LONG WAVES AND INDUSTRIAL REVOLUTIONS

André Piatier

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INTERNATIONAL INSTITUTE FOR APPLIED SYSTEMS ANALYSIS
2361 Laxenburg, Austria

FOREWORD

This is an extended version of the paper that Professor Piatier read at the IIASA–IRPET Conference on "Long Waves, Depression, and Innovation: Implications for National and Regional Policy", held in Siena and Florence in October 1983. It is an important summary of his work on innovation and its relationship to the long-wave phenomenon at the microeconomic level. In the paper the author explores several features of innovation using the results of research activities and surveys made for the OECD and CEC. Here the word "innovation" is used in the widest context.

Professor Piatier's paper is significant because it describes the idea of innovation-based industrial revolutions, a theme developed in his numerous works and in the works of others, especially of French researchers. The paper also fulfills an important function of liaison between the French-speaking and English-speaking research communities – in spite of the widely held view that no gaps exist between these communities, much remains to be desired. In addition, by publishing this work separately we wish to serve our "long waves" constituency.

I would like to express my appreciation to Vivien Landauer, who did a splendid job of translating the paper from French, and to Steven Flitton for assisting with the English version.

Tibor Vasko
Leader
Clearinghouse Activities

CONTENTS

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André Piatier

Ecole des Hautes Etudes en Sciences Sociales
63 rue Claude Bernard
F-75005 Paris
France

ABSTRACT

1. The microeconomic analysis of innovation allows one to identify the salient features that will be useful for explaining the course of industrial revolutions, which in turn are characterized by clusters of major innovations. Innovation is the final result of a process (research, development, experiments, implementation of a production system, manufacture, and commercialization). It constitutes an extensive range: from major innovations to the improvement of processes; from inventions that are new throughout the world to the introduction of products already manufactured elsewhere.

2. The establishing of the existence of long-term movements, generated by waves of innovation over a period of about two centuries in the industrialized countries, is based on the observation of three industrial revolutions during each of which innovations in the areas of energy, transport, and basic industries took place. The resulting long-term movement follows a logistic curve (from youth to maturity and thence to decline). The biological and demographic analogy is obvious (population of a space up to saturation).

3. The author makes the following terminological distinctions:

   - A *long-term movement* is the most general expression: its evolution is not continual but consists of phases of unspecified highs and lows.
   - A *long-term cycle* is a movement that has regularity and periodicity, with alternating phases of highs and lows.
   - "*Long waves*" has a less restrictive meaning and does not imply regularity in the alternation of highs and lows.

   This paper deals with long waves, and has the aim of adding a number of characteristics:

   a) Long waves are a succession of ascending movements having the form of logistic curves.
   b) These logistic curves are separated by periods of uncertainty that more often take the form of recessions than of periods of stagnation.

c) The origin of long waves and the intervals separating them may be found in the economic mechanism itself. Thus technological progress is endogenized.

4. Innovations do not occur by chance, but are bunched at certain times that correspond to the decline of the preceding wave of innovations. It is at this point that the economic conditions combine to favor the onset of a new wave. Unemployed manpower and available capital will be put to work in risky ventures that did not stand the slightest chance of being undertaken whilst all industries were at the height of prosperity and were using up all available resources.

To verify this theory the author uses the tables of G. Mensch on the frequency of the appearance of innovations at times coinciding with the great crises, which are shown by the author's logistic curves. A great crisis is caused by the superposition of a logistic curve that has come to a decline upon the next one, which is still in the embryonic phase (Section 3.4).

The small cycle is perturbed and extended at the turning point of the long wave (Section 3.5), whilst parabolic laws determine numerous examples of transition from expansion to saturation or recession.

INTRODUCTION

This paper is the direct result of a series of studies dealing with innovation and technology [1]. *A priori* we may say that it is profoundly different to studies of long cycles (as defined by Kondratiev), which sought to identify such cycles throughout the history of humanity and which, above all, emphasized long price cycles.

Here, we are dealing more with long waves of activities rather than with the succession of symmetric periods of expansion and recession.

Schumpeter was the great forerunner of research on innovation. His line of thought was a great stimulus to the present author. But he only carried out a rapid analysis of innovation, and came very quickly to a cyclic explanation: his cycle of either two or four turns justifies short as well as long cycles.

There have been many technological changes and other events since the work of pioneers such as Schumpeter. By observing these very objectively, a significantly different structure may be perceived.

1. IMPORTANT ELEMENTS OF A MICROECONOMIC ANALYSIS OF INNOVATION

The first *operative* definition of innovation dates from 1980. It was expressed by the OECD (Frascati Manual) as: "An idea that is transformed into something saleable" [2]. The present author has suggested modifying it to "... transformed into something *sold*", since if it is not possible to diffuse the product successfully, it is not an innovation in the economic sense of the term; it remains but a plan, a dream, or a failed attempt.

Another improvement would be to say: "sold or *utilized*" since some innovations cannot be marketed.

1.1. The Dualism of Innovation: Process and Result

The concept of innovation commonly covers at one and the same time a succession of operations (the transition from the idea to its materialization) and a result: the product or the new process, first saleable, then sold or used.

Innovation is a *succession of risks*. The risks are related first to the idea, then to its *feasibility*, and then to its *reproducibility* (an innovation does not exist in the industrial sense of the term if it is not possible to repeat endlessly what it was possible to do the first time). Finally, there is risk associated with the *diffusibility* of the product: does it correspond to the possible demand of a user? This is what market surveys or interviews with users outside the market (nonmarket analysis) must show. The risks are thus related to the *adaptability* to requirements, the *price*, the *reliability*, and the *quality* of the innovation.

1.2. The Process Leading to Innovation

The following outline describes the process that results in innovation. It begins with scientific research, which has a dual aim: to know and understand, on the one hand, and to act, on the other. Only the part of the scientific output that leads to action can be considered as part of this process.

There follow next the tasks of applied research and of research and development (R & D). It is to this phase that the term "technology" may best be applied. The terms "research" and "development" cover numerous complex and varied operations. There are loops in the process and returns from technology back to science and from industry back to technology. There is a feedback of this kind every time a further piece of research or development becomes directly applicable either to the invention itself or to connected activities: a nuclear industry would not have come into being based merely on ideas regarding plans for thermonuclear power plants (decisive progress was also necessary in the areas of information processing, cement technology, and boiler engineering).

The technological process requires *long periods*. In the examples studied both by C. Freeman and by G. Mensch they lie between 10 and 50 years, with an average of 25 years. In the field of electronics the transition period from the invention to the innovation is probably the shortest, and is tending to become shorter.

The tests that have to be carried out, the transition from laboratory to factory prototype, the construction of new production plants, and the invention and completion of new machines all account for the long periods, the costs, and the risks involved.

The cost structure of technology is falsely perceived. General opinion stresses the cost of research, but practice has shown the cost of development to be the greater. In the USA, the expenditures for military R & D over the last ten years came to 5% for research, 10% for exploratory development, 70% for development of the new product, and 10% for administration and maintenance. For example, the US aeronautics industry devotes 97% of R & D costs to development. In many other examples that we have had occasion to observe, the costs for the realization of the prototype for industrial manufacture exceed the entire sum invested to produce the laboratory prototype.

In economic theory efforts have been made to improve the presentation and explanation of production processes. In the beginning, capital and labor were the only two factors considered. Then the production functions were expanded to cover energy and materials (KLEM functions). In the case of innovation it is essential to expand them still further to cover research (fundamental and applied), as well as technology and development.

