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INNOVATION: A VIGOROUS RIVER WITH HIGH BANKS

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PREFACE

The Core Concepts Project of the System and Decision Sciences Program is concerned with the development of new ideas and concepts to extend and enhance traditional methods of systems analysis. This work includes studies of the role of cultural and social factors in the perception of problems and the influence such factors exert on possible means of solution.

In this paper, prepared for the Beijing International Conference on Science and Technology Policy and Research Management, Dr. Cesare Marchetti explains that economics is basically an expression of culture rather than a mere assembly of money, managers, and machines, and argues that economic decisions should always be weighted and selected in a cultural context if they are to have a lasting and constructive effect. He shows that the introduction of new technologies in the western world seems to demonstrate the same behavior as a biological species filling an ecological niche, and that this leads to long waves, or cycles, of innovation. Finally, he considers the implications of these results for technology development in China.

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INNOVATION: A VIGOROUS RIVER WITH HIGH BANKS

THE PAST SHOULD SERVE THE PRESENT
Mao Tse Tung

INTRODUCTION

A large river can be perceived as a great flow of potential energy that expresses itself in a geographical and topographical context. Geography in fact determines the course of the river. The drive for evolution and progress is again a great flow of social energy, and my studies of invention and innovation processes in Western countries during the last three centuries [1] show the existence of very strong boundary constraints of social origin. They appear to determine the course of the process itself.

Constraints tend to be resented by the arrogant decision maker, as they appear to limit his freedom, but they are highly appreciated by the wise one, as they help exclude barren pathways. Science can be seen as a search for constraints. A physical law is a painful reminder of the infinite things that cannot be done. But the few that can showed the way to land a man on the moon. The core of my results is that economy is basically a cultural expression much more than an assembly of money, managers and machines. Consequently economic decisions have to be always weighted and selected in a cultural context, if they have to have a lasting and constructive effect. I must

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say, my explorations were done inside Western countries only, but the basic homogeneity of the human race and the breakneck consequences of anticultural initiatives, like the westernization of Persia, let me expect that the statement has a general value.

Culture is a very complex thing. One may define it as a tested formula for survival. It does not lie only in the books of the mandarins, but in the head of the people, in the language, in the objects, in the manipulated landscape. Searching for compatibilities appears very much as a democratic and poetic soul-searching.

THE WESTERN CASE HISTORY

The immense success of Western countries in dominating technology, which in a thousand years brought them from obscure populaces nested in the crumbles and remains of the classical Roman Empire to world absolute power, is an object of great interested and learned investigations. The why's are always difficult and fleeting, but the cultural context is inescapable if we see that many decisive inventions were brought in as seeds from other areas, the Chinese one in particular, but only in the West came to a vigorous bloom.

I will quote three of them: the gun powder, the spinning wheel, and the paper, to illustrate my line of thought. The first is well-known and publicized. The potential of a technique for the "instant production of high pressure gases" was deployed in the direction of the visual arts in China, and in a most sophisticated and dreadful military panoplia in the West.

The spinning wheel was a machine for fast spinning, which appeared in China around the year 1000 [2]. It removed an essential bottleneck in the production of textiles and, in the West where it spread a couple of centuries later, generated a boom in the use of vegetable fibers, basically flax. And also a boom in rags production, the raw material for paper, the Chinese paper.

Cheap material to write on soon overflowed writing capacity of the time, and another Eastern idea cam to bail out, the printing pad of Tibetan-Chinese origin. Because Western languages were modularized with letters, the astute Gutenberg made the pads in the shape of the modules. Cheap books meant information went from the Mandarins to the people, a democratic process that eventually put the basis for Western democracy.

Seen in retrospect, the book and the gun--central tools of Western dominance--come from Chinese seeds in European soil. The most synthetic reasons for that I found in the explorations of Lynn White in medieval history. They are almost theological, as they must be. The belief of man as the master of nature, of Judeo-christican origin. It liberates aggressivity and it may lead to self-destruction if wise feedbacks are not put to work. The belief of open time, from third century Christian theology, making history providential and progressive, liberating energy and sense of purpose. The belief of value in manual work, of Judean origin, which made our mandarins interested in machines simulating their handwork, they in depth disliked. Working monks were essential during Lower Middle Age in Europe, in inventing and spreading mechanical contrivances.

Now is time open in the Chinese Weltanschauung, is man the master or the guest of nature, was manual work holy for the learned? If not, meshing of Western science and technology to the Chinese way of life may lead to dangerous stresses unless the appropriate neasures are taken. What the appropriate measures are, however, has to be found out,

On the other side, sitting in the Empire of the center, and developing only the weapons for its defence, may prove shortsighted in the long run, as it did for the Moslem Empire when--by decision of its ruling elite around the year 1000--the door of inquire, the Ijtihad, was closed in, and innovations were de facto forbidden in the empire, except for imitating new technology in weaponry.

At the same time, mechanical clocks were brought into the churches of competing Christianity, as symbols of the divine regularity of the world, and sacredness of the machine [3].

