THE AUTOMOBILE IN A SYSTEM CONTEXT: THE PAST 80 YEARS AND THE NEXT 20 YEARS

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PREFACE

Twenty-odd years ago the French anthropologist Lévi-Strauss revolutionized our understanding of myths by reversing the arrow of their creation. Far from myths being the conscious creations of men, he suggested that they operated largely through a discoverable logic of their own. "Myths", he said, "think themselves out in men". In this provocative paper Marchetti attempts something not too dissimilar for some of those humanly mediated processes that we are accustomed to calling "the economy".

This paper is one product of the Core Concepts Project (COR) within the System and Decision Sciences area (SDS) at IIASA. Applied systems analysis is an historical process that is continually bringing new concepts to the surface and sucking old ones down into oblivion. The Core Concepts Project is particularly concerned with this process and tries to identify, explore and clarify those newly emerging concepts and the shifts in research direction that they entail.

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CESARE MARCHETTI

ABSTRACT

The diffusion of automobiles in nine countries is seen in terms of the Volterra equations developed for ecological systems. Three parameter logistic equations fit the evolution of the car population perfectly. The behavior suggests a quasi-biological, internally generated determinism that belies the significance of engineering, economics, marketing, and media as diffusion stimuli. Their role is seen to be more a response to, than an initiator of, change. Once diffusion is complete, their significance increases, however. Car safety appears to be controlled by societal "set points."

This study was originally started in order to try to evaluate the effect of innovation and promotional efforts on the acceptance and market dynamics of cars. It somehow expanded beyond the original task, and came to show some unexpected and counter-intuitive aspects of the car system, in particular, a very high level of determinism, most probably due to strong and efficient social feedback loops. I will usually refer to them when speaking of homeostasis, a term borrowed from physiology.

Much of my analysis in fact is borrowed from biological thinking and methodology, as I am fairly convinced that the equations Volterra developed for ecological systems are very good descriptors of human affairs.

In a nutshell, I suppose that the social system can be reduced to structures that compete in a Darwinian way, their flow and ebb being described by the Volterra equations, the simplest solution of which is a logistic.

Filling the Niche

I examined the evolution of the car population, i.e., the number of cars on the road, in nine different countries. Because the population of a new species fills its eco-niche following a logistic trajectory, I tried to fit the evolution in time of the car stock in the nine countries using three parameter logistic equations. Of these parameters, the first localizes the process in time, the second gives the rate of the process, and the third the saturation point, or the capacity of the niche. The result is given in Figures 1–9.

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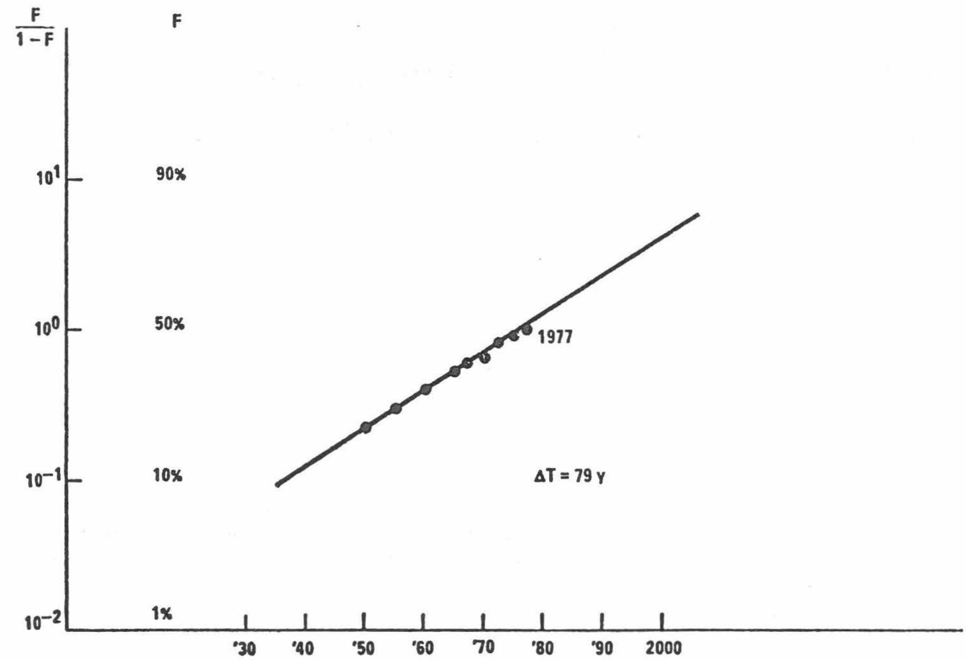