1.3. Innovation as Result

Consideration of innovation as a result also requires a refinement of the analytical approach. According to Schumpeter the innovator was surrounded by imitators and the innovation was rapidly analyzed. Today we have to establish a typology of innovations. That suggested by the present author distinguishes the following:

- *Criteria relating to the technological level*: e.g. radical, usual, trivial.
- *Criteria relating to degree of novelty*: e.g. the first ever; realization of something that has already been developed elsewhere (at the national level, then at the regional level, and then at the company level): there are imitator-innovators, for example those who work as subcontractors, or with a license granted by the "original" innovator; industrial espionage, the stealing of ideas or techniques, which has been widely practiced in certain parts of the world, also produces innovators whom this author will call "local" or "relative" (as opposed to "original").
- *Criteria of extent*: the product or the process is entirely new, or it is in the nature of an improvement incorporated in the product or earlier process, or it is an *added* improvement to an earlier product (e.g. in the form of a separate accessory).
- *Criteria relating to tangibility*: the innovation is either visible or invisible. For example, the first television set was a visible innovation. On the other hand, over a period of ten years the automobile has generally remained outwardly unchanged, whilst invisible progress has been made (lubrication, reduced petrol consumption, etc.)
- *Criteria relating to application*: the novelty concerns the product itself, or one of its inputs, or the method of its production or sale. Recent technical history is full of new materials that are used in manufacturing traditional products.

  The author has suggested a presentation, in matrix form, of this typology [3] and proposed a number of additional criteria. The most important of these is certainly the *criterion relating to transferability*: an innovation that originates in one sector, or performs a well defined function, passes on (or does not pass on) to other sectors or other functions. For example, a grape-picking machine will remain useful only in the wine-growing sector, but an electronic device will gain a foothold in all sectors of industry, medicine, recreation, the arts, and culture.

In recent years transsectoral innovation appears to be playing an increasing role, with electronics branching out into informatics, télématique, robotics, office technology, automation of financial transactions, etc., and with biotechnologies supplying the agro-food, chemical, pharmaceutical, and energy industries.

As this happens, multisectoral mixes in the structure of industry are emerging, and the redefinition of new industrial entities makes our present statistical nomenclature obsolete.

1.4. Economic History Rewritten in Light of the Microeconomic Analysis of Innovation

In the beginning, man was both producer and consumer. Then, compared with the previous autarkic situation, surplus became available to non-producers. This is related to the tripartite view held by Boisguilbert of the exchanges between peasants, the upper classes (landlords), and craftsmen (1695).

Later, the leading producers, faced with heavy demand, were strengthened by solid backing: the production of raw materials, intermediate goods, and equipment goods was added to the production of consumer goods. The production process continues to grow longer, and the innovation process brings with it the tasks of science and technology. Society as a whole, as well as industrial firms, assigns increasingly large resources to innovation and a vast area of knowledge is formed between scientists upstream and contractors downstream. There is an increase in jobs for the development, diffusion, and adaptation of knowledge, and to convert ideas into objects (transition from the intangible form to the tangible form), as well as jobs involving the transport of ideas and information (telecommunication), following the long period during which only men and materials were transported.

Such an outline does not yet help explain the movements of human activities, with their propitious phases and setbacks. But we should not forget that the same applied to the economic thinking of the past: all the classical works (e.g. Adam Smith and J.B. Say with the law of market openings) were directed at the automatic adjustment of the system and the analysis of cycles only appeared a century later (Juglar and Bagehot) [4], when it was considered something of a heresy.

A similar gap must be filled between the theories of innovation and those of long-term movements. But before examining the *conditions* necessary for the emergence of such movements as a result of the innovations (see Section 3), we must *establish* their existence based on observations.

2. ESTABLISHING THE EXISTENCE OF LONG-TERM MOVEMENTS LINKED TO INNOVATION: THE INDUSTRIAL REVOLUTIONS

We are dealing here only with long-term movements caused by waves of radical innovations. In no case will we return to the point of view held by Kondratiev on century-long movements.

The concept of industrial revolution is a recent one: the transition from the Paleolithic Age to the Neolithic Age, due to the widespread cultivation of plants and animal husbandry, was never called an industrial revolution; yet it was the first time that solar energy was ascribed an economic value [5].

According to C.M. Cipola, animal husbandry and the cultivation of plants represented the first great upheaval in the life of man. What he did was to replace the natural converters of solar energy, which he found through hunting and gathering, by the first ever industry, which consisted of producing these energy converters: it was possible for man to produce animals and plants in larger quantities and in proportion to his needs. The economic effect of this first revolution has been described elsewhere [6].

The industrial revolution of the Middle Ages was "discovered" only recently [7]. But, at that time no great technical changes took place. The example of the 12th century is nonetheless most noteworthy: although no really new technology was introduced, innovation, in the broad sense of the term, did occur: iron, which up to that time had been used for weapons and armor, was now used to make plowshares. This resulted in a long boom, which began with the clearing of land for cultivation.

Four centuries later, a major innovation, namely printing, probably led to a long-term expansion similar to that which Marc Porat presently envisages with the growth of the "information sector" [8].

2.1. The Three Revolutions of Modern Times

The *first industrial revolution*, based on coal, was situated at the end of the 18th century and in the 19th century (first in Great Britain, then in France and, at the end of the 19th century, in Germany). But it became the subject of study only much later [9]. This revolution involved the development of iron and steel manufacture, the railways, mineral chemistry, and many industries manufacturing consumer goods (textiles, clothing, leather, shoes, etc.).

The foundations of the *second industrial revolution* were already laid by the end of the 19th century. The first cars had been driven, petrol and electricity were being used. At the beginning of the 20th century the first aeroplanes had flown, but their production was still at the embryonic stage. The First World War impaired the "purity" of the long-term movement. As early as the end of the 19th century, for example, the railway companies provided all rail connections that it was feasible to construct at the time – and even a little more than that (e.g. Freyssinet plan). Military needs extended the growth curves (for railway transport and particularly for iron and steel manufacture) and deferred the drawbacks of maturity and decline.

The crisis of 1930 probably marks this transition from the mature operations to the young, as yet little-developed ones, that is to say, those that have not yet taken up all their "possible space". These new industries brought with them a new source of energy (petroleum), new means of transport (the automobile and the aeroplane), a new chemistry (organic chemistry), new iron and steel processes and products (sheet and plate steel), new kinds of textiles with the introduction of artificial and synthetic tissues, etc. All the elements were ready and available between the two World Wars, but it was after the impetus of the postwar rebuilding period that industrial growth intensified before slowing down from 1973–74 onward. The petroleum crisis that occurred at this time was probably the outward sign of a slowing down in growth already inherent in the long-term development.

Now, at the end of the 20th century, a *third industrial revolution* is beginning. It includes new forms of energy, new means of transport, and new means of communication (integrated networks for telephone, telegraph, electronic mail, teleinformatics, photocopying, video conferencing, etc.). Satellites and space rockets will no doubt coexist with the dirigibles and new sailing ships that have been rescued from oblivion by already visible technical changes. Genetic engineering and automation open up vast prospects with respect to manufacturing whilst the ocean economy increases man's food production and industrial potential: we will find here both factors conducive to prosperity and well-being and, at the same time, sources of conflict. The biotechnologies will pervade a large number of activities.

2.2. The Substance of Industrial Revolutions

With regard to the three industrial revolutions we can identify major innovations in four areas: energy, transport, tools or equipment, and "manufacture". An industrial revolution is therefore, at first sight, a combination of activities. It constitutes a cluster of major innovations, linked to each other (for example, coal, the steam engine, iron and steel manufacture, and railways). Another, more recent link is, technically speaking, even more obvious: electronics, informatics, télématique, robotics, office technology, etc. These activities grow simultaneously and later their outlets become saturated simultaneously.

Table 1 outlines roughly the substance of the industrial revolutions.

Table 1

	Energy	Transport	Tools	Basic products
Neolithic Period: Agricultural Revolution	Wood Charcoal	Draught animals Wheel	Plough Loom	Cereal & crops, animal husbandry Textiles Stone
19th Century: First Industrial Revolution	Coal	Railway	Mechanical Industry	Steel bars (rails) Mineral chemistry All kinds of manufacture (textiles, etc.)
Beginning of 20th Century: Second Industrial Revolution	Petroleum Electricity	Automobile Aeroplane	Electrical Industry	Plate steel (sheets) Organic chemistry Plastic
End of 20th Century: Third Industrial Revolution	Nuclear Solar Other new forms of energy	Rocket, satellite Telecommunications Airship Cargo sailing boats	Electronics Informatics Robotics Office technology Biotechnologies Genetic engineering Fiber optics	Steel and special alloys Synthetic–plastic products Aquaculture (Neolithic marine) All production processes using biomass

2.3. The Form of Industrial Revolutions

An industrial revolution starts only very slowly. For it to become established, two phases are necessary: the objective in the first phase is to accumulate a stock of knowledge and of appliances for practical application (discoveries, inventions, tests, combinations of ideas, and anticipation of progress of adjacent technologies). All this must first be available, then accessible, and finally financeable before it can be put into practice: this explains the second phase, which lasts until the diffusion of the products and new processes.