The great start of Western technology I drew with seven brush strokes, in imitation of the Chinese great masters who could depict a horse as true as living. I hope my image is living enough to wisper suggestions. The great blossom of the last three centuries with the immense amount of information available, calls however for a more finely graded picture [1].

The general idea that will help organize the mainlines of the process is very simple: the operation of our society can be decomposed into the competition of substructures, described by Darwinian mathematics, i.e. the Volterra-Lotka equations. So their simplest solution, the logistic equation, is the simplest descriptor of human affairs, as it is for the biological ones.

The idea is obviously of heuristic character, but it works powerfully any time it has been properly applied. In the case of the introduction of new technologies in the Western world, I mean of basic innovations, all worked as if a societal need for innovation opened up, and innovations were created to fill it. The set of innovations in each wave did grow as if it were a biological species filling an ecological niche. This means the cumulative number of innovations grew in time following a logistic path. Because the total number in the set, the saturation level of the logistic, can be calculated at intermediate times from the dynamics of growth, it appears that the final number of innovations was a priori determined. It did not happen by luck and fight alone, as the protestant ethics suppose, although perhaps luck and fight was essential for getting the entrance ticket.

That the waves have a so precise time description is for me a good test of societal intervention and control in the affairs of entrepreneurs. The same is true for R&D as inventors, at least the successful ones, also produce in waves, with the same mathematics, if with different parameters. The story is condensed in Fig.1, where the first six strokes quantify invention and innovation in Western countries during the last three hundred years. I did beat the great masters by one stroke!

The waves follow each other with such regularity that it is possible to assess with precision the shape of the following ones, at least the first one. We are in fact living in the birth pangs of a new wave of innovation represented by line No.8. The inventions feeding it, described by line No. 7 tell a little sad story for R&D people, that the real breakthroughs for this round are basically done already. The wise policy then is to funnel R&D potential into streamlining what already exists, better than taking chances (very few are still left really) in blank territories.

In the Sacred Book, the Bible, God said to man: grow and multiply till you fill the Earth. This is nothing new. In the last three billion years, all living species always tried just that. It is a quintessential tenet of life. This is reflected in Volterra-Lotka model, where however the Earth is more realistically substituted by the Niche. Once a technology has taken its start, as described by the even number lines of Fig.1, then it has to conquer the world. The process can be followed by counting the relative objects at any time, e.g. if the innovation is the car, the number of cars on the road. Fig.2 gives the result of the analysis for Italy, in linear form, to show in a convincing way the precision of the fit to the logistic of population growth.

I wish now to introduce an important concept, the time constant of a growth process, defined as the time to go from 10% to 90% (or from 1% to 50%) of the saturation point (the size of the niche) in Fig.2. This time constant is not arbitrary and I doubt it can be manipulated. It represents the characteristic response of the system involved. In the case of Fig.2, the Italian society face of the automobile [4].

Using the coordinates of Fig.1, penetration of cars in eight different countries is reported in Fig.3. We see there a curious fact: countries where wholesale introduction of car came later, e.g. Japan, enjoy a shorter time constant. The search for a regularity between the starting years for massive car penetration and time constant was successful as shown in Fig.4. This relationship hints to an implicit "world order" in the deployment of technologies. The same analysis made for steel production in the dominant countries, Fig.5 and 5bis, shows finally a similar relationship, although vastly different time scales (Fig.6).

The distance between the centerpoints of the innovation waves is 54 years, a period of time which seems to play a great role in modulating the activity of Western societies. Most innovations are once-through. They appear and grow during one cycle and then are abandoned or slowly die out. An interesting example is that of railways. They appeared in Cycle II. The starting dates of railway nets the world over are organized in Fig.7. They are practically all contained in a period of 50 years. Each net developed logistically with a time constant of 50 years. No net was started anywhere after this wave, i.e. after 1900.

Ohter innovations show new bursts of implementation at each wave. Typical is underground transportation for world cities. The cumulative starting dates are organized in Fig.8. The centerpoints of the waves are spaced about 54 years. Because these dates organize quite well along a logistic, it is possible to fit it and calculate the saturation point. In other words to predict how many cities will start an underground and when. This high selfconsistency of world activity also points out at some kind of unwritten world order. A question I am pondering and for which I still have no convincing answer, is whether cars belong to the once-through category, like railway nets, or whether they will keep blossoming each cycle, like undergrounds. The answer would obviously be of greatest importance for planners in developing countries.

I am ending my presentation commenting on the title: A river between high banks. Children and young enthusiasts want to try everything. As the mutation-selection processes in biological systems show, this is a very fruitful if extremely expensive procedure. Old people and pessimists do not want to try anything. They assume everything has been tested and nothing new can be found under the sun. The vigorous and responsible follow a middle course, where the most efficient pathway is identified on account of the boundary conditions. Physical laws are obviously limitations, but the leaps of the tiger subtly exploits them. I only prepare maps for the generals to exploit.

