The Impact of Major Innovations: Guesswork or Forecast ?

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This article suggests a different approach to ranking and understanding innovations, looking at their socioeconomic dimension. It is shown that there is a strong synergism among major innovations in each new technological paradigm, as well as a forceful determinism in human socioeconomic behavior, implying a determinism in the evolution of technology. Although it is not yet possible to forecast the precise path of the evolution of a given major innovation and its synergistic relationship with the entire set of novel technologies in each emergent technological paradigm, it is pointed out that a new trend in socioeconomic analysis is presently burgeoning, a new scientific paradigm that in the near future will help humankind to overcome the present impasse. Finally it is concluded that the evolution of society, regarded as an open complex system with technoeconomic subsets, is not a question of chance, but of necessity, following some iron rules of nature.

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Foreword

A number of authors[1-5] have already pointed out the inherent difficulty of forecasing the future of some new technologies or inventions. Cerf and Navarsky[1] report many errors in expert judgement about the future of new technologies. Schnaars[2] examined hundreds of technology forecasts in his book, and found that there is a myopia, even among experts, that causes them to consider the future in terms of present needs, attitudes, tastes, and desires. Biondi and Galli[3] highlight the fact that technological paradigms have a powerful exclusionary effect- "efforts and imagination are focused in fairly precise directions, but remain *blind* to other technological possibilities". Rosenberg[4] recently published an analysis of the causes of these failures and speaks of a "problem-solving myopia" as one, among several, motives for these systematic failures.

Some of the abysmal forecasts that we find in the history of technology seem exceedingly naive, like von Neumann's[1] 1956 "foresight" "... a few decades hence, energy may be free, juse like unmetered air", or Marconi's belief that only steamshipcompanies would use radios. Collopy[5] wrote recently that "forecasting the future of technology is a dangerous enterprise", and then asked: "of what value are forecasts that try to predict the impact of future technologies ? "

In the following section a different approach to ranking and understanding *innovations* is proposed, looking at their socio-economic dimension.

Innovations and their social impact

Innovation can be defined as the successful exploitation of a new idea. It can be applied in the area of technology, in the functional area embracing manufacturing, marketing, and distribution, or in the organisational area embracing management style and company culture. But changes in the ways goods are produced and marketed have no great social impact. Only those new ideas dealing with a *new* way to satisfy *quantitative* purposes have real social impact. As defined by Steele[6], *technology* is the manipulation and control of physical objects for *quantitative* objectives. The word *quantitative* is used here to distinguish it from art, which can be defined as the manipulation and control of physical objects for *qualitative or aesthetic* objectives. On the other hand, it is important to emphasise that many manufactured goods, such as automobiles for example, are actually a combination of both[6].

From this perspective innovations can be ranked in at least three groups, according to their impact on society:

i — *no impact* -these are innovations that consist in a simple modification of the product, some small improvement in performance, either to capture or regain a market niche, or to meet new standards. *There is no influence on the behaviour of individuals,* no new habits or customs are created or induced in society. The introduction of this kind of innovation to the market requires some forecasting to measure the market and the likelihood of acceptance of customers.

ii — *samll or medium impact* -these are innovations that embody a new way of using an existing technology. Three recent examples are the fax machine, the laptop and the cellular telephone. Some new habits were developed in society with the introduction of these innovations, mainly among business men. But society as a whole and the economy were not so strongly affected by them; one has perhaps only a new dynamic in the socioeconomic process. In many cases this kind of innovation has the character of *technological substitution,* as in the case of diesel or electric locomotives being substituted for steam, or jet aircraft for conventional propeller aircraft. This was the case too with the introduction of synthetic fibers in the clothing industry. These innovations too require technological forecasting.

iii — *very great impact* -these are innovations that create new industries and new human activities, and introduce radically new habits and customs in society. This was the case for *major innovations*, like electric illumination, the refrigerator, the typewriter, the locomotive, the telephone, the television, the automobile, the airplane, etc. Perhaps a more appropriate name for this class of innovations in *basic* *innovations*, as proposed by Forrester[7] and Mensch[8], and this will be adopted hereafter. Is interesting to observe that many of these innovations, perhaps all of them, represent the realization of an ancient dream of humankind: communication over great distances, easy individual locomotion, flight, etc. They are the results of a search, a long quest.