The way time is used in these two periods seems to vary according to the progress of an industrial revolution. At the beginning of a long-term movement, research is the most important factor. But throughout the long period of growth the role of development increases. Afterwards, the sales only increase slowly, both because it takes time for the demand to become more certain and for the necessary purchasing power to be built up, and because it takes time for the supplier to position the production factors and to create sufficient production capacity.

2.3.1. *The Embryonic Phase* of the long-term movement lasts a long time; growth is very slow. It appears like a period of proliferation of "attempts" of all kinds. The idea is there, and we feel certain that it can be realized. The need for the new product takes shape very slowly: very many heads of companies combine the information from the technical field with market information and deliver the fruit of their imagination. Thousands of models existed for the automobile and aviation industries when these were in their infancy. Today the same overabundance has developed in the field of information technology and télématique with regard to "péri-informatique", "péri-téléphonie"*, office material, etc.

Thus the embryonic phase sees a proliferation of small and medium-size companies, and even of isolated producers who may launch their products before they have gathered a team of collaborators.

The large company, however, plays a role with regard to major innovations, which can be tackled only with large financial means. Even more significant innovations are taken over by the state or by international bodies. But even here we find once again the multiplication of proposals – for example, with regard to nuclear power there were more than ten different processes using uranium for the production of electricity. Little by little the selection was made and two or three systems remained in the running when the growth phase really started.

The same evolution applies to the automobile and aeronautics industries, and to electronics/information technology/télématique in the future: there is a tendency towards unification of models and types.

The small and medium-size companies, including those that were created as a result of the branching out of large companies, suffer. They have a very high "death rate": only a few, which enjoy technoeconomic success, survive and grow. And these must take care to avoid "accidents" in the course of their growth, such as a cash-flow crisis.

2.3.2. *The Phase of Accelerated Growth* corresponds to the phase of "populating a space", which corroborates the biological thesis of societal growth.

The concentration of industry becomes more pronounced, which is as much a result of the success of certain small and medium-size companies that have conquered a market as it is of certain others having been bought back by the big groups. It results also from sharing the spoils of yet others (which in turn allows an investment to be realized at very low cost).

The number of models or types of a product decreases, and monotony increases. Innovation changes in nature: it will be effected through imitation, through improvements, and through combinations of these.

* Equipment used in conjunction with information technology, télématique, etc.

The great innovation has given way to secondary innovations. Little by little there is less space to conquer, and the strategy is directed at enlarging the shares of the market.

When growth slows down, that is, when the point of inflection of the logistic curve has been passed, the most obvious strategy is the search for new openings. The new markets are reached first through export, then by direct investment abroad, and finally by technology transfer. Such an evolution signifies that the long wave is approaching maturity.

Similar results for trying to prolong the growth are obtained through innovation in connection with new functions of the product. The typical example is that of nylon [10]: Figure 1 shows the successive conquests of the market through adaptation to new uses.

The re-release of a product after changing the model, as is done in the automobile industry, is another illustration of this extensive procedure. There is also another, intensive, approach for when openings remain constant: growth will occur through increase in demand, which itself is related either to individual need or to the number of customers. Marketing provides numerous examples of this, which could be compared with more macroeconomic, or biological, themes.

Figure 2 presents the example of electric lighting: the curve is an envelope plotted from successive logistic curves (in semilogarithmic coordinates) [11].

2.3.3. *The Mature Phase* appears when signs of saturation of the solvent demand at a certain fixed price become manifest. Secondary innovations now play a greater role: they tend to improve productivity and lead to price drops or to increases in quality and performance, or to both at the same time.

The growth may continue, but with a slower rhythm. This marks the end of the exponential phase of the preceding growth. At this point, one could refine the typology of innovations by suggesting *innovation* (beginning of the industrial revolutions) and *renovation* (the moment when the revolutions are spent).

This distinction can lead to an additional interpretation. Certain innovations that follow the radical innovation may, during the long-term movement, represent the renovation. Alternatively, sometimes, after a period of latency during the end of an industrial revolution, they may become decisive elements of the next revolution. Figure 3, taken from G. Simon [12], shows the case of the space rocket, which originated during the second revolution and which will only be exploited completely during the third revolution. On the other hand, the jet plane has been fully integrated in the second revolution.

2.3.4. *The Phase of Stationarity, Decline, or Death* ends the evolution of the innovation clusters that were responsible for the beginning of an industrial revolution a few decades earlier. Some continue at a certain level: this stationarity, far from being ideal, is disturbed by short fluctuations. Others suffer a complete setback before finding a sort of survival level (e.g. the railway having to compete with road and air travel). And finally, there are others that collapse: the most extreme example of rapid growth and equally rapid decline, all within a few years, was that of the Vespa, which still survives today, a quarter of a century later, at an insignificant level of production.

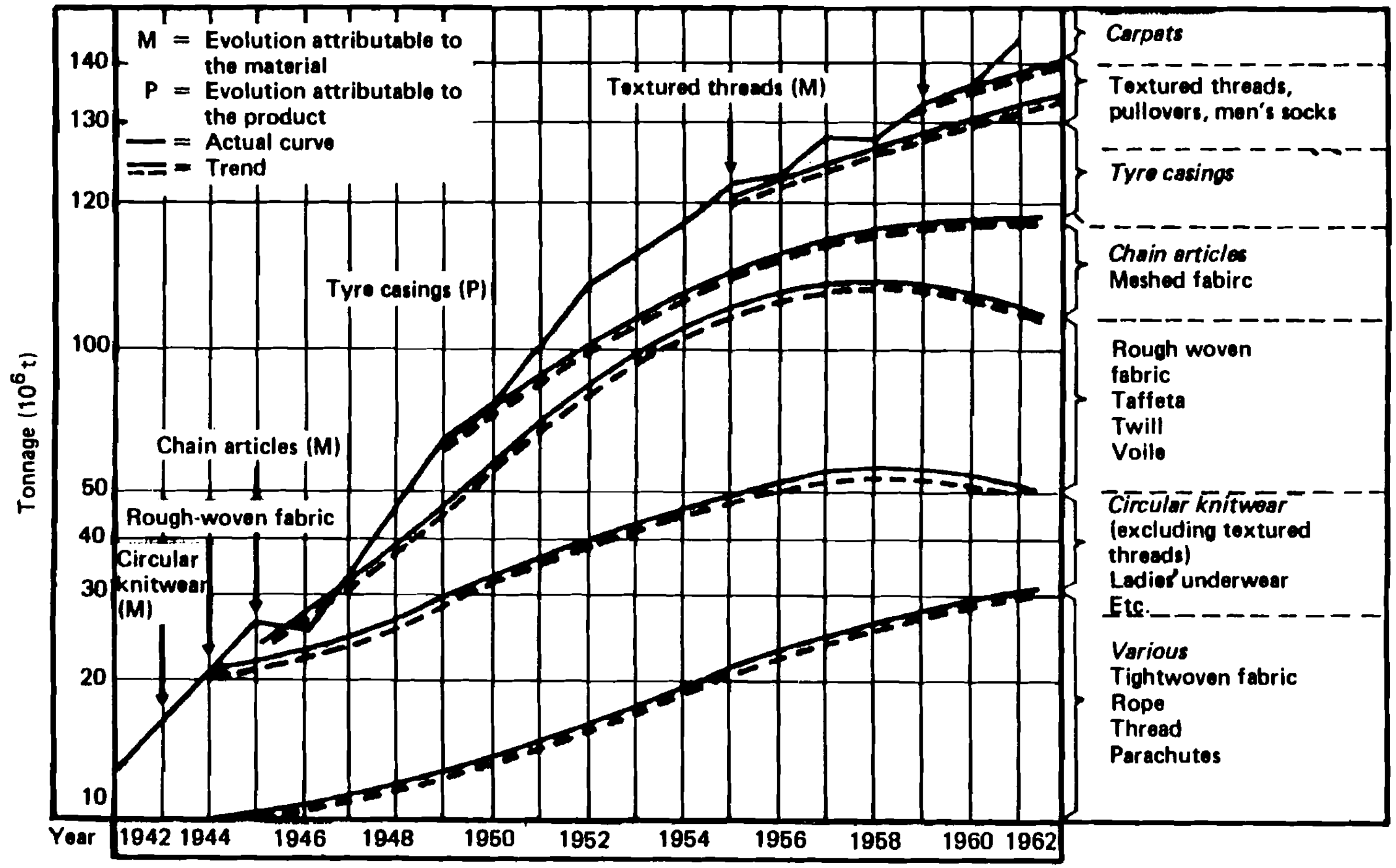


Figure 1 The conquest of successive markets: the example of nylon.

