International Institute for
Applied Systems Analysis
IIASA www.iiasa.ac.at

Long Waves in World Industrial Production, Energy Consumption, Innovations, Inventions, and Patents and their Identification by Spectral Analysis

Haustein, H.-D. & Neuwirth, E.

IIASA Working Paper

WP-82-009

January 1982

Haustein H-D & Neuwirth E (1982). Long Waves in World Industrial Production, Energy Consumption, Innovations, Inventions, and Patents and their Identification by Spectral Analysis. IIASA Working Paper. IIASA, Laxenburg, Austria: WP-82-009 Copyright © 1982 by the author(s). http://pure.iiasa.ac.at/id/eprint/2006/

LONG WAVES IN WORLD INDUSTRIAL PRODUCTION, ENERGY CONSUMPTION, INNOVATIONS, INVENTIONS, AND PATENTS AND THEIR IDENTIFICATION BY SPECTRAL ANALYSIS

Heinz-Dieter Haustein and Erich Neuwirth

January 1982
WP-82-9

INTERNATIONAL INSTITUTE FOR APPLIED SYSTEMS ANALYSIS
2361 Laxenburg, Austria

PREFACE

Scientists like to make the irregular regular, to draw curves even in cases where nothing can be seen at all. Periodical wave curves are an excellent means of organizing the unorganized, of arranging the unarranged. Recent studies on long waves in economic development have found a periodicity in the time series of inventions and innovations that works exactly like a clock with an accelerating mechanism. What we have done here is simply to collect some interesting empirical figures and to exploit them by spectral analysis in order to find out whether regularities exist, and if so, whether they are statistically significant.

CONTENTS

CHAPTER 1

THE PROBLEM

There is no doubt that in the course of history, industrial growth has experienced a number of upswings and downswings. Looking at world industrial production from 1850 to 1979, we see that growth rates have been rather unstable during this period. Using an exponential function to describe long-term trends, one obtains a path of industrial growth measured in deviations from the long-term average (see Figure 1). Here we see the major downswings and upswings in industrial production, among them the unprecedented downswing at the end of the 1920s.

Long-term cycles have been much discussed in the literature since Kondratieff (1926). Some years ago Gerhard Mensch (1975) described these "long-waves" in terms of clusters of innovations, using the frequency distribution of major technological changes over time.

In the past 200 years, several major technical revolutions have significantly affected industrial activities. Despite differences in their technical character, they have had two main features in common:

1. Each of them was caused by a bottleneck in the production system. The railroad, for example, became necessary during the industrial revolutions because of the urgent need to transport coal and cotton.
2. Each of them appeared in one area of the production system and then passed through a chain or network, step by step affecting the whole production system, and later, lifestyles and consumer patterns. (See Figure 2.) For example, the spinning

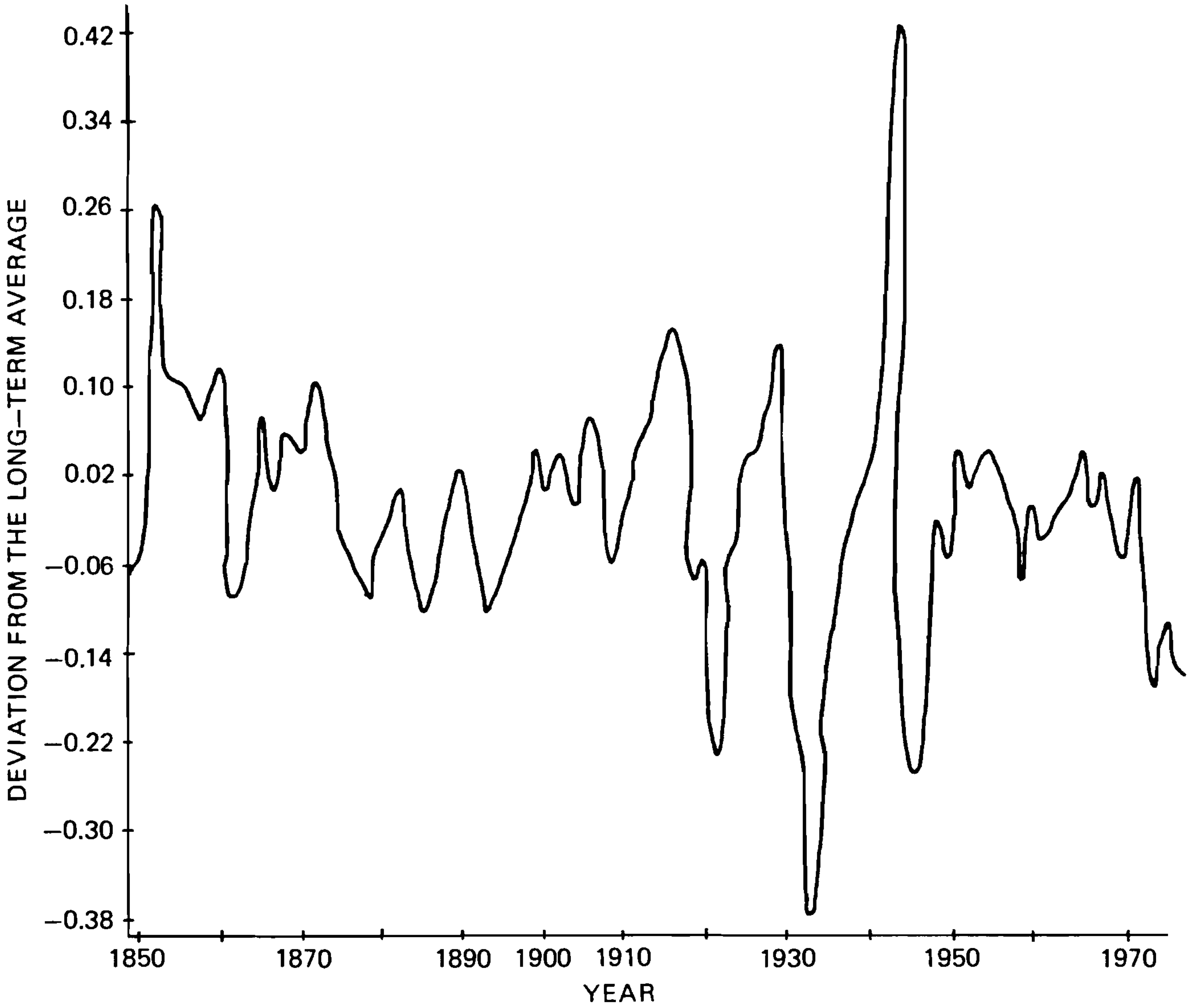


Figure 1. World industrial production logarithm (1850-1979).

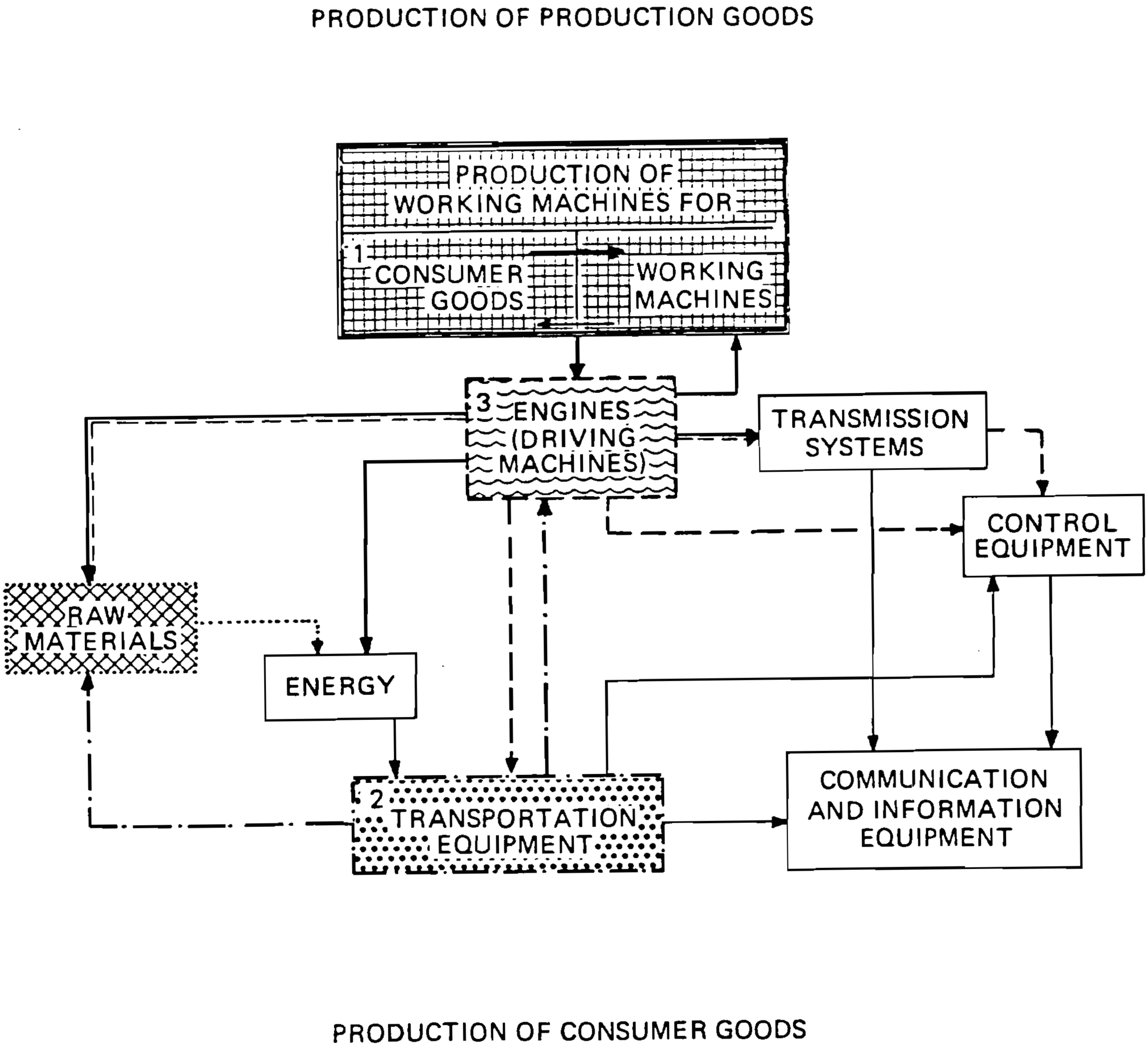


Figure 2. The two production sectors and their inner feedbacks.

machine led to the mechanization of weaving, and later to the improvement of bleaching, textile printing, and dyeing (Marx 1963). 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 iron to produce machinery increased, more coal was needed to produce the iron, and so forth.

Table 1 gives an overview of general periods of industrial development since 1740 and their characteristics. Each period can be described in terms of:

- changes in resources
- changes in demand
- changes in labor functions
- gaps in the production system and in growth industries

However, it is difficult to define an exact time-frame for each historical period. Table 1 presents more or less a qualitative judgment based upon several sets of information and data. This can help examine further historical progress by analyzing the inner logic in the development of resources, demand, labor functions, and other dimensions.

Looking at various data on innovations, inventions, industrial production, energy consumption, and patents, which will be presented in the next chapter, it is again possible to distinguish certain periods that more or less coincide with the periods characterized in the first table (see Table 2). Other authors have obtained results that differ more or less from ours (see Table 3).

"Cycles", of course, is a quite arbitrary term for these time periods. History does not actually repeat itself; nor can a strict stable periodicity be observed. But people like to think in terms of cycles. This seems to be an old pattern of human thought, influenced by the patterns observed in agricultural periods, weather changes, and tides, in which mechanisms work recurrently.

Our historical periods might be better called quasi-cycles, because we are not sure whether the same fundamental causes are present in all upswings and downswings. So when applying spectral analysis in the investigation of long time series in industrial production, innovations and inventions, we know that we will not necessarily find an underlying pattern in the true sense of the word. Spectral analysis can merely reveal certain quantitative and formal properties of the whole process.

Table 1. Period of industrial development since 1740 and their characteristics.