Fig. 1. Car registration in the United States—saturation: 200 million. Cars registered in the United States are reported as fractions *F* of the "perceived" maximum (200 millions). The perceived maximum is calculated best fitting the data with a three parameter logistic. I actually did it by trial and error and by hand, using the above transform. The flex, or the 50% penetration point is indicated with a date, and ΔT represents the time constant, or the time to go from 10% to 90%.

To facilitate reading of the curve, fractions *F* are reported for the levels indicated.

Perceived maximum can be considered as the size of the eco-niche for the car species. If other modes compete, the niche may never be filled, as multiple competition between primary energies clearly shows. It can also be "overshot," the approach to the asymptomatic level becoming then oscillatory.

As can be seen, the fitting to logistics is perfect, so that the third parameter—the saturation point, i.e., the total size of the market—can be calculated with fair precision. The values for each nation are reported in the legend in each of the figures, together with the time constants and central point dates that serve to characterize the logistic.

It is well known that fitting three parameter logistics is a slightly fishy process because the trajectory of the function is fairly insensitive to the position of the maximum, at least up to the inflection point. Consequently, the slight differences in twist are easily masked by the noise in the data.

Contrary to expectation, the data are exceptionally free of noise, as one can verify by inspecting Figure 10, reporting car population for Italy on a linear scale. Furthermore, I interpolated by eye on the transforms, where logistics appear as straight lines and where the eye is more sophisticated in my opinion than most computer programs. The most important point, however, is the fact that—as shown in Figure 13—there is a further link between the various logistics, which eliminates large errors through a check of internal consistency.

Therefore, most of the conclusions I will draw are not finely sensitive to the level of saturation, so that bickering about one million cars more or less in that level makes really

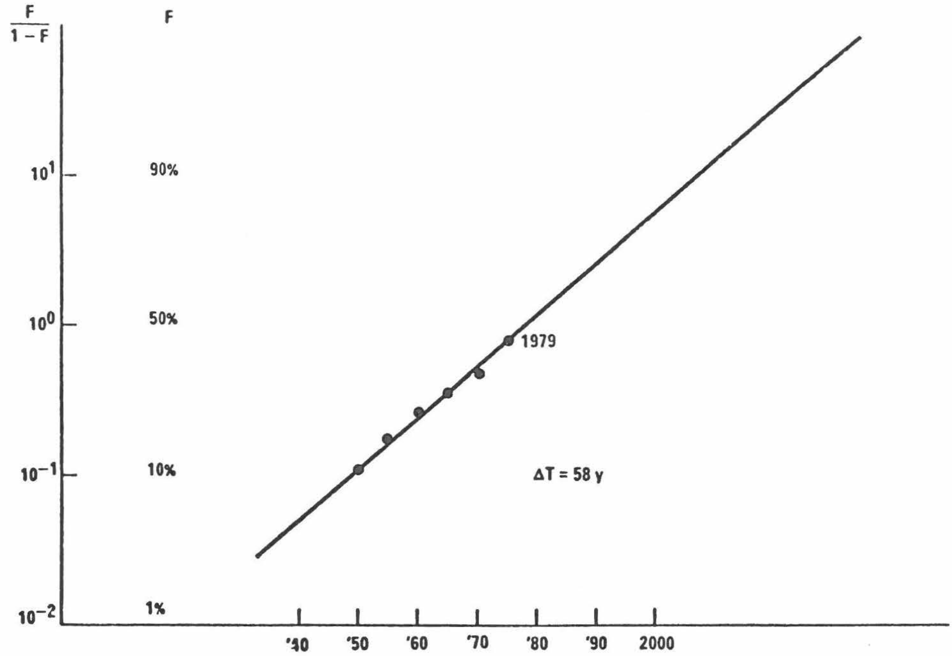

Fig. 2. Car registration in Canada—saturation: 20 million. (For an explanation see Figure 1.)