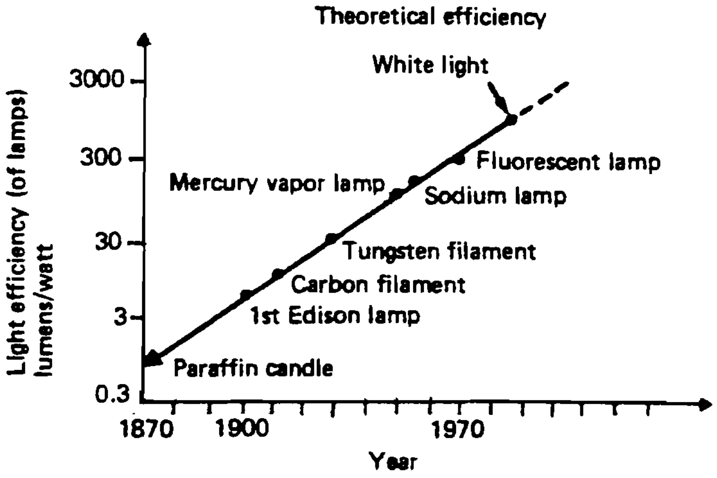


Figure 2 Electric lighting.
Source: *Recherche Scientifique et Innovation Technique, Facteurs de Développement de l'Entreprise*, p.9, by Dr. Ferdy Mayer, LEAD, Grenoble.

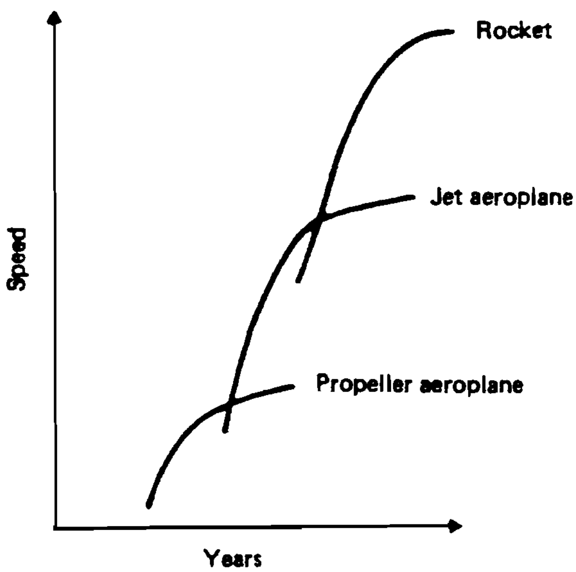


Figure 3 Some innovation "relays" in aerospace transport.

2.3.5. *The Best Approximation of the Entire Movement is a Logistic Curve.* The above descriptions show that most of the approximations that have been made (fortunately over relatively short periods) are hardly able to describe the evolution fully. The infatuation with the exponential explains the short-sightedness of the statisticians during the second phase (rapid growth). The only description likely to give a full account of the four phases (embryonic phase, rapid growth, slower growth (or maturity), and old age) is that provided by logistic curves. A further adjustment must be added to the logistic curves for the final phase since they tend, in general, towards an asymptotic value, which only applies to a small number of observable cases.

With regard to the other cases, that is, to those where a *downturn* appears, a different adjustment must be used, which, after this point, will account for the more or less pronounced decline.

Figure 4 (taken from [8]) traces the long waves that followed the three industrial revolutions of the last 150 years. For the third revolution, different forecasts, depicted by the broken lines, pose the problem of the aptitude of society to accelerate the transition from the embryonic phase of activities to their adolescent phase, i.e. to accelerate growth.

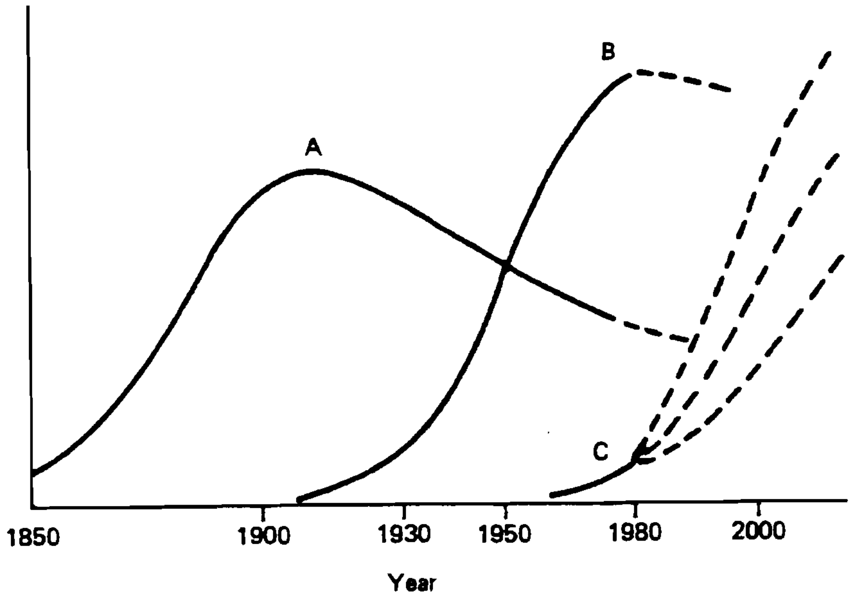


Figure 4 The three industrial revolutions. A: coal, steel, railway, textiles, mineral chemistry. B: petrol, electricity, automobile, steel (sheet), mechanical engineering, aeroplane, organic chemistry. C: new forms of energy (including nuclear), oceanic development, biomass, electronics, télématique, robotics, office technology, biotechnologies, genetic engineering, etc.

The envelope curve resulting from the superimposition of the industrial revolutions distinctly shows the long fluctuations. In the case of the first revolution the ascending and descending phases are about half a century long

(1840–1890 and 1890–1940). For the second, which is from 1900–1910 onward, progress is very marked over the 20 or 25 years from 1945–50 to 1970–74.

It is difficult to determine the turning points exactly: the fluctuations vary with the component activities and also depend on the data used. At present, we do not have adequate statistics at our disposal since, for example, the serial decompositions include under each heading old activities and new activities. An aggregate is made up of series in terms of volume multiplied by alternative prices: a high price may equally well correspond to starting up in production for which there are as yet no scale economies (as is the case for innovation when it begins), as it could to an old and high-capacity production for which the components have become scarcer. A low price may indicate that the producer has had to make a sacrifice on a reluctant market, or, on the contrary, that he has very successfully increased his productivity.

The aggregate values incorporate all this information and much more. And for the time being we do not know how to "aggregate" statistics in kind (do we need series with alternative fictitious prices?). We do not have the necessary nomenclature: an innovation only appears in the statistics if the observer is able to differentiate these products from those he is accustomed to recording – which means that when we give the innovation a place next to the other products it is then no longer an innovation. Can we blame this on the customs officer or any other agent responsible for producing statistics [13]?

