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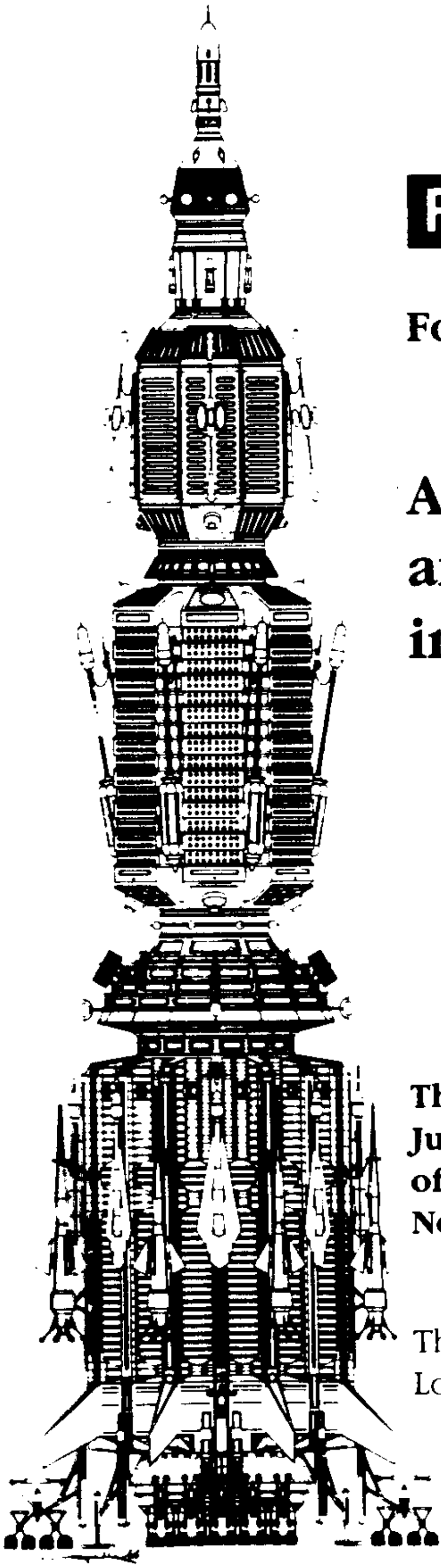

R+D

For the 21st Century

An Analysis of trends affecting strategies for industrial innovation

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The Kondratiev Cycle — Predicting For The Next 25 Years.

Cesare Marchetti

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Long business cycles have been a subject of controversy between economists for the past hundred years. In this paper I show that when a fresh approach is taken, forgetting money indicators, and looking instead at physicals and patterns of social behaviour, this new perspective very clearly reveals cyclic or pulsed behaviour in many areas. These cycles have shown a period of about 55 years for at least two centuries.

In the 1920's Kondratiev perceived the existence of these long economic cycles based on the thin evidence, available to him at that time, obtained from economic indications alone. About one cycle later several investigators including myself analysed extensively other physical indicators which seem to prove beyond doubt the existence of these cycles and reveal their deep influence on technological, entreprenurial and social behaviour of Western societies.

The patterns that emerge can be expressed in close mathematical form permitting quantitative forecasting to be made. A brief mathematical analysis follows as introduction to the more than 50 graphs which show the wide range of varying physicals that have been examined. Brief descriptions explain each diagram.

Mathematical Analysis

The equations for dealing with different cases are reducible to the general Volterra-Lotka equations.

$$\frac{dN_i}{dt} = K_i N_i + \beta_i^{-1} \sum_{n}^{j=1} a_{ij} N_i N_j \quad , \qquad (1)$$

where Ni is the number of individuals in species i, and a,β, and K are constants. The equation says a species grows (or decays) exponentially, but for the interactions with other species. A general treatment of these equations can be found in Montroll and Goel (1971) and Peschel and Mende (1986). Since closed solutions exist only for the case of one or two competitors, these treatments mainly deal with the general properties of the solutions.

In order to keep the analysis at a physically intuitive level, I use the original treatment of Verhulst (1845) for the population in a niche (Malthusian) and that of Haldane (1924) for the competition between two genes of different fitness. For the multiple competition, we have developed a computer package which works perfectly for actual cases (Marchetti and Nakicenovic,1979), but whose identity with the Volterra equations is not fully proven (Nakicenovic, 1979).

Most of the results are presented using the coordinates for the linear transform of a logistic equation originally introduced by Fisher and Pry (1970).

The Malthusian Case

This modeling of the dynamics of population systems started with Verhulst in 1845, who quantified the Malthusian case. A physically very intuitive example is given by a population of bacteria growing in a bottle of broth. Bacteria can be seen as machinery to transform a set of chemicals in the broth into bacteria. The rate of this transformation, coeteris paribus (e.g. temperature), can be seen as proportional to the number of bacteria (the transforming machinery) and the concentration of the transformable chemicals.

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Since all transformable chemicals will be transformed finally into bacterial bodies, to use homogeneous units one can measure broth chemicals in terms of bacterial bodies. So N(t) is the number of bacteria at time t, and $\bar{N}$ is the amount of transformable chemicals at time 0, before multiplication starts. The Verhulst equation can then be written

$$\frac{dN}{dt} = aN(\bar{N} - N) \quad , \tag{2}$$

whose solution is

$$N(t) = \frac{\bar{N}}{1-e^{-(at+b)}} \quad , \tag{3}$$

with b an integration constant, sometimes written as t_0, i.e. time at time 0; a is a rate constant which we assume to be independent of the size of the population. This means that there is no "proximity feedback". If we normalize to the final size of the system, $\bar{N}$, and explicate the linear expression, we can write equation (2) in the form suggested by Fisher and Pry (1970).

$$\log\frac{F}{1-F} = at + b \quad , \quad \text{where } F = \frac{N}{\bar{N}} \quad . \tag{4}$$

Most of the charts are presented in this form. $\bar{N}$ is often called the niche, and the growth of a population is given as the fraction of the niche it fills. It is obvious that this analysis has been made with the assumption that there are no competitors. A single species grows to match the resources ($\bar{N}$) in a Malthusian fashion.

The fitting of empirical data requires calculation of three parameters $\bar{N}$, a, and b, for which there are various recipes (Oliver, 1964; Blackman, 1972; Bossert, 1977). The problem is to choose the physically more significant representation and procedure.

I personally prefer to work with the Fisher and Pry transform, because it operates on ratios (eg. of the size of two populations), and ratios seem to me more important than absolute values, both in biology and in social systems.

The calculation of $\bar{N}$ is usually of great interest, especially in economics. However, the value of $\bar{N}$ is very sensitive to the value of the data, i.e. to their errors, especially at the beginning of the growth. The problem of assessing the error on N has been studied by Debecker and Modis (1986), using numerical simulation.

The Malthusiam logistic must be used with great precaution because it contains implicitly some important hypotheses:

- That there are no competitors in sight.
- That the size of a niche remains constant.
- That the species and its boundary conditions (e.g., temperature for the bacteria) stay the same.

The fact that in multiple competition the starts are always logistic may lead to the presumption that the system is Malthusian. When the transition period starts there is no way of patching up the logistic fit.

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One-to-One Competition

The case was studied by Haldane for the penetration of a mutant or of a variety having some advantage in respect to the pre-existing ones. These cases can be described quantitatively by saying that variety (1) has a reproductive advantage of k, over variety (2). Thus, for every generation the ratio of the number of individuals in the two varieties will be changed by $\frac{1}{(1-k)}$. If n is the number of generations starting from n=0, then we can write

$$\frac{N_1}{N_2} = \frac{R_0}{(1-k)^n} \quad , \quad \textbf{where } R_0 = \frac{N_1}{N_2} \textbf{ at } t = 0 \quad . \tag{5}$$

If k is small, as it usually is in biology (typically 10^{-3}), we can write

$$\frac{N_1}{N_2} = \frac{R_0}{e^{kn}} \quad . \tag{6}$$

We are then formally back to square one, i.e. to the Malthusian case, except for the very favorable fact that we have an initial condition (Ro) instead of a final condition ($\overline{N}$). This means that in relative terms the evolution of the system is not sensitive to the size of the niche, a property that is extremely useful for forecasting in multiple competition cases. Since the generations can be assumed equally spaced, n is actually equivalent to time.

As for the biological case, it is difficult to prove that the "reproductive advantage" remains constant in time, especially when competition lasts for tens of years and the technology of the competitors keeps changing, not to speak of the social and organizational context. But the analysis of hundreds of cases shows that systems behave exactly as if.

Multiple Competition

Multiple Competition is dealt using a computer package originally developed by Nakicenovic (1979). A simplified description says that all the competitors start in a logistic mode and phase out in a logistic mode. They undergo a transition from a logistic-in to a loginstic-out during which they are calculated as "residuals", i.e. as the difference between the size of the niche and the sum of all the ins and outs. The details of the rules are to be found in (Nakicenovic, 1979). This package has been used to treat about one hundred empirical cases, all of which always showed an excellent match with reality.

An attempt to link this kind of treatment to current views in economics has been make by Peterka (1977).

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FIGURE 1. In Figure 1a, the size of a bacterial colony is reported versus time. By normalizing it to the final size of the population, we can express it as a fraction F of that population. We can represent then the logistic curve of Figure 1a in the form log F/1 — F, which is a straight line (Figure 1b). SOURCE: Lotka (1956).

Growth of Bacterial Colony (cm²)

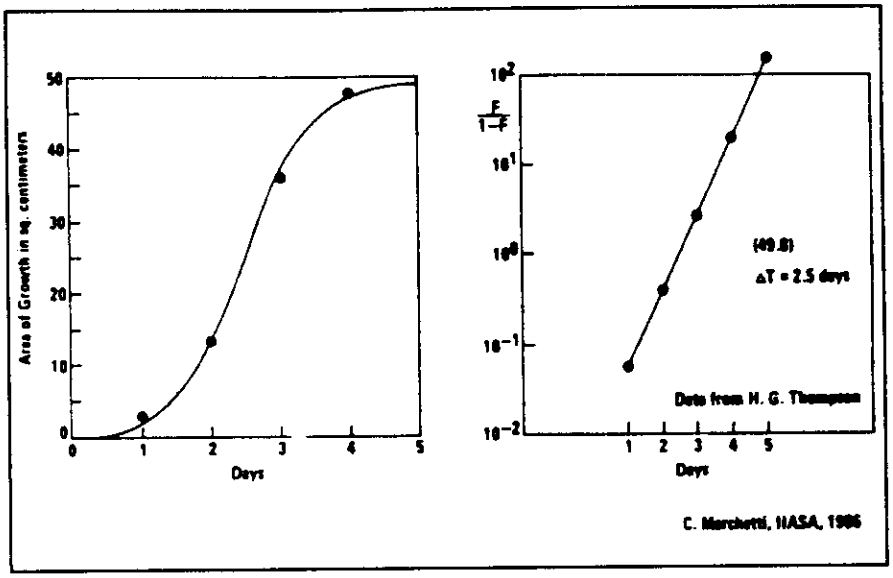

FIGURE 2. Here we mimic Figure 1 taking the number of installed mainframe computers in Japan. The "niche" is calculated by best fit of the partial data. SOURCE: Vacca (1966).

Mainframe Computers Japan (.000)

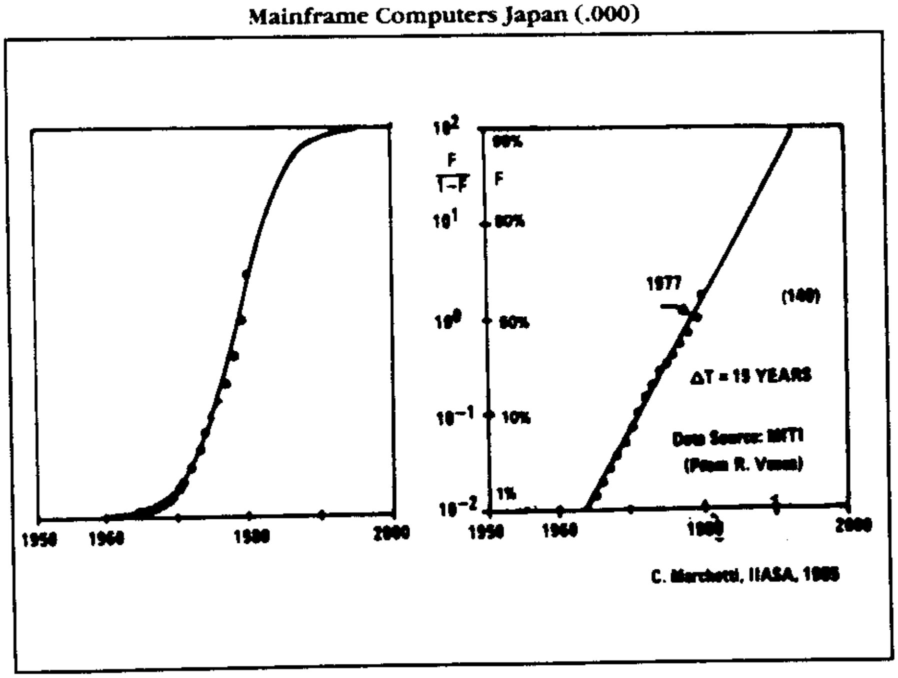

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FIGURE 3. The growth of a sunflower (height) follows a neat logistic curve. One can see a plant as a population of cells, but most probable cause is a simple regulatory system as outlined in the text. DATA SOURCE: Lotka (1956) and Reed and Holland (1919).

Growth of Sunflower Seedlings (cm)

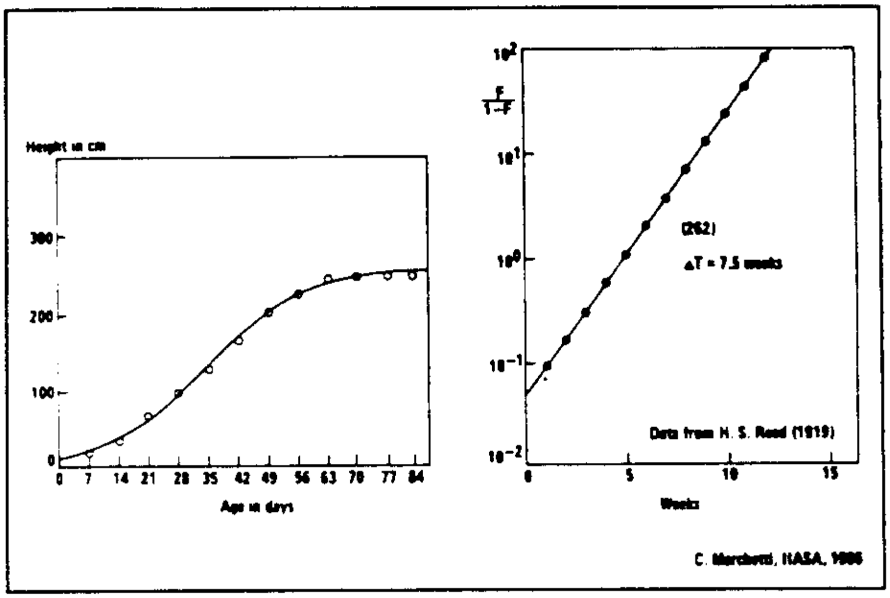

FIGURE 4. The first spurt of railway technology in Italy is here mapped in terms of track length. SOURCE: Marchetti (1966).

