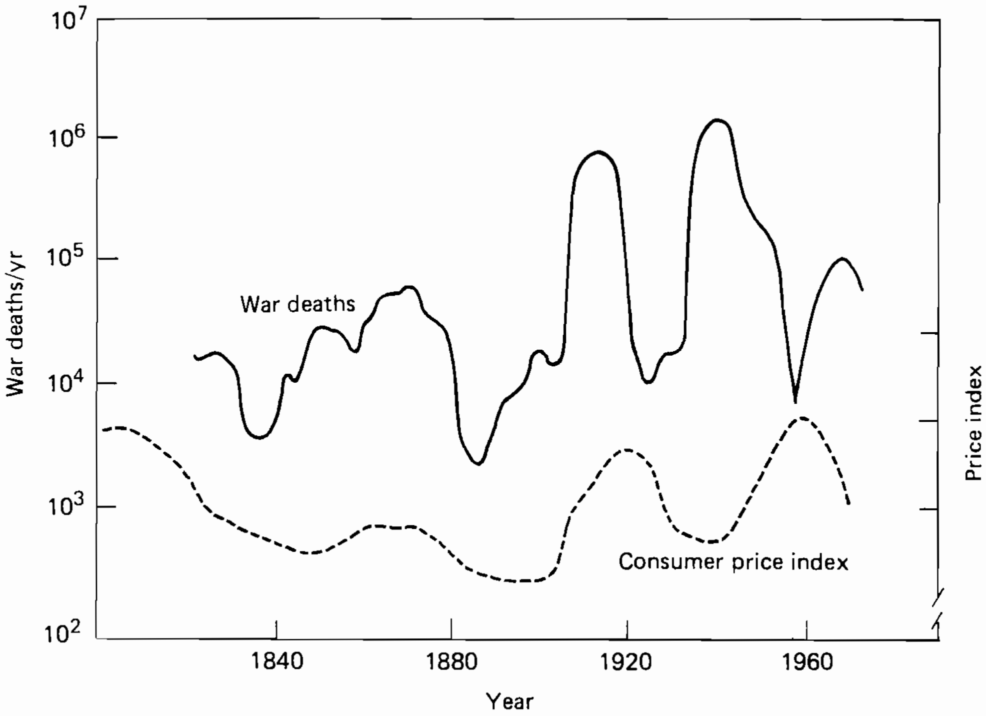

Figure 30.1. War deaths correlated with consumer price index, 1800–1960.

30.2. The Models

At the IIASA Siena Conference on Long Waves in October 1983, we presented work exploring the correlations between certain socioeconomic variables and war deaths (Craig and Watts, 1985). The key results are shown in *Figure 30.1.* Four economic cycles are found in the US consumer price index, with the peaks and valleys in excellent agreement with long-wave dates as summarized by van Duijn (1983). The qualitative conclusions are captured in *Figure 30.2.* Here the solid lines point to economic turning points, the upward arrows to the times of maximum annual war deaths, and the downward arrows to the times when annual war deaths were at minima. The consistency of the pattern

$$\text{peace} \Longrightarrow \text{recession} \Longrightarrow \text{war} \Longrightarrow \text{good times} \Longrightarrow \text{peace} \cdots$$

is apparent. This regularity motivates our work.

It is all too easy to build models that are, or are perceived to be, opaque. The problems of computer models have been well documented, for example, in the history of the Limits to Growth model in the IIASA Energy Model.