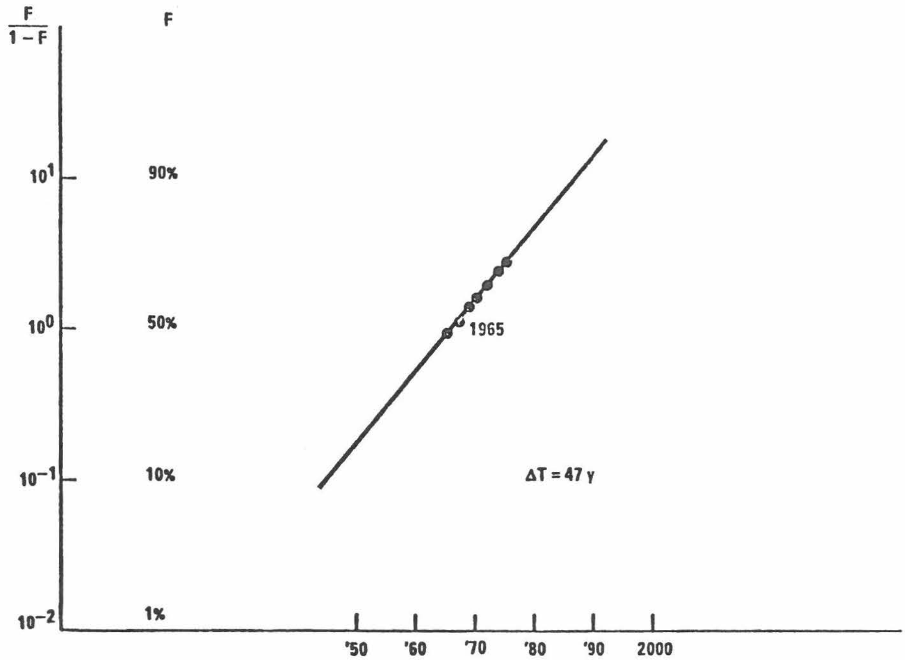

Fig. 3. Car registration in Sweden—saturation: 4 million. (For an explanation see Figure 1.)

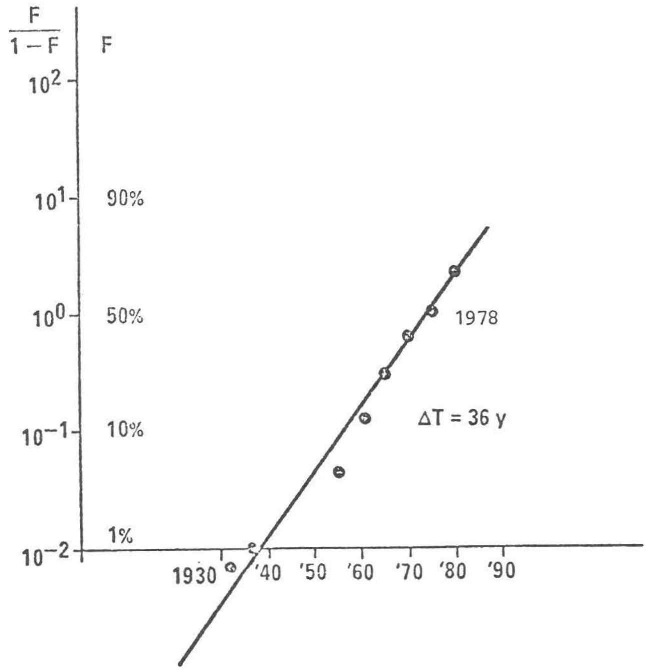

Fig. 4. Car registration in Austria—saturation: 3.2 million. (For an explanation see Figure 1.)