Italian Railways – First Spurt (10000km)

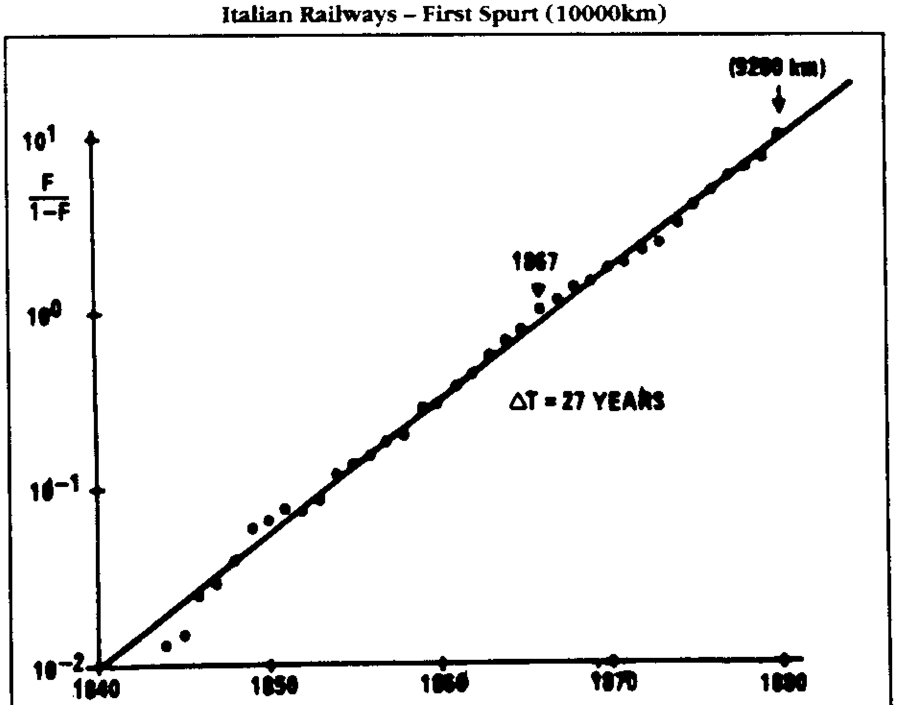

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FIGURE 5 Number of robots of all classes in operation in Japan.

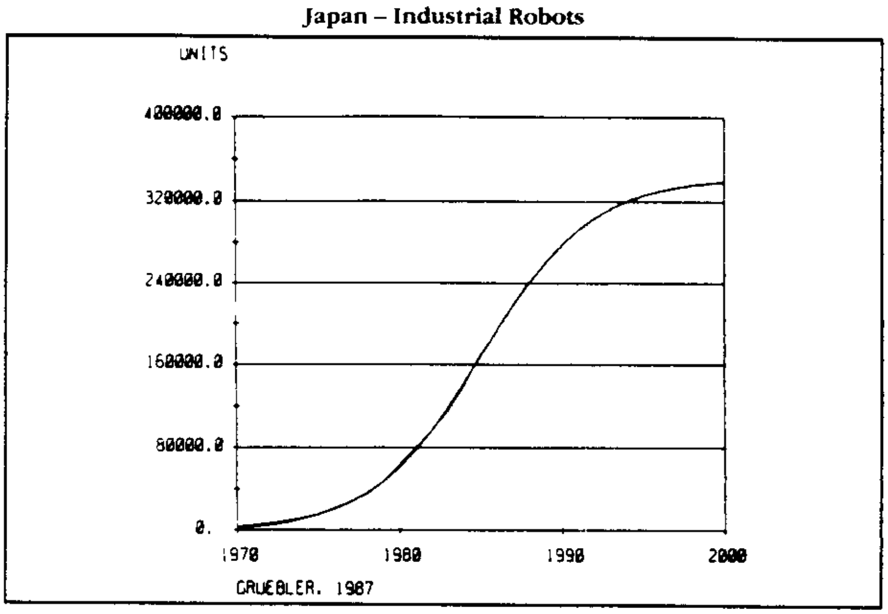

FIGURE 6. Same robots of Figure 5 divided into six classes: A — manual manipulator; B — fixed sequence robot; C — variable sequence robot; D — playback robot; E — numerical control robot; and F — intelligent robot. Classes A, B, C are put together as primitive and D, E, F as advanced robots.the automobile as a process of technological substitution. *Technological Forecasting and Social Change* 29:309-340

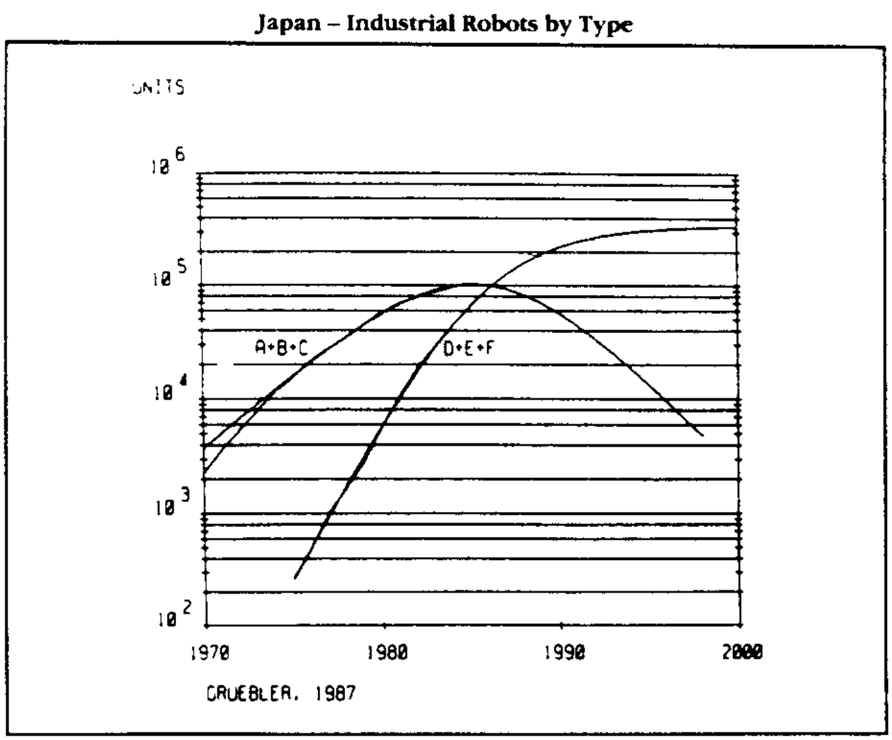

FIGURE 7. The competition between advanced and primitive robots should end by the year 2000 in favor of the advanced ones.

Japan – Industrial Robots by Type

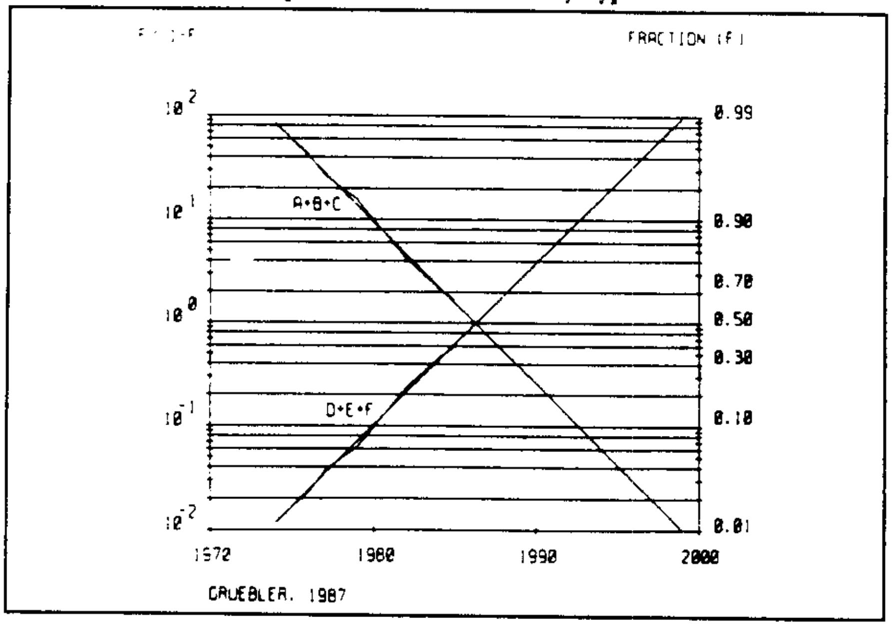

FIGURE 8 The number of horses and cars in the USA. There is clearly a transition between 1900 and 1930, where practically all horses have been replaced by cars. SOURCE: Nakicenovic (1986a).

USA – Substitution of Horses by Automobiles

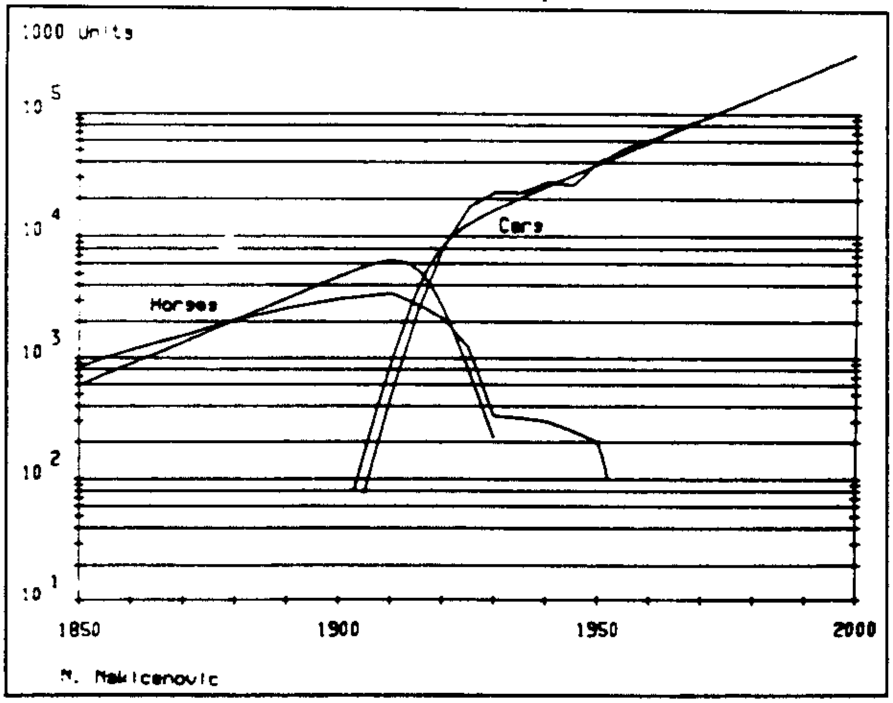

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FIGURE 9. Substitution of automobiles by horses in logistic terms. SOURCE: Nakicenovic (1986a).

USA – Substitution of Horses by Automobiles

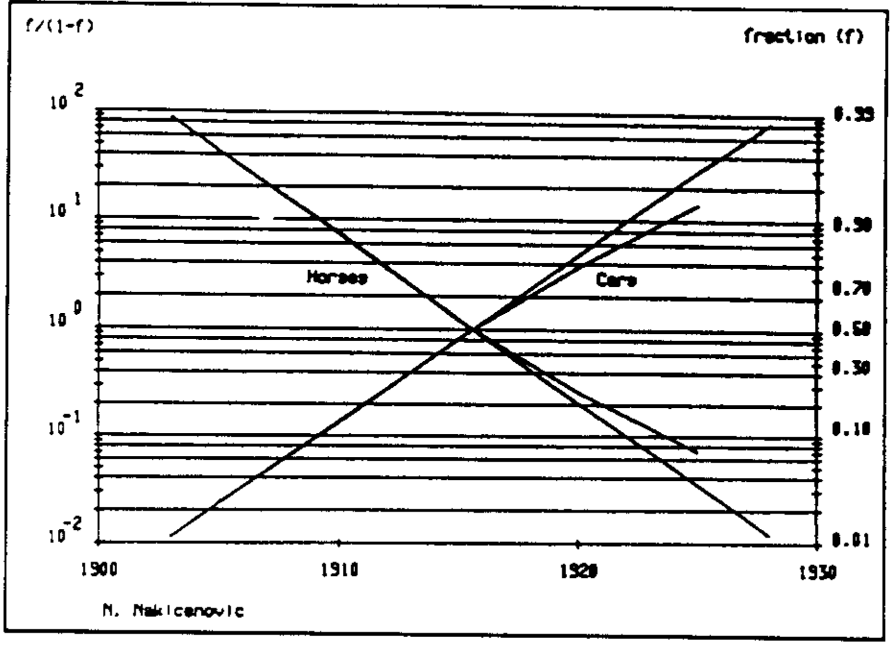

FIGURE 10. The general energy market can be decomposed into primary energies contributing to it. Their competition is the source of the dynamics. SOURCE: Marchetti and Nakicenovic (1979).