Our goal is to develop simple models focusing on a few issues. We want to find out the extent to which we can mimic certain dominant types of socioeconomic behavior using sparse assumptions. *Figure 30.3* shows the flow diagram – though not the internal structure – of the model. We focus on the

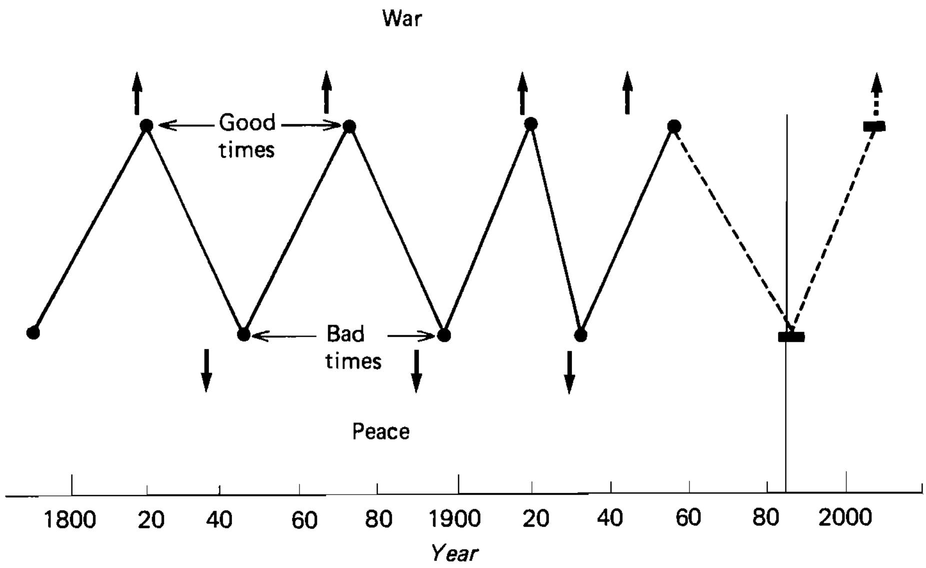

Figure 30.2. **War and peace correlated with economic long waves (solid lines = economic peaks and valleys; upward arrows = maximum annual war deaths; downward arrows = low annual war deaths).**

interaction between productive capacity and arms production. The model contains four production sectors: capital, consumption, military, and energy. Production capacity in each sector is constrained by some limiting resource: physical plant, available labor, or energy. [Energy is included as an example of a depletable resource that can be renewed (or replaced) by sufficient investment in research and development. Our intent here is to explore ideas related to those of Cesare Marchetti (1985).] In the results discussed in this paper the energy sector is disconnected, and resource depletion plays no role.

In each model year productive capacity increases due to allocation of new productive capacity, and decreases due to obsolescence (retirement).

Although, as *Figure 30.1* shows, there is a systematic trend toward ever-larger numbers of deaths in wars, yet wars themselves do not occur with regularity. As Singer and Small (1972) demonstrated, the occurrence of wars (though not their size) is random. More precisely, the onset of wars is described by a Poisson distribution. This fundamental observation about the historic occurrence of war is captured in the model by introducing a random variable.

Each year a probability of war occurring is computed. This probability is proportional to the product of the size of the existing military stock times the rate of change of military production. The chance of war is high when stockpiles are large, or when they are increasing fast. Occasionally the random procedure leads to war, at which point resources are shifted toward the military sector.