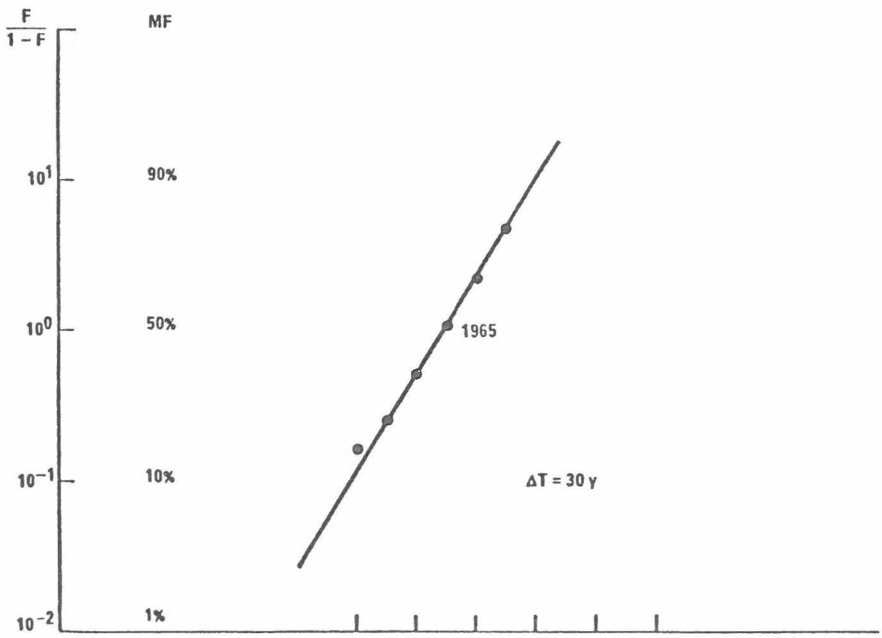

Fig. 5. Car registration in the United Kingdom—saturation: 17 million. (For an explanation see Figure 1.)

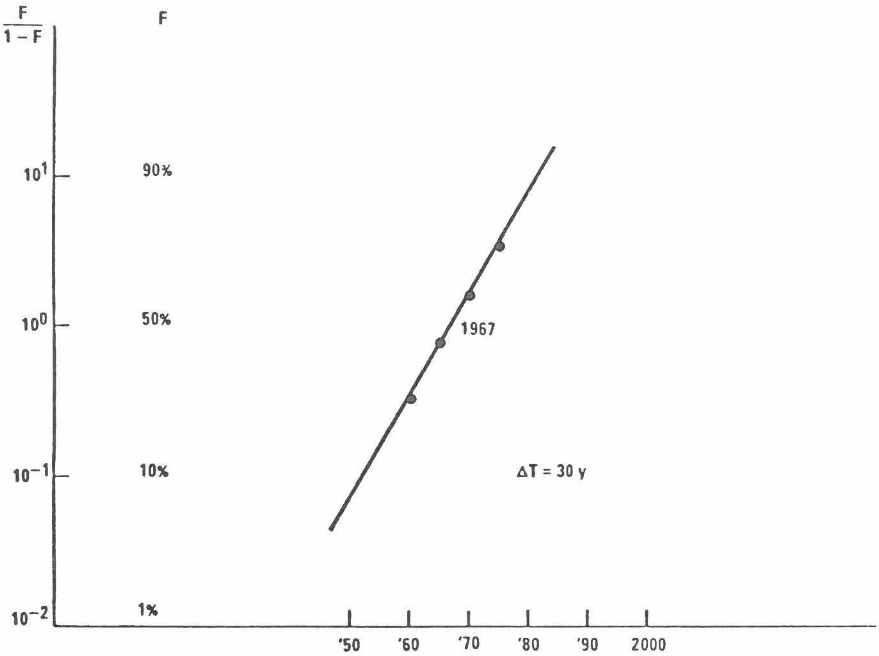

Fig. 6. Car registration in France—saturation: 20 million. (For an explanation see Figure 1.)