Periods	Length	Social Characteristics	Changes in Resources	Changes in Demands	Change in Labor Functions		Main Gaps in the Production System	Main Growth Industries
					Substitution for	Extension of		
1740-1808	69	Early industrial capitalism	High growth of wood products and copper (Brass goods)	Increasing food demand	Manual (energetic)	Manual (energetic)	Spinning, Power source (driving machine), Fabrication of working machines necessary	Textile industry (spinning)
1809-1869	61	Free competition system	High growth of pig iron	Increasing food demand	Manual (energetic)	Manual (energetic and executive)	Coal demand, iron demand, and need for transportation system	Textile industry (weaving), mining, coal, pig iron, shipbuilding
1870-1908	39	Transition to monopolies	Peak growth of coal (1880)	Increasing food demand	Manual (energetic)	Manual (energetic and executive)	Need for mass production of machines, Steampower exhausted in its possibilities	Railroad, iron, and steel
1909-1930	22	Expansion of monopolies	High growth of rubber products	Decreasing expenditures for food (relatively)	Manual (executive)	Manual (executive)	Exhaustion of raw material basis (natural fibres)	Electricity, automobiles, and mechanical engineering
1931-1949	19	Growing of state interference	High growth of aluminum	Increasing expenditures for housing	Manual (executive)	Manual (executive assembling)	Need for flexible transportation system	Automobiles, chemicals
1950-1965	16	Fast growth of postwar capitalism	Peak growth of synthetic fibres	Fast growing demand for durable goods	Transport, Manual transportation, Manual work	Supervision of machines, Operating machines, Maintenance, Quality control	Fast growth of control mechanisms, requiring space and materials necessary	Chemicals, aircraft
1966-1981	16	Expansion of multinational corporations	Peak growth of oil consumption (1975)	Increasing travel expenditures	Machine operation, Assembling, Office work, Mediation	Maintenance, Installation, Health service, Education	Need for better information handling Energy gap	Electronics
After 1980			Alternative energy sources	Increasing expenditures for education	Scheduling, Office work, Information function	Guidance, Consultation, Education	Need for better information handling	Telecommunications

Table 2. Observed periods, their peak years, and their length in years.

Basic Innovations	Industrial Production	Energy Consumption	Basic Inventions	Dominating Fields	Patents	
1740-1808 69* 1764**	1750-1808 59 1785		1700-1780 80 1745	Textile machinery		
1809-1869 61 1838	1809-1865 56 1855	1600-2000 400 1800 (wood)	1750-1819 70 1780	Textile machinery	1710-1819 110 1764	England
1870-1908 39 1882	1866-1910 44 1898	1780-2050 270 1915(coal)	1790-1850 60 1820			
1909-1930 22 1922	1911-1932 21 1922	1890-2060 170 1975 (oil)	1821-1867 46 1841		1820-1867 48 1845	
1931-1949 19 1938	1933-1953 20 1941		1845-1882 37 1860	Basic industries Mechanical engineering	1868-1892 35 1880	
1950-1965 16 1958	1954-1974 20 1966		1879-1911 32 1895		1893-1920 28 1908	US
1966-1980 15 1971	1975-1988 13 1982		1894-1925 31 1906		1921-1945 25 1931	
1981-1994 14 1988	1989-2001 12 1995		1916-1945 29 1928	Chemicals :	1946-1976 30 1959	
			1930-1950 20 1940	Electrotechnique		
			1948-1965 15 1958	Electronics		

*Length of period
**Peak year

Table 3. Historical periods observed by various authors.

Kondratiev			Mensch			Marchetti (on the basis of Mensch's data)						Thomas Kuczynski	
National Economy			Innovations			Innovations			Inventions			Innovations	Inventions
Period (Low Years)	Peak Year	Length	Period	Peak Year	Length	Period	Peak Year	Length	Period	Peak Year	Length		
1776-1824	1800	48	1740-1785	1764	45				1720-1845	1775	125	1829-1877	1815-1884
1825-1882	1858	57	1794-1862	1825	68	1780-1860	1828	80	1800-1890	1833	90	1878-1898	1805-1904
1883-1938	1913	55	1838-1915	1882	77	1850-1900	1880	50	1850-1920	1905	70	1899-1921	1905-1941
1939-1992	1967	53	1890-1960	1937	78	1910-1945	1937	70	1930-1990	1968	60	1922-1941	
						1975-2000	1992	25				1943-1955	

Sources: Kondratiev 1926, Mensch 1975, Marchetti 1980, and T. Kuczynski 1978.

CHAPTER 2

METHOD

A graphical inspection of all the variables for this period showed that the variables production, energy, and patents granted in England show roughly exponential growth. This exponential growth was not constant over the whole period; but for each of these variables sub-periods could be found in which the exponential growth was rather smooth (see Table 4). The homogeneous structure of these periods is best seen by drawing the curves of the logarithms of the variables.

Since the aim of our analysis was to find out possible cycles in the dependencies among our variables, we had to remove all long-term trends. To do this we created new variables from the one originally given by taking logarithms and removing linear trends in the logarithms.

Linear regressions were calculated for each of the intervals given above and for all the three variables considered. Using the variable y for the year 1800, we have displayed the equations defining our new variables in Table 4.

The idea behind transforming these variables was that there was a homogenous exponential trend for each of the periods and that superimposed over this trend was a certain cyclical behavior, i.e., our variables showed the same structure for all these periods. (No transformations are given for energy in periods 1 and 2 and for "patents England" in period 5 because data were not available for these periods).

Table 4. Defining equations according to periods.

PRODUCTION			ENERGY			PATENTS ENGLAND		
Period	**Years**	**Production new**	**Period**	**Years**	**Energy new**	**Period**	**Years**	**Patents England new**
1	1738-1780	$\log(P)-0.01032y-1.41632$	3	1821-1919	$\log(E)-0.04260y-2.38231$	1	1738-1780	$\log(PE)-0.05011y-4.63197$
2	1781-1820	$\log(P)-0.0288y-1.88504$	4	1914-1947	$\log(E)-0.01807y-5.06690$	2	1781-1820	$\log(PE)-0.02686y-4.31706$
3	1821-1919	$\log(P)-0.03606y-1.70817$	5	1947-1979	$\log(E)-0.04949y-0.92752$	3	1821-1919	$\log(PE)-0.02500y-4.64945$
4	1914-1947	$\log(P)-0.02980y-2.25681$				4	1914-1947	$\log(PE)-0.02949y-3.5944$
5	1947-1979	$\log(P)-0.05057y-0.88030$						

The data for US patents did not exhibit exponential growth but showed partly linear behavior. The intervals with homogenous linear trends were not the same as for the variables production, energy and patents England. So we tried to remove the long term trends in this variable by using ordinary linear regression and taking the residuals as new variables. Using this method we arrived at the results in Table 5.

Table 5. Defining equatons for US patents.

PATENTS USA

Years	Patents USA new
1790-1850	log(PU.S.)-12.1134y-51.0100
1851-1930	log(PU.S.)-586.83y-30823.42
1931-1947	log(PU.S.)+1779.53y-285364.97
1948-1976	log(PU.S.)-1629.91y+210146

The invention and innovation variables showed no long-term trends and thus were used untransformed in the rest of the analysis. The transformed variables for production, energy, patents England, and patents USA; and the untransformed variables for innovation number and invention index, invention power, and innovation number were used for time-series analysis via spectral analysis.

To determine the cyclical behavior of each of the variables, autocovariances, spectra, and spectral densities were calculated. In short the underlying theory is: Every stochastic process X_t can be written as a stochastic integral:

$$Y_t = \int_0^\pi \cos\lambda t \; d\,C(\lambda) + \int_0^\pi \sin\lambda t \; d\,S(\lambda)$$

where $C(\lambda)$ and $S(\lambda)$ are uncorrelated processes of uncorrelated increments (i.e., $C(\lambda_4) - C(\lambda_3)$ and $C(\lambda_2) - C(\lambda_1)$ are uncorrelated for $\lambda_4 > \lambda_3 \geq \lambda_2 > \lambda_1$ and the same is true for S and for correlations between C and S and $E(S(\lambda)) = E(C(\lambda)) = 0$ for all $0 \leq \lambda \leq \pi$. From this representation one can see that Y_t tends to have periodic coomponents which period λ for values of λ where the variance of $C(\lambda)$ and/or $S(\lambda)$ is increasing very rapidly. (These variances can be shown to be monotonically increasing functions of λ).

In general terms, the reason for this is:

$$Y_t(w) = \lim(\sum \cos\lambda_i t\,(C(\lambda_i)(w) - C(\lambda_{i-1})(w)) + \sum \sin\lambda_i t\,(S(\lambda_i)(w) - S(\lambda_{i-1})(w))$$

We will not specify the mathematical theory of stochastic integrals, so we will not argue about the exact nature of the limits occuring in this formula. For a detailed discussion, see Anderson 1971.

In this formula, we see that if the difference $C(\lambda_i) - C(\lambda_{i-1})$ tends to result in large values, then the process Y_t will with great probability have periodic components with frequency $2\pi\lambda_i$. So one instrument for detecting periodicities in Y_t is to study the function

$$E(C^2(\lambda)) = E(S^2(\lambda))$$

(Theory shows that these variance functions are identical).

It can be shown that this function is identical to the spectral distribution function $G(\lambda)$ with the property

$$cov(Y_t Y_{t+k}) = \int_{\pi}^{-\pi} \cos\lambda k dG(\lambda)$$

(The right-hand integral is an ordinary Riemann-Stieltjes integral and this function can be calculated from the original process Y_t.

An interesting case is when G possesses a density $g(\lambda)$. This means roughly that there is no dominating cycle in the behavior of Y_t.

If we have values of λ for which $g(\lambda)$ is high with respect to other λ's, then the process tends to have common periodic components with frequency $2\pi\lambda$. Since we do not know the process Y_t but only a realization of it we cannot calculate $g(\lambda)$; we can only estimate it. $g(\lambda)$ is the Fourier transformation of $\sigma(k) = cov(Y_t, Y_{t+k})$. Therefore we used the usual estimate to calculate $\sigma(k)$ and then took its Fourier transformation to estimate $g(\lambda)$.

However, there is a problem is this. The autovariances in the sample do not produce a consistent estimate of the real covariances. So one has to use smoothing procedures to get consistent estimates of these parameters. We used the Parzen weighting function for smoothing the autocoravainces. This weighting function yields consistent estimates for $g(\lambda)$ when $\sum k^2\sigma(k)$ converges and with increasing T given T observations we use only autocovariances of orders smaller than $C \cdot f(T)$ to calculate the estimator of the spectral density where

$$\lim_{T \to \infty} f^2(T) / T = 0.$$

$f(T) = T^{1/3}$ would be such a function.

This means roughly that the covariances of widely separated observations are moving rapidly enough toward zero that one can safely omit them from the smoothing procedure for estimating spectral density.

Using these smoothed autocovariances, we calculated the estimates for the spectral density. In order to determine the interactions between the periodic components of our time series we calculated coherences and phase shiftings for each pair of variables. Intuitively speaking this means that we decompose the processes into their periodic components and calculate "correlations" between these components and also calculate the typical lag between the peaks of the sine waves.

For a detailed and mathematically more appealing description of the method used see Hannan (1970). It would go far beyond the aim of this paper to give a detailed description of the mathematical theory used.

As in the case of the autocorrelations we also used the Parzen weighting function for smoothing the cross-covariances. Since we did not have data for all the variables we had to use "smoothing windows" of different lengths for calculating estimations of the spectral densities and coherences. Tables 6 and 7 give all these window lengths.

Table 6. Autocovariances and spectral densities.

Variables	Window Length
Production	80
Energy	50
Patents USA	80
Patents England	80
Innovation	80
Invention	80

Table 7. Coherences and phases.

Pairs of Variables	Window Length
Production, Energy	50
Production, Patents England	80
Production, Patents USA	80
Production, Innovation	80
Production, Invention	80
Energy, Patents England	30
Energy, Patents USA	50
Energy, Innovation	50
Energy, Invention	50
Patents England, Innovation	80
Patents England, Invention	80
Patents USA, Innovation	80
Patents USA, Inventions	80
Innovation, Invention	80

CHAPTER 3

THE DATA

The data used are presented in Appendix 1. For world industrial production, we used the data collected by Juergen Kuczyuski (1967) and Thomas Kuczynski (1978) for the period 1850-1976 and completed them by using the Hoffmann Index (Hoffmann 1955) for the period 1740-1849 and UN Statistics (Monthly Bulletin 1975-1981) for the last years.