It is therefore too early to discuss the comparative qualities of the various logistic approximations, or of their properties, used to describe the aggregates studied. Whereas Marchetti usually studies evolutions by products and by sectors (e.g. the automobile sector), the present author is more inclined to examine the evolutions as national wholes or parts. In other respects Marchetti uses only a single logistic curve, namely that of Volterra, whereas this author would be inclined to keep groups of approximations. The chronological regularities that Marchetti obtains are excellent but perhaps they are partly due to the technique used. *A priori* the present author prefers more irregularities in the rhythms and less rigidity in the calculations.

2.3.6. *New Beginnings in the Logistic Curves.* What I called "relays" above in connection with long-term movements may reappear here as the word "boost" (or "re-release") in the logistic curves. In fact, it appears that a movement that is observed can be broken up into two superimposed logistic curves.

The logistic curve of naval construction in the first industrial revolution includes vessels with coal-fired boilers and riveted iron plates. Naval construction in the second industrial revolution released a logistic curve superimposed on the first one as a result of the introduction of the fuel engine and soldered iron plates.

The steam-driven automobile had no economic success whatever during the first revolution. With the introduction of the petrol engine the automobile industry grew rapidly during the second revolution. The textile industry (first revolution) went through successive phases of expansion, first with linen and hemp, then wool, and finally cotton. During the second revolution, the textile industry began a new logistic curve with the introduction of a new series of synthetic fibers.

The chemical industry was based on minerals during the first revolution, whereas organic chemistry prevailed during the second. During the third revolution new possibilities for the chemical industry will be discovered in the field of biotechnologies, etc.

A last element must be considered: it may happen that a new product cannot gain access to the market because of its price: produced in small quantities, it is expensive and cannot compete with the old product, which occupies all of the market. This was the case for quite a long time for synthetic rubber. It was only through the Second World War, which brought with it a rise in the price of natural rubber, related to growing military needs, that synthetic rubber was able to make a breakthrough. Its increasing production made scale economies and price decreases possible. When the price of natural rubber decreased, the price of synthetic rubber could also drop and its share in the market increased in step with technical progress (new uses possible).

2.3.7. *Is Logistic Growth a Form of Biological Evolution?* I do not wish here to refer to the life-span curve of a product, which is a macroeconomic concept widely used in teaching business management. But the most convincing analogy can be made with saturations: a population occupies a certain "terrain" and the number of individuals grows according to a logistic curve until the space is completely occupied. This evolution may be observed in the case of bacteria on a film of gelatine as well as for more developed living species. It probably applies to human societies with a constant level of equipment and education.

A change in the environment may lead to a new logistic movement and postpone the stationarity or decline. A good example of this relationship between environment and population that had to be changed is offered by the industry that produces proteins from raw petroleum. In order to prevent the development of yeasts on a certain quantity of petroleum from being severely restrained, it was necessary to conceive a device for withdrawing the "population formed" in order to make room for a new, younger population: such a device linearizes the growth and makes it endless.

We recall here that the growth of living organisms (animal, vegetable) is logistic. The same holds true for the organs of the body. An example is the human brain, the capacity and performance of which grow rapidly, but with some results better than others depending on the "environment", education, etc. And we must not forget that the capabilities of the brain begin to decrease at a time when the individual has not yet completed his total growth; he continues the rest of his life with a declining "cerebral instrument". This decline is compensated, to a greater or lesser extent, by other, acquired factors, such as experience.

If we transpose this example into our field, it shows that logistic curves that are linked with each other can unfold with different rhythms: for example, the logistic curve of electronic chips is probably very different to the logistic curve of computers or of robots.

3. AN ATTEMPT TO CONSTRUCT A THEORY OF LONG WAVES

In order for there to be a long wave, we must prove that major innovations are launched simultaneously and that, in the course of the evolution, there is a moment during which it is possible for them to be launched.

3.1. Innovation Does Not Appear in a Random Fashion

It is often assumed on principle that discovery and invention are random events, that is, that they are distributed haphazardly over time (which, to the author, is not obvious). But it is impossible to search for "laws" according to which a clustering of inventions and discoveries could take place. These laws are only very indirectly related to economic life and all the more linked with the progresss of scientific thought, with methodological changes, with the fashions and contagion of ideas with which we are still unfamiliar.

Even in the case of a random discovery in time, its practical result – be it a new product or process that has been diffused on to the market – is not random.

Several arguments must be examined: learning and experience are accumulated in various "reservoirs" such as the mind, scientific publications, and patents and remain available until a favorable time for their use arrives [14].

In order for them to be put to use, one may call to mind the following:

- *Technical conditions*: complementary discoveries in the same field, or discoveries in adjacent fields are necessary for the initial discovery to become operational (e.g. to allow its mass manufacture or to facilitate production by reducing the cost of the new product). The concept of a complementary discovery is illustrated by the equipment used by Norwegian whaling ships [15]. A series of patents issued before the First World War were not enough for this equipment to go into use. A second series of patents issued between the two World Wars sufficed for the fleet to be fully equipped within a very short time. A noteworthy example of the need for discoveries in adjacent fields may be found in the nuclear industry: impracticable as it would be with only the knowledge of how to master the atom, it is made possible through informatics and by the progress made in boiler engineering and cement technology, as stated previously.
- *Psychological conditions*: it is not sufficient that something is realizable. One must also have a notion as to its usefulness. The steam engine, according to J.P. Vernant, does not date back to Denis Papin. It was already known in Greek antiquity and was used only to wave banners in the temples. Gunpowder, for which the Chinese found a use in the form of fireworks, is another good example.

The modern age is full of similar examples where it was necessary to wait for the "crystallization" of a demand in order to develop the manufacture. T. Gaudin [16] points out numerous innovations that did not require any extraordinary technical achievement, but which brought about profound changes in everyday life: for example, the prefabrication of buildings, containers, the felt pen, the mixer and other domestic appliances, the cotton-harvesting machine, the zip, cassettes for tape recorders, etc. A lot of time was needed before some of these were completely ready for use (a century was necessary for the cotton-harvesting machine), but all of them "essentially testify to a perception of the market".

Surveys on innovation (CETEM in France and the IFO Institute in the Federal Republic of Germany) confirm that, at least in the 1980s, close to half the innovations brought on to the market are not high-technology products but constitute responses to market demands. Certain ages have "crystallized" customers, for example for radio broadcasting, and then for television. In France, this crystallization is slow, and not yet over for the dish washer; in 1984, it was very hesitant for videotex (cf. tests carried out by Prestel in Great Britain and Télétel in France) and yet the technique is complete and very large serial production is ready to start up.

3.2. The Economic Conditions for the Start of Production: A Certain Complementarity

Once the aforementioned conditions have been fulfilled, we must be in a position to produce. For this to be possible, ideas are needed that can be turned into products: we have these ideas at our disposal. Manpower and capital are needed.

First of all, as we have seen, it is also necessary to have substantial intersectoral complementarity, i.e. innovations in the energy field, in the transport sector, in the technical infrastructure, and in the important new manufacturing industries.

Energy innovations are perhaps the driving force behind all other innovations: they are born of necessity. Coal, which had been known for a long time, was exploited industrially following a very severe crisis affecting the previous source of energy, namely wood.

Wood was unable to respond both to the demand of an iron industry that had grown because of innovations in agriculture at the end of the 18th century (such as the shoeing of horses, agricultural tools made of iron, etc.) and to the predicted consumption of the steam engine and the daily needs of a growing population (demographic boom after 1750).

Petroleum exploration was activated as a result of the drawbacks involved in the use of coal, which were most strongly felt when the internal combustion engine appeared.

Electricity production based on nuclear power began after uranium had come into use for military purposes. Its development was slow at first for technical reasons (choice between technologies with different safety measures) and psychological reasons (opposition from ecologists, for example). It entered phase 2 (acceleration) earlier in certain countries than in others.

Ecological restraint played an important role in the last countries in Table 2, especially in Japan and in the Federal Republic of Germany. In Great Britain and in the United States the abundance of other energy resources also made a difference.

The International Atomic Energy Agency (IAEA) predicts a rapid increase in these figures. World production is likely to increase from 191 GW in 1983 to 275 GW in 1985, 370–400 GW in 1990, and 580–850 GW in 2000. In terms of growth, this is no greater than the growth predicted for petroleum during the second revolution.