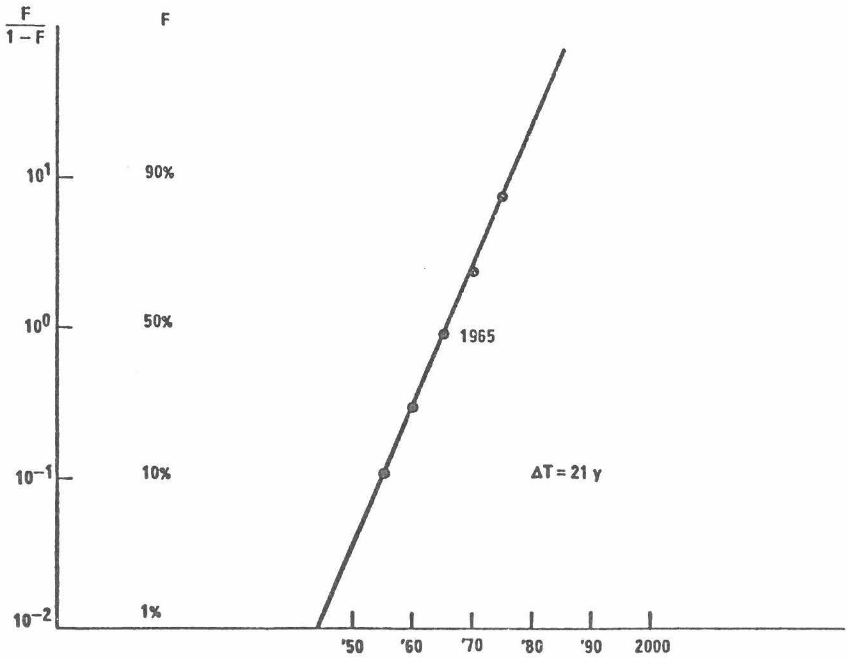

Fig. 7. Car registration in the Federal Republic of Germany—saturation: 19 million. (For an explanation see Figure 1.)

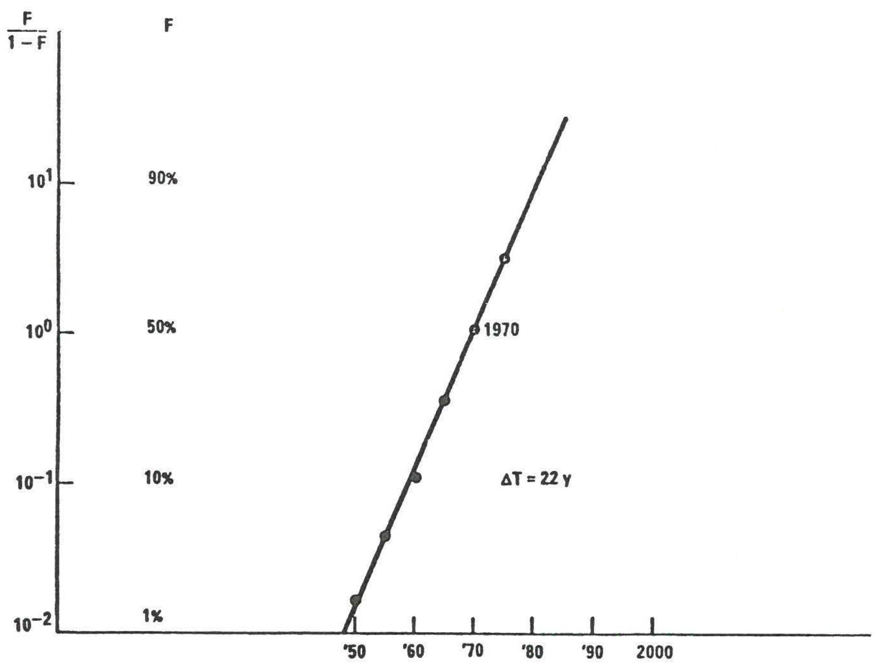

Fig. 8. Car registration in Italy—saturation: 20 million. (For an explanation see Figure 1.)