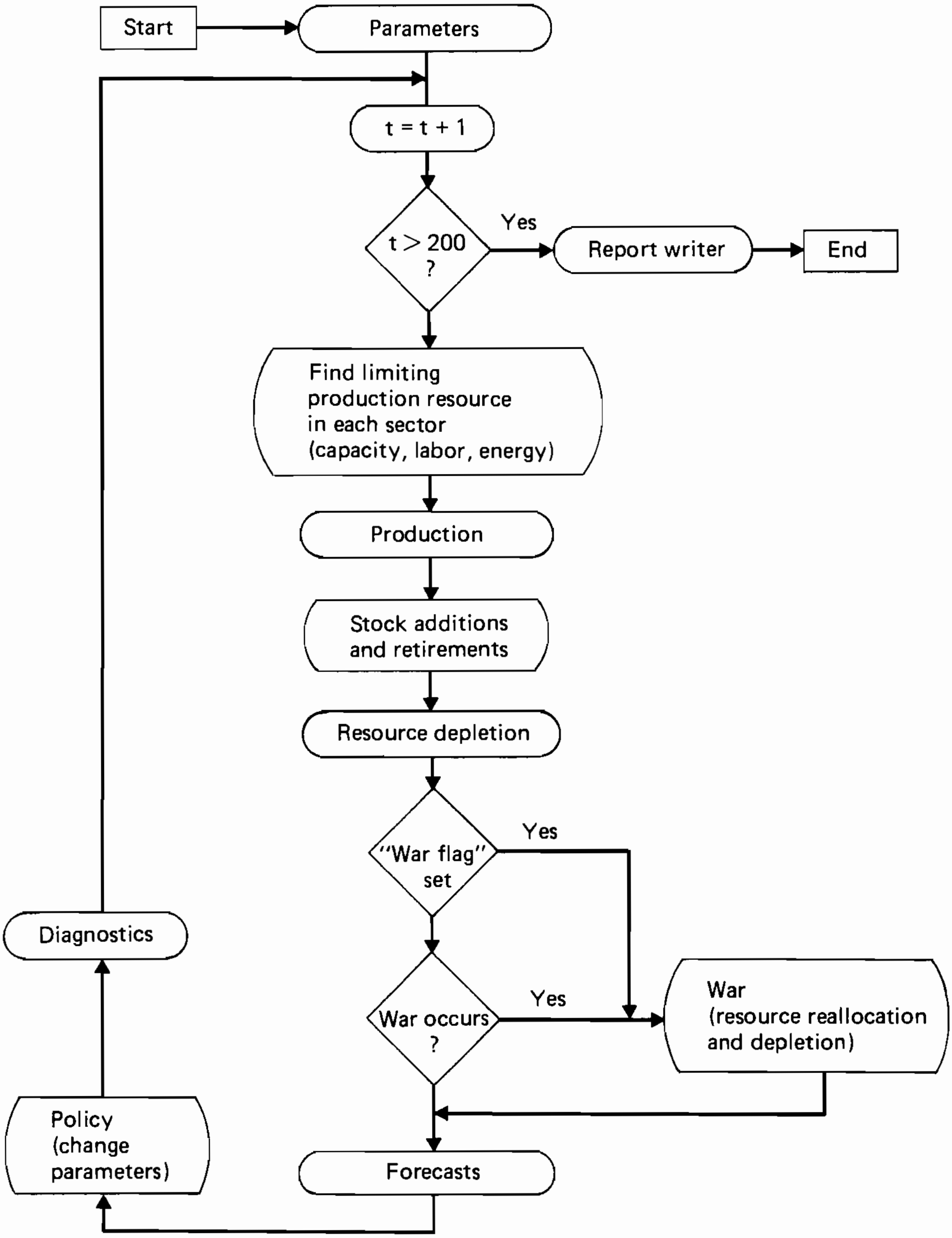

Figure 30.3. **Model flow diagram based on four production sectors: capital, consumption, military, and energy.**

Decisions on how to operate an economy are heavily governed by perceptions. In depressions there exist both the capital and the labor to produce goods. Without optimism, there will be few purchases and little capital investment. The economy stagnates. We include this behavioral phenomenon in a quantity we call "optimism". Optimism is a multiplier that affects investment and employment. Optimism is high when employment is high. Optimism is low when the economy is declining, when unemployment is high, or when consumer output is low. When war breaks out, optimism (at least regarding jobs in the military sector) increases.

Low optimism is expressed in the model by reluctance of investors to invest. When optimism decreases, the utilized fraction of the available capital stock decreases. This decreases the number of jobs, which in turn further decreases optimism.

The policy part of the model (the government) attempts to escape from this downward spiral by stimulating investment (thus creating jobs) in one area over which it has control – the military sector.

Each year a forecast is made, and new policies are implemented. The only policy variable in the model is the allocation of productive resources among the four industrial sectors. Allocations to the military sector are particularly important. They increase when war occurs, thereby removing resources from other sectors and allowing them to deteriorate. When war is over, there is need to build up decayed sectors, and this permits economic growth for some time.