World – Primary Energy Consumption

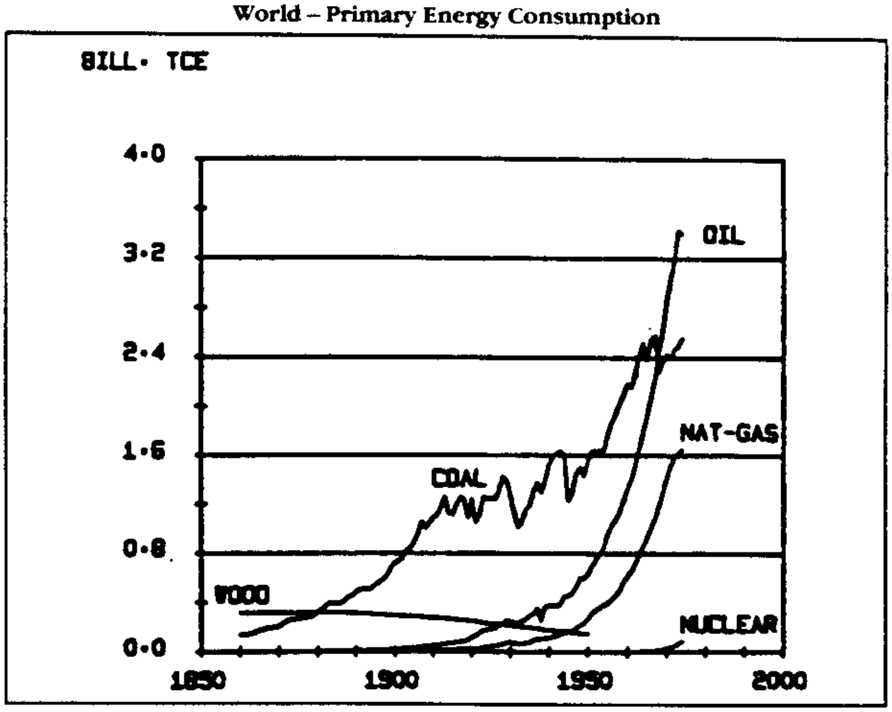

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FIGURE 11. Primary energy market share dynamics using the logistic function system solution of Volterra-Lotka equations to fit the statistics. The stability of the substitution process over 100 years is really remarkable. SOURCE: Grubler and Nakicenovic (1987).

World – Primary Energy Consumption

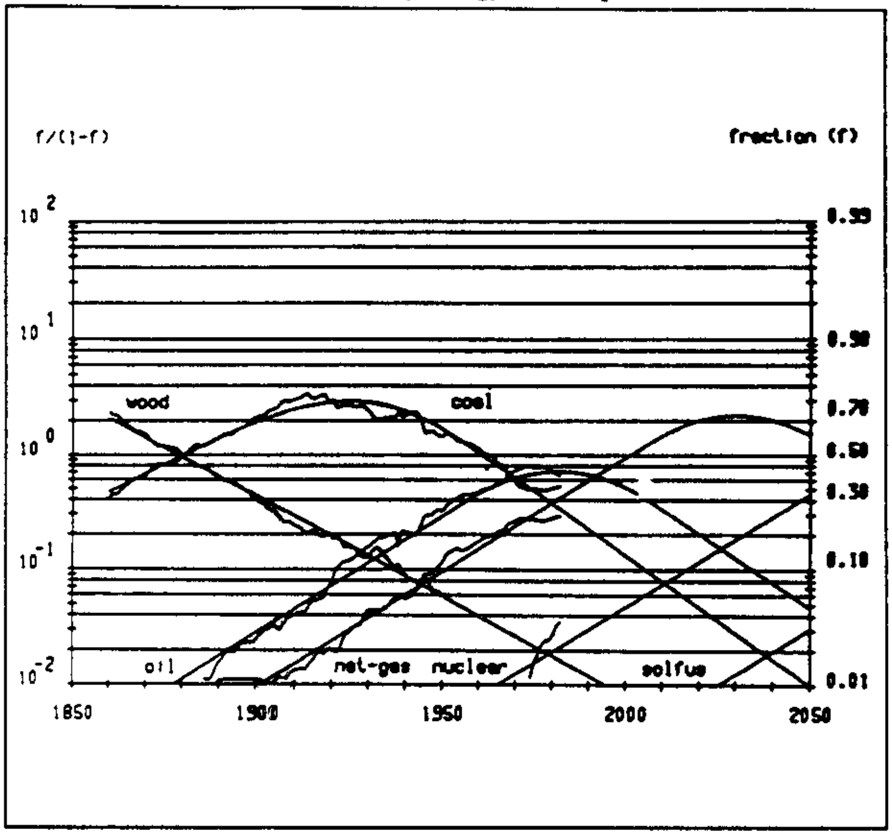

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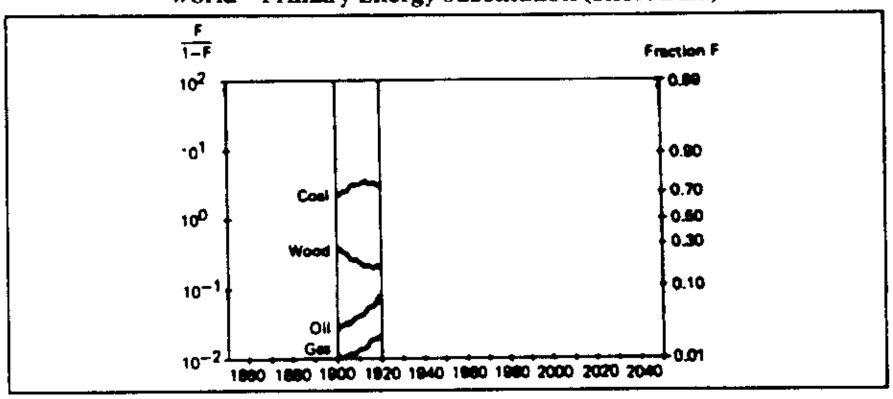
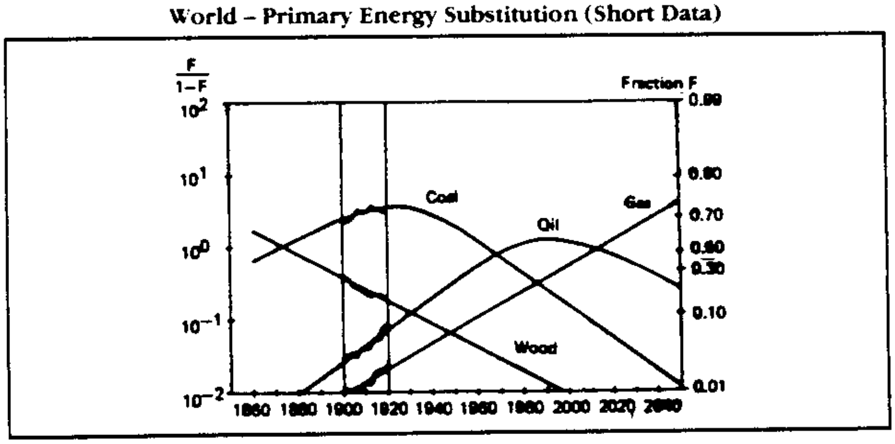
FIGURE 12. The great stability in the dynamics of the competition is what makes such an analysis a precious tool for forecasting. An example is given here, where a 20-year data swath (1900-1920) constitutes the base (Figure 12a) on which the equations are set (Figure 12b) and then compared with actual statistics (Figure 12c). The forecast, which could have been made in 1920, is embarrassingly precise for coal and oil. The predicted growth of methane does not come out so well, because the penetration was still small at the end of the base period (about 2%). SOURCE: Marchetti and Nakicenovic (1979).

World – Primary Energy Substitution (Short Data)



World – Primary Energy Substitution (Short Data)



World – Primary Energy Substitution (Short Data)

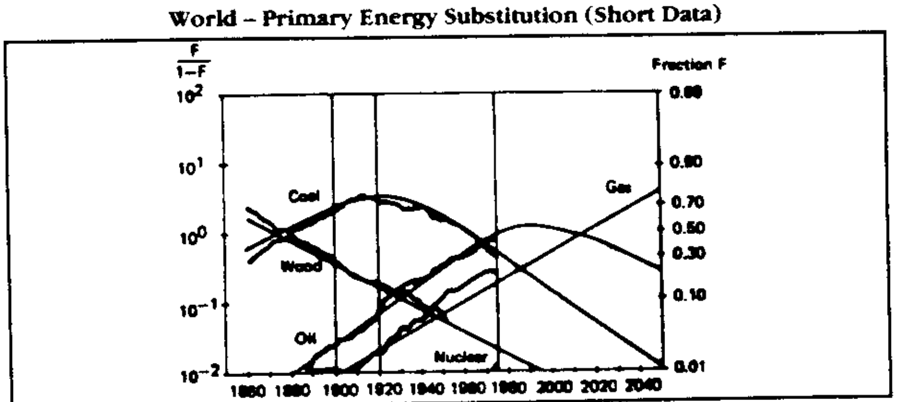


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FIGURE 13. Substitution of transport infrastructures in the USSR in terms of total lengths.

USSR – Infrastructure Growth

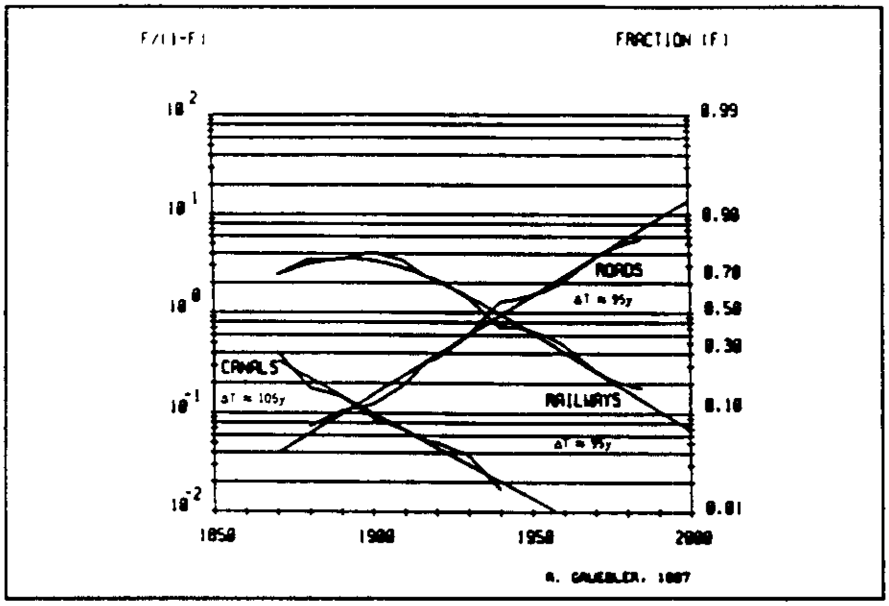

FIGURE 14. Cumulative number of people killed by the London plague of 1485. An infectious illness is the prototype of a diffusion process.

London's Plague (1665)
Cumulative Deaths (Officially counted)

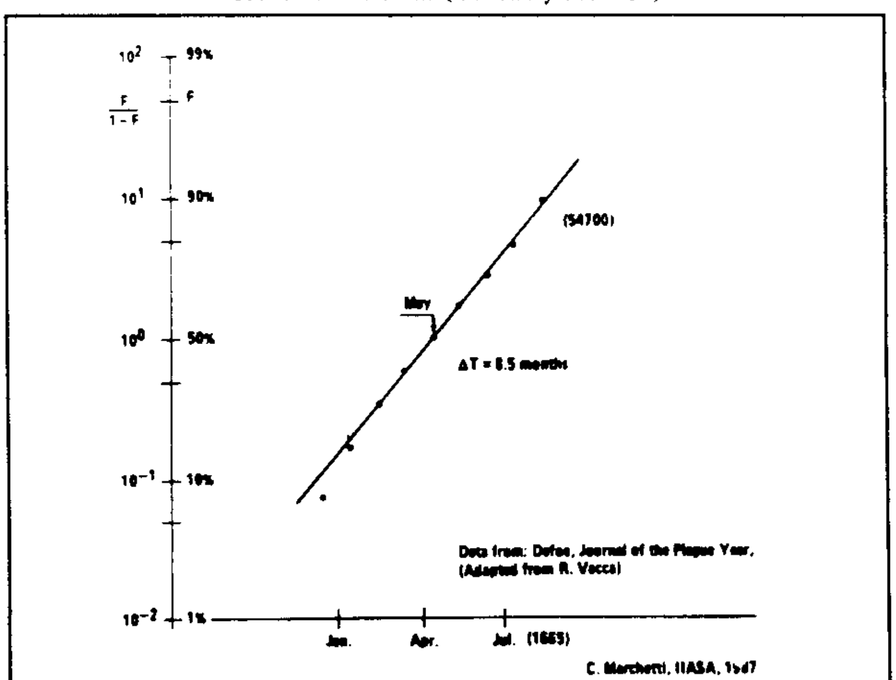

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FIGURE 15. Also ideas can diffuse, e.g. the idea that processing (and burning) witches is good for the system. Here the cumulative number of witches processed in Scotland is fitted to a logistic showing the diffusive character of the phenomenon.

Prosecutions for Witchcraft in Scotland 16th to 18th Century

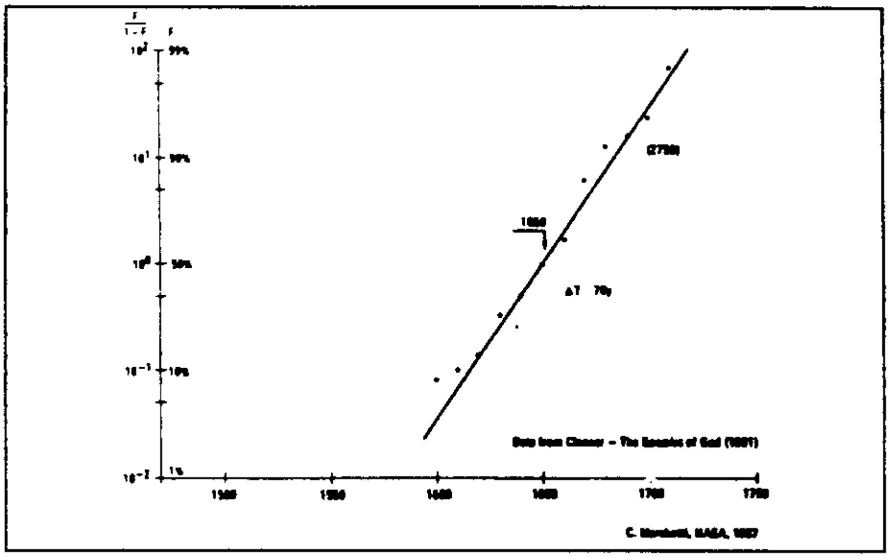

FIGURE 16. Another type of diffusing idea is that a certain area of research can give good results. The exhaustion of the field takes care of the saturation. Here the cumulative number of base papers is reported.