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INVENTION AND INNOVATION WAVES – THE SECULAR SET

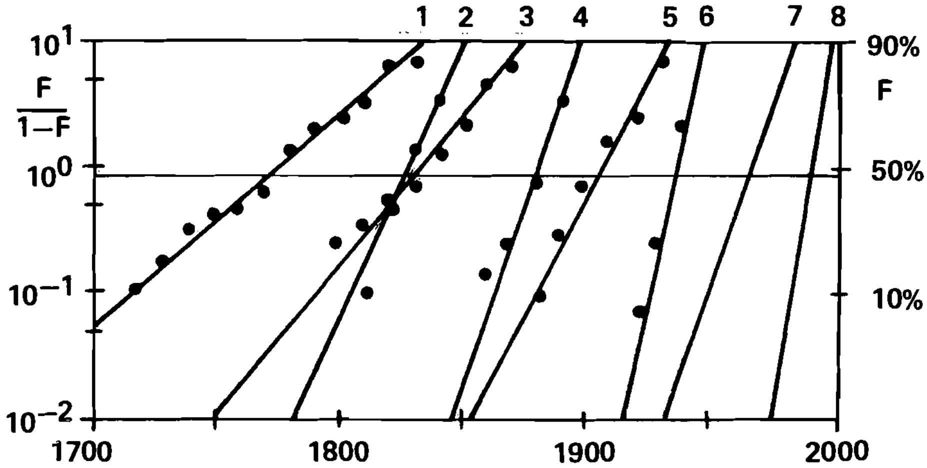

Figure 1.

The lines in this figure condense the basic invention and innovation process in the Western world during the last three centuries. They come in waves. The cumulative number of innovations or inventions is expressed in time as the fraction of the total number in the wave. This fraction is F. In the graph y = log(F/1-F). The reason for choosing this kind of ordinates is because the logistic functions expressing F are represented by straight lines. Invention lines are marked with odd numbers and innovations lines with even numbers. Up to number 6 they represent actual data. The rest are calculated from the regularities of the succession. Number 7 and 8 represent the invention-innovation process linked to the recession in which we are living now.

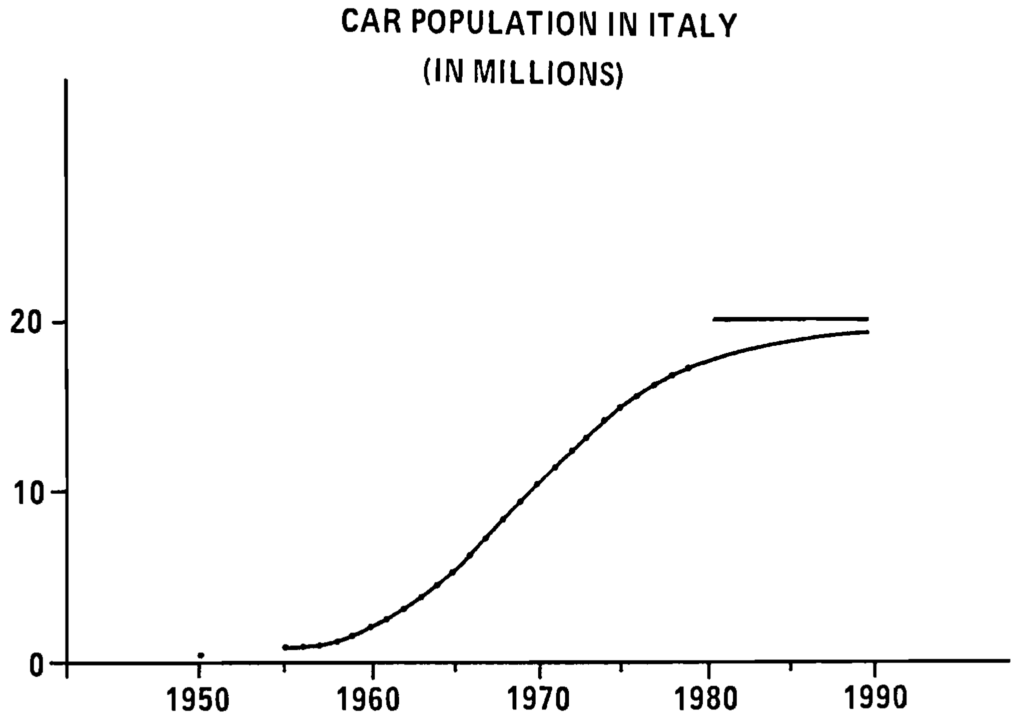

Figure 2.

Car population, i.e. registered cars for Italy are reported here in millions. The points are actual statistical data, and the fitting curve is a logistic. The saturation point, here about 20 millions, can be calculated from the data, without any supplementary knowledge of the system.