An important aspect of this kind of innovation, is that it goes through all seven stages of innovation proposed by Bright[9] in 1968: 1-the scientific finding, 2-laboratory feasibility, 3-the operating prototype, 4-commercial introduction (or operational use), 5-widespread adoption, 6-diffusion to other areas (adoption in other areas of possible application, for which the innovation was not invented), and finally, 7-social and economic impact. Not every innovation goes through all these stages. The innovations with no or small social impact normally skip the early stages. The development of a basic innovation, from its discovery until its full, widespread adoption, consists in an authentic *learning process* and will grow along *a logistic curve*[10].

Another interesting characteristic is that no technological forecasting is practiced for a basic innovation. Being an absolute novelty, it has a global market, and nobody worries about evaluating the limits of growth. This is very probably the main cause of the successive depressions observed in the history of economics, as discussed in the following section.

The synergism of basic innovations

The historical record shows that innovations are concentrated in certain eras. From time to time there occurs a phenomenon, first identified by Schumpeter[11], consisting of a *cluster* of basic innovations, coinciding with a period of economic stagnation and depression. After this clustering there follows a period of rapid growth and economic expansion, with the appearance of many new branches of industry and new economic activities. After this growth, perhaps in an uncontrolled way, there follows another depression, and another new cluster of innovations. An entire cycle is completed-these are the so-called *long waves of economics, or Kondratiev cycles.*

In the last fifteen years debate on long waves has grown significantly, and many articles have been published, as well as some books[12-15]. In August 1981 a special issue of *Futures* appeared on the theme "*Technological Innovation and Long Waves in World Economic Development*". This was the first of a series of publications in the 1980s and 1990s in which not only economists, but also physicists, engineers, and other natural or social scientists debated the question of long waves in economics. An extended list of references can be found in the articles of Ayres[16], Bieshaar and Kleinknecht[17], and in a recent publication of Freeman[18].

There is today very strong and robust empirical evidence of the existence of these long waves in world economic activity. The cluster of innovations at the start of each wave is associated with a shift towards a new meso-scale technological transformation, with a *synergistic* combination of new technologies, the development of new industrial activities and a deep transformation of human behaviour. Each *new technology system* grows logistically until it reaches market saturation and then declines and begins to be replaced by a newer technology system-there is successive alternation of growth and decadence with a duration of 50-60 years. The succession of technological revolutions has received many names, such as Schumpeter's "successive industrial revolutions"[11], "change of technological regime"[19], "oscillation of technological and social moods"[20], and "technoeconomic paradigms"[21,22], the last being perhaps the most appropriate.

But the most important aspect of each new cluster of basic innovations is its *synergism*, the way in which each innovation influences others, helping to improve them. This is what Rosenberg[4] calls *complementary innovations and systems integration*; in his word-"Technological systems comprise clusters of complementary inventions".

Historically one can observe the first wave at the end of the 18th century and beginning of the 19th century, with the rise of the Industrial Revolution. This wave saw the growth of the iron industry, the development of the first steam engines, the construction of canals throughout Europe (the infrastructure for a new transportation system), and the mechanization of the cotton industry. This last was the consequence of several new mechanical devices introduced in the art of weaving at the end of the 18th century.

The second wave, by the middle of the 19th century, was dominated by the railroads in Europe and the USA, and the generalized use of steam power by the textile industry and transportation systems (railway and steamships). The development of the railroad network also triggered the creation of the telegraph network, in a very synergistic way. All these new activities also triggered another development: gas lighting for better illumination.