Data on world primary energy consumption are available from 1850 (Schilling, Hildebrandt 1977). Further, data on patents granted in England and in the US are presented in Mitchell (1975) and Technology Assessment and Forecast (1977). Data on English patents between 1700 and 1890 might best represent world technological progress, followed by US patents from 1890 to the present.

We collected data on 182 inventions and innovations, including the list of 90 inventions and innovations used by Gerhard Mensch (1975), and calculated the following indicators (see Apppendix II):

t_L = the date of invention according to the date
of the first major patent application or other sources

t_E = the date of innovation, normally the date of
first production or market introduction

T_E = the time period between invention and innovation
($= t_E - t_L$), also called "lead"

v_E = the speed of innovation ($=100/T_E$)
The earlier an invention is realized as an
innovation, the higher this indicator will be.

V_K = the range of application of a given innovation

i_K = the scientific-technological level of a given
innovation. V_K and i_K are explained
in Table 4.
w_K = the coefficient of importance ($= i_K \cdot V_K$)
p = the innovation potential
($= w_K / T_E$).
p* = the innovation power ($=p \cdot v_E = w_K^2 / T_E$)

The dates of invention and innovations, taken from historical sources, determine t_c, t_E and T_E.

The coefficients i_k and V_k were calculated on the basis of Table 8. We used 7 levels for each indicator and evaluated them quantitatively. The main assumption here was the existence of an exponential frequency distribution of different classes of innovations (Haustein, Maier, and Uhlmann 1981).

If we assume that the importance of innovations w (a coefficient between 1 and 100) follows an exponential function and the parameters i_k and u_k are connected in a multiplicative form, we can write

$$w = i_k V_k$$

$$w = e^{ak} e^{bk}$$

and

$$w = e^{(a+b)k}$$

Taking a simple symmetrical scheme ($a = b$), we then have

$$w = e^{2ak}$$

where

$$k = 0,1,\dots,6.$$

According to $1 < w \leq 100$ (percent), we find for k = 6

$$100 = e^{12a}$$

$$a = \ln \frac{100}{12} = 0.38376$$

From this we find the coefficients of importance for each level within the 7 x 7 = 49 field (see Table 8).

When we try to adjoin one innovation to the 7 x 7 = 49 field, we realize that we often have difficulty in making an exact estimation. So it is clear that the invention and innovation indicators are by no means exact figures.

Each of the inventions and innovations is represented by three indicators:

- number
- coefficient of importance w

Table 8. Classification of innovations by scientific/technological level and range of application.

			Range of application						
			II				BI		
No.	Scientific/ technological level	ν_k	Quantitative growth of existing demand	Simple modification of existing demand complex (improved parameters of existing products or processes)	Essential modification of existing demand complex (new parameters of existing products and processes)	Development of new demand (new product or process) in existing demand complex	Essential modification of existing demand complex (new products or processes)	Development of new demand complex or subcomplex	Change in entire system of needs
	I_k		1	1.5	2.2	3.2	4.6	6.8	10
1	Quantitative growth of existing technical basis	1	1	1.5	2.2	3.2	4.6	6.8	10
2	Improvement within well-known technical principle	1.5	1.5	2.3	3.5 (Bentwood furniture)	4.8 (Bicycle)	6.9	10	15
3	Improvement within well-known technical principle with essential changes in one factor (materials, tools, or function design)	2.2	2.2	3.3 (Oxygen process)	4.8 (Thomas-gilchrist process)	7 (Diesel engine)	10 (Paper production)	15	22
4	Improvement within well-known technical principle with essential changes in several factors	3.2	3.2	4.8	7 (Stitching bond)	10 (Atomic ice-breakers)	15 (Electric railway)	22	33 (Spinning jenny)
5	New solutions within well-known basic principle	4.6	4.6	6.9	10 (Gyrocompass)	15 (Polyethylene)	22 (Detergents)	33 (Vacuum lamp)	46
6	New basic principle within same form or structural level of matter	6.8	6.8	10	15	22	33 (Synthetic fibers)	46 (Incandescent lamp)	68
7	New basic principle changing form or structural level of matter	10	10	15	22	33	46 (Radar)	68 (Transistor)	100 (Electricity)

NOTE: Examples are given for illustrative purposes in some cases.

Source: Haustein et al. 1981.

- power coefficient p*

These indicators are calculated according to the data on 182 inventions and innovations contained in Appendix II. We think that the coefficient of importance better represents the real weight of an innovation or invention than does their simple number. The definition of the innovation potential $p = i\frac{V}{T}$ seems to be analogous to the physical definition of energy. The higher the innovation potential, the shorter the lead and the bigger the importance of the innovation. It can be assumed that the diffusion of such innovations will then also be quicker. The power coefficient is the potential coefficient weighted by the importance coefficient.

CHAPTER 4

RESULTS AND CONCLUSIONS

As it has been shown in many studies, the demands of the production system give an important push to innovations and inventions. But this does not necessarily imply that innovations and inventions directly follow patterns of industrial production growth. A spectral analysis using the time series

Industrial Production N = 240
Energy Consumption N = 119
Innovations N = 227
Inventions N = 237
Patents England N = 198
Patents US N = 187

showed the following results.

The longest cycle we could identify was a fifty year cycle. The straight lines in Figure 3 show the results of an analysis carried out with the help of auto- and cross-correlation on the basis of the Parzen weighting function.

The 40-60 year cycle is often called the Kondratieff cycle. The Russian economist N.D. Kondratieff probably did more than anyone to make the idea known in the USSR and the world in general while he was head of the Konjunktur Institute in Moscow in the 1920s. Kondratieff, Parvus, van Gelderen, de Wolff and others regarded 1815, 1849, 1873, and 1896 as years of crucial turning points. Karl Marx was aware of the cyclical character of capitalist reproduction and linked it with the duration of long-term fixed capital (Marx 1963).

Schumpeter considered the irregular clusters of innovations crucial for economic development (Schumpeter 1939). However, he was unclear about why innovations occur in clusters. Gerhard Mensch (1975) updated Schumpeter's theory and tried to give it an empirical base. He identified periods with a lack of basic innovations : 1814-1827, 1870-1885, 1925-1939, and 1975-?. Cesare Marchetti (1980) used Mensch's figures, plotted them as logistics and added his findings on energy sources and price development (see Figure 3). The logistic pattern seems to be very convincing. But using our data we could not find any logistics in the development of industrial production, patents, or energy consumption. In the case of inventions, logistics could be identified only for the periods 1738-1860, 1930-1950, and 1950-1966. In the case of innovations this was true only of 1859-1908, 1909-1930, and 1950-1966. So we have some doubts when looking at the regular patterns of inventions and innovations by Mensch and Marchetti.

According to Figure 4, industrial production is influenced by the innovation index within the 50 years cycle with a lag of 21 years and a coherence of 0.40 which is of course not very high. But this result seems to be plausible: in the past it took about two decades before a major innovation wave led to a major upswing in industrial production. The innovation wave between 1931 and 1949 was followed by the upswing in world industrial production after the Second World War.

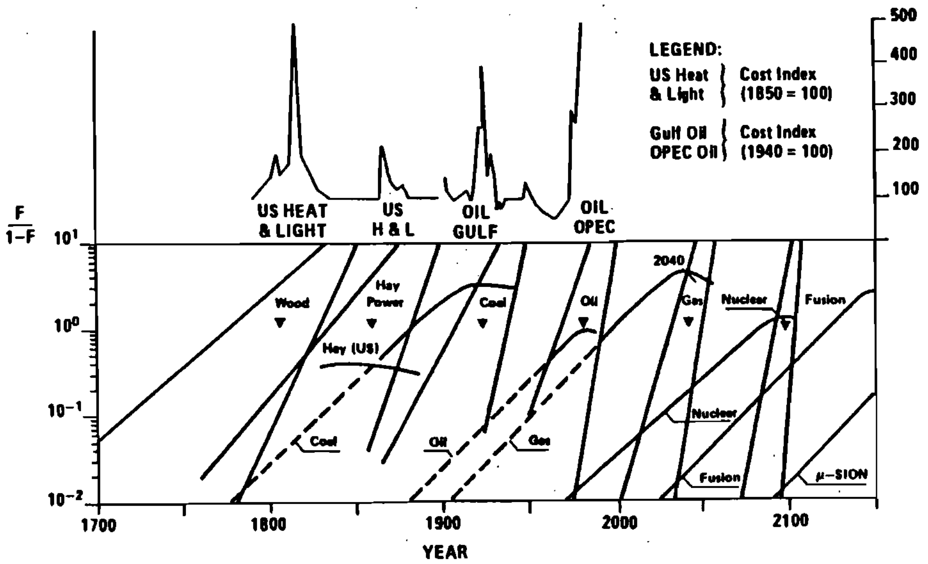
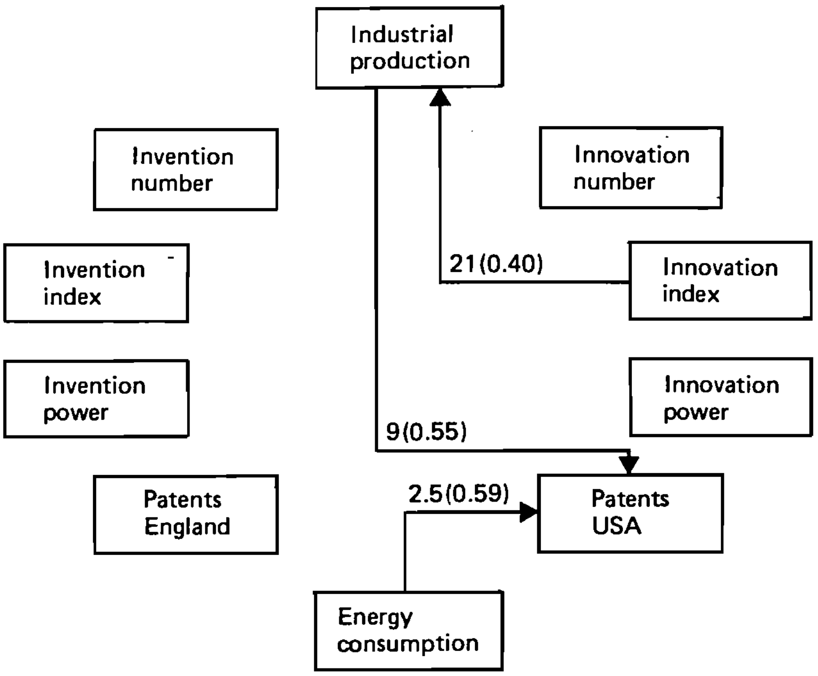


Figure 3. Invention and innovation waves--the secular set. (Source: Marchetti 1980.)



Figures give the lengths of the time lags between the 50 year cycles in years, and in brackets, the coherence.

Figure 4. The 50-year cycle (50, 53.3 years).

A direct 50 year cycle of autocorrelation could not be identified for any of the variables. This means that a dominating internal long cycle exists in none of the variables. But non-dominant cycles do appear when analyzing interactions between any two of these variables.

A second interesting result is the influence of industrial production on US patents with a lag of 9 years and a coherence of 0.55. Here the interpretation is not so difficult. The innovation index represents basic innovations. But the number of patents is of course a measure of improvement innovations. Improvement innovations follow the path of industrial production much more clearly than the clusters of basic innovations that occur not simply as a result of production downswings. Our result is in line with Schmookler's (1966) finding that the number of patents awarded in an industry increases only after demand has increased.

The relation between energy consumption and patents can be interpreted in the same way. The improvement cycle seems to be closely connected with the energy consumption cycle and a lag of 2.5 years is not long enough to judge about the causal direction.

The fifty year cycle is difficult to explain in economic terms. Are 50 years a kind of reproduction period of national wealth--including the innovative potential of human society? Does it reflect the exhaustion period of a reserve of given natural and social resources? Clusters of basic innovations were always ready for the next production upswing. But which mechanism guides the 50 year cycle, if it exists at all?