Table 2. Atomic Energy: Percentage of Total Production per Country in 1983

France	48.3
Belgium	45.9
Finland	41.5
Taiwan	37.0
Sweden	36.9
Bulgaria	32.3
Switzerland	29.3
South Korea	18.4
Japan	18.0
FRG	17.8
Great Britain	17.0
USA	12.6
World Total	12.0 (estimated)

In reality, three factors act together to start a long wave: coal/railways/iron and steel manufacture (first wave), petroleum/automobile/iron and steel manufacture (second wave), electricity/telecommunications, rockets and satellites/electronics and optical fibers (third wave).

One author had already identified this type of relationship during long-term movements: with his Transport–Building cycle, W. Izard showed how a new means of transport changed the localization of activities – which led to new factories having to be built elsewhere, followed by the housing to accommodate the people working in the factories.

Even if it is not the most important aspect, this form of migration should not be forgotten.

3.3. Economic Conditions (continued): Availability of Manpower and Capital

The knowledge is available, having been collected for many decades. One now waits for the available manpower and capital: only a crisis can provide them.

3.3.1. *Nothing is Possible During the Long Growth Period....* Indeed, during the greater part of this period there is full employment and plenty of opportunities for investment in flourishing industries and with high returns. Company capital and debts increase in order to permit an extension of capacity.

Later on, expansion is less pronounced, the profit-making capacity a little weaker, and full employment only just assured. But one hopes for a return to greater rates of expansion. Staff are not reduced – and people invest, not in major innovations, but in the improvement and perfection of existing products and processes, which will diminish costs and make it possible for prices to be reduced, and thus to adapt the products to fit into new sectors of the market.

Thus a state of full employment permits only a limited type of growth. There is not a single Keynesian, from Harrod via Joan Robinson to Kaldor, who did not see that an industrial revolution during a time of full employment was impossible. One is limited to secondary innovations.

3.3.2. *...Nor at the Beginning of the Great Crisis.* Of course, investment in threatened industries is discouraged. But there is little available capital: it is being used up and blocked in growing debts that are no longer meant for productive investment but for plain survival.

People seek jobs, but these are not created for want of the financial resources necessary for new posts. The gross margins of the companies are small or zero and bankruptcies increase. Little by little, through the liquidation of stocks and the reduction of employment, it is possible to build up the resources necessary for financing anew, but owing to the existing pessimism there are doubts as to the possibilities of investing in an economy that does not look as though it will recover.

3.3.3. *All Things Become Possible at the End of the Depression.* The second phase of the depression, with its lack of optimism, will lead people to believe that risky investments in things that have not been made before are preferable to having inert capital.

The takeoff becomes either a complete success or a total failure, bringing with it prospects of considerable profit or, on the other hand, the possible total loss of the committed resources. But the hope of making a profit on a single venture, that is, on a single innovation, appears sufficient to compensate several losses. In view of the distribution of risks, a profit seems likely, and there is a rush of capital. Reemployment will follow, but with some delay as the creation of new jobs will be slowed by the caution and general dilatoriness of the embryonic phase of the new wave.

Moreover, the lowering of the rate of interest, which remained very high during most of the depression, now makes the whole process easier. States, companies, and private individuals will have ceased to borrow either because they have been able to salvage what was most essential or because they have disappeared in insolvency, which in turn also results in the availability of equipment and installations at low prices when the monetary and financial rates go down. But the traditional activities, the openings for which still do not seem very certain, lack attractiveness. Only those activities likely to result in a large margin between the rate of interest and the marginal efficiency of real capital will bring about a convergence of initiatives. ***The innovation is therefore the sole recourse***. Far from being the outcome of chance, as certain people have claimed, it appears to be the only means of concentrating the forces made inactive by the crisis. But we are speaking here only of radical innovations; an industrial revolution does not take place unless they start up simultaneously within the broad range defined in Section 3.2.

3.4. An Attempt to Verify the Theory of Long Waves: Interpretation of the Tables by Mensch

Mensch [17] collected lists of discoveries and innovations. Commentators have used them, above all, to show the considerable time lags (from ten years to one century) between discovery and innovation: the mean and the mode lie between 30 and 40 years.

In the graph by Mensch (Figure 5) we see that the innovations appeared very frequently during short periods of about ten years each, namely 1820–30, 1880–90, 1930–40. Thus the inventions and discoveries were *condensed* into short periods during very long stretches of time. Mensch indicates clearly the times during which discoveries are latent, and it is on these that the present author bases his line of argument.

This analysis is completed with Figure 6, which combines Figures 4 and 5. We see that the economic activities ensue from the three waves of innovation shown in the figures. The industrial start-up is very slow at the time when the innovation takes shape, then it speeds up and becomes exponential before slowing down and, still later, receding.

It is at the point when an industrial revolution reaches its ceiling that the major innovations appear. The three great crises were strongly felt in the years 1880, 1930, and 1975. Each time, the activities created by beginning industrial revolutions could not make up for the difficulties and the loss of jobs caused by the declining industries.

When Mensch has prepared his chart on the frequency of occurrence of innovation for the present period, we shall know whether the fourth point lies between 1975–85 or between 1980–90. It will then be possible to locate with greater certitude the point of departure of a great crisis, which, like the preceding ones, will probably last for 10–15 years. But we already know that the deep recession of 1974–75 marked its beginning.

The remaining unknowns are the possible accidents during the great crisis, such as *the worldwide financial Krach*, which was clearly heralded by the records of debt of the Third World, of certain eastern countries, and of some western countries, such as France and the United States (these two alone had twice the debts of the Third World).

In 1929, the stock exchange and bank crash anticipated and began the great crisis. This time, such a crash threatens to occur ten years after the beginning of the crisis.

3.5. Long-Term Movements and Short Cycles: the Short Cycle Becomes Longer at the Turning Point of the Long Drift

Based on present studies, we may summarize a number of proposals. The experts on economic fluctuation, and especially those of the National Bureau of Economic Research, working between the two World Wars, were almost all agreed on the 6–8-year duration of the Juglar cycle (or short cycle). During the same period, Kitchin announced that he had uncovered a shorter cycle (3 to 3.5 years). In all probability the same cycle is meant. Indeed, the observation periods of most of these authors covered, at the most, periods from 1875 to 1950.