Myastenia Gravis – Acetylcholine Role (specimen 96)

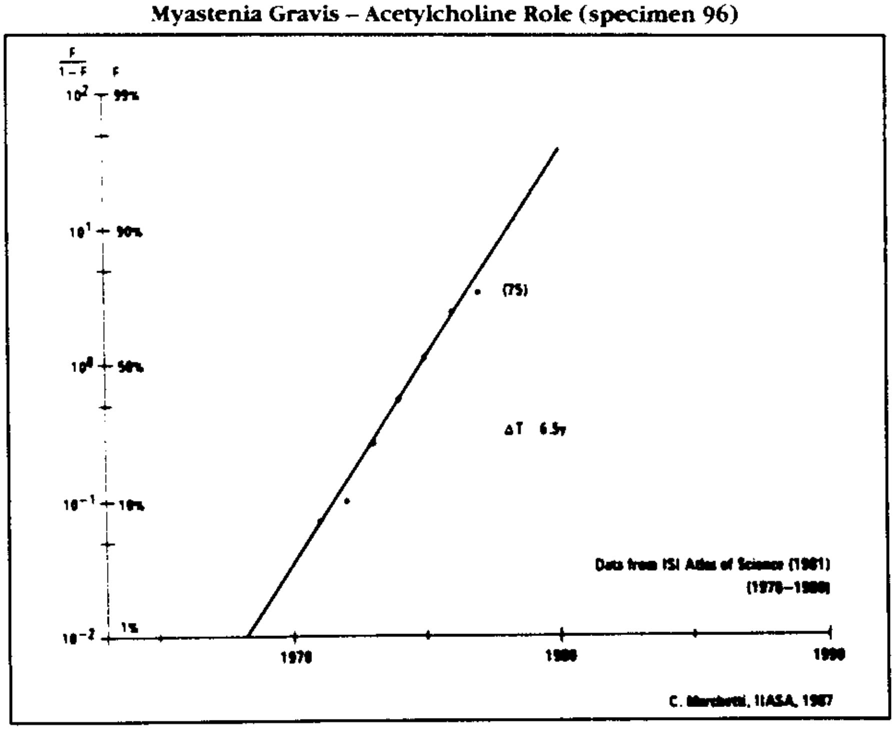

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FIGURE 17 Installed nuclear power plants (GW) in Western world. Nuclear energy has been the subject of immense debate, and it might be consoling to observe it was mostly hot air. The penetration curve (in GW) shows a business as usual trend as for any other technology. Saturation around 1995 just shows the end of a Kondratiev cycle. Fresh penetration curves will start from there, and their saturation points will depend on the way the nuclear-hydrogen industry will create appropriate packages.

Western World – Installed Nucelar Power Plants (GW)

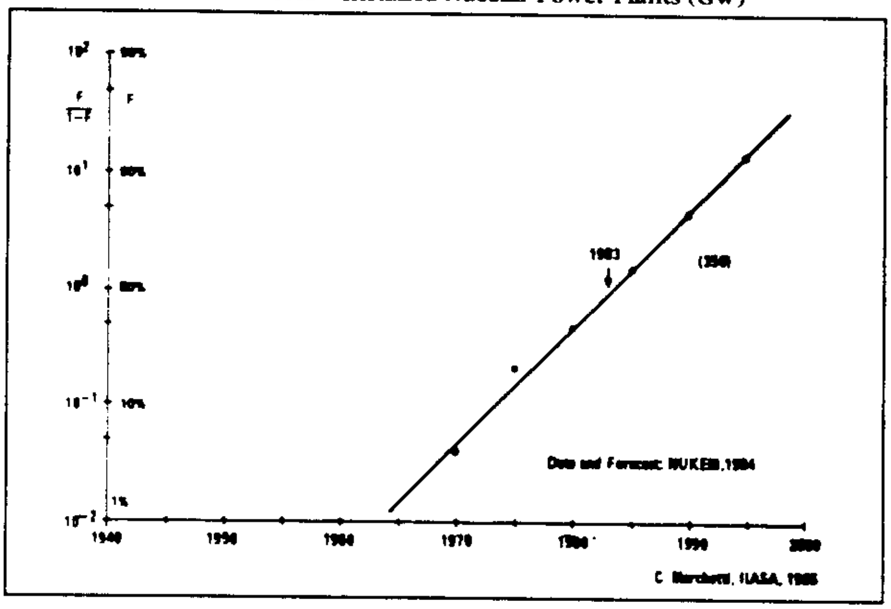

FIGURE 18. Mensch's methodology of selecting specific dates for quantifying inventions and innovations is shown here for the case of the steam engine, i.e. the locomotive. Invention is a working prototype, innovation is the first commercial solo.

The Locomotive Case as in Example of Dates Definitions

1769	Watt: Low pressure machine
1770	Cugnot: Steam gun vehicle
1790	Read: Steam road vehicle
1800	Watts: Patent on steam engines expires
1801	Trevithick starts work on locomotives
1804	Evans: Road locomotive
1811	Blenkinskop: First toothed gear locomotive
1813	Hadley: Locomotive on rails
1814	Stephenson starts work
1824	Stephenson builds first locomotive plant
1825	Stephenson opens Stockton-Darlington line

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FIGURE 19. Number of basic innovations, for periods of ten years, as counted by Mensch. The process is clearly pulsed.

Frequency of Basic Innovations, 1740 to 1960

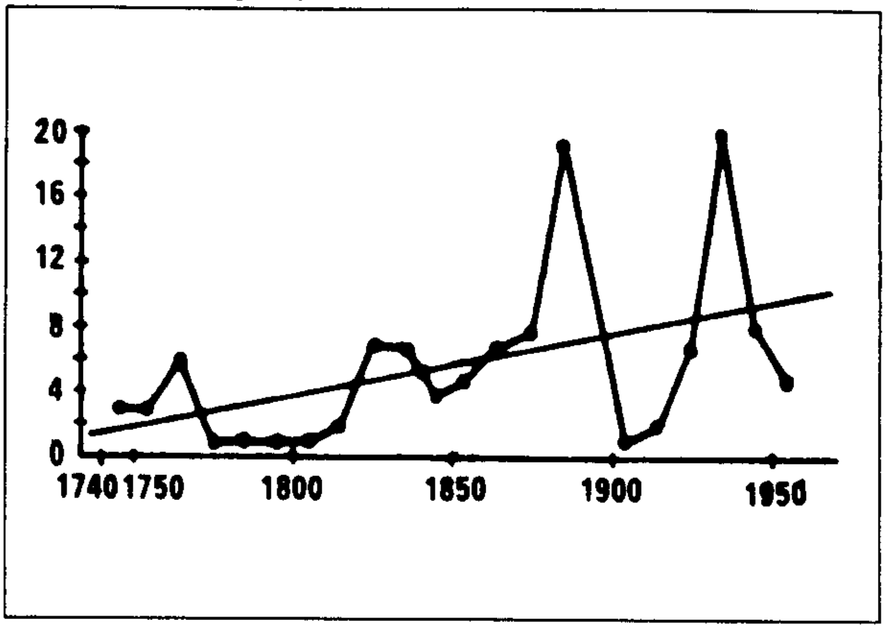

FIGURE 20. The analysis of an invention-innovation wave (1.2 in Figure 2) shown in detail. The line for coal represents market penetration of coal, at world level, into the primary energy market as from Figure 4. SOURCE: Marchetti (1981).

The 1802 Wave

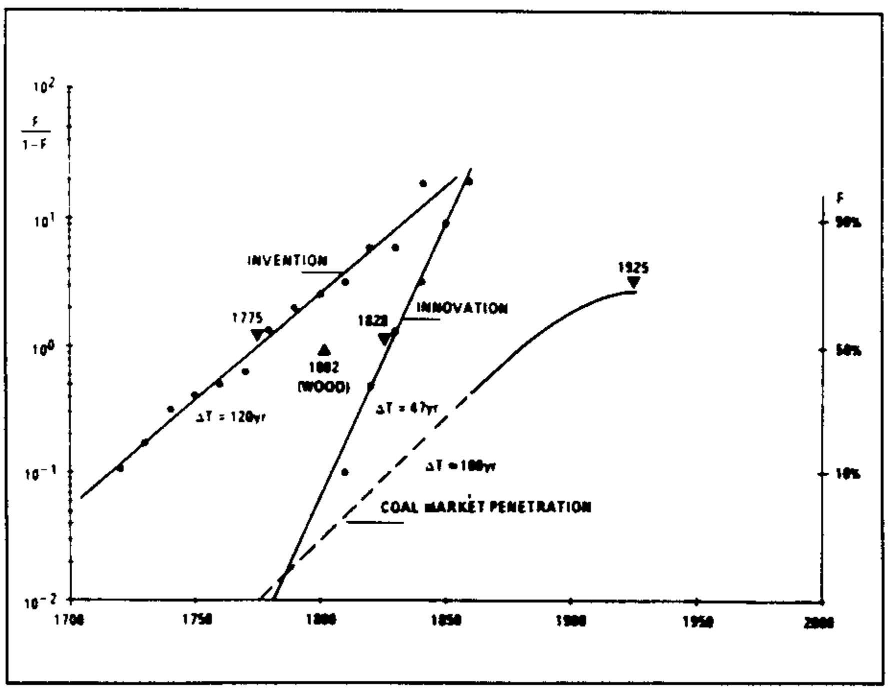

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FIGURE 21. As in Figure 20. This is wave 3,4 in Figure 24.

The 1857 Wave

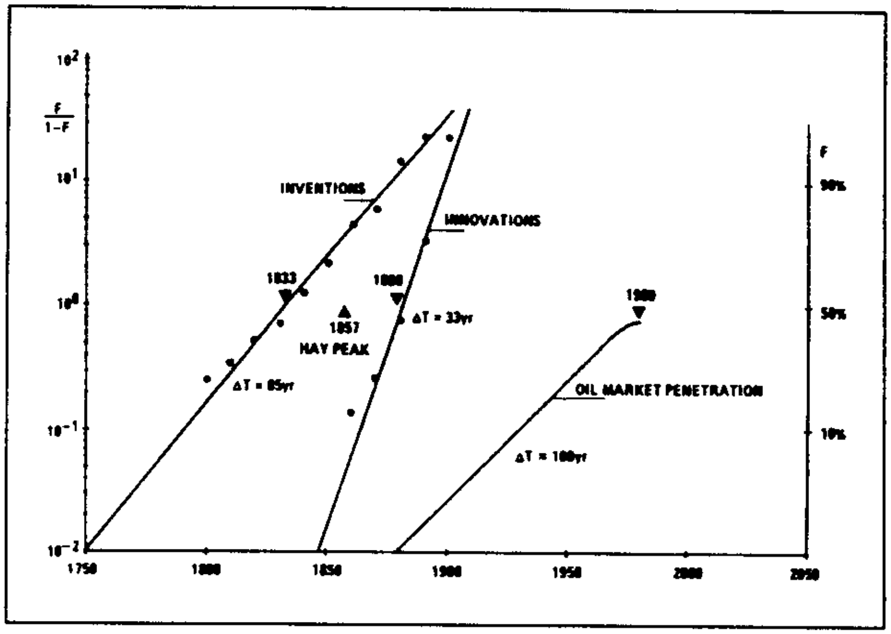

FIGURE 22. The wave (5,8) of Figure 24. The penetration of natural gas in the world market is shown in the same notation.

The 1922 Wave

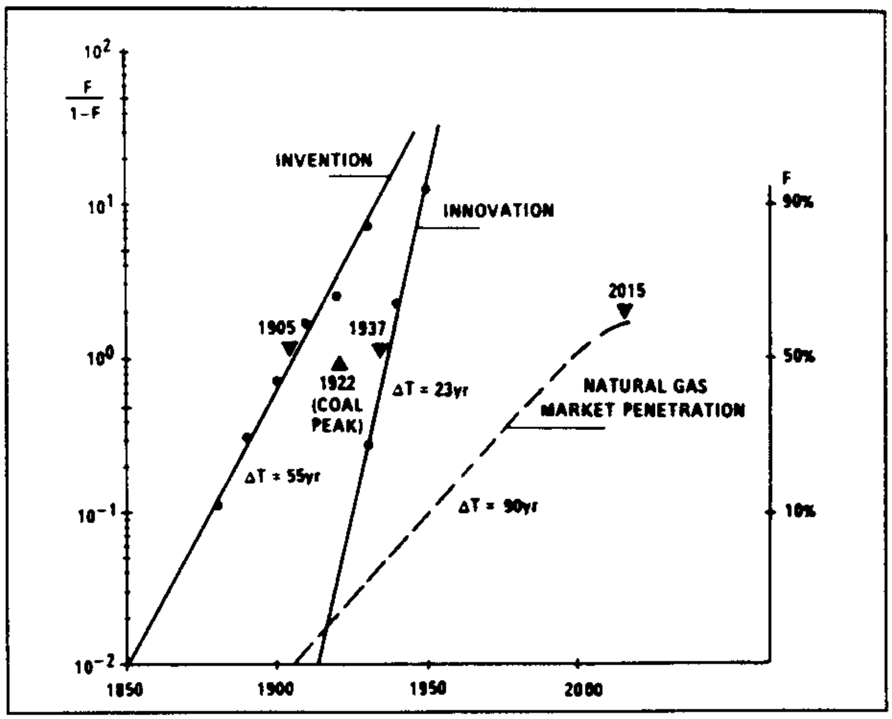

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FIGURE 23. The invention-innovation wave in which we live as calculated from the regularities of the previous ones. The start in penetration of nuclear is a check on the quality of the forecast, as the saturation of oil at the center of the wave. SOURCE: Marchetti (1981).

The 1980 Wave

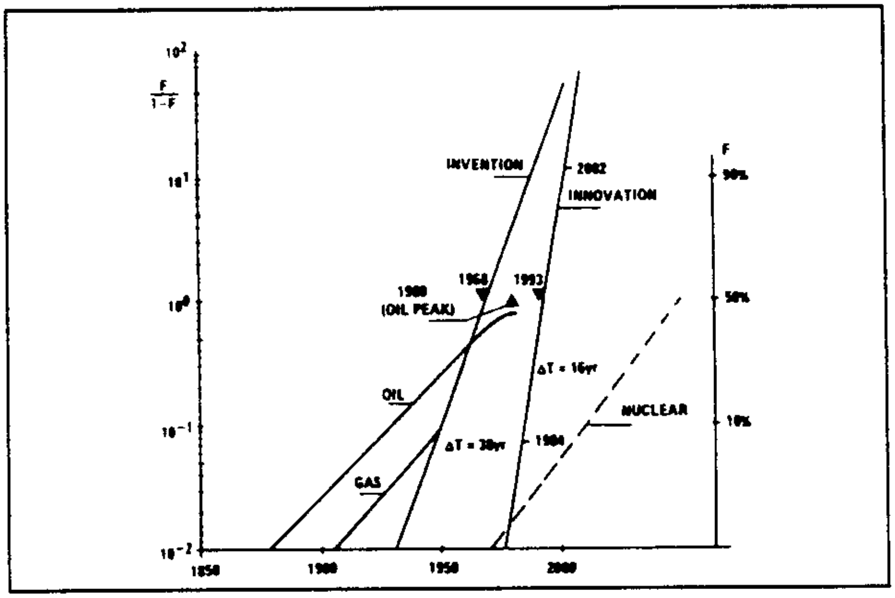

FIGURE 24. Cumulative number of inventions (odd numbers) and innovations (even numbers) in three historical waves, and one calculated (7,8).