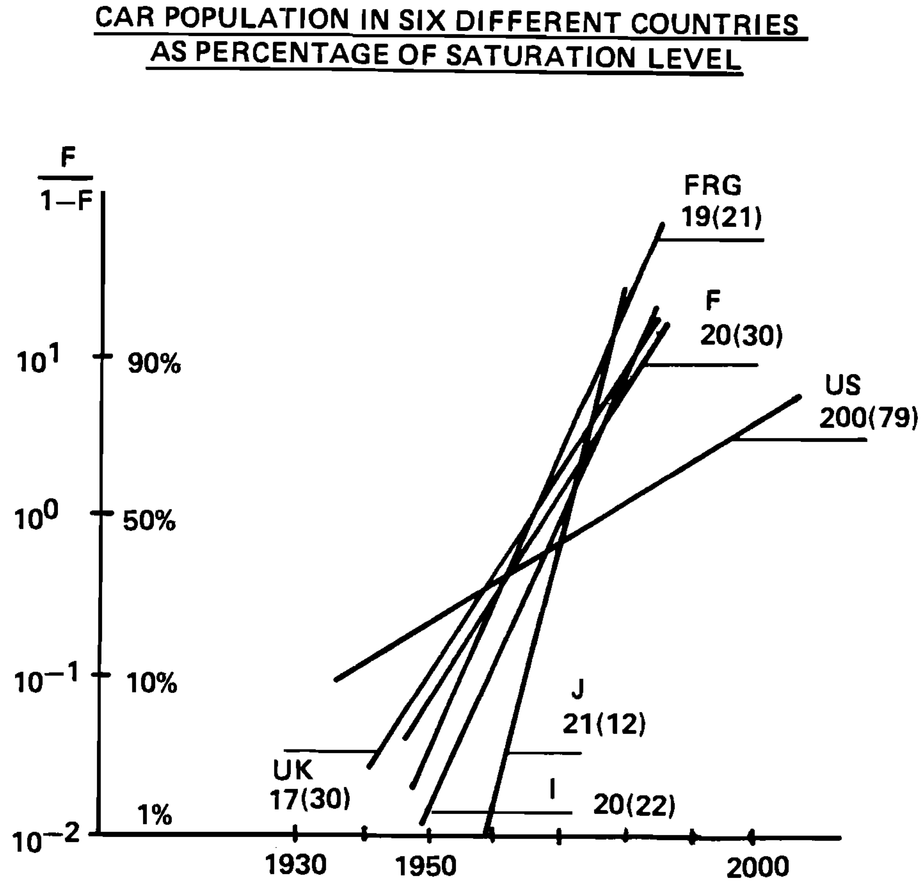

Figure 3.

Car population in a country can be expressed as a fraction F of the saturation level, calculated as in Fig.2, and presented with the same ordinates as in Fig.1. If penetration is logistic, then it appears as a straight line. The car international symbols indicate the country, the first number next to it the saturation level in millions, the number in brackets the time constant. This constant represents the dynamics of the penetration process and it measures the time to go from 1% to 50% of saturation, or from 10% to 90%. Because of some irregularities at the beginning, the second definition is preferable.