According to Figure 4 we are dealing here with lag cycles and not with life cycles. Lag cycles are a well-known economic phenomenon. They can be demonstrated using the following example from the shipping industry.

After a year of high freight rates, more ships are ordered. After about a year these vessels are launched. These tend to depress freights, and would continue to do so as long as they kept running--on an average about 17 years for the first shipowner and another 17 years for the second or third shipowners. Tinbergen (1981) has shown that the resulting waves have a length equal to about four times the time lag involved.

The same can be said of the relationship between innovations and industrial production and industrial production and patents. A major driving mechanism of economic development is the relationship between the growth of the investment goods sector and the consumer goods sector, a relationship that lies at the core of Marx' reproduction theory. This idea was used in Forrester's National Model.

> The process involves an over-building of the capital sectors in which they grow beyond the capital output rate needed for long-term equilibrium. In the process, capital plant throughout the economy is overbuilt beyond the level justified by the marginal productivity of capital. Finally, the overexpansion is ended by the hiatus of a great depression during which excess capital plant is physically worn out and financially depreciated on the account books until the stage has been cleared for a new era of rebuilding. (See Forrester 1981.)

Assuming this theory, the model revealed what was expected: that clusters of innovations are not necessary a cause for this mechanism. On the other hand, the bunches of innovations are caused by the long economic cycles themselves. This is an idea that has also been expressed in recent Marxist literature (T. Kuczynski 1978).

But careful empirical studies are necessary to prove or to disprove this hypothesis. Forrester's model is insufficient for a substantial and convincing argument.

At least it is undisputed that innovations occur in clusters over time. The cluster phenomenon does not need an exogenous explanation: the inner feedbacks and the systems character of technology lead necessarily to chain reactions, causing a tendency toward very uneven technological progress (Haustein 1975).

With regard to the long cycle, Marx' theory on the "tendencious falling of profit rates" seems to provide a better answer for the future analysis of long waves. A cornerstone of this theory is the organic composition of capital, that is, the value relation between constant and variable capital $c:v$, as far as it expresses its technological composition between technological means and labor.

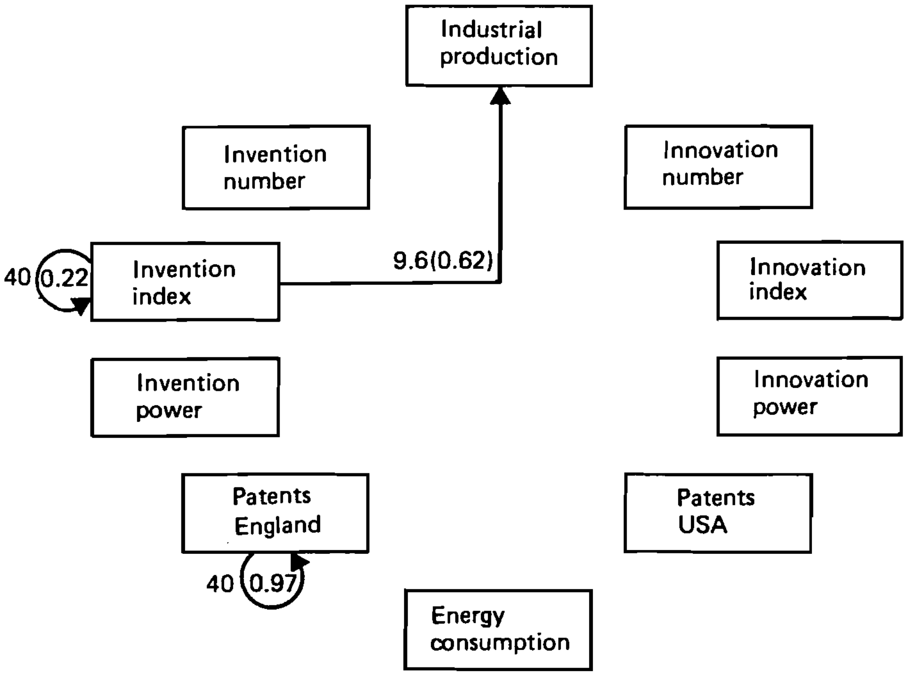
In its maturation and saturation stage, technological progress leads to a higher organic composition of capital, which presses the profit rate down. But there is another tendency superimposed over the first one: the innovative industries, which are the leaders of the industrial growth, have very rapid productivity growth and this influences profit rates in a positive direction. The organic composition of new industries is normally lower than the industrial average.

A. Kleinknecht (1879, 1980) has shown this using the example of West German industry. This is a somewhat paradoxical development. The same process that leads to a lower profit rate gives rise to an opposing force that paralyzes the falling rate. Marx (1963) was fully aware of this trade-off in the movement of profit rates.

The next long cycle discovered by the spectral analysis was a 40 year cycle. The results were poor: two autocorrelations in the invention index and in patents Englands, and a cross-correlation between the invention index and world industrial production with a lead of 9.6 years (see Figure 5).

This lead is difficult to explain. On the average it takes 30.2 years from invention to innovation according to the set of data in Appendix II (standard deviation s = 26.1; N = 182). The thirty year lag could be the result of roughly $\frac{40}{2} + 9.6$; this means that an upswing in inventions is followed thirty years later by a downswing in world industrial production. This would correlate with Mensch's argument that innovations take place in the deep crisis phase.

Figure 6 shows the next 32 year cycle, which exists mainly in the relation between invention indicators and US patents with a lead of 11 years. As a matter of fact, basic inventions cause a stream of improvement inventions represented by patents.



Encircled figures (autocorrelation loops) indicate spectral density

Figure 5. The 40-year cycle.

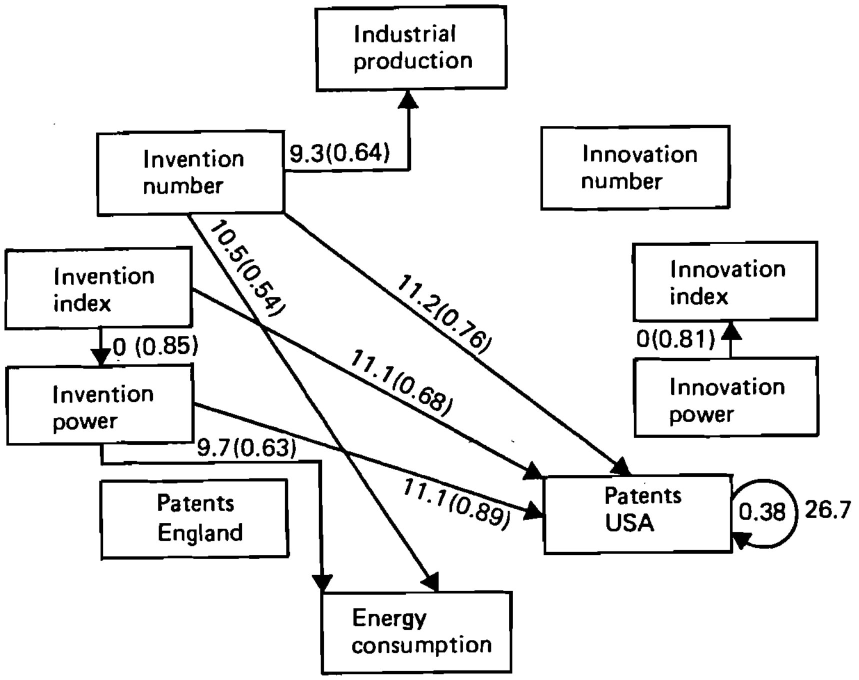


Figure 6. The 32-year cycle (26.7, 32, 33.3 years).

Next is the 20 year cycle (see Figure 7), a rather strange one, presenting a cross-correlation between inventions and innovations with a lag of 3 or 4 years. Since all of these variables were constructed from the same data set, one should not overestimate the importance of these cross correlations.

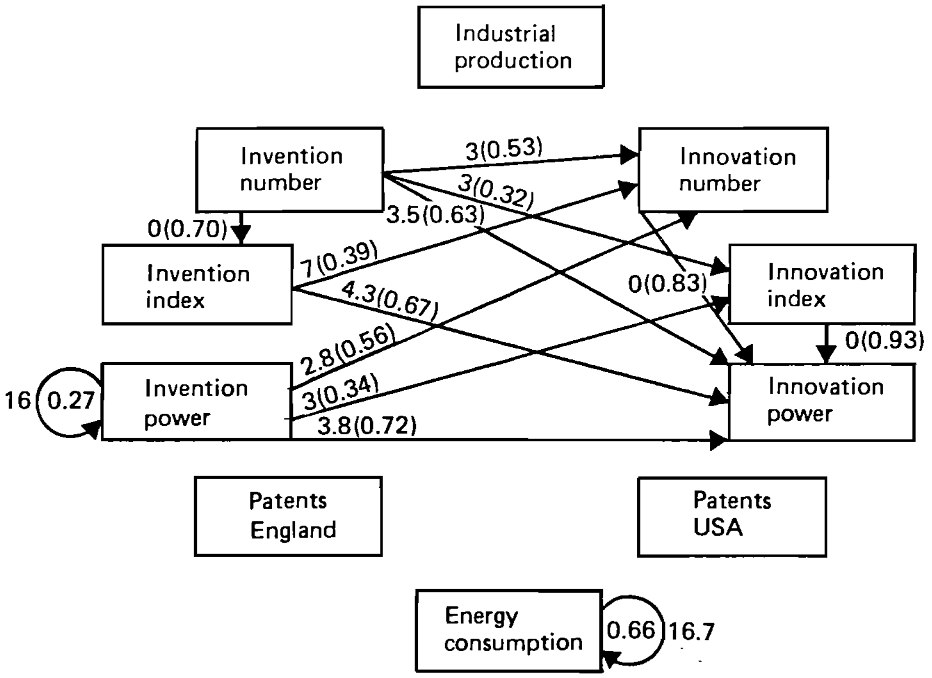


Figure 7. The 20-year cycle (16, 16.7, 20, and 22.6).

Figures 8 and 9 show the next 13 years and the shorter cycles. At present there are a number of interesting and significant relationships, mainly between innovations and industrial production or energy consumption.

The seven year cycle is sometimes called the Juglar cycle. In 1889, the French economist Clement Juglar wrote one of the first major studies of business cycles. Before World War II, the cycles generally had a duration of 7 to 11 years, but they have since been shorter.

Juglar cycles are the ordinary medium-term business or trade cycles that are central to Keynesian theory and policy prescriptions. In early capitalism between 1815 to 1847, they had a length of about five years; after 1848 this became ten years (Marx 1963).

In his fundamental work, E. Varga (1937) identified the following depression years in world economy: 1857, 1866, 1873, 1882, 1890, 1900, 1907, 1920, and 1929. Again, after the Second World War, the business cycles became shorter.