Invention and Innovation Waves – The Secular Set

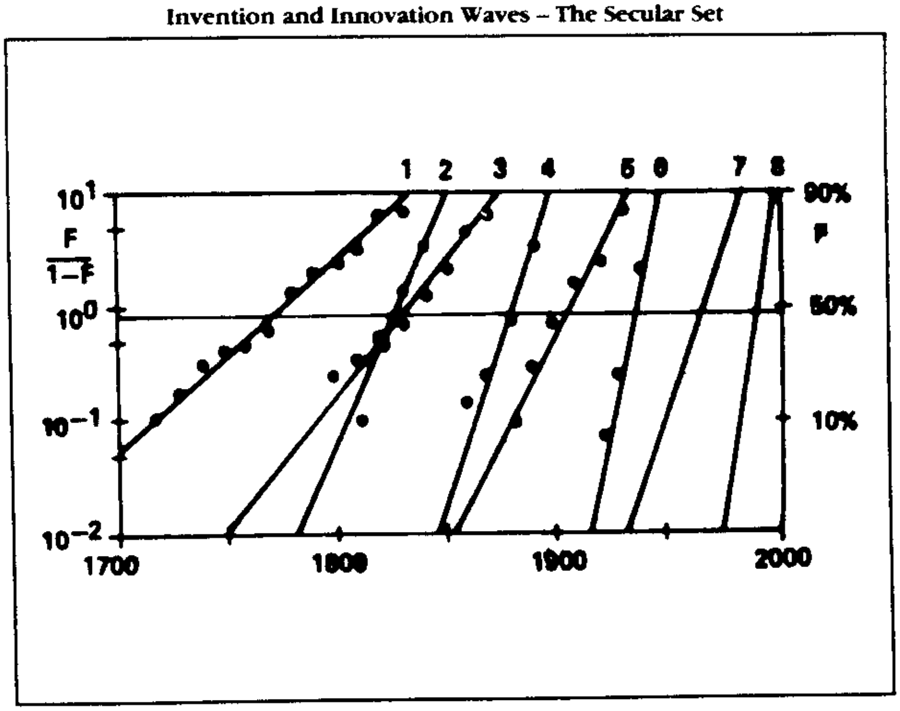

FIGURE 25 Every innovation wave is associated with the introduction of a new primary energy in the world market. Waves 8 and 10 are calculated and the coincidence is remarkable between the introduction of nuclear energy (1% of total primary energy in 1972) with the beginning of the calculated innovation wave n.8. The same logic would predict a new primary source of energy, *presumably* fusion, around 2025.

Innovation Waves and the Start of New Energy Sources

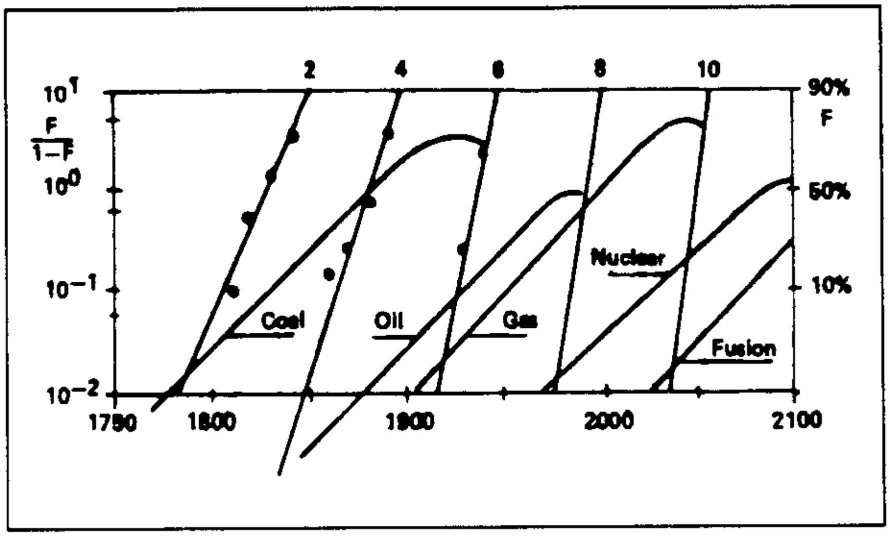

FIGURE 26 By fitting total energy and electric energy growth curves with logistics and plotting the residuals as percent deviations from the fitting curve, B. Stuart of Nuteveco did obtain this chart. The sinusoid oscillation of the deviations has a period of 54 years, and we took it as a clock to measure social activity in an all encompassing form. Center points of innovation waves always occur around the deep of the wave, i.e. the end of recession.

Center of Innovation Waves Located on Energy Indicator

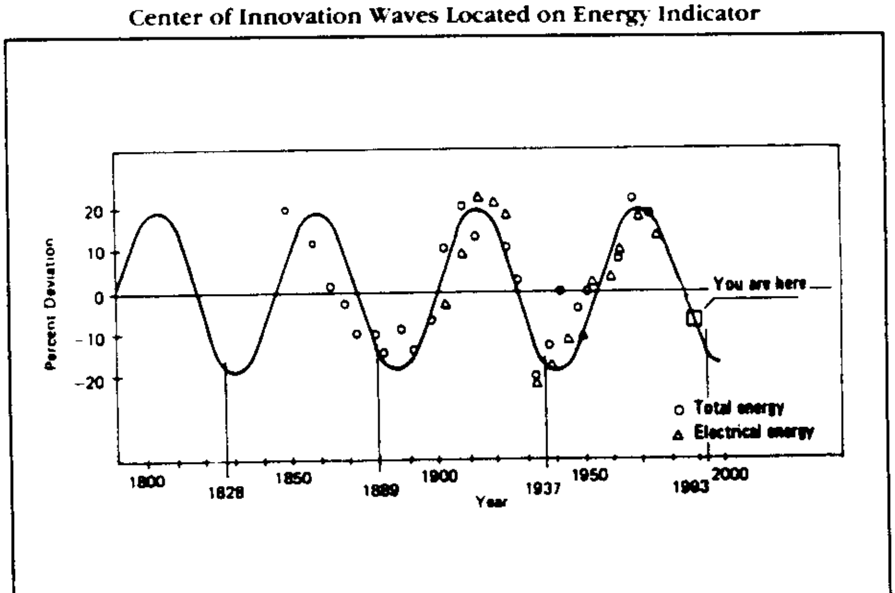

FIGURE 27 Many things are reported here to show the high synchronization of the system. To invention, innovation, and primary energy we have added oscillations in primary energy and electricity consumption in the USA (percentage deviations from the logistic long term trend) and price for energy in the USA and the world, taking the best from statistics. It is clear the tuning of prices flares with the general structure; this makes predictable the fall in oil prices. SOURCE: Marchetti (1981).

Invention and Innovation Waves – The Secular Set

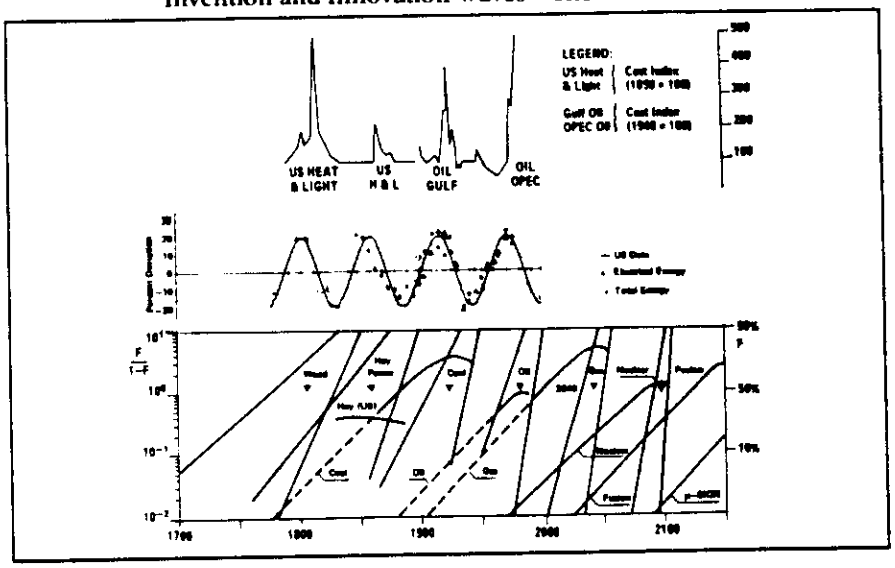

FIGURE 28 Substitution of simple technologies, like water versus oil paint, or complex metallurigical technologies in the US, show basically the same time constant. This points to a social process of diffusion, basically not associated with capital investments, incremental gains, etc.

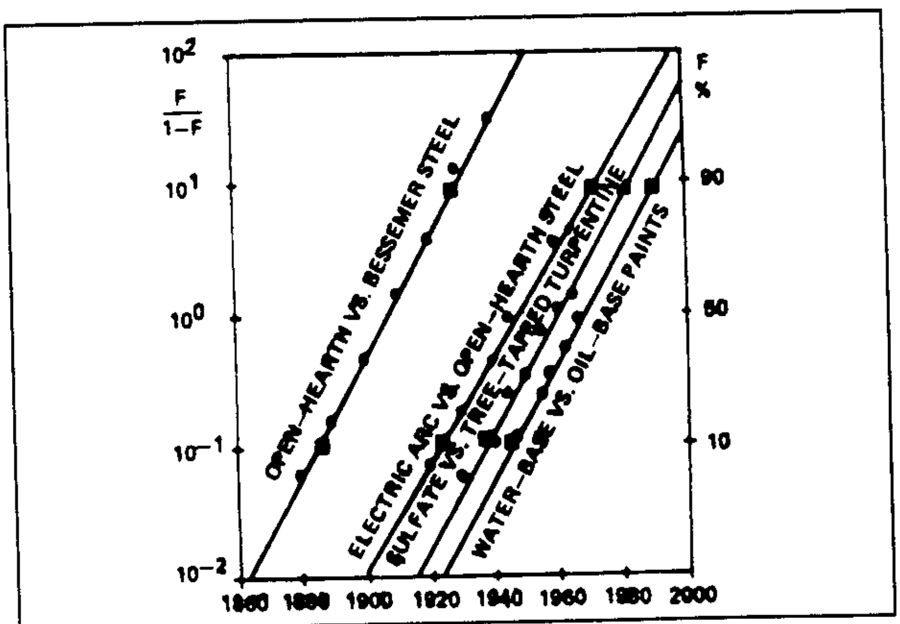

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FIGURE 29. We are here fully into sociology, measuring crime rates in an area where statistics are fairly credible: death rates by homicide. The link with the K-cycles depicted on top of the chart, using the Stuart curve as a clock, is evident. It would be very interesting to try to interpret the difference in phase. Most remarkable is the fact that, e.g. type of weapons (shoot or stab) have a similar period and very high modulation (factor of three!). It seems obvious that people act under the influence of deep social moods, flowing and ebbing with a 55 year cycle.

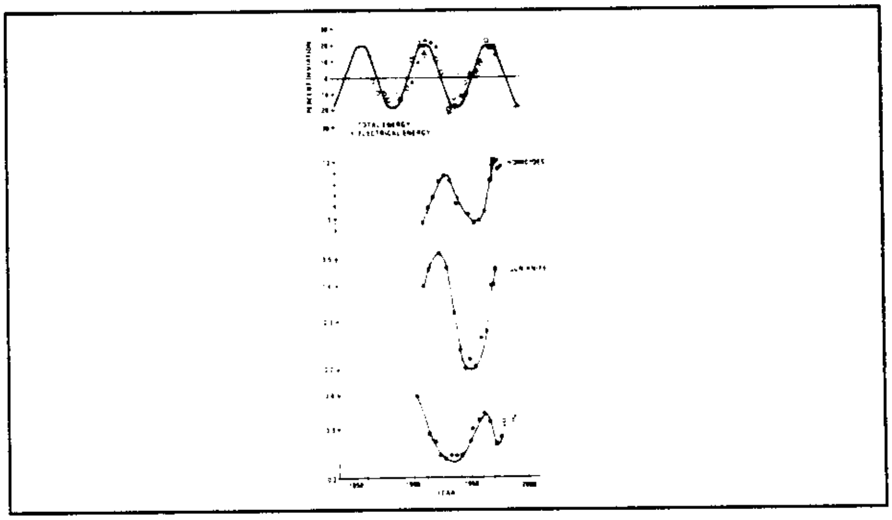

FIGURE 30. If we look at metro transport for cities we find also a pulsation pattern. Every K-cycle seems to spawn a new population of metro networks. The chart reports cumulative numbers of cities opening the first metro line. There were only two in the first wave and 18 in the second. For the present wave there should be 70. Another wave is calculated using regularities in the first three. Distance between center points of waves is 55 years.

"Metro" Starters – World

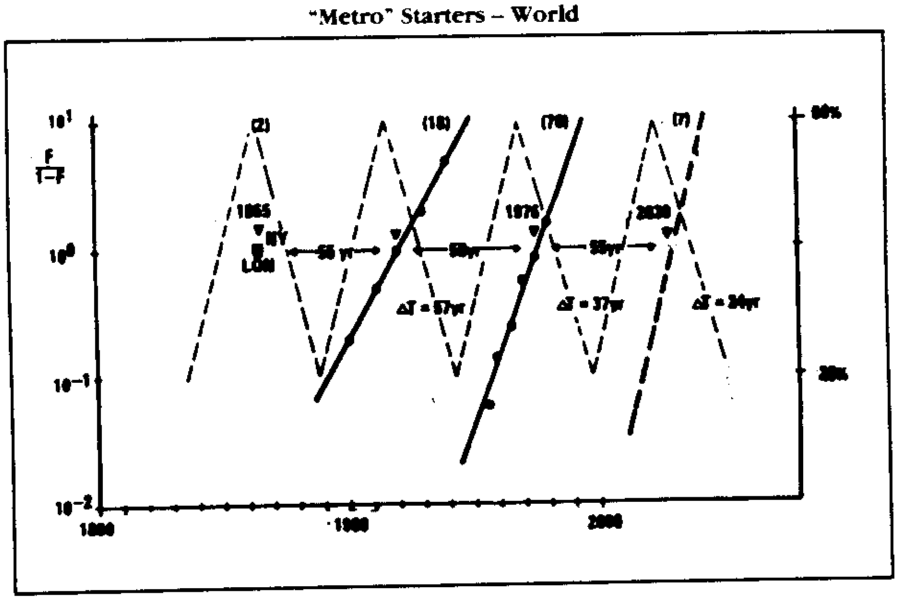

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FIGURE 31. Pulses in transportation infrastructure construction in the USA. Each mode grows to be substituted by the next one which is much longer, i.e., has a finer network. This can be seen from the saturation level at the top of the graph. Railways were 10 times longer than canals, and paved roads 10 times longer than railways.