RELATION BETWEEN ΔT AND TIME WHEN CAR POPULATION WAS 1% OF SATURATION

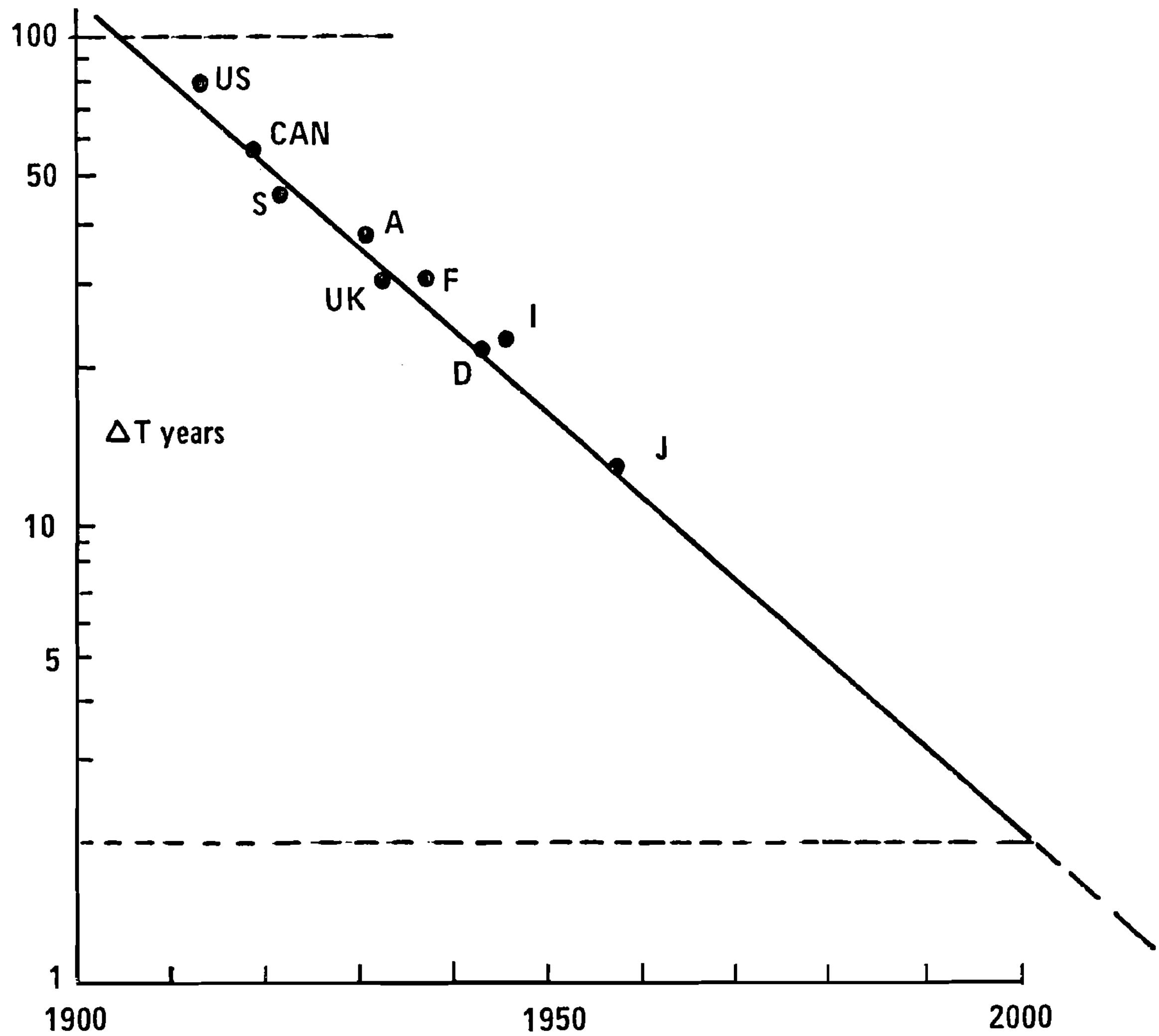

Figure 4.

As it can be seen from Fig.3, latecomers have steeper penetration, i.e. shorter time constants. The link between the starting date (1% market penetration) for the massive penetration of car and the time constant is reported here. The fact that the relationship leads to absurdly short penetration times in the future probably means that the function is valid only inside one 54-year economic cycle.

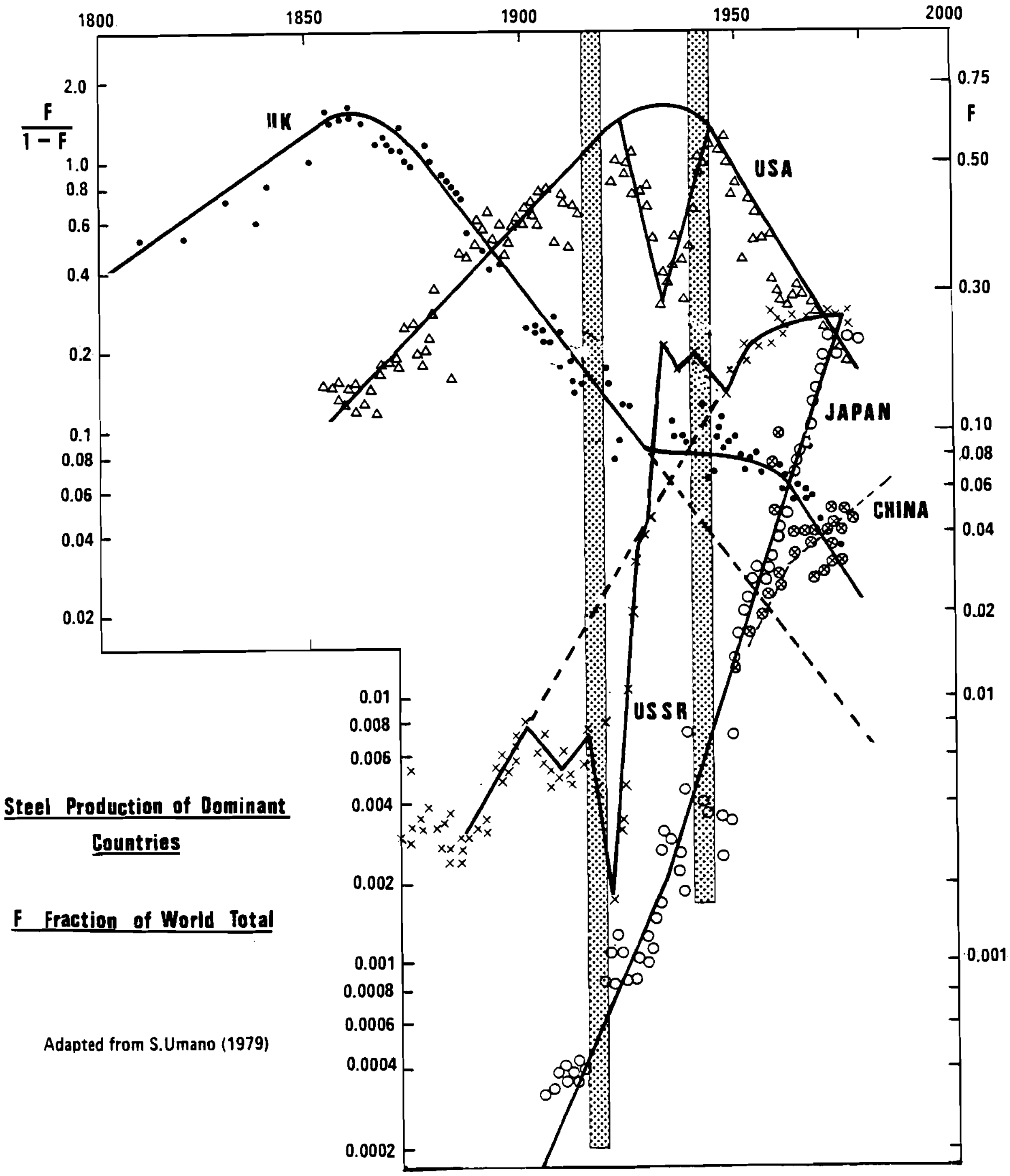

Figure 5.