The third technological revolution, starting at the end of the 19th century and expanding at he beginning of the 20th century, was far more complex, as Ayres[16] has pointed out. There was a greater proliferation of new industrial branches than that observed in both preceding waves, with two different clusters of innovations: those in the steel-petroleum-chemistry (and photography!) industries, and those in the expanding electric power-telephone-automobile industries. So many new industrial activities brought to economics the factor of *complexity*, ever growing since the beginning of this century. But the synergistic aspcet of this wave was very strong. The chemistry industry expanded very fast, as the growing use of textiles triggered greater use of soaps, bleaches and dyes (Bayer and Hoechst were founded in 1870!). The steel industry, as well as the petrochemical industry, opened the way for the internal combustion engine-this was the birth of the automobile, and soon after that of the airplane. The rapid expansion of the automobile industry triggered the expansion of another branch of industry-the Portland cement industry for the construction of paved road networks. It is important to observe the synergistic combination of telephone and road networks-the necessity of a more efficient communication system as individual freedom of movement grew. We are now at the end of the fourth wave, in its depression phase. Its cluster of innovations began during the recession of the 1930s and expanded during and shortly after the second World War, with the introduction of radio, television, computers, synthetic materials (plastics and polymer fibers), transistors (and all electronics), rockets, masers, etc. In this wave also a strong synergism can be seen. To quote Rosenberg[4]: "...a main reason for the modest future prospects predicted for the computer in the late 40s was that the transistor had not yet been incorporated into computers of the day. Introducing the transistor-and then integrated circuits-into computers turned out to be momentous events that transformed the computer industry". The development of rockets opened the way for satellites, which for their part boosted television broadcasting and communications activities. The maser made possible the invention of the laser, which in the beginning was used only for laboratory research and to generate concentrated heat. Nobody foresaw the importance of the laser for telephone communications-another invention, the optical fibre, was needed to revolutionise telephone communications.

For the chronology of these four waves according to some different authors, and for some speculations about what is coming on, see the recent article by Devezas[22]. Recent years have seen the *synergistic integration* of different innovations introduced during the present depression: personal computer, microsoft windows, cellular telephone, fax, CD-Rom, Internet, etc., that will reshape the communications capability of this planet. Also within the Internet many innovations and software inventions of the 1990s, such as WWW, http, html, Mosaic and others are synergistically contributing to its explosive growth all around the world. Many others innovations are yet in stages 2-3-4 of Bright's classification, especially in the fields of bioengineering (including genetics), advanced materials (advanced ceramics and polymers, intelligent materials, superconductors...), transportation (Maglevs), space activities (space shuttle, orbital stations), to name only a few. The next technoeconomic paradigm, or perhaps better, the next *techosphere* is already burgeoning.

There has been vigorous discussion in recent years as to whether these waves last for 50-60 years.[13-22]. In any case, it seems that there is a rhythm for human activities on this planet.

Determinism in the evolution of technology

Natura non nisi parendo vincitur (Only by obeying Nature can we conquer it)

Francis Bacon

Some authors[3,23] have shown that the technological shifts already observed seem to follow the same pattern of evolution, the same technological trajectories. If there is a rhythm in human socio-economic activities on this planet, is there a kind of *determinism* in the evolution of technology? If yes, is there then *determinism* in future human actions?

At this point one can go through the following reasoning-there is robust evidence that these cycles really exist and if we scan through history is not difficult to observe that the habits and customs, the way of life of human society is completely changed each 50-60 years, at least during the last two centuries[24]. This implies that in the next 50-60 years another through and through change will occurr-this dramatic change is already beginning with the rise of the multimedia phenomenon. So, something underlying social behaviour is *determining* that life on this planet will change dramatically in the near future. And what causes change in the human way of life? The only possible answer for today's society is *technology!* Thus we can conclude that there is actually *determinism* in the evolution of technology, and therefore *determinism* in the future of economics.

Society is a *learning complex open system* living on spaceship earth, fuelled by the sun's energy. It must obey the laws of nature like any other physical system in the universe. The evolution of the socioeconomic system is a flow of human energy, that must obey some constraints of physical origin, such as the learning time necessary to deal with a basic innovation. The constraints are the laws of physics, that are simply the translation into mathematics of the great number of things that cannot be done.

The individual path of a molecule in a gas is unforeseeable, and if it we try to locate with precision its position in space, its momentum is disturbed, or if it we try to measure its momentum, we can not say nothing about its position-this is Heisenberg's uncertainty principle. But on the other hand, the collective or macroscopic behavior of the gas is well described by a set of physical laws, such as the Gay-Lussac, Boyle and Clapeyron equations and the three laws of thermodynamics. The same can be said for society-the individual behaviour of a human being can not be foreseen, but the collective behaviour of a set of individuals can. Let's take a very simple example-the crowd after a football match. The path of an individual going out of the stadium can not be foreseen, but if we know the number of gates and the total population in the stadium, and the flow of people at each gate is measured, we can foresee very precisely how long it will take the stadium to empty. And if one asks a person to which gate he is intending to go, his movement will be disturbed, suggesting the ubiquity of the uncertainty principle. This is not only statistical aggregates of actions, there are much more under these collective behaviour.