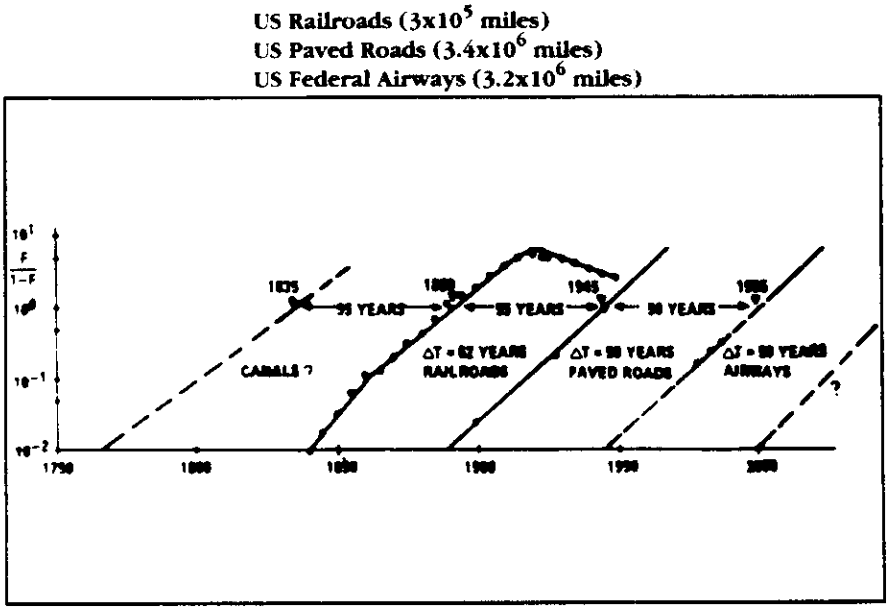
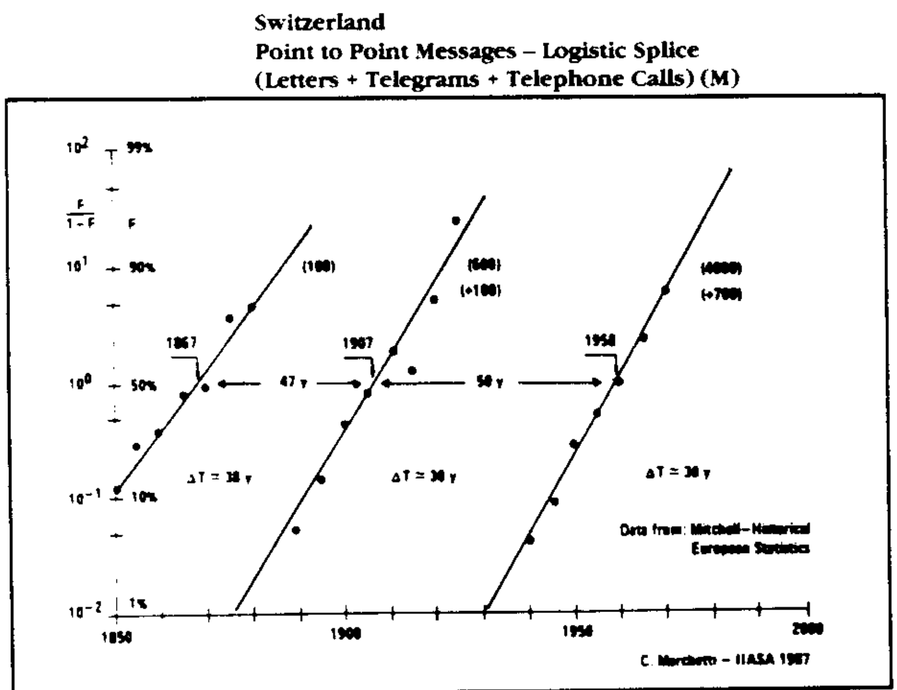


FIGURE 32. Message transmission in Switzerland (letters + telegrams + telephone calls), separated into three populations or pulses, holding respectively 100, 600, and 4000 (x 10^9) objects. DATA SOURCE: Mitchell (1981).



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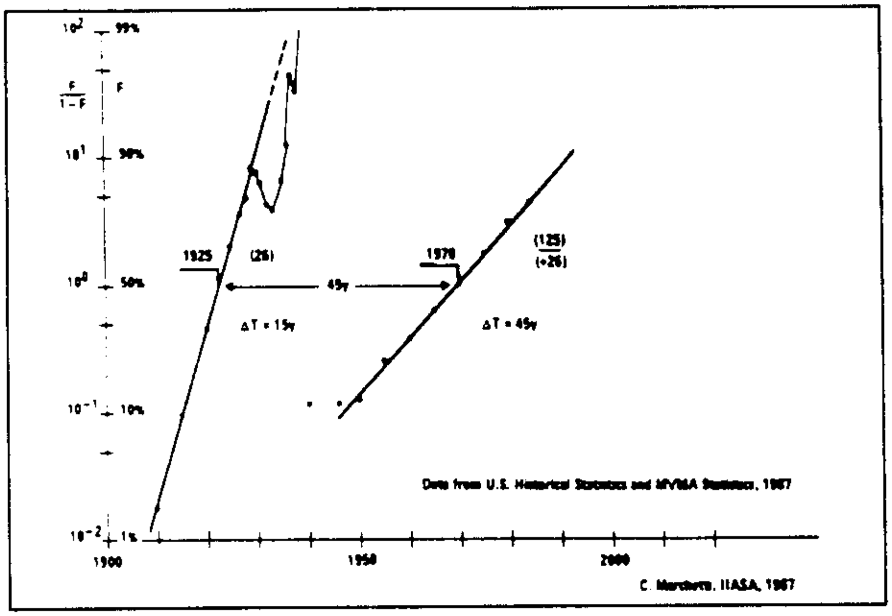
FIGURES 33 and 34. The number of registered cars did grow in Europe and the USA along similar lines. A first pulse ending in 1940 and a second one ending in 1995 well in tune with Kondratiev cycles. The first pulse was larger in the USA, bringing total number of cars in circulation to 25 million in the 1930s. In Europe they were about 7 million at the beginning of World War II. Europe did catch up after the war, with a larger pulse, and the two car populations are going soon to be almost equal.

US Passenger Cars
Total Registration (M)



Car Circulation
in Europe (M)

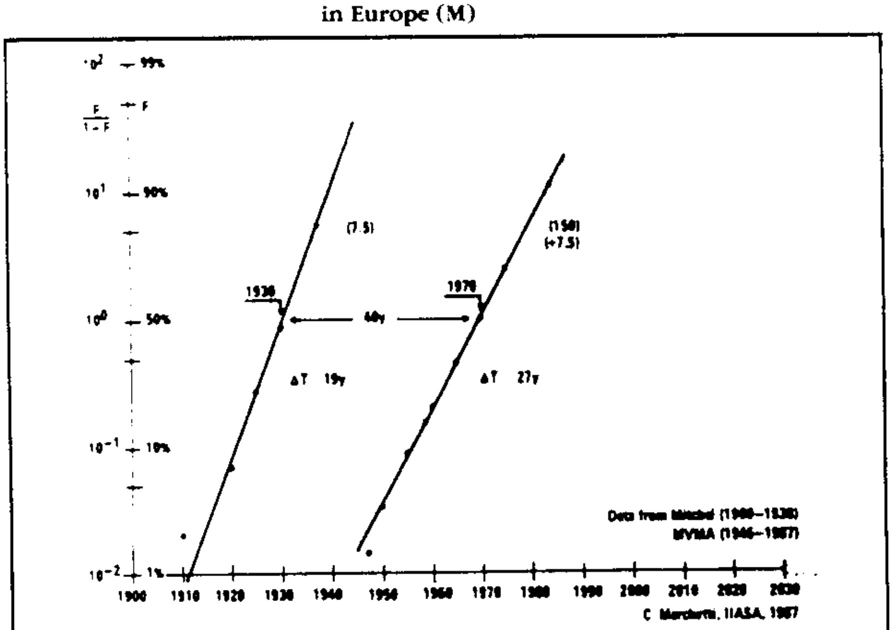


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FIGURE 35. A pulsed career can be observed for coal extraction in the UK, where two waves of growth tuned to Kondratiev cycles are followed by a stable (and jittery) level of production during the Kondratiev ending in 1940, and by a downward logistic for the present Kondratiev. The horizontal segment starting in 1975 comes from a legislative decision fixing the level of coal production to 125 MT, as a protection against the oil crisis. After the extensive strikes of 1984, this position has been much eroded and production is now near the fitting logistic, in spite of the still high cost to the tax payer.

UK – Coal Production (MT)

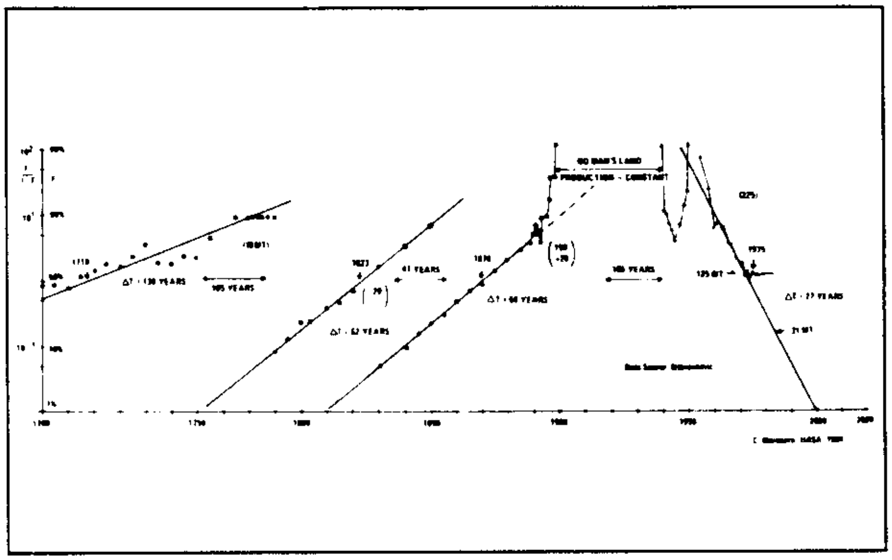

FIGURE 36 The output of raw steel production at world level is here reported. Two waves with jittery ends are clearly delineated. Saturation points lean at the end of the cycles. The position of World Wars I and II are also indicated.

World Steel Production (Mtons)

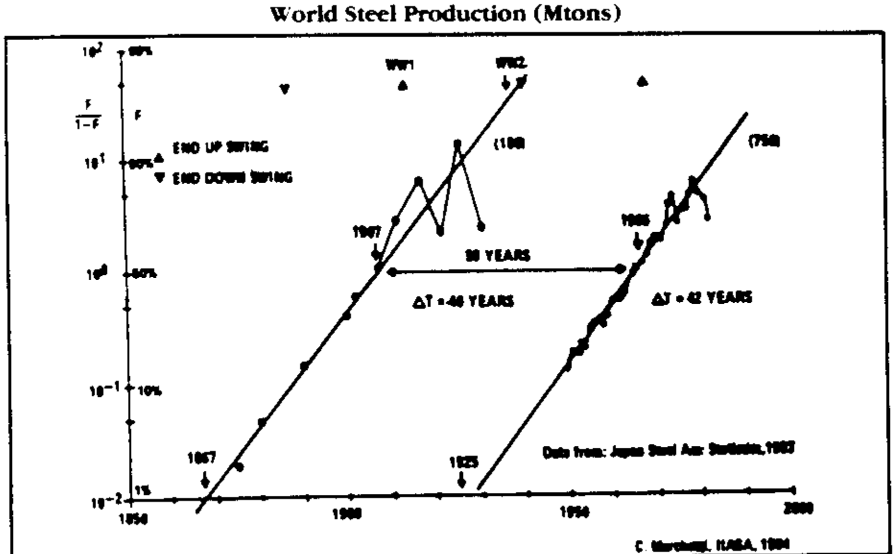

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FIGURE 37. Here we observe two waves for the US exports of raw cotton, a very important commodity for the south of the country during the last century. The history of slavery in the US is much linked to cotton cultivation. This US dominance on the world market ended actually in 1900, not really with a downward logistic but with a jittery market basically stable at a much reduced level by respect to prewar.

US Cotton Export (MIb) Unmanufactured

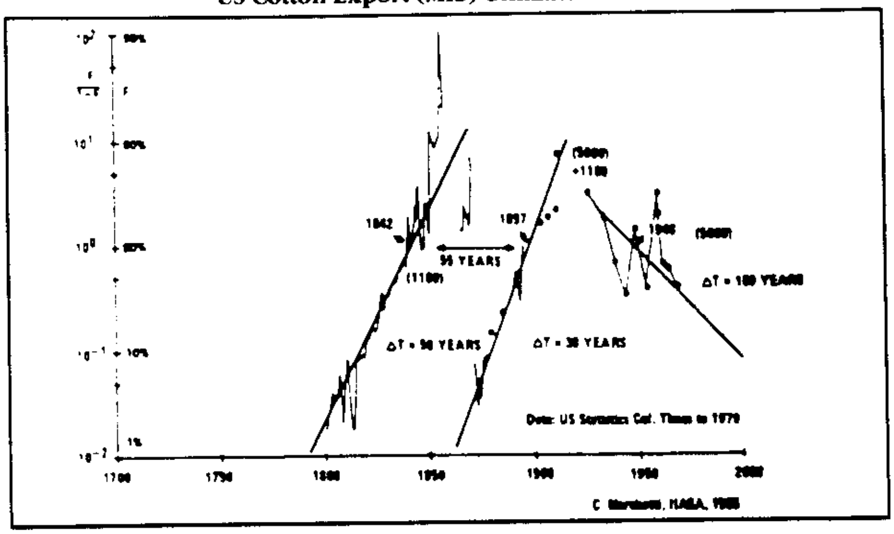

FIGURE 38. The charts show the gliding mean (three years) of unemployment in four different economies. Saturation of markets leads to zero growth of production which works basically for substitution e.g. of cars. Increasing productivity leads then automatically to reduce employment. Because everything as we have seen saturates around the end of a K-cycle (1940), then unemployment piles up just a few years before. Because of the phenomenon is worldwide, there is no escape as the chart shows and unemployment levels are strongly synchronized.