The fraction of world steel output produced by the dominant countries during the last two centuries is reported here. The two grey bars represent World War I and World War II. Remarkable is the long-term stability of the substitution. The particular case of the Soviet Union is striking, where the communist revolution brought in a powerful disturbance, which was however reabsorbed in about 50 years. Steel production in Soviet Union after World War II picks up again a trend established during Czarist times.
Also remarkable is the fact that Japanese dominance had already set in towards the end of the last century, and it is not a consequence of post-war recovery. The situation for China is confuse and no clear pattern appears yet from the data.

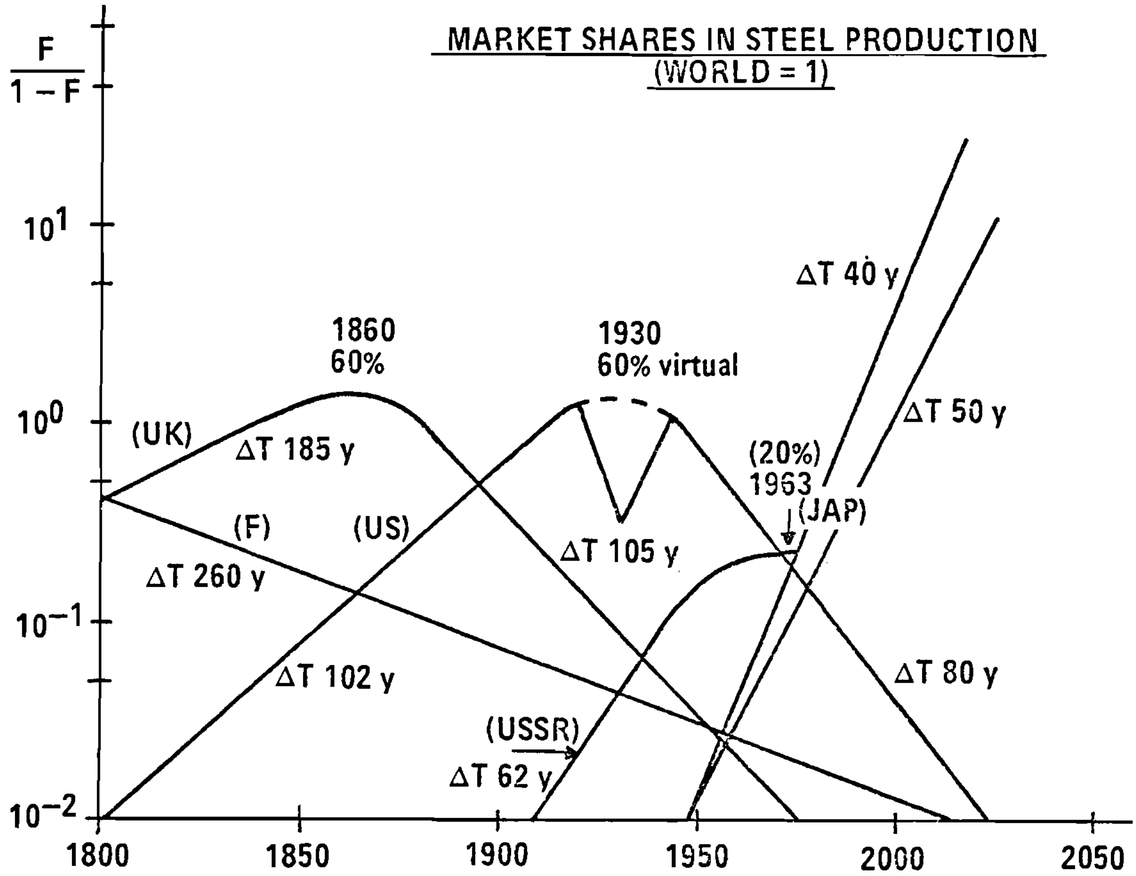

Figure 5bis.

This graph reproduces in simplified form that of Fig.5, with the addition of France. Here the quantitative characteristics of the substitutions are reported. The time constants are given in years, both for the upward and the downward branches. Also in the case of steel, it is apparent that these time constants become shorter and shorter with time.