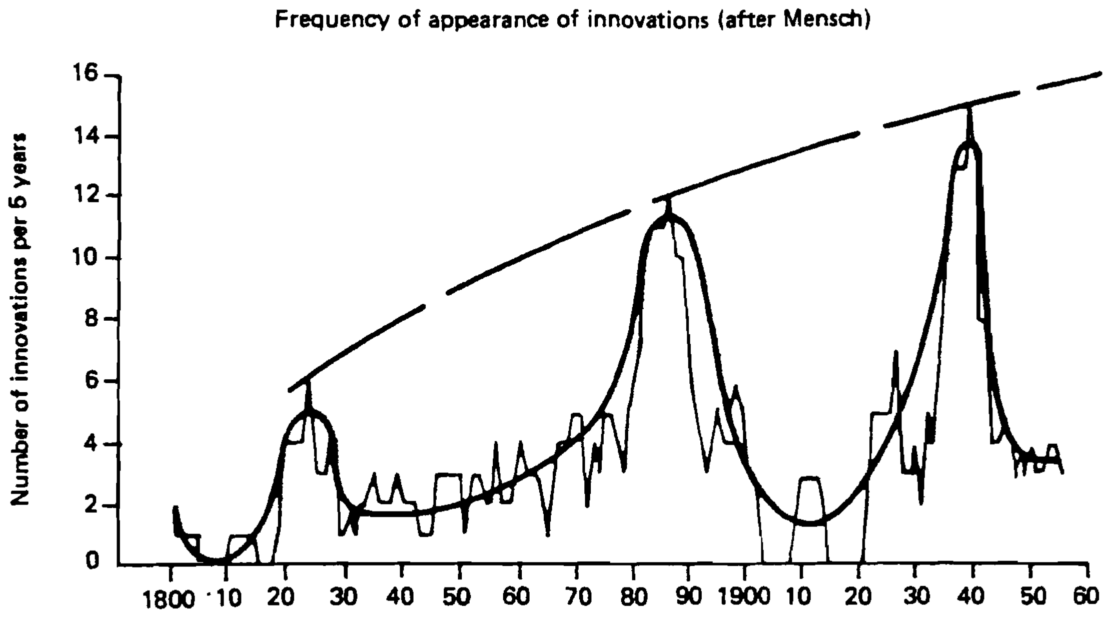


Figure 5

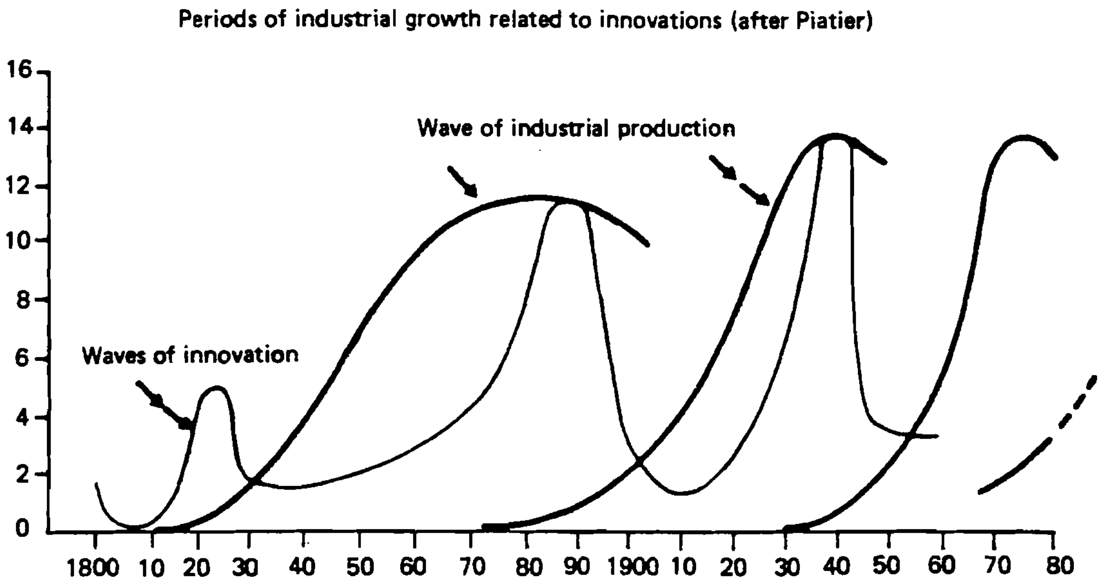


Figure 6

During this space of time there are two turning points in the long-term movement. And it is probable that the experts on economic fluctuation were the victims of a regularity of which they were not aware – they would have had to know that at the turning point of a long drift, the short cycle doubles in length. Likewise, the following cycles are often longer.

If we consult the *Business Annals* of W. Thorp [18], we observe that during the periods of long growth the short cycle lasts on average from 3 to 4 years. But we observe significant extensions of the cycle round about 1880.

USA	1873–1882	=	9 yr
Great Britain	1873–1883	=	9 yr
	1883–1890	=	8 yr
	1890–1900	=	10 yr
France	1882–1890	=	8 yr
	1890–1900	=	10 yr
Germany	1882–1890	=	8 yr
	1890–1900	=	10 yr

In the case of a turn in the long-term movement from 1929 to 1930, we notice the forecasting errors made by the Harvard barometer: the probable crisis is predicted to begin as early as 1925. The mistake is repeated innumerable times and the forecasters lose all credibility. Figure 7, which reproduces the Harvard curves, shows clearly the distortion of the short cycle: the period from trough to trough, i.e. from 1924 to 1932, is 8 years.

For the present period, Figure 8, which is the present author's graph calculated using the data of the survey of economic fluctuation carried out by the Bank of France, shows that the turning point of the long-term trend (1973–74) coincides with the doubling in length of the short cycle (period from one trough to the next – spring 1970 to spring 1975). The plateau that replaces the peak of prosperity expected ever since the beginning of 1971 could be interpreted as heralding the end of the long growth period.

New studies will be necessary to establish with more precision the nature of the links between the short cycle and the long-term movements. Might we put forward the view that both are superimposed and interdependent regulatory systems?

The long-term movement expresses the evolution of the life of an entire economy. Every half-century we witness the birth, development, and aging of a new society. The short cycle would express a kind of pulsatory adjustment of the different ages of life and the occurrence of maturity would leave a profound effect on the society, after which the short cycle would resume its regulatory role in the painful period of gestation of a new phase of life.

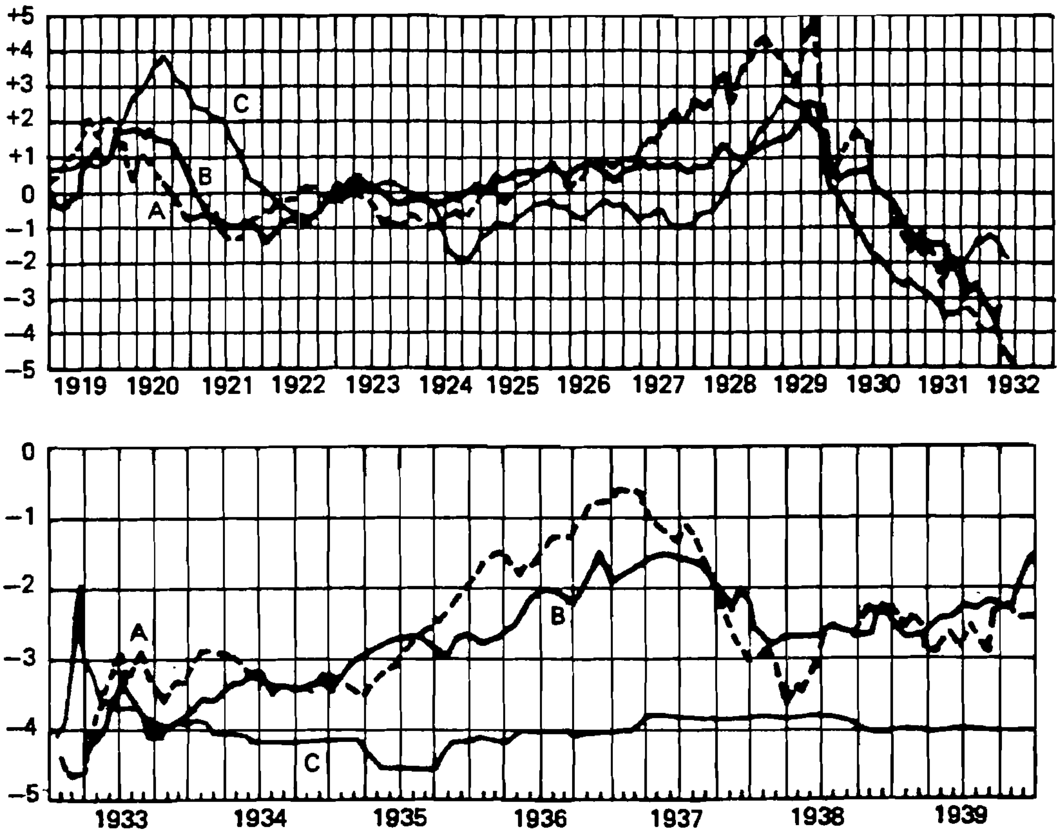


Figure 7 The Harvard barometer.

3.6. Parabolic Laws?

Let us now bring together the preceding analysis with another, so that we can compare various definitions with the aim of determining an optimal point.

In economics we find very many "laws" that appear to have the same behavior as the law of thermodynamic efficiency (Figure 9). The oldest of these is without doubt King's law, which states that when the harvest exceeds a certain size the farmers' returns decrease [19]. The most recent law is that of A.B. Laffer, which says that once taxation has exceeded a certain rate, a further increase in the tax rate leads to a drop in tax revenue [20]. But the highest point of the curve is not fixed once and for all. A plan of austerity that is accepted by the population, or a war effort, changes the form of the curve and shifts it to the right, whereas, for example, a peace-time economy, a recession, and other events shift it to the left.