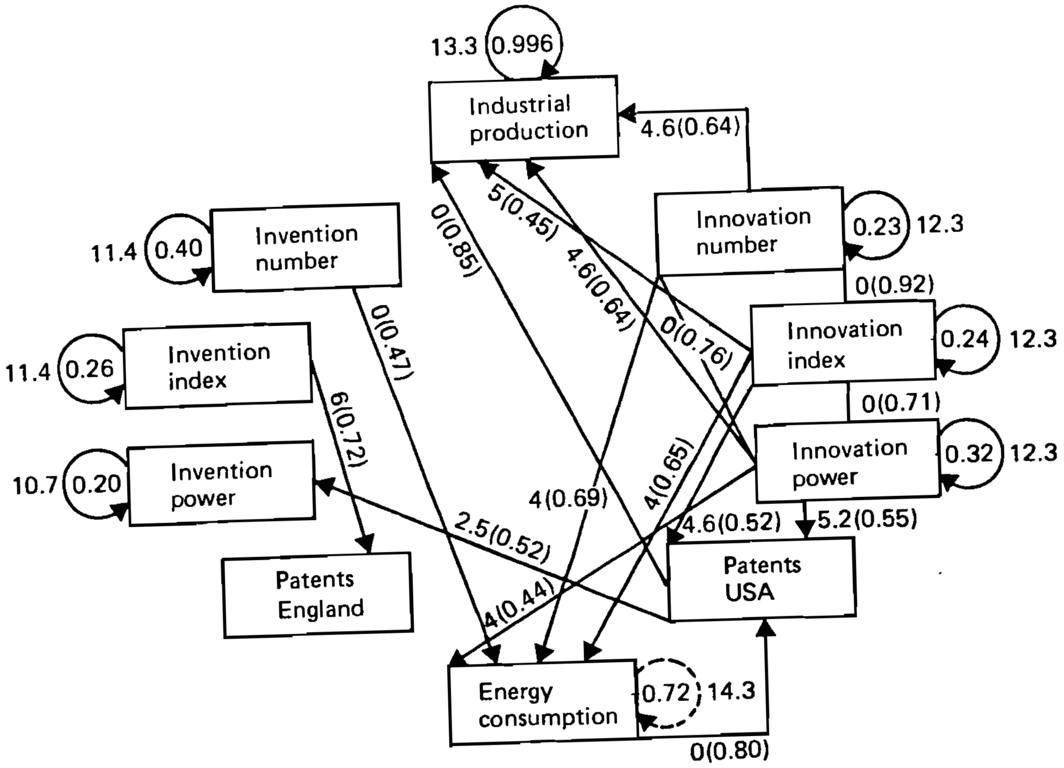


Figure 8. The 13-year cycle (10.7, 11.4, 12.3, 12.5, 13, 13.3, 14.3, 14.5 years).

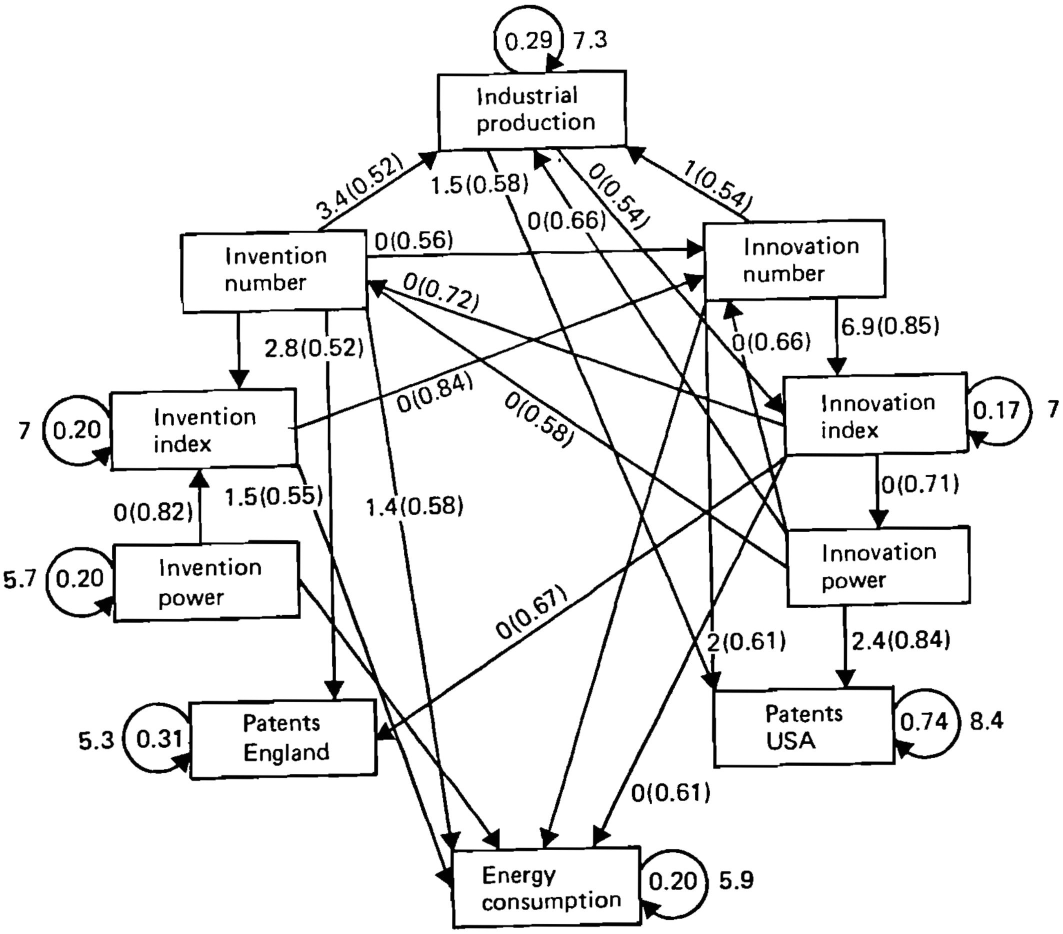


Figure 9. The 7-year cycle (5.9, 6.1, 6.3, 6.7, 6.9, 7, 7.3, 7.6, 8.0, 8.4, 8.9 years).

We resume our description of the results of our investigation with Figure 10, which shows the long-term relationships of world inventions, innovations, industrial production, energy consumption, and patents. A lag of 27 years exists, for example, between the invention and the innovation index. This is close to the average T_E period of 30.2 years. But these lags are taken from the whole sample and in reality, the cycles become shorter and shorter.

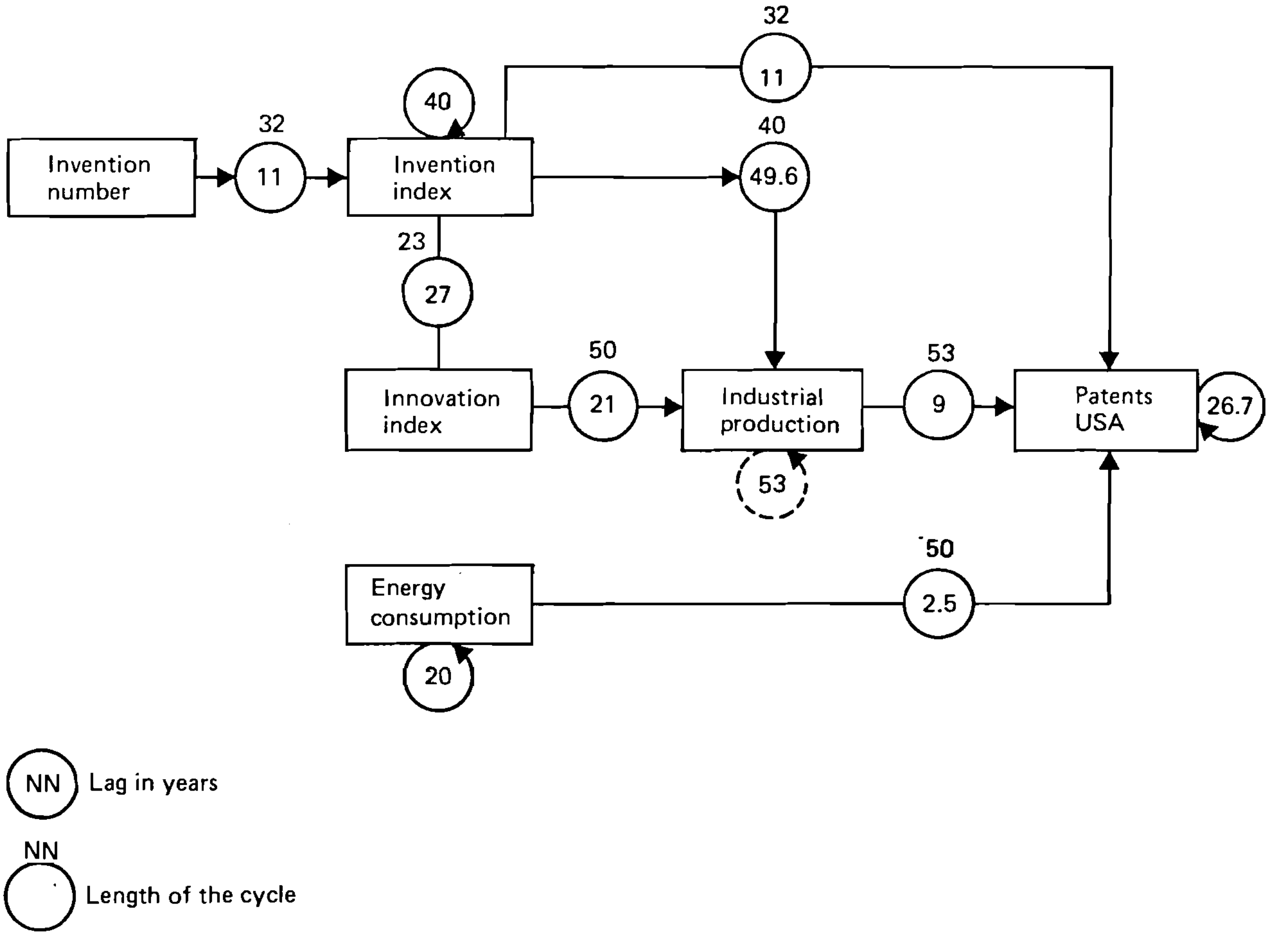


Figure 10. Long-term relationships of world inventions, innovations, industrial production, energy consumption, and patents.

It is interesting to note the 21 year lag between innovation index and industrial production. The most recent historical example of this is the innovation index of 1936, which can be linked to the production peak 24 years later between 1960 and 1966.

Because of the interference of quasi-cycles and their historical deviations, it is rather difficult to make forecasts. What one can expect is that we are now experiencing a new innovation upswing due to microelectronics and telecommunications, which might peak in 1985. The invention peak of this quasi-cycle occurred in 1958, when the number of inventions in electronics reached its absolute historical maximum (Dummer 1977).

The current upswing in innovations is related to the downswing in world industrial production growth, which might continue until 1985 or even longer. Spectral analysis did not reveal any "Laplace demon" in history. Historical determinism exists, but not in a pure and mechanical form. For any kind of forecasts, we are referred back to concrete investigations of unique historical factors, such as those shown in Table 1.

APPENDIX A: DATA ON WORLD INDUSTRIAL PRODUCTION (100 MIL. $ IN PRICES OF 1913), PRIMARY ENERGY CONSUMPTION (MIL. T.C.E.), INNOVATION (INDEX, POWER, NUMBER), INVENTION (INDEX, POWER, NUMBER), PATENTS ENGLAND, PATENTS USA

YEAR	Indus. Prod.	Energy Consm.	Innov. Index	Innov. Power	Innov. Number	Inven. Index	Inven. Power	Inven. Number	Patents England	Patents USA
1738						32.00	39.4	1	6	
1739						0	0	0	3	
1740	2.1					6.30	12.3	2	4	
1741	2.0					42.92	8.4	1	8	
1742	2.2					0	0	0	6	
1743	2.1					0	0	0	7	
1744	2.4					2.25	0.1	1	1	
1745	2.3					82.72	52.0	2	4	
1746	2.4					0	0	0	4	
1747	2.5					0	0	0	8	
1748	2.7					0	0	0	11	
1749	2.4					0	0	0	13	
1750	2.7					10.24	1.0	1	7	
1751	2.7					21.16	3.6	1	8	
1752	2.7					0	0	0	7	
1753	2.8					0	0	0	13	
1754	2.7					0	0	0	9	
1755	2.8					0	0	0	12	
1756	2.5					0	0	0	3	
1757	2.6					0	0	0	9	
1758	2.6					3.30	0.1	1	14	
1759	2.5					0	0	0	10	
1760	2.5					0	0	0	14	
1761	2.6					0	0	0	9	
1762	2.6					0	0	0	17	
1763	2.5					0	0	0	20	
1764	2.7		32.00	39.4	1	32.24	45.1	2	18	
1765	2.7		0	0	0	0	0	0	14	
1766	3.1		0	0	0	0	0	0	31	
1767	3.1		0	0	0	0	0	0	23	
1768	3.0		0	0	0	0	0	0	23	
1769	3.2		0	0	0	21.76	8.7	1	36	
1770	3.1		0	0	0	0	0	0	30	
1771	3.1		0	0	0	46.00	18.7	2	22	
1772	3.4		0	0	0	0	0	0	29	
1773	3.2		0	0	0	26.60	10.5	2	29	
1774	3.0		0	0	0	0	0	0	35	
1775	3.1		22.00	44.0	1	0	0	0	20	
1776	3.2		0	0	0	0	0	0	29	