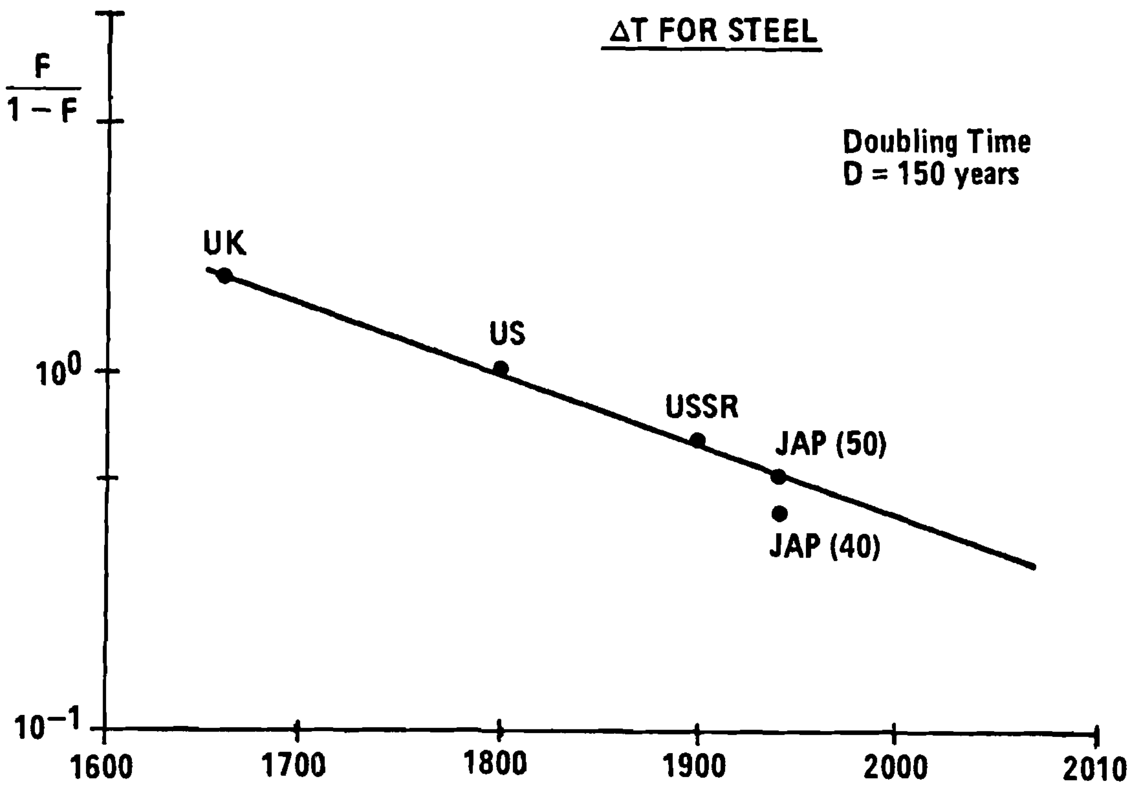

Figure 6.

This graph organizes phase-in penetration times of steel production of Fig.5bis in analogy with penetration times of cars in Fig.4. The result is similar, although time constants are very different. Incidentally this relationship permits to choose between possible fits of otherwise much scattered data for the Japanese steel industry.

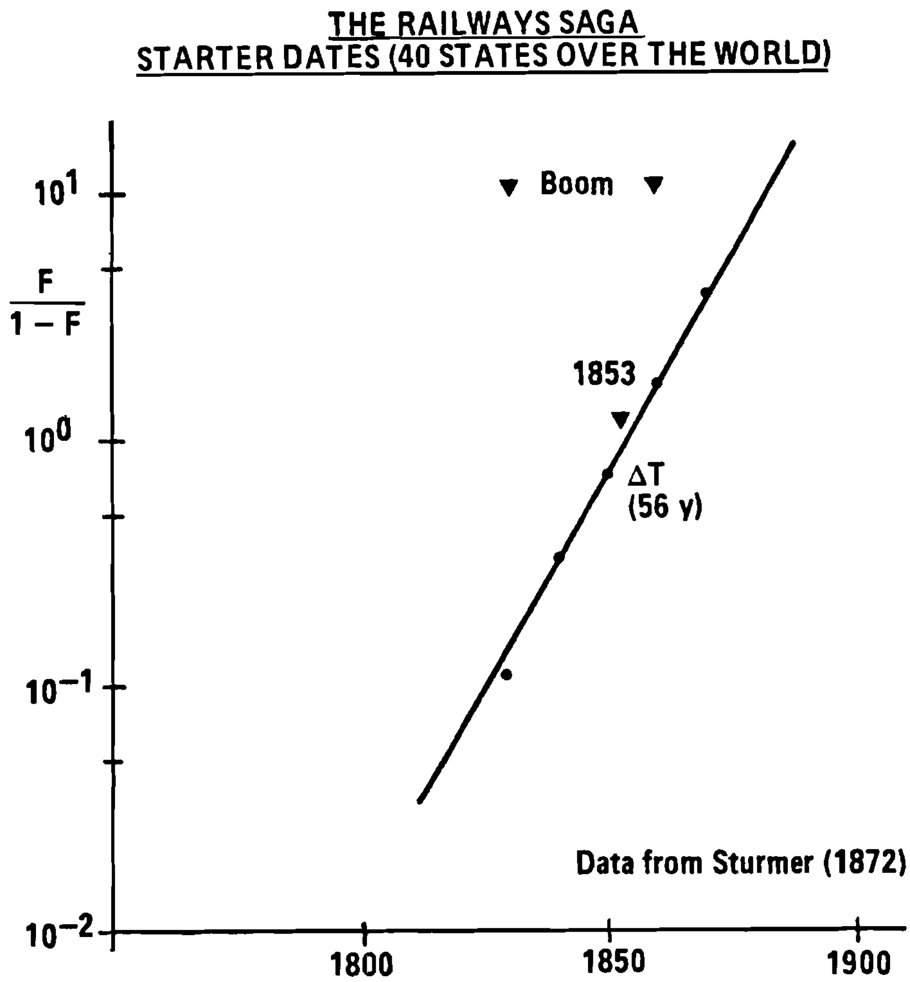

Figure 7.