Model parameters are very roughly based on the USA. They are adjusted so that, if war is forbidden, steady growth occurs.

Our original goal was to use the model to explore strategies for dealing with resource depletion and the effect of memory on planning decisions. We were interested in the idea that the decisions individuals make as adults are conditioned by the conditions that existed when they were growing up. Thus persons growing up in bad times may tend to think conservatively, while those who grow up in good times tend to be more expansive. Thus long lag times would be introduced.

We soon learned that such richness (complexity) is not required to obtain interesting results. Policy in the present version of the model is based only on short-term forecasting. We now turn to results. We present results for a single model. The differences in the runs result from the random element in the algorithm that calculates the onset of war.

Figure 30.4(a) shows the gross national product over a 200-year period. The vertical scale is logarithmic. War is indicated by the dark regions below the x-axis. At the beginning of the run the economy was sliding. Policy changes intended to arrest this decline led to increases in investment in the military sector. This increased the chance of war, which soon occurred. During the war the economy deteriorated. Once the war ended, many jobs were available to rebuild the infrastructure. About 40 years of peace ensued, which was finally broken by a series of wars. Over the 200-year period, there were seven wars and a 1.5% per year long-term upward trend in the gross national product.

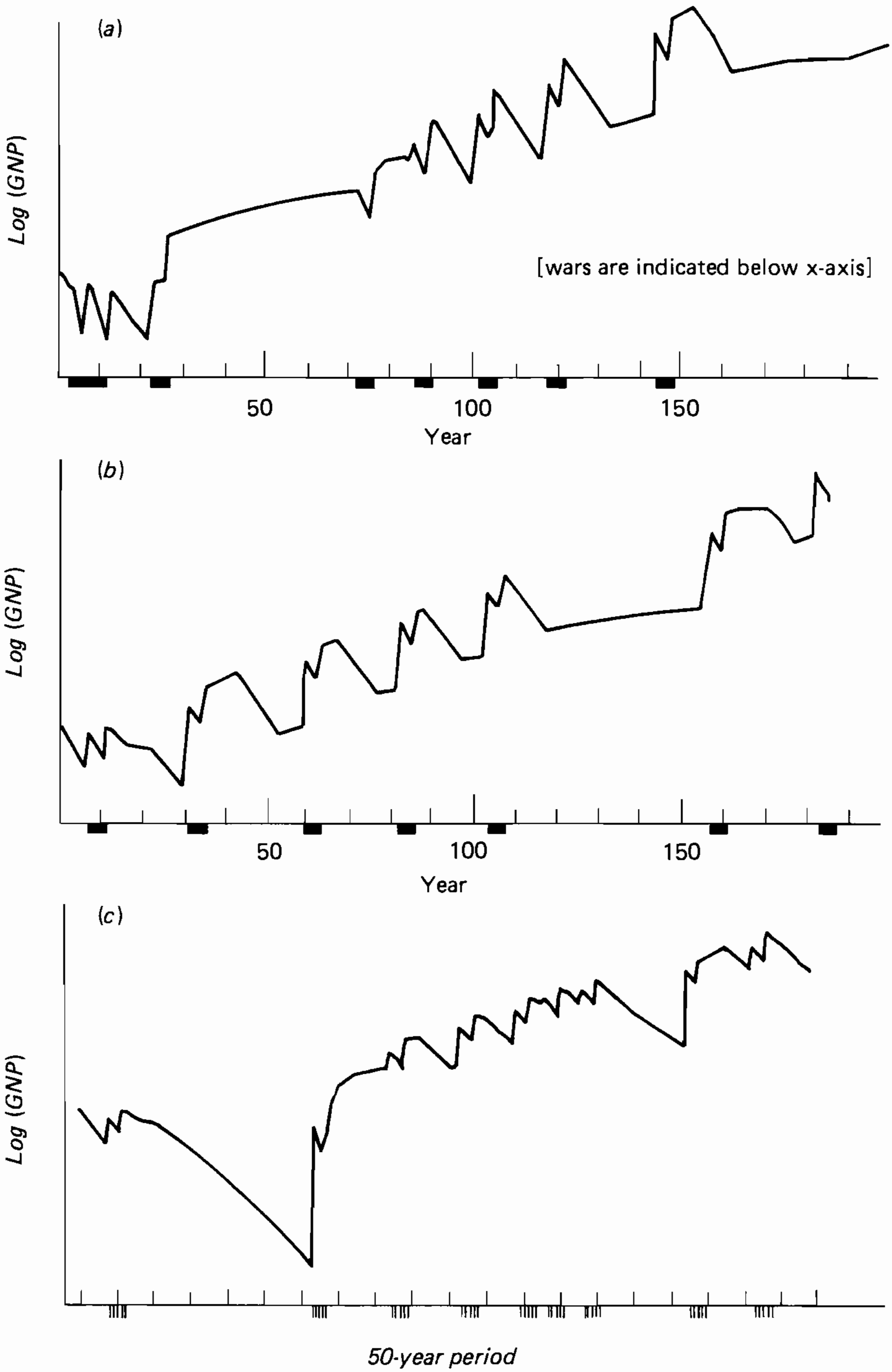

Figure 30.4. Model run results.

Figure 30.4(*b*) is another run on the identical model. While the detailed results differed from the first run, again there were seven wars. The longest period of peace was 30 years. The average economic growth rate over the two centuries was about the same as before.

Figure 30.4(*c*) shows a sustained economic decline over a 50-year period. By the end of the long decline, the economy was in poor shape. Optimism was low, and unemployment was high. The probability of war continued to decrease, as available resources for investment in the military declined. Nevertheless, eventually a war occurred. When it ended, recovery took place very quickly. The remainder of the chart is similar to the other runs. Over the two centuries modeled, average economic growth rate was about the same as before.

30.3. Conclusions