1777	3.3	0	0	0	14.72	4.0	1	33	
1778	3.4	0	0	0	0	0	0	30	
1779	3.2	0	0	0	0	0	0	37	
1780	3.2	14.72	6.2	1	68.00	58.5	1	33	
1781	3.1	0	0	0	0	0	0	34	
1782	3.7	0	0	0	0	0	0	39	
1783	3.6	0	0	0	10.12	2.5	1	64	
1784	3.7	0	0	0	0	0	0	46	
1785	4.4	0	0	0	53.76	30.7	2	61	
1786	4.6	0	0	0	0	0	0	60	
1787	4.7	0	0	0	31.28	29.6	1	55	
1788	4.6	0	0	0	0	0	0	42	
1789	5.5	0	0	0	46.00	21.6	1	43	
1790	5.4	0	0	0	14.72	7.2	1	68	3
1791	5.5	0	0	0	10.12	1.4	1	57	33
1792	5.9	0	0	0	0	0	0	85	11
1793	5.1	0	0	0	68.00	107.5	1	43	20
1794	5.3	21.16	8.4	1	21.76	9.3	1	55	22
1795	5.6	0	0	0	0	0	0	51	12
1796	6.0	14.72	2.6	1	0	0	0	75	44
1797	5.5	0	0	0	0	0	0	54	51
1798	6.0	0	0	0	0	0	0	77	28
1799	7.1	0	0	0	31.28	28.8	1	82	44
1800	7.5	0	0	0	0	0	0	96	41
1801	7.1	0	0	0	0	0	0	104	44
1802	7.5	0	0	0	0	0	0	107	65
1803	7.6	0	0	0	0	0	0	73	97
1804	7.8	0	0	0	31.28	24.5	1	60	84
1805	8.0	0	0	0	7.04	0.8	1	95	57
1806	8.1	0	0	0	0	0	0	99	63
1807	8.4	0	0	0	0	0	0	94	99
1808	8.0	0	0	0	0	0	0	95	158
1809	8.2	21.76	4.6	1	0	0	0	101	203
1810	8.9	21.76	18.9	1	6.80	1.4	1	108	223
1811	9.4	21.16	6.3	1	4.84	0.3	1	115	215
1812	8.8	0	0	0	0	0	0	118	238
1813	8.9	0	0	0	0	0	0	131	181
1814	9.0	0	0	0	0	0	0	96	210
1815	10	0	0	0	0	0	0	102	173
1816	10	0	0	0	0	0	0	118	206
1817	10	0	0	0	0	0	0	103	174
1818	12	0	0	0	4.80	1.1	1	132	222
1819	11	21.76	6.0	1	31.28	17.5	1	101	156
1820	11	70.01	47.0	4	119.60	83.5	4	97	155
1821	11	0	0	0	0	0	0	109	168
1822	12	0	0	0	14.72	3.7	1	113	200
1823	13	0	0	0	0	0	0	138	173
1824	13	31.88	11.2	2	31.28	48.8	1	180	228
1825	14	0	0	0	0	0	0	250	304
1826	13	0	0	0	0	0	0	141	323
1827	15	31.28	15.8	1	21.16	7.2	1	150	331
1828	16	0	0	0	10.24	1.9	1	154	368
1829	15	0	0	0	0	0	0	130	447
1830	17	0	0	0	0	0	0	180	544
1831	17	14.72	4.0	1	50.60	26.7	3	151	573
1832	16	0	0	0	129.44	35.0	3	147	474
1833	18	99.28	136.3	2	53.16	47.9	2	180	586
1834	19	0	0	0	21.16	15.4	2	207	630
1835	20	4.84	0.4	1	0	0	0	231	752
1836	22	0	0	0	0	0	0	296	702
1837	20	0	0	0	0	0	0	256	436
1838	22	68.00	41.5	1	0	0	0	394	515
1839	24	4.84	1.1	1	10.12	3.0	1	411	404
1840	24	0	0	0	21.76	10.4	1	440	458
1841	24	0	0	0	78.00	78.5	2	440	490
1842	23	0	0	0	18.02	4.2	2	371	488
1843	24	0	0	0	0	0	0	420	494
1844	27	69.36	74.7	3	61.38	52.4	4	450	478
1845	29	21.76	4.3	1	22.00	25.9	2	572	475
1846	29	82.72	60.2	2	0	0	0	493	566
1847	28	0	0	0	14.72	11.3	1	493	495
1848	31	0	0	0	0	0	0	388	584
1849	31	34.58	35.3	2	32.00	20.9	1	514	988
1850	31	0	0	0	0	0	0	513	884

1851	34		0	0	0	0	0	0	455	757
1852	37		24.96	11.8	2	52.44	25.0	2	469	890
1853	40		0	0	0	10.24	2.3	1	499	846
1854	42		15.00	24.8	1	46.24	82.3	1	430	1759
1855	44		0	0	0	4.84	1.0	1	467	1892
1856	48		28.26	23.6	4	21.16	11.5	1	478	2315
1857	47		0	0	0	31.28	29.7	1	463	2686
1858	47		0	0	0	0	0	0	446	3467
1859	50		68.00	58.5	1	10.24	4.6	1	452	4165
1860	53	134.2	0	0	0	78.24	114.8	2	472	4363
1861	53	142.1	10.12	1.4	1	36.48	27.9	1	467	3040
1862	47	141.6	0	0	0	14.72	7.2	1	501	3221
1863	51	152.4	21.16	15.4	1	14.72	11.4	1	478	3781
1864	54	165.5	0	0	0	7.04	5.5	1	463	4638
1865	55	175.3	10.10	4.9	1	0	0	0	499	6099
1866	63	185.2	21.76	12.1	2	0	0	0	486	8874
1867	62	198.4	52.26	52.1	2	0	0	0	522	12301
1868	67	196.6	0	0	0	31.28	36.2	1	569	12544
1869	70	203.9	32.00	28.4	1	14.72	6.8	1	458	12957
1870	68	208.5	0	0	0	0	0	0	549	12157
1871	74	232.8	0	0	0	0	0	0	498	11687
1872	82	252.9	32.00	11.8	1	31.28	97.9	1	543	12200
1873	81	270.9	17.12	8.5	2	14.72	24.1	1	633	11616
1874	81	264.2	0	0	0	7.04	1.9	1	680	12230
1875	79	272.4	32.00	17.5	1	21.76	18.9	1	722	13291
1876	82	275.3	0	0	0	0	0	0	710	14172
1877	83	281.8	0	0	0	57.04	78.8	4	785	12920
1878	85	282.6	47.76	32.5	3	0	0	0	757	12345
1879	87	298.6	46.00	55.7	1	21.76	29.6	1	757	12133
1880	94	326.8	61.72	86.0	2	21.16	20.3	1	801	12926
1881	99	351.4	0	0	0	0	0	0	818	15548
1882	106	377.4	221.80	372.4	7	0	0	0	854	18135
1883	110	402.2	24.96	6.1	2	4.84	1.9	1	902	21160
1884	107	405.1	14.72	4.0	1	0	0	0	991	19122
1885	106	399.6	53.00	161.1	4	0	0	0	895	23282
1886	112	403.7	99.40	117.7	3	0	0	0	914	21768
1887	121	432.3	67.16	66.4	2	0	0	0	864	20399
1888	126	468.3	17.24	3.5	2	7.04	1.1	2	900	19552
1889	137	478.5	0	0	0	14.72	6.6	1	974	23322
1890	144	510.1	52.16	36.9	2	31.28	40.8	1	973	25308
1891	146	529.7	46.72	33.0	1	10.24	3.3	1	973	22310
1892	148	535.5	35.88	13.4	2	24.96	9.5	2	1021	22645
1893	143	524.2	0	0	0	28.20	46.9	2	1055	22747
1894	148	545.4	21.16	26.3	1	0	0	0	1070	19833
1895	162	579.0	109.96	79.2	4	68.00	171.3	1	1114	20855
1896	166	595.0	0	0	0	0	0	0	1140	21825
1897	174	624.3	7.00	12.4	1	60.96	169.3	2	1299	22065
1898	190	658.0	42.24	23.2	2	0	0	0	1286	20375
1899	204	720.1	0	0	0	0	0	0	1295	23288
1900	205	767.1	28.76	20.8	2	4.84	2.7	2	1204	24656
1901	213	793.7	14.72	6.8	1	0	0	0	1194	25554
1902	230	811.8	32.12	24.3	2	0	0	0	1258	27121
1903	235	892.2	0	0	0	74.90	209.1	3	1380	31032
1904	236	904.8	0	0	0	81.44	27.4	4	1352	30259
1905	260	955.0	0	0	0	0	0	0	1345	29777
1906	272	1029.5	21.00	34.5	1	115.36	623.2	5	1378	31169
1907	280	1143.0	0	0	0	96.20	180.9	2	1487	35860
1908	257	1093.3	0	0	0	0	0	0	1489	32736
1909	282	1145.0	10.12	20.4	1	0	0	0	1378	36562
1910	302	1200.4	46.00	268.7	2	14.72	54.2	1	1487	35130
1911	307	1227.7	46.24	152.6	1	0	0	0	1569	32856
1912	334	1295.7	0	0	0	10.12	4.5	1	1446	36196
1913	350	1391.1	46.00	302.3	1	33.48	41.1	2	1518	33915
1914	319	1260.5	46.28	95.0	2	10.34	5.7	2	1375	39899
1915	329	1251.8	7.00	4.0	1	21.16	22.4	1	1047	43117
1916	354	1351.9	6.80	4.6	1	0	0	0	771	48892
1917	357	1430.9	0	0	0	7.04	1.3	1	854	40927
1918	336	1411.6	0	0	0	10.24	26.2	1	988	38450
1919	308	1260.5	0	0	0	0	0	0	1125	36795
1920	326	1455.2	31.00	69.8	1	0	0	0	1298	37057
1921	280	1262.3	0	0	0	0	0	0	1618	37792
1922	343	1355.6	93.00	204.1	3	21.16	37.2	1	1588	38361
1923	361	1548.7	24.96	10.3	2	34.58	29.1	2	1562	38614
1924	382	1537.9	0	0	0	3.30	0.3	1	1541	42572
1925	413	1547.2	14.72	2.6	1	0	0	0	1572	46432