This is the case for society and economics, which can be understood as the transfer of money, services and goods from one individual (whether a person or a company) to another in a way analogous to that in which energy is transferred from gas molecule to gas molecule by collisions, in a chaotic movement. Marchetti's modell[20,25] of society operating like a *learning system*, governed by logistic (or Volterra-Lotka) equations, was very sucessful in describing the succession of past waves and demonstrated very clearly that invention, innovation and entrepreneurship, generally perceived as the most *free* of human activities, are actually governed by iron rules, in a very deterministic way. In his words: "To a physicist's eye, present day econometric models still look much like toddling and stuttering. What I think most dangerous and misleading is their blind devotion to monetary concepts. All my analysis of economic systems tends to show that monetary variables are the manifestation of a deeper statum, where the real mechanisms lie".

As it is so clear that there is a determinism in the evolution of technology and society, the definitive question is: can we forecast the future of society ? The answer is obviously yes, but not yet.

The future of society: guesswork or forecast ?

Not yet because the rules of the game are not yet known. But it is not difficult to see that science is already fumbling towards a better understanding of the mechanisms. Today, futures studies are to some extent guesswork, but in the near future there will arise a real science of forecasting. The rise of this trend began with the pioneering work of René Thom(1972) and E. C. Zeeman(1977) on Catastrophe Theory, and with Hermann Haken, who created in 1970 the concept of *Synergetics- "Die Lehre vom Zusammenwirken"* (Science of acting together, or cooperation)[26]. These were the first attempts to describe some instabilities and complex phenomena not only from the physical world, but also from biology, society and economics. With *Synergetics* it is possible to understand the phenomenon of *self-organization and negentropy,* and even to explain the origin of life, seen as the self-organization of complex macro-molecules. Manfred Eigen's book, "Das Spiel" [27] was another attempt to describe complex systems, by using an approach that differed from Haken's.

In the 1980s this trend was accentuated with many publications on Chaos Theory, culminating with the publication of the excellent book by James Gleick[28]. More recently a special issue of *Futures* with the title "*Complexity: Fad or Future*" [29] was entirely dedicated to this subject. Today one can see the increasing use in economics of mathematical models originating in biology[20,25,30,31], and the use of the logic of physics to describe human society. Very recently De Greene[32] has developed a new theory of Kondratiev Cycles/Structures based on evolving informational fields and looking for suitable *complex-systems indicators*.

Something else to be pointed out is the fact already observed by Devezas[22] that at each innovation wave one has seen the birth of new scientific fields. The first wave saw the birth of *Chemistry*. The pioneering work of Lavoisier and Laplace was carried out between

1776 and 1789, immediately followed by the discoveries of Proust(1806), Gay-Lussac(1808), Avogadro(1811) and Berzelius(1814). More than fifty new elements were discovered between 1750 and 1850. Approximately fifty years after Lavoisier and Laplace pioneering work, new breakthroughs appeared in two areas of physics: the first publications of Faraday(1831), Carnot(1823) and Clapeyron(1834), setting the groundwork for *electromagnetism* and *thermodynamics*. With the start of the third wave there was another revolution in physics with the publications of Planck(1900) and Einstein(1905): this was the birth of *quantum mechanics* and *the theory of relativity,* which dominated the scientific scene during the first half of the 20th century.

Half a century later came new breakthroughts-the discovery of DNA(1955) and the beginning of the nuclear era (Project Manhattan, the atomic bomb, 1945, and the first nuclear reactor, 1948). In the 1950s there was a race to discover new subatomic particles.

For the next future it is reasonable to expect some breakthroughs in at least four fields of science[33]: genetics, nuclear fusion, brain studies and physics (*parallel universes and the many-universe hypothesis*). However, the most important scientific transformation in the next wave might not be a particular breakthrough in any field of science; it may be the birth of a *new paradigm in science*-the convergence of different fields of science to explain *open complex systems,* i.e., to explain *society and economics.* As already foreseen by Marchetti[25]: "The concept of a learning society...hints at the possibility of a unified theory for genetic evolution, ecology, sociology, and economics". With the development of this *new scientific paradigm-a theory for complex bio-socio-economics,* futures studies will grow into a valid and working science.