Unemployment Rate 1887-1979

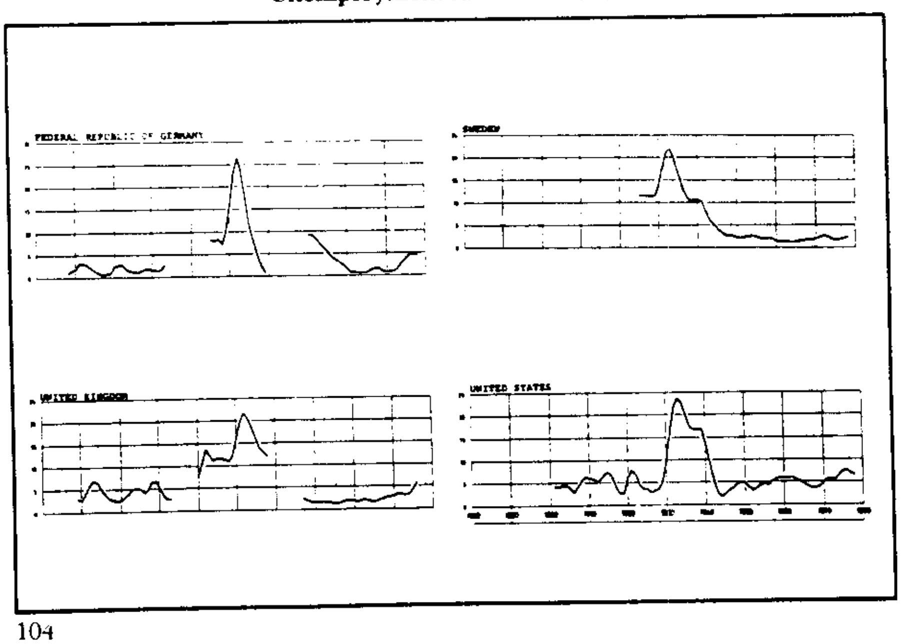

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FIGURE 39. The peak of unemployment is shown in detail with the four cases superimposed to verify the synchronization of the process.

Synchronization of 1930-1940 Unemployment

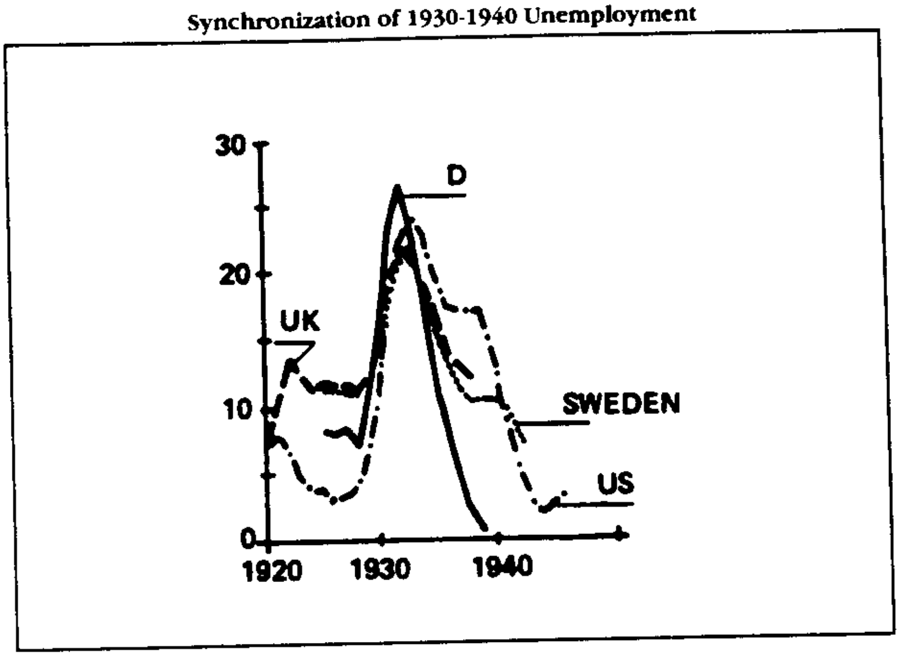
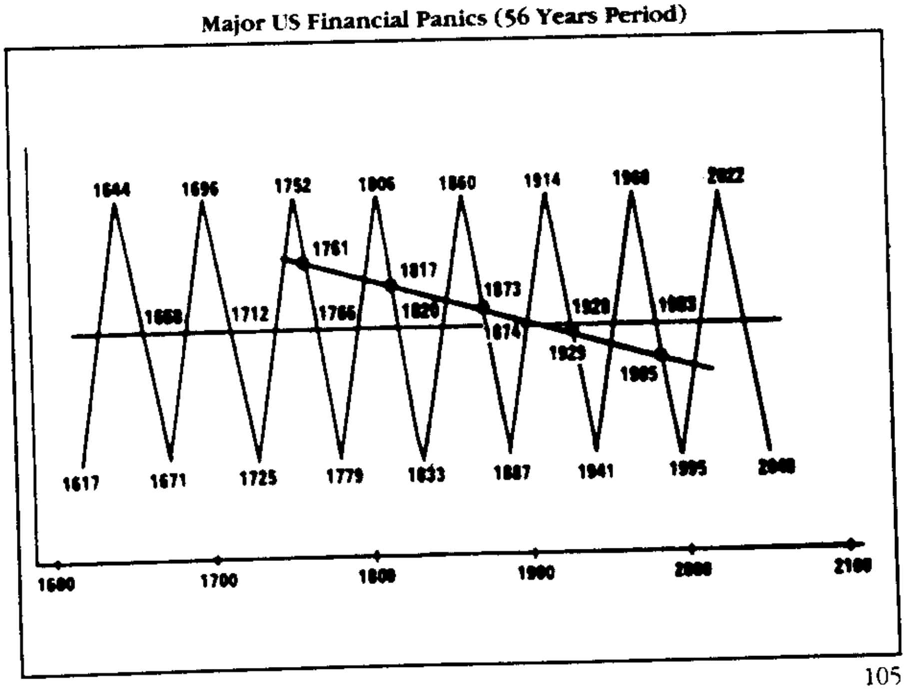


FIGURE 40. An exercise in coincidences. Major financial cracks in the US are reported against a 54-year schematic sinusoid. Four points show a synchronization with a one year shift. Although there is not a logic to base forecastings, these synchronizations merit a further study.

Major US Financial Panics (56 Years Period)



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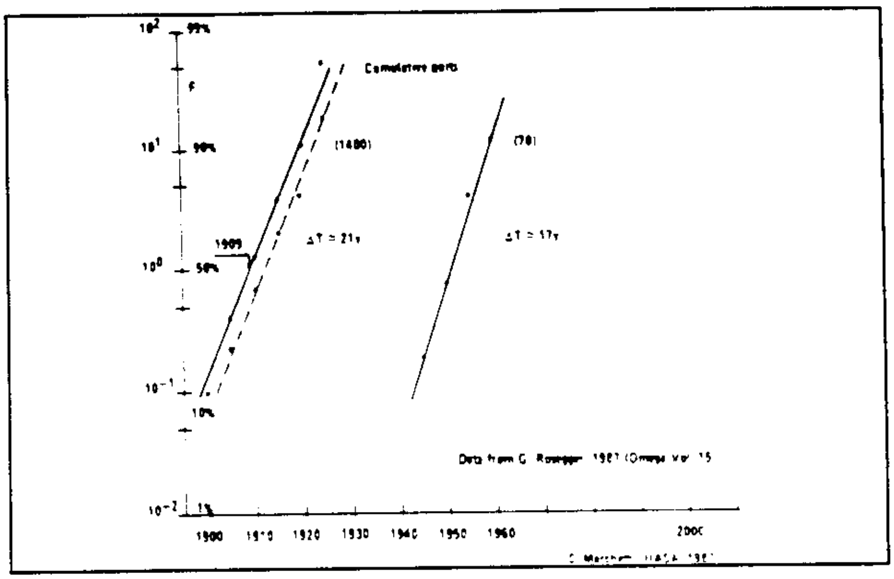
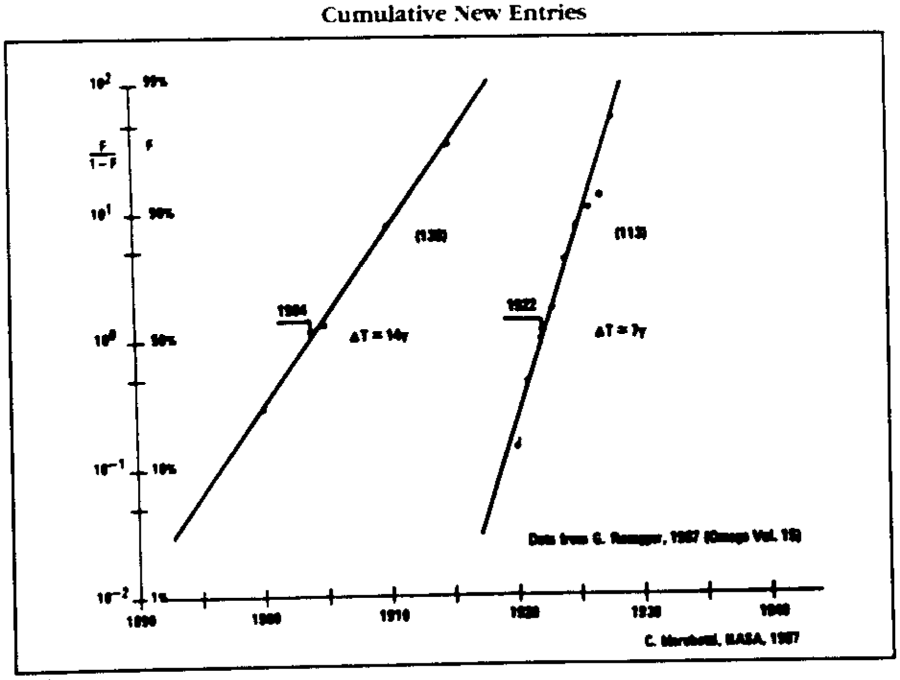
FIGURES 41 and 42 Once a basic innovation enters the markets, a flurry of courageous entrepreneurs try their luck. Most of them disappear, sometimes absorbed by others. These two charts show the development of parallel phenomena in the US and the FRG: the opening of companies manufacturing cars. The cumulative number of companies entering market is reported in the solid lines. For the US, also the cumulative number of quits is reported (dashed line). The mean time on the market is four years, and survivors are almost nil out of the 1400 entrants.

US – Car Makes
Cumulative New Entries



Germany – Car Makes
Cumulative New Entries



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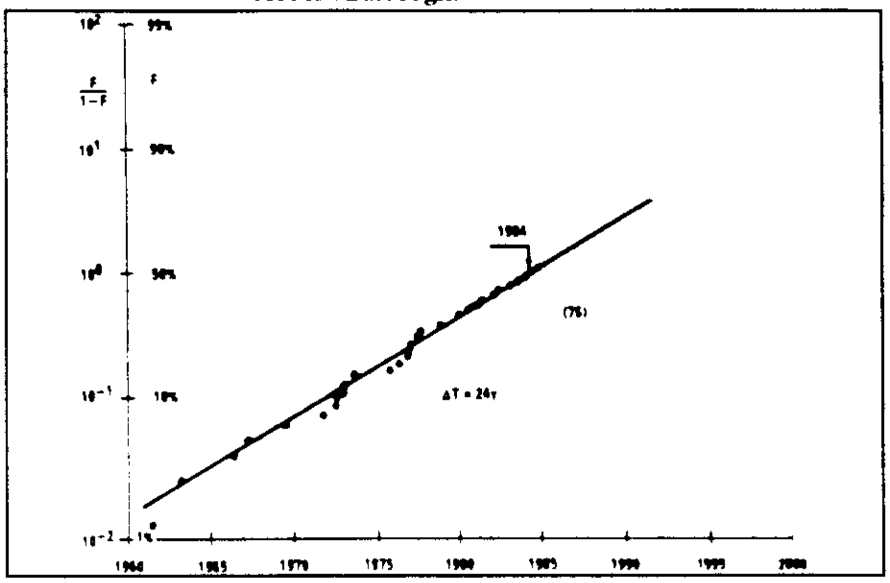
FIGURES 43 and 44. These two charts show the *cumulative* number of new mainframe computer models put on the market by Borough and by Wang. This innovative activity is also a measure of the vitality of the companies, and of their position on their life cycle. Wang is in fact much younger then Borough, in absolute sense and in auto-relative sense.

Innovation in Computer Industry
Mainframe Computer
Models: Burroughs



Innovation in Computer
Industry Mainframe Computer
Models: Wang

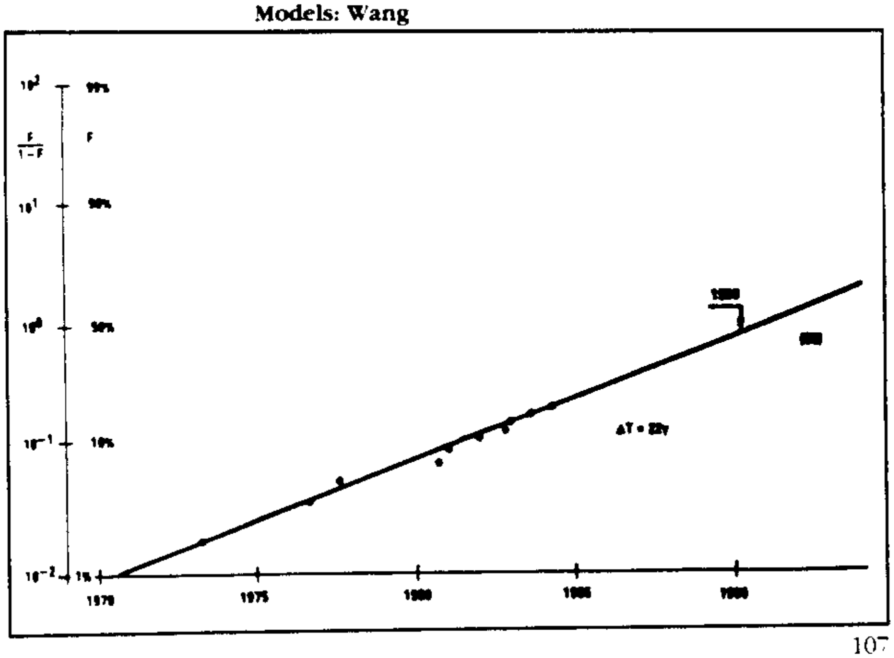


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FIGURE 45. This chart reports the growth of *main frame computer models*. A logistic fits well again their cumulative number since 1960, saturating at the respectable number of 3000 toward the year 2000. The chart includes all computer manufacturers.