Despite its extreme simplicity, the model shows considerable variation in behavior. It mimics some of the major trends found in industrial societies. The inclusion of a single random element in the simulation appears to capture something important about modern societies.

An objection sometimes raised is that our approach may be relevant to a world without nuclear weapons, but is irrelevant today. We think the relevance remains. "War" appears in the model as a reallocation of national treasure *from* areas that help the society to grow, *into* nonproductive areas. Actual warfare is not required. The only requirement is a sector that can consume resources and that is under governmental policy control. Infrastructure repair would serve as well. To a considerable degree so also would shipment of goods overseas.

If the world view explored in this model has even a modest relation to reality, it suggests that new methods for stabilization of economies are desperately needed. Having one's society at risk to random adverse events is not so bad if the consequences are modest. Today they are not.

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The Long-Wave Debate

For over a century, some economists have pointed out that upswings and downturns in economic activity (along with some key economic variables) seem to follow a surprisingly regular pattern – a pattern sometimes labeled simply "Kondratieff long waves" in honor of the Russian economist who first rigorously described some of the phenomena leading to these changes.
What might be the causes and consequences of these long-term fluctuations? What is the relationship between these so-called long waves and other structural changes, technical revolutions, financial and monetary variables? Finally, if the mechanisms of long waves can be understood, will it be possible to avoid the recurrent recessions in economic development that are as painful for the less developed countries as for the developed ones – be they socialist or capitalist in orientation?
By invitation, an international panel of distinguished scholars met in Weimar, GDR, to discuss these fascinating questions about the existence and nature of long waves. This conference was organized and sponsored jointly by the International Institute for Applied Systems Analysis (IIASA), Laxenburg, Austria, and the Institute of Theory, History and Organization of Science of the GDR Academy of Sciences, Berlin. A select group of 30 contributions comprise *The Long-Wave Debate,* which thus represents the state of the art in the theory and empirical observation of long-term economic cycles.

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