Conclusion

At this point it is interesting to recall Isaac Asimov's trilogy *Foundation*[34]. This trilogy is a science fiction epic, set some millenia in the future, when humanity has spread throughout the galaxy. One of the heroes of this epic, a scientist and mathematician named Hari Seldon, has established the foundation of a new scientific theory, the *psicohistory,* which could allow a mathematical-statistical-historic analysis of the evolution of galactic events and in this way could forecast a possible future crisis, so that there can be adequate planning to overcome the crisis. Without doubt we are observing the embryo of such a theory. The utopia will become reality sometime in the future. Perhaps Asimov's vision was prophetic.

Two aspects of major innovations mean that the future of technology is still unforeseeable. G for great impact, U for unforesseable, E for enormous potential, S for synergistic. We need another S to complete the acronym GUESS. We can find the lacking S in another characteristic of basic innovations: they have a touch of *serendipity*. As Rosenberg observed[4]: "Inventions have very serendipitous life stories". A basic innovation, once established for one kind of application, normally has two kinds of consequences: first, new applications are found by users (or other inventors, scientists, engineers, etc.) and second, it sparks further innovations and investment across a wide frontier. The steam engine was first developed to pump water out of flooded mines and for a long time it was regarded as a pump. With successive improvements it became a feasible source of power for industry, and in the course of the early 19th century became a generalizable source of power for transportation. Computers were developed to speed up calculations and decryption. Today they are even displacing the old typewriters; who could have forecast this some forty years ago?

Another aspect appears in Macrae's comment[35] in 1972: "... we are already doubling our stock of knowledge in some of the most important sciences every ten years (and thus multiplying it by 16 every 40 years). An acceleration of this rate presumably means that far more than fifteen-sixteenths of what will be relevant in some of the most important sciences by 2012 will be knowledge that nobody has thought of yet". How to overcome this fact remains an open question.

The future possibilities of a given basic innovation are very *difficult* to forecast mainly because it is inherently *difficult* to identify all possible uses for this innovation. I can give here a very simple example: two of the references cited in this article are WWW homepages–who could have forecast this a decade ago? Perhaps we don't even need to look back as far as this.

While the new theory of complex bio-socio-economics is waiting for the birth of a Hari Seldon, the best we can do is, with creativity, insight and some measure of intuition, to build *future scenarios,* a common practice today among futurists and decision makers. Schwarz[36] recently wrote: "Scenarios are powerful planning tools precisely because the future is impredicable. Unlike traditional forecasting or market research, scenarios present alternative images instead of extrapolating current trends from the present. Scenarios also embrace qualitative perspectives and potential for sharp discontinuities that econometric models exclude".

The publication by Macrae already cited [35] is a good example of how, with insight and intuition, and good information, a very accurate future scenario about a new technology can be constructed. At the beginning of the 1970s he wrote: "... we are going to enter an age when any duffer sitting at a computer terminal in his laboratory or office or public library or home can delve through unimaginably increased mountains of information in mass-assembly data banks...". This has already become reality with the Internet today. Particularly interesting was his observation that "even before the end of this century telecommunications may become virtually costless, and should certainly be in no way dependent on distance for its price". This agrees with the vision of Arthur C. Clark[37], another greater builder of future scenarios of this century, who a few years ago wrote: "... with the historical abolition of long distance charges on 31 December 2000, every telephon call became a local one, and the human race greeted the new millienium by transforming itself into one huge, gossiping family".

The main thrust of this analysis is that the way is open to develop a more precise method of forecasting the impact of major innovations, and it lies in the modern trend of using chaos and complex systems theory to describe socio-economic phenomena[29,38,39] In order to find this method, we need to understand society as a *learning complex open system,* obeying the laws of nature like any other physical system in the universe. We just need to learn more about these laws underlying the behaviour of complex systems.