Innovation in Computer Industry New Models, All Manufacturers

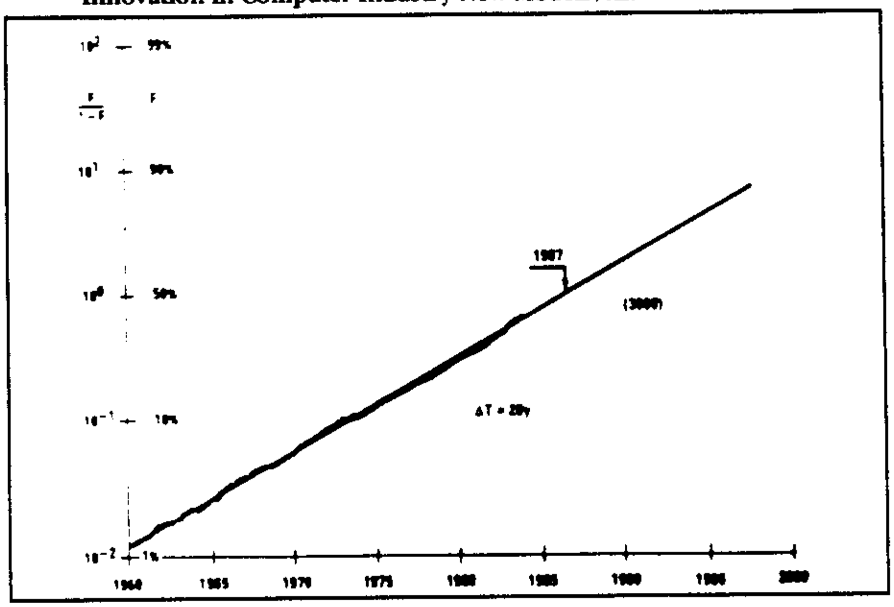

FIGURE 46. This chart compares the important computer manufacturers in terms of models generated, as in Figures 44 and 45. The actual data points have been eliminated for clarity. The first number on top of the lines indicate saturation point for number of models, and the second, time constant. There is a clear similarity of behavior with the exception of IBM who seems to span two Kondratiev cycles in a single go.

Innovation in Computer Industry Mainframe Computer Models

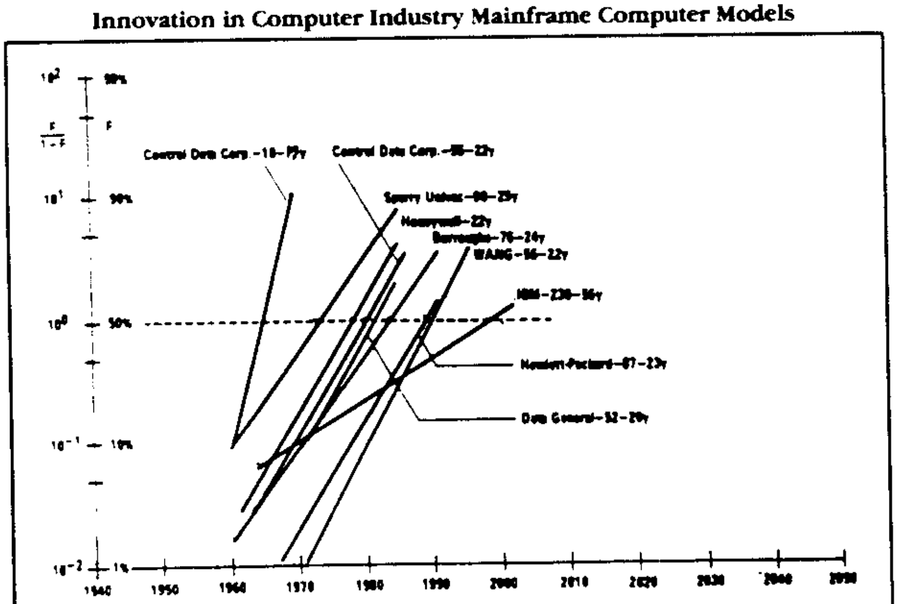

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FIGURE 47. Looking at the production of actual number of objects (not models) by a company we find analogous relationships. Here the case of Mercedes Benz is reported, moving very smoothly to its saturation point of 0.5 million cars, practically already reached. It seems a good idea for them now to concentrate on qualitative growth.

Germany – Mercedes Passenger Car Production (.000)

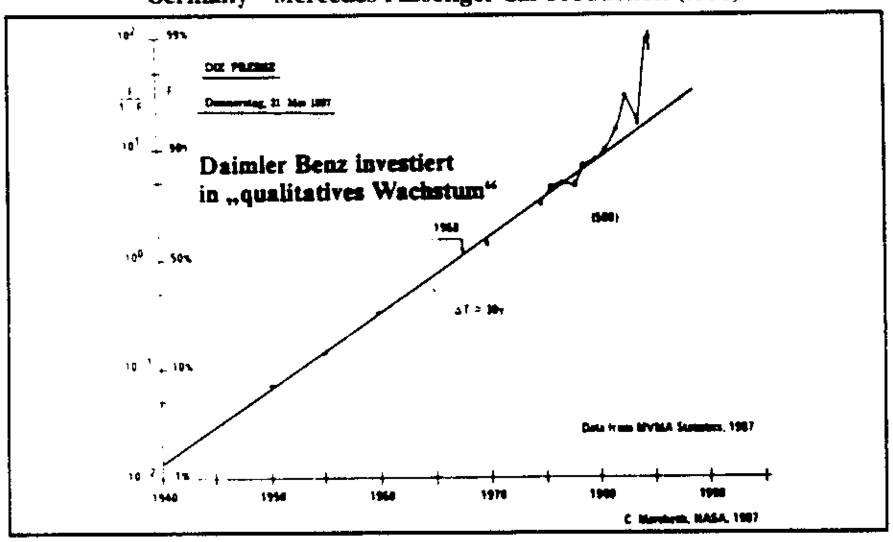

FIGURE 48. The ton-km performed by the air traffic system at world level can be very snugly fitted by a simple logistic equation. Saturation toward 1995 does not mean the end of the growth of air transport, but the end of a Kondratiev cycle of growth. The next pulse of growth will start in 1995. The remarkable absence of fluctuations as reactions to important changes in context, like the stiff increase in fuel prices, reveals powerful homeostatic correction inside the system.

World Air Traffic (tons km/yr (10^9)

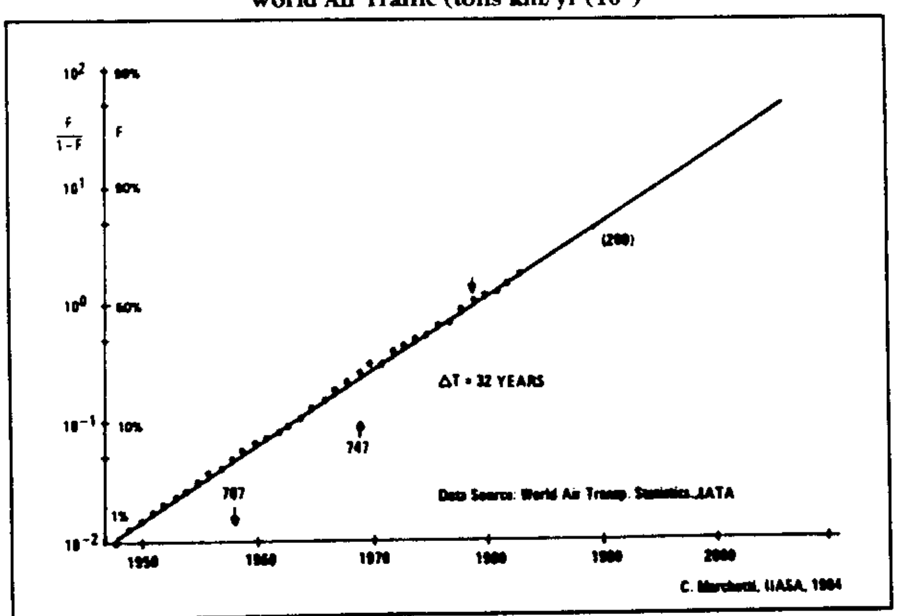

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FIGURE 49. The meshing of planes productivity and volume of traffic reveals very simple rules, which may help understand the lines of future developments in the characteristics of aircraft and organization of traffic flows. SOURCE: Nakicenovic (1987).

Passenger Aircraft Perfromance (1000 Passenger -km/h)

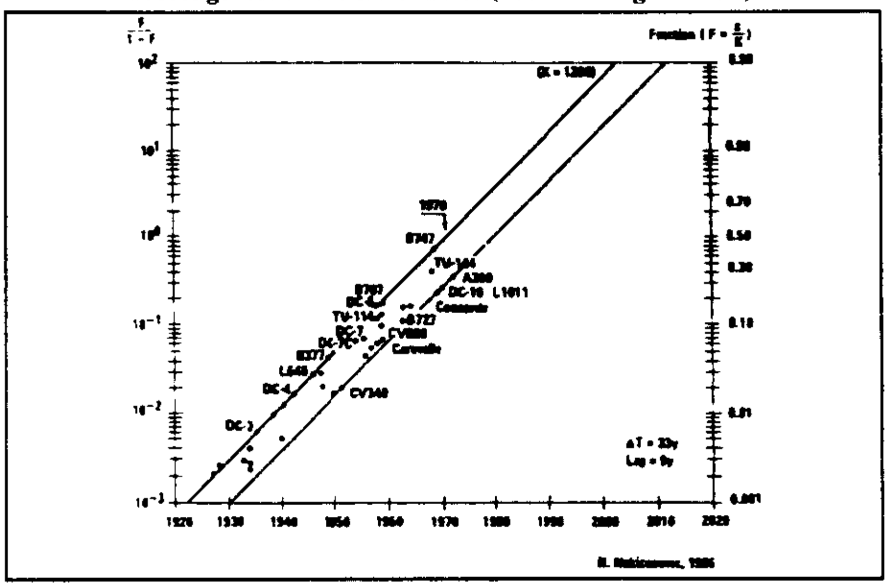

FIGURE 50. Development of power plants for airplanes show a possible shortcoming in the capacity of engine manufacturers to provide more powerful subsonic machines. This may open an opportunity window for very fast machines, possibly in the Mach 7 range. SOURCE: Grubler (1987b).

Aero Engines Capacity (World)
Best on Market

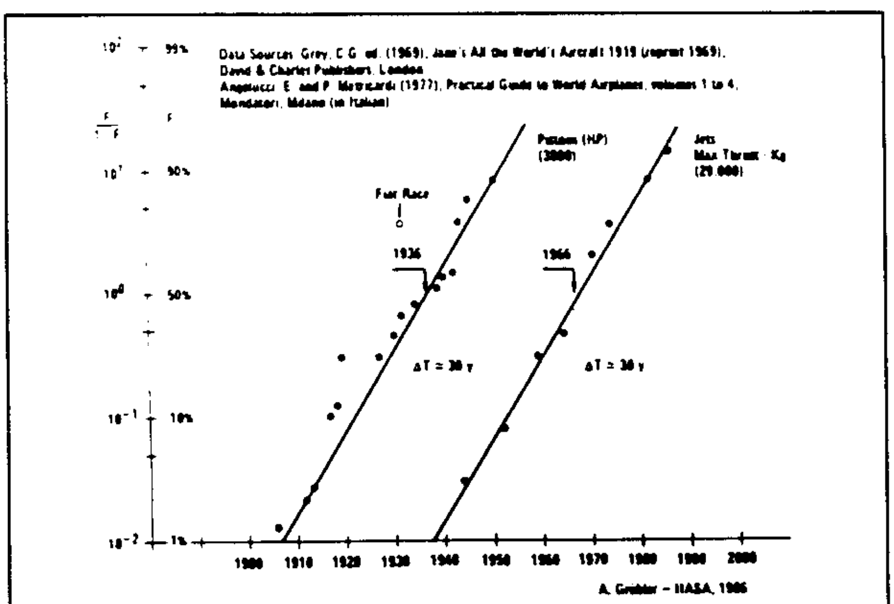

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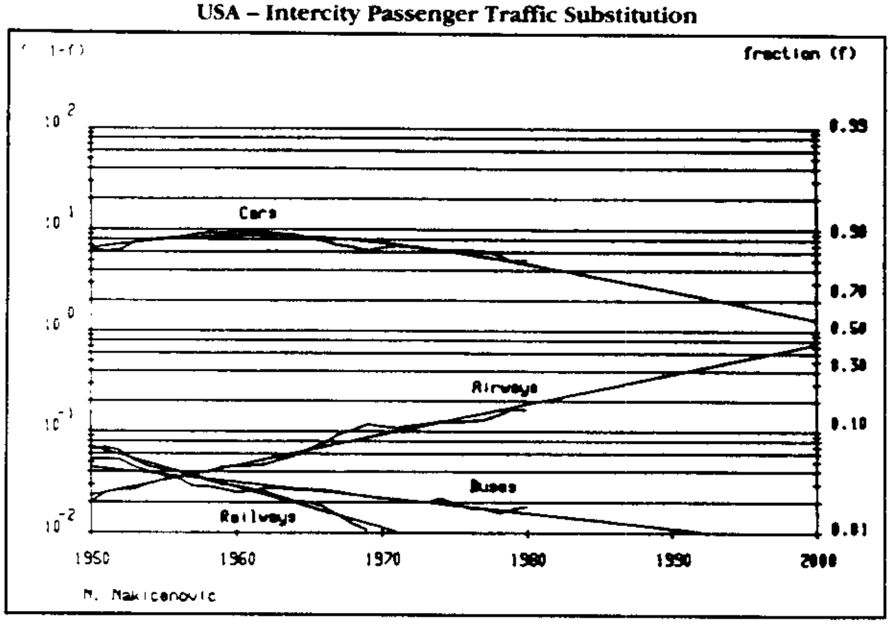
FIGURE 51 Intercity passenger-mile traffic in the USA is here analyzed in terms of modal competition. Cars reached their maximum traffic share already in 1958. The winning mode is air transport, but the time constant of penetration is not short, about 60 years. SOURCE: Nakicenovic (1987).

USA – Intercity Passenger Traffic Substitution



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