The same remark can be made for the last curve of Figure 9, with regard to economies and diseconomies of scale: organizational progress or deterioration of the system will shift the optimal size of the organization from one side or from the other side of the broken line.

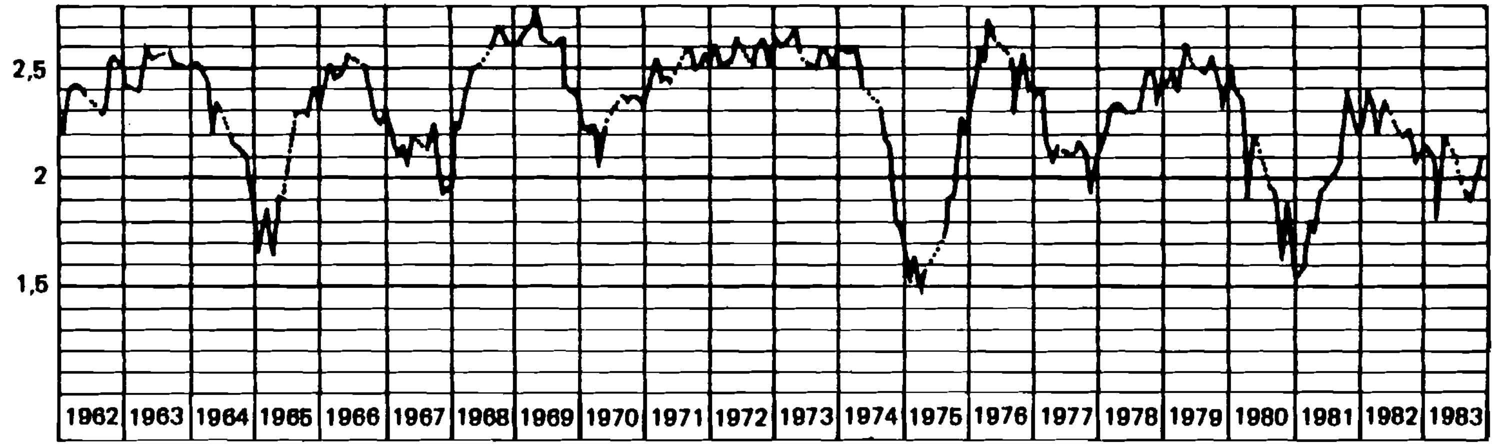
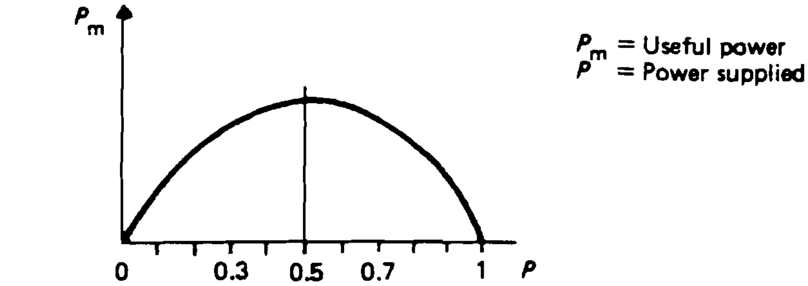
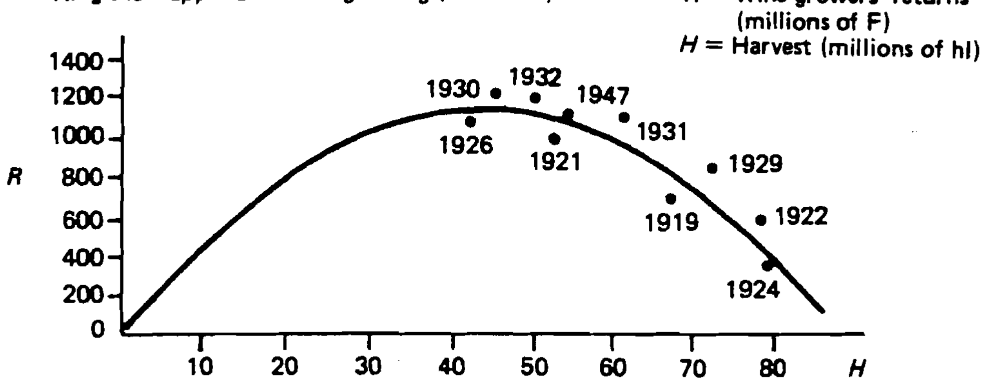


Figure 8 Every month the Bank of France publishes the results of surveys (covering the whole of France) of industry, commerce, and services. The graph synthesizes these observations in a form similar to that of the INSEE surveys: there is no long-term trend, and fluctuations are shown up. On the 15th of each month it is possible to tabulate the results of the activities of the preceding month. The method is based on diffusion indices. The second half of 1983 is marked by a tendency towards recovery. (Source: A. Piatier, Bank of France).

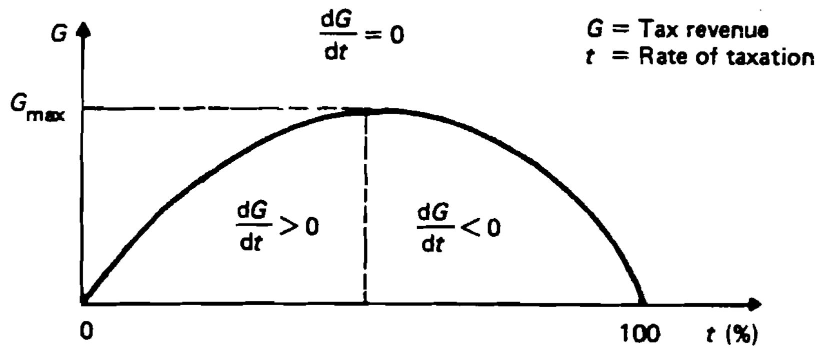
Thermodynamic system with constant potential (J. Voge)



King's law applied to wine growing (J. Milhau)



Laffer's curve



Size of organizations (companies, towns, etc.)

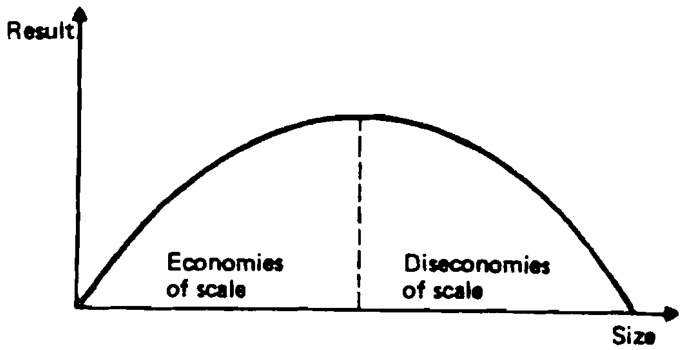


Figure 9

The present author has tried to give this type of analysis a place in an extended scheme of "economic science" [9]. It is of no use to recapitulate it here since it goes beyond our present subject.

All that we can recapitulate is the view that stagnation is not unavoidable: there are two reasons for the usual pessimism:

- it is centered on the profound crisis of transition – and it is momentarily very justified;
- there is a lack of awareness of the deep-seated transformations of societies. These transformations always accompany major techno-economic changes. And here this pessimism is not justified.

Jean Voge [21] already saw a solution in decentralization: communication and organization, for example, function more efficiently in smaller units. The progress of informatics and telecommunications increases the efficiency of public organizations, companies, laboratories, towns, etc.

The system does not have a constant potential. The number of people involved and the investment in terms of human effort are strategic variables. Many sectors aim to increase productivity (computer-aided teaching – productivity of "bureaucracy", productivity of research). Innovative processes will boost productivity where it would otherwise tend to decline. The third industrial revolution could be defined as the opportunity to shift the curves of Figure 9 to the right.

Just as Wagemann [22] described the economic evolution of societies as successive phases of overpopulation and underpopulation, whereby the reversal of the population trend is due to the emergence of other productive combinations, so we also believe that economic history consists of a succession of expansions and saturations, each new start reflecting the appearance of innovations that allow new areas of activity to be filled. But it is essential not to forget that technical progress must precede economic progress, which, in turn, absolutely must come before social progress.

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