The actions of an individual are characterized by *chance*. The individual himself is the consequence of chance events-the casual encounter of his parents, the chance of conception, one among millions of possibilities. According to François Jacob[40], Nobel Prize -winner in 1968, even the existence of mankind is consequence of chance-if the Dinosaurs had not been exterminated by some cataclysmic event (perhaps a comet colliding with the Earth) or some chance mutation in the shell of their eggs-the appearance of man on this planet would not have been possible.

This is perhaps a very difficult thought (concept) for our common sense, which is normally very anthropocentric, to accept. Perhaps it is as difficult as thinking about infinity or eternity, two concepts familiar to physicists and mathematicians, who are also familiar with the concept of chance. The following issue arises: if da Vinci, Galileo, Leibniz, Newton, Marx, or Einstein are merely the products of chance, what would our world have been like if they had not been born? Perhaps the Mona Lisa would not now be admired in the Louvre, or the Russian Revolution would not have occurred in October 1917, but certainly the entire edifice of Mathematics, Physics and Politics would have the same structure that we now know.

What place then for free will? Perhaps none, if we look forward in a collective sense. There is apparently a weakness in the comparison between individuals in a crowd or in society and molecules in a gas. In the first case there is free will; each individual knows well where he is intending to go, or what he intends to do with his money. But on the other hand, it can be said that the end effect is the same: entropy grows inside the subsystems, work is produced, and energy dissipated.

Thus, *chance* governs individual behaviour, but not collective behaviour. In collective behavior there is a certain *ncecssity*. The *necessity* of following the laws of nature. Or to quote Marchetti[20]- "... decisionmakers-they are only the active tendrills of Big Brother, the *System*".

The balance between *chance and necessity*-this is the rule of thumb of the origin and evolution of the universe. And human society is just a very small part of an enslaving universe.

Notes and References

1.C. Cerf and V. Navasky, *The Experts Speak* (New York, Pantheon, 1984)

2.S. P. Schnaars, *Megamistakes* (New York, The Free Press, 1989)

3.L. Biondi and R. Galli, "Technological Trajectories", *Futures*, July/August 1992, pages 580-591.

4.N. Rosenberg, "Why Technology Forecasts Often Fail", *The Futurist*, July/August 1995, page 16-21.

5.F. Collopy, http://weatherhead. cwru/wbc/forecast/html-homepage from April 1994.

6.B. D. Steele, "An Economic Theory of Technological Products", *Technological Forecasting and Social Change* 48(3), 1995, pages 221-242.

7.J. Forrester, Innovation and Economic Change", *Futures* 13, 1981, pages 323-331.

8.G. Mensch, *Das Technologische Patt: Innovationnen Überwinden Die Depression* (Frankfurt, Umschau Verlag, 1975).

9.J. R. Bright, "The Manager and Technological Forecasting", in J. R. Bright, editor, *Technological Forecasting for Industry and Government* (New Jersey, Prentice-Hall, 1968).

10.T. C. Devezas, "Market Penetration Forecasting for Advanced Ceramics: A Tchnological Substitution Model", in P. Vicenzini, editor, *New Horizons for Materials*(Faenza, Techna, 1995), pages 779-786.

11.J. A. Schumpeter, *Business Cycles: A Theoretical, Historical And Statistical Analysis of the Capitalist Process* (New York, McGraw-Hill, 1939).

12.A. Tylecote, *The Long Wave in the World Economy* (London, Routledge, 1992).
13.B. J. L. Berry, *Long-wave Rhythms in Economic Development and Political Behavior* (Johns Hopkins University Press, Baltimore, 1991).
14.T. Modis, *Predictions-Society's Telltale Signature Reveals the Past and Forecasts the Future* (New York, Simon & Schuster, 1992).
15.A. Vasko, *The Long Wave Debate: Selected Papers* (Berlin, Springer Verlag, 1987).
16.R. Ayres, "Technological Transformations and Long Waves", *Technological Forecasting and Social Change* 37, 1990, Part I -pages 1-37, Part II-pages 111-137.
17.H. Bieshaar and A. Kleinknecht, "Kondratieff Long Waves in Aggregate Output ? An Econometric Test", *Konjunktur Politik,* 30. Jahrg. H.5, 1984, pages 279-303.
18.C. Freeman, *Long Waves: Selected Writings: 1913-1994* (Aldershot, Elgar Reference Collection, 1995).
19.R. R. Nelson and S. G. Winter, "In Search of a Useful Theory of Innovation", *Research Policy* 6(1), 1977, pages 36-76.
20.C. Marchetti, "Fifty Years Pulsation in Human Affairs: Analysis of Some Physical Indicators", *Futures* 17(3), 1986, pages 376-388.
21.C. Perez, "Structural Change and Assimilation of New Technologies in the Economic and Social Systems", *Futures*, October 1983, pages 357-375.
22.T. C. Devezas, "The New Technoeconomic Paradigm", *Papers de Prospectiva* 4, November 1995, pages 29-46.
23.G. Dosi, "Technological Paradigms and Technological Trajectories", *Research Policy* 11(3), 1982, pages 147-163.
24.This is a very exciting, provoking, and yet open question. I have found only two references suggesting that these cycles could be much more older than we think. The main obstacle to analysing this issue is the scarcity of trustful data. R. Metz in "Long Waves in English and German Economical Series from the Middle of the Sixteenth to the Middle of the Twentieth Century", published in R. Fremdling and P. K. O'Brien, editors, *Productivity in the Eco-*