1926	427	1558.4	7.04	1.9	1	0	0	0	1585	44733
1927	455	1657.7	2.00	0.4	1	33.48	107.8	2	1612	41718
1928	476	1783.6	21.00	21.8	1	56.24	149.8	3	1618	42326
1929	511	1828.1	0	0	0	68.00	257.3	2	1732	45267
1930	448	1693.1	5.00	0.8	1	14.72	12.1	1	1899	45226
1931	389	1522.1	0	0	0	0	0	0	2006	51756
1932	333	1383.8	7.04	1.9	1	0	0	0	1934	53458
1933	375	1455.7	0	0	0	29.44	35.0	2	1515	48774
1934	417	1582.3	73.24	51.6	3	92.00	219.1	2	1545	44419
1935	466	1658.3	50.12	246.6	7	0	0	0	1616	40618
1936	525	1823.5	78.00	162.4	2	0	0	0		39783
1937	573	1959.1	31.00	40.7	1	35.88	77.4	2		37683
1938	518	1862.6	31.28	107.6	1	3.20	39.2	2		38062
1939	606	1997.5	61.08	64.0	3	42.32	238.7	3		43073
1940	651	2138.8	31.28	81.5	1	105.24	376.6	2		42237
1941	777	2236.5	3.30	0.3	1	0	0	0		41108
1942	907	2248.0	35.16	149.2	1	0	0	0		38449
1943	1033	2336.0	21.16	32.0	1	46.24	194.2	2		31054
1944	980	2342.3	43.16	153.4	2	0	0	0		28053
1945	679	1984.3	3.20	0.6	1	0	0	0		25694
1946	578	2096.1	31.28	163.0	2	0	0	0		21805
1947	651	2334.2	0	0	0	0	0	0		20139
1948	700	2483.4	17.72	12.1	1	28.20	49.7	2		23961
1949	714	2412.2	10.00	10.4	1	0	0	0		35131
1950	812	2647.8	160.24	566.4	3	0	0	0		43039
1951	882	2857.8	4.00	0.8	1	10.24	17.5	1		44326
1952	903	2928.1	0	0	0	0	0	0		43616
1953	970	2997.8	28.72	24.4	2	32.00	10.24	1		40467
1954	970	3065.0	46.24	194.2	1	21.76	118.4	1		33809
1955	1085	3334.9	0	0	0	0	0	0		30432
1956	1138	3558.9	7.04	1.3	1	7.04	134.8	1		46816
1957	1176	3709.9	40.00	46.3	2	0	0	0		42745
1958	1145	3924.2	57.00	302.9	4	99.16	784.0	4		48330
1959	1274	4156.8	46.00	84.6	1	10.24	52.4	1		52408
1960	1358	4415.7	42.24	154.8	2	3.30	3.6	1		47169
1961	1407	4523.4	32.24	210.2	2	16.84	54.0	2		48368
1962	1500	4834.8	46.00	529.0	1	58.24	220.1	3		55691
1963	1576	5186.7	13.54	71.4	3	0	0	0		45679
1964	1705	5494.3	18.72	146.7	2	0	0	0		47371
1965	1831	5577.7	0	0	0	21.16	72.2	1		62854
1966	1975	6025.8	3.30	0.3	1	0	0	0		68397
1967	2004	6264.6	0	0	0	0	0	0		65647
1968	2130	6287.0	52.66	118.6	3	0	0	0		59101
1969	2283	6707.3	0	0	0	25.06	240.3	2		67556
1970	2335	7150.2	21.76	59.2	1	0	0	0		64427
1971	2382	7410.1	43.52	289.3	2	0	0	0		78314
1972	2568	7747.7	3.00	3.6	1	21.76	118.4	1		74808
1973	2802	8089.0	0	0	0	29.44	180.5	2		74139
1974	2825	8181.5	0	0	0	0	0	0		76274
1975	2638	8118.6	14.72	108.3	1	0				71994
1976	2895	8574.9	36.48	191.1	2	0				70236
1977	3039	8920.2	0			0				
1978	3157	8996.0	0			0				
1979	3318		0			0				

APPENDIX B: INDICATORS OF HISTORICAL INNOVATIONS

No	Name	tL	tE	TE	VE	IK	VK	WK	P	P*
001	Generator of curr.	1820	1849	29	3.44	4.6	6.8	31.28	1.08	33.7
002	Deep-sea cable	1847	1866	19	5.26	3.2	10.0	32.00	1.68	53.9
003	Electricity	1832	1882	50	2.00	10.0	10.0	100.00	2.00	200.0
004	Optoelectronic diodes	1923	1966	43	2.33	2.2	1.5	3.30	0.08	0.3
005	Light-emitt.f.display	1961	1968	7	14.29	2.2	1.5	3.30	0.47	1.6
006	Light-tunnel technol.	1969	1972	3	33.33	2.2	1.5	3.30	1.10	3.6
007	Implementat.of ions	1960	1963	3	33.33	2.2	1.5	3.30	1.10	3.6
008	Synthetic rubber	1906	1916	10	10.00	6.8	1.0	6.80	0.68	4.6
009	Diesel locomotive	1892	1934	42	2.38	3.2	3.2	10.24	0.24	2.5
010	Thonet furniture	1842	1949	7	14.29	1.5	2.2	3.30	0.47	1.6
011	Steel pen	1758	1856	98	1.02	2.2	1.5	3.30	0.03	0.1
012	Thomas steel	1855	1878	23	4.33	2.2	2.2	4.84	0.21	1.0
013	Aluminium	1845	1854	9	11.11	2.2	6.8	14.96	1.66	24.8
014	Synthetic leather	1938	1964	26	3.85	3.2	1.0	3.20	0.12	38.4
015	Polyester	1939	1949	10	10.00	3.2	3.2	10.24	1.02	10.4
016	Telephone	1861	1878	17	5.88	3.2	6.8	21.76	1.28	27.9
017	Sulzer loom	1928	1945	17	5.88	3.2	1.0	3.20	0.19	0.6
018	Zip fastener	1891	1923	32	3.13	3.2	3.2	10.24	0.32	3.3
019	Electric heating	1859	1882	23	4.28	3.2	3.2	10.24	0.45	4.6
020	Locomotive	1769	1824	55	1.82	3.2	6.8	21.76	0.40	8.7
021	Spinning machine	1738	1764	26	3.85	3.2	10.0	32.00	1.23	39.4
022	Rolled rails	1773	1835	62	1.61	2.2	2.2	4.84	0.08	0.4
023	Stitching bond	1948	1958	10	10.00	3.2	2.2	7.04	0.70	4.9
024	Synthetic fibres	1927	1939	11	9.09	6.8	4.6	31.28	3.44	107.6
025	Airplane	1897	1911	14	7.14	6.8	6.8	46.24	3.30	152.6
026	Computer	1929	1950	21	4.76	10.0	6.8	68.00	3.24	220.3
027	Isolated conduction	1744	1820	76	1.32	1.5	1.5	2.25	0.03	0.1
028	Arc lamp	1810	1844	34	2.94	6.8	1.0	6.80	0.20	1.4
029	Bicycle (pedal)	1818	1839	21	4.76	1.5	3.2	4.80	0.23	1.1
030	Nickel	1751	1878	127	0.79	4.6	4.6	21.16	0.17	3.6
031	Magnesium	1852	1886	34	2.94	4.6	4.6	21.16	0.62	13.1
032	Radar	1904	1939	35	2.86	10.0	4.6	46.00	1.31	60.3
033	Plexiglass	1877	1935	58	1.72	4.6	3.2	14.72	0.25	3.7
034	Ball-point pen	1888	1935	47	2.13	2.2	3.2	7.04	0.15	1.1
035	Radio	1895	1922	27	5.88	10.0	6.8	68.00	2.52	171.3
036	Rockets	1903	1935	32	3.13	10.0	6.8	68.00	2.13	144.8
037	Transistor	1940	1950	10	10.00	6.8	6.8	46.24	4.62	213.6
038	Vitamins	1913	1937	24	0.43	4.6	6.8	31.28	1.30	40.7
039	Automobile	1868	1895	27	3.70	7.6	6.8	31.28	1.16	36.2

040	Antibiotics	1928	1940	12	8.33	4.6	6.8	31.28	2.61	81.5
041	Deep frozen food	1842	1925	83	1.20	3.2	4.6	14.72	0.18	2.6
042	Steam engine	1764	1775	11	9.09	2.2	10.0	22.00	2.00	44.0
043	Nuclear power station	1943	1954	11	9.09	6.8	6.8	46.24	4.20	194.2
044	Xerographie	1934	1950	16	6.25	10.0	4.6	46.00	2.88	132.5
045	TV	1907	1936	29	3.45	10.0	6.8	68.00	2.34	159.1
046	Silicons	1940	1946	6	16.67	4.6	6.8	31.28	5.21	163.0
047	Hydraulic gear	1904	1939	35	2.86	3.2	3.2	10.24	0.29	3.0
048	Helicopter	1904	1939	32	3.13	3.2	3.2	10.24	0.32	3.3
049	Titanreduction	1937	1944	7	14.29	4.6	4.6	21.16	3.02	63.9
050	Air ship	1874	1900	26	3.85	2.2	3.2	7.04	0.27	1.9
051	Ammonia synthesis	1910	1914	4	25.00	3.2	4.6	14.72	3.68	54.2
052	Production of Anilin	1834	1863	29	3.45	4.6	4.6	21.16	0.73	15.4
053	Diesel engine	1893	1897	4	25.00	2.2	3.2	7.04	1.76	12.4
054	Fischer-Tropsch-Proc.	1922	1934	12	8.33	4.6	4.6	21.16	1.76	37.2
055	Tare colours industry	1833	1856	23	4.35	4.6	4.6	21.16	0.92	19.5
056	Polyethylene	1933	1953	20	5.00	4.6	3.2	14.72	0.74	10.9
057	Detergents/synthetic	1907	1928	21	4.76	4.6	4.6	21.16	1.03	21.8
058	Power steering	1900	1930	30	3.33	2.2	2.2	4.84	0.16	0.8
059	Gyro compass	1904	1909	5	20.00	4.6	2.2	10.12	2.02	20.4
060	Tank	1903	1915	12	8.33	1.5	4.6	6.90	0.58	4.0
061	Steam turbine	1883	1895	12	8.33	2.2	2.2	4.84	0.40	1.9
062	Long dist. conduction	1873	1882	9	11.11	3.2	4.6	14.72	1.64	24.1
063	Photoelectric cell	1902	1936	34	2.94	10.0	4.6	46.00	1.35	62.2
064	Incandescent lamp	1854	1880	26	3.85	6.8	6.8	46.24	1.78	82.3
065	Atomic ice-breaker	1951	1957	6	16.67	3.2	3.2	10.24	1.71	17.5
066	Heavy water	1933	1942	9	11.11	4.6	3.2	14.72	1.64	24.1
067	Synthesis of methanol	1918	1922	4	25.00	3.2	3.2	10.24	2.56	26.2
068	Coal hydrogenation	1913	1927	14	7.14	2.2	1.0	2.20	0.16	0.4
069	Catalytic cracking	1915	1935	20	5.00	4.6	4.6	21.16	1.06	22.4
070	Chemical fibres	1857	1890	33	3.03	4.6	6.8	31.28	0.95	29.7
071	Pheno plastics	1906	1910	4	25.00	4.6	4.6	21.16	5.29	111.9
072	Acetylen	1893	1906	13	7.69	4.6	4.6	21.16	1.63	34.5
073	Oxygen-process	1914	1946	32	3.13	2.2	1.5	3.30	0.10	3.3
074	Photography	1727	1838	111	0.90	10.0	6.8	68.00	0.61	41.5
075	Puddling furnace	1783	1824	41	2.43	2.2	4.6	10.12	0.25	2.5
076	Electronic tubes	1906	1920	14	7.14	4.6	6.8	31.28	2.23	69.8
077	Integrated circuits	1958	1961	3	33.33	3.2	6.8	21.76	7.25	157.8
078	Microprocessor	1969	1971	2	50.00	3.2	6.8	21.76	10.88	236.7
079	Magnetophone	1898	1935	37	2.70	3.2	6.8	21.76	0.59	12.8
080	Quartz clocks	1934	1959	25	4.00	10.0	4.6	46.00	1.84	84.6
081	Cement	1824	1844	20	5.00	4.6	6.8	31.28	1.56	48.8
082	Colour film	1914	1935	21	4.76	2.2	3.2	7.04	0.34	2.4
083	Space travel	1923	1957	34	2.94	4.6	6.8	31.28	0.92	28.8
084	Typewriter	1864	1873	9	11.11	2.2	3.2	7.04	0.78	5.5
085	Air compress.building	1917	1956	39	2.56	2.2	3.2	7.04	0.18	1.3
086	Tyres with air compr.	1845	1888	43	2.33	2.2	3.2	7.04	0.16	1.1
087	Electric steel-making	1880	1902	22	4.55	4.6	4.6	21.16	0.96	20.3
088	Paper from wood	1844	1865	21	4.76	2.2	4.6	10.12	0.48	4.9
089	Continous steelmaking	1927	1948	21	4.76	2.2	1.0	2.20	0.10	0.2
090	Cotton picker	1924	1941	38	2.36	2.2	1.5	3.30	0.09	0.3
091	Fluorescent lamp	1852	1934	82	1.22	6.8	4.6	31.28	0.38	11.9
092	Insuline	1889	1922	33	3.03	4.6	3.2	14.72	0.45	6.6
093	Automatic gears	1904	1939	35	2.86	2.2	2.2	4.84	0.14	0.7
094	Combustion engine	1860	1886	26	3.85	6.8	6.8	46.24	1.77	81.8
095	Electric railway	1879	1895	16	6.25	3.2	4.6	21.76	1.36	29.6
096	Transformers	1831	1885	54	1.85	4.6	4.6	21.16	0.39	8.3
097	Sulphuric acid prod.	1819	1875	56	1.79	4.6	6.8	31.28	0.56	17.5
098	Dynamite	1844	1867	23	4.35	4.6	6.8	31.28	1.36	42.5
099	Electrolyse	1789	1887	98	1.02	10.0	4.6	46.00	0.47	21.6
100	Double-floor railway	1938	1951	13	7.69	2.2	1.5	3.30	0.25	0.8
101	NC-machines	1930	1948	18	5.56	4.6	3.2	14.72	0.82	12.1
102	Steamer	1707	1809	102	0.98	3.2	6.8	21.76	0.21	4.6
103	Water turbine	1827	1890	63	1.59	4.6	4.6	21.16	0.34	7.2
104	Steel concrete	1877	1902	25	4.00	2.2	4.6	10.12	0.40	4.0
105	Urban gas	1799	1833	34	2.94	4.6	6.8	31.28	0.92	28.8
106	Synthesis of Indigo	1875	1900	25	4.00	6.8	3.2	21.76	0.87	18.9