The cumulative number of starting dates for railway nets all over the world are organized in this graph. The coordinates are as in Fig.1. Practically all world railway nets (about 40) were started during this 50 year swing, and none after that. The development of a net after start was usually logistic again, with a time constant of about 50 years.

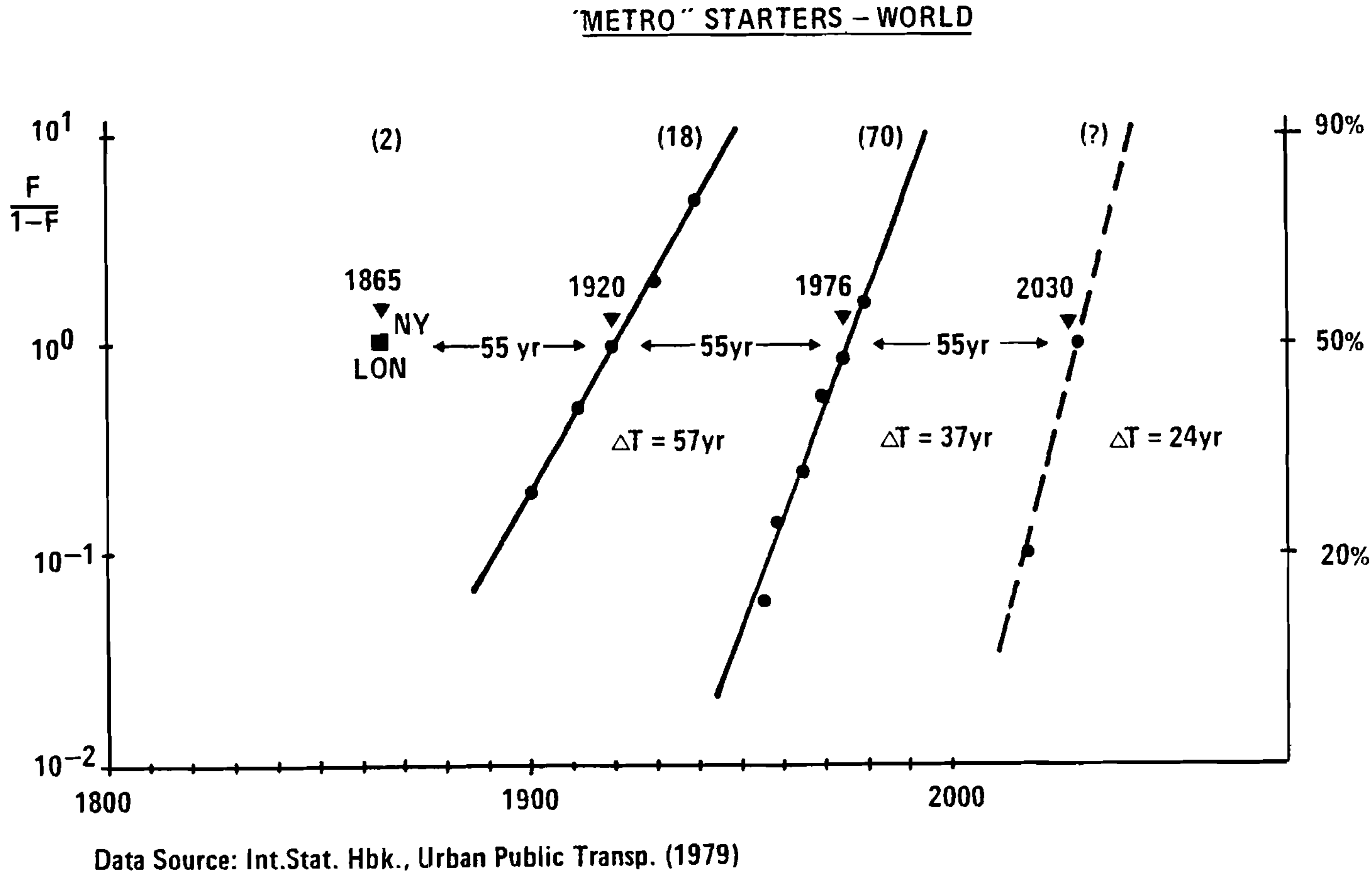

Figure 8.

Starting dates for underground metro transportation. In this case waves of construction follow each other with a spacing of about 54 years, the main economic cycle in Western countries. The shortening of the time constants simply means starting dates are progressively bunched around the central dates in narrower and narrower peaks. The dashed line is calculated. The 1976 lines suggest many new undergrounds will be launched during recession.