nomics of Europe (Stuttgart, Klett-Cotta, 1983), by analysing price and production time series, has found some evidence of flutuations of typical Kondratiev or Kuznets cycles, in the time frame appearing in the title. C. Marchetti in "Kondratieff Revisitato: Dopo un Ciclo di Kondratieff", publised in *Rassegna della letteratura sui i cicli economici* (Roma, Instituto Nazionale per lo Studio della Congiuntura, 1989), and in a private communication, comments that some of his own investigations into the naval industry in England have shown cycles of approximately 55 years between 1480 and 1950.

25.C. Marchetti, "Society as a Learning System", *Technological Forecasting and Social Change* 18, 1980, pages 257-282.

26.H. Haken, *Erfolgsgeheimmisse der Natur-Synergetik. Die Lehre vom Zusammenwirken*, (Stuttgart, Deutsch Verlags-Anstalt,1981).

27.M. Eigen and R. Winker-Oswatisch, *Das Spiel* (Munich, Piper, 1975).

28.J. Gleick, *Chaos* (New York, Viking, 1988).

29.Special Issue, "Complexity: Fad or Future", *Futures* 26(6), July/August 1994, presenting 8 papers and two essays on this theme.

30.C. Farrel, "A Theory of Technological Progress", *Technological Forecasting and Social Change* 44, 1993, pages 161-178.

31."Evo-Economics-Biology meets the dismal science", *The Economist*, 25th December 1993-7th January 1994, pages 91-93.

32.K. B. De Greene has published several papers developing his theory. Some recent ones are: "Evolutionary Structure in the Informational Environmental Field of Large-Scale Human Systems", *Journal of Social and Evolutionary Systems* 16(2), 1993, pages 215-230; "Will there be a Fifth Kondratiev Cycle/Structure?, *Systems Research* 10(4), 1993, pages 41-55; "The Rocky Path to Complex-Systems Indicators", *Technological Forecasting and Social Change* 47, 1994, pages 171-188.

33.J. F. Coates, "A 50-Year Look Ahead", *Technological Forecasting and Social Change* 48, 1995, pages 103-105.

34.I. Asimov, *The Foundation* (New York, Avon Books, 1964)

35.N. Macrae, "The Next Forty Years-A Reprise", *Futures* 26(4), 1994, pages 382-390. This paper is a republication of the introductory pages to Macrae's book *The Next Forty Years* published by The Economist in 1972.

36. P. Schwarz, http://www.gbn.org/Main/usingsp.html-homepage from August 1994.
37. Arthur C. Clark, *2061-Odyssey Three* (London, Grafton, 1988)
38. H. R. Priesmeyer, "Logistic Regression: A Method for Describing, Interpreting, and Forecasting Social Phenomenon with Nonlinear Equations", paper presented at *The Chaos and Society Workshop*, Universitê du Quebec a Hull, Hull, Quebec, June 1994.
39. H. R. Priesmeyer, *Organizations and Chaos: Defining the Methods of Nonlinear Management* (Westport, CT, Quorum Books, 1992).
40. This was a statement by François Jacob in an interview in Rio de Janeiro given to the Brasilian periodical Veja, published 1st March 1995.