107	DDT	1939	1942	3	33.30	4.6	4.6	21.16	7.05	149.2
108	Streptomycine	1939	1944	5	20.00	4.6	4.6	21.16	4.23	89.5
109	Jet engine	1929	1943	14	7.14	4.6	4.6	21.16	1.51	32.0
110	Cellophane	1900	1926	26	3.85	2.2	3.2	7.04	0.27	1.9
111	Gasoline	1912	1935	23	4.35	2.2	4.6	10.12	0.44	4.5
112	Cinematography	1888	1895	7	14.29	4.6	6.8	31.28	4.47	139.8
113	Safety matches	1805	1866	61	1.69	2.2	3.2	7.04	0.12	0.8
114	Cooking fat	1811	1882	71	1.41	2.2	2.2	4.84	0.07	0.3
115	Soda works	1791	1861	70	1.43	2.2	4.6	10.12	0.14	1.4
116	Welding by Acetylene	1862	1892	30	3.33	4.6	3.2	14.72	0.49	7.2
117	Synthetic fertilizers	1840	1885	45	2.22	3.2	6.8	21.76	0.48	10.4
118	Preservatives	1839	1873	34	2.94	2.2	4.6	10.12	0.30	3.0
119	Antitoxines	1877	1894	17	5.88	4.6	4.6	21.16	1.24	26.3
120	Chloroforme	1831	1884	53	1.89	3.2	4.6	14.72	0.28	4.0
121	Jodoforme	1922	1880	58	1.72	3.2	4.6	14.92	0.25	3.7
122	Veronal	1863	1882	19	5.26	3.2	4.6	14.72	0.77	11.4
123	Aspirin	1853	1898	45	2.22	3.2	3.2	10.24	0.23	2.3
124	Antipyrin	1828	1883	55	1.82	3.2	3.2	10.24	0.19	1.9
125	Baking-powder	1764	1856	92	1.09	3.2	3.2	10.24	0.11	1.1
126	Plaster of Paris	1750	1852	102	0.98	3.2	3.2	10.24	0.10	1.0
127	Cinerama	1937	1953	16	6.25	3.2	4.6	14.72	0.92	13.5
128	Synthetic Alcaloids	1844	1885	41	2.44	3.2	3.2	10.24	0.25	2.6
129	Refined steel	1771	1856	75	1.33	3.2	4.6	14.72	0.20	2.9
130	Continous rolling	1892	1923	31	3.23	3.2	4.6	14.72	0.47	7.0
131	Crease-resist.fabrics	1906	1932	26	3.85	2.2	3.2	7.04	0.27	1.9
132	Inductor	1831	1846	15	6.67	4.6	3.2	14.72	0.98	14.4
133	Rolled wire	1773	1820	47	2.13	6.8	3.2	21.76	0.46	10.1
134	Blast furnace	1713	1796	83	1.20	3.2	4.6	14.72	0.18	2.6
135	Cruncible cast steel	1740	1811	71	1.41	4.6	4.6	21.16	0.30	6.3
136	Telegraphy	1793	1833	43	2.33	10.0	6.8	68.00	1.58	107.5
137	Lead-chamber-process	1740	1819	79	1.27	6.8	3.2	21.76	0.28	6.0
138	Pharma-fabrication	1771	1827	62	1.61	4.6	6.8	31.28	0.50	15.8
139	Chinin-fabrication	1790	1820	30	3.33	3.2	4.6	14.72	0.49	7.2
140	Hard rubber	1832	1852	20	5.00	3.2	4.6	14.72	0.74	10.8
141	Caliumchlorate	1777	1831	54	1.85	3.2	4.6	14.72	0.27	4.0
142	Electrodyn. measuring	1745	1846	101	0.99	10.0	6.8	68.00	0.67	45.8
143	Lead accumulator	1780	1859	79	1.27	10.0	6.8	68.00	0.86	58.5
144	Dynamo	1820	1867	47	2.13	4.6	4.6	21.16	0.45	9.5
145	Commutator	1833	1869	36	2.78	10.0	3.2	32.00	0.89	28.4
146	Drum rotor	1785	1872	87	1.15	10.0	3.2	32.00	0.37	11.8
147	Electric locomotive	1841	1879	38	2.63	10.0	4.6	46.00	1.21	55.7
148	Cable	1820	1882	62	1.61	10.0	4.6	46.00	0.74	34.1
149	Arc welding	1849	1898	49	2.04	10.0	3.2	32.00	0.65	20.9
150	Electric welding	1841	1886	45	2.22	10.0	3.2	32.00	0.71	22.8
151	Melting by induction	1860	1891	31	3.23	10.0	3.2	32.00	1.03	33.0
152	Electric counter	1844	1888	44	2.27	3.2	3.2	10.24	0.23	2.4
153	High volt. isolation	1897	1910	13	7.69	3.2	4.6	14.72	1.13	16.7
154	Holography	1948	1958	10	10.00	4.6	4.6	21.16	2.12	44.8
155	Maser	1953	1960	7	14.29	10.0	3.2	32.00	3.20	102.4
156	Video-tape recorder	1958	1968	10	10.00	4.6	4.6	21.16	2.12	44.8
157	Laser	1958	1962	4	25.00	10.0	4.6	46.00	11.50	529.0
158	16384 bit RAM	1973	1976	3	33.33	3.2	4.6	14.72	4.91	72.2
159	16-bit microprocess.	1973	1975	2	50.00	3.2	4.6	14.72	7.36	108.3
160	Electronic calcul.	1962	1971	9	11.11	3.2	6.8	21.76	2.42	52.6
161	Quartz watches	1962	1970	8	12.50	3.2	6.8	21.76	2.72	59.2
162	Microcumputer	1972	1976	4	25.00	3.2	6.8	21.76	5.44	118.4
163	Transistor radio	1954	1958	4	25.00	3.2	6.8	21.76	5.44	118.4
164	Diffusion process	1956	1958	2	50.00	3.2	2.2	7.04	19.15	134.8
165	Micro moduls	1958	1960	2	50.00	3.2	3.2	10.24	5.12	52.4
166	Planar process	1959	1961	2	50.00	3.2	3.2	10.24	5.12	52.4
167	Epitaxy	1961	1963	2	50.00	3.2	3.2	10.24	5.12	52.4
168	Transistor-laser	1962	1964	2	50.00	4.6	3.2	14.72	7.36	108.3
169	Minicomputers	1965	1968	3	33.33	4.6	4.6	21.16	3.41	72.2
170	Sliding carriage	1741	1794	53	1.39	4.6	4.6	21.16	0.40	8.4
171	Automatic band-loom	1745	1780	35	2.86	4.6	3.2	14.72	0.42	6.2
172	Cartwright's loom	1787	1820	33	3.33	4.6	6.8	31.28	0.95	29.6
173	Whitney's method	1785	1810	25	4.00	3.2	6.8	21.76	0.87	18.9
174	Jacquard loom	1804	1844	40	2.50	6.8	4.6	31.28	0.78	24.5

175	Lathe	1794	1845	51	1.96	3.2	6.8	21.76	0.43	9.3
176	Drilling mach.f.ming.	1856	1895	39	2.56	4.6	4.6	21.16	0.54	11.5
177	Phonograph	1877	1887	10	10.00	4.6	4.6	21.16	2.12	44.8
178	Coals whisks	1832	1883	51	1.96	4.6	3.2	14.72	0.29	4.2
179	Tractor	1890	1914	24	4.17	4.6	6.8	31.28	1.30	40.8
180	Accounting machine	1820	1892	72	1.39	4.6	4.6	21.16	0.29	6.2
181	Holing machine	1869	1901	32	3.13	4.6	3.2	14.72	0.43	6.8
182	Conveyor belt prod.	1906	1913	7	14.29	4.6	10.0	46.00	6.57	302.3

REFERENCES

Anderson, T.W. 1971. *The Statistical Analysis of Time Series*. New York: Wiley and Sons.

Dummer, G.W.A. 1977. *Electronic Inventions 1747- 1976*. Oxford, New York, Toronto, Sydney, Paris, Frankfurt: Pergamon Press.

Forrester, J.W. August 1981. Innovation and Economic Change. Found in *Futures*. Vol. 13, No. 4. United Kingdom: Oakfield House.

Hannan, E.J. 1970. *Multiple Time Series*. New York: Wiley and Sons.

Haustein, H.-D. 1975. *Die Proportionalitaet der technischen Basis in Sozialismus*. Berlin (East): Akademie Verlag.

Haustein, H.-D., H. Maier, and Uhlmann. 1981. *Innovation and Efficiency*. RR-81-7. Laxenburg, Austria: International Institute for Applied Systems Analysis.

Hoffman, W.G. 1955. *British Industry 1700- 1950*. Oxford: Basil Blackwell.

Kleinknecht, A. 1979. *Innovation, Accumulation, and Crisis* (in German). Berlin (West): Prokla 35.

Kleinknecht, A. 1980. Ueberlegungen zur Renaissance der "langen Wellen" der Konjunktur (Some thought on the renaissance of long waves). In *Historische Konjunkturforschung*. Stuttgart: Klett-Cotta.

Kondratieff, N.D. 1926. *Die langen Wellen der Konjunktur*. Vol. 56. Tuebingen: Archiv fuer Sozialwissenschaft und Sozialpolitik.

Kuczyuski, J. 1967. *A World Survey of the Situation of Workers* (in German). Berlin (East): Akademie Verlag.

Kuczynski, Thomas. 1978. *Spectral Analysis and Cluster Analysis as*

Mathematical Methods for the Periodization of Historical Processes. Paper for the 7th International Congress on Economic History. Edinburgh.

Marchetti, C. 1980. Society as a learning system: Discovery, invention, and innovation cycles revisited. *Technological Forecasting and Social Change*. Vol. 18. Pp. 267-282.

Marx, K. 1963. *Das Kapital*. Marx-Engels-Werke Bd. 25. P. 506. Berlin: Dietz Verlag.

Mensch, G. 1975. *Das technologische Patt (Statemate in Technology)*. Frankfurt am Main: Umschau Verlag.

Mitchell, B.R. 1975. *European Historical Statistics 1750- 1970*. London: The Macmillan Press Ltd.

Monthly Bulletin of Statistics 1975- 1981. United Nations. Vol. 30-35. New York: UN Statistical Office.

Schilling, H.-D. and R. Hildebrandt. 1977. Primary energy--electrical energy (in German). *Raw Materials Economy International*. Vol 6. Verlag Glueckanf Gmbh Essen.

Schmookler, J. 1966. *Invention and Economic Growth*. Cambridge: Harvard University Press.

Schumpeter, J.A. 1939. *Business Cycles*. Vol. 2. New York: McGraw Hill.

Technology Assessment & Forecast. 1977. Seventh Report March 1977. US Department of Commerce. Washington, D.C.: Patent and Trademark Office.

Tinbergen, J. 1981. Kondratiev cycles and so-called long waves: The early research. *Futures*. Vol. 13. No. 4. August.

Varga, E. 1937. *World Economic Crises 1848- 1935* (in Russian). Moscow: Ogis.