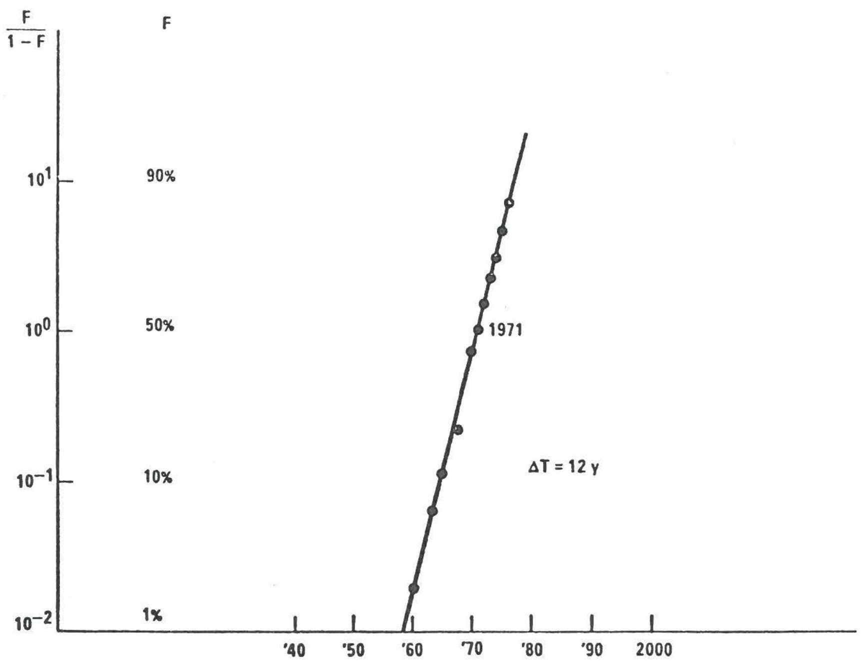

Fig. 9. Car registration in Japan— saturation: 21 million. (For an explanation see Figure 1.)

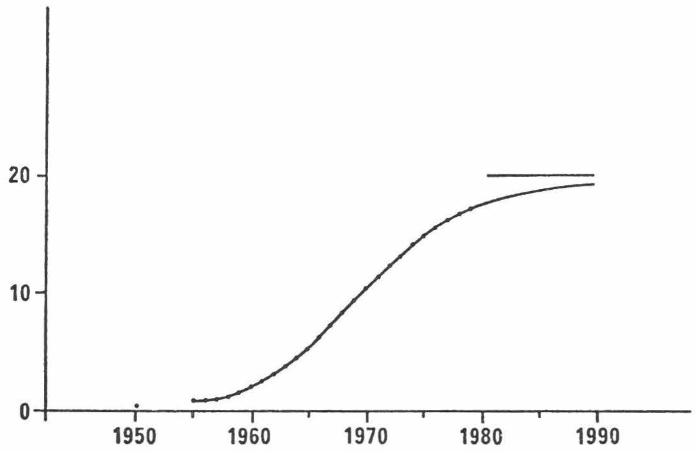

Fig. 10. Car population in Italy (in millions). To show the extremely low level of noise, data for the Italian car population are reported in linear terms.

no sense. One thing I cannot answer, however, is if, in analogy with the biological case, a subtle and progressive matching to the eco-niche does not progressively enlarge its size, in other words, whether the saturation level has a secular drift.

Shunning the Media

The first comment on Figures 1–9 could be that the effect of launching new models, introducing new tricks, and slashing prices, is of no consequence in the determination of owning a car, which seems to follow a perfect path, controlled perhaps by the usage values of the car that are not influenced greatly by a new shape or new bumpers.

The fact that the consumer may be indifferent to marketing ventures is hard to swallow. But there is a path out of the stalemate, if we think that there is a pool of good ideas in manufacturing, product design, and advertising that are dormant and are picked up and used when (and only when!) there is the menace of falling behind the perceived path. This is more or less what happens in biological systems where mutants are usually kept in a recessive state till the change in environment draws them into the limelight.

In this rationalization, innovation and brain softening throughout the media, usually seen as basically aggressive operations, acquire the much softer connotation of purely defensive acts. In other words, innovation and promotion are basically seen as homeostatic processes in the same sense that sweating and shivering protect our body temperature from changes in the boundary conditions. The fact that this temperature keeps its set point does not mean that sweating and shivering are unimportant.

A typical reaction, when I presented these results, was that if car ownership is a pre-set goal, companies certainly compete to get larger shares of this market, using *inter alia* innovation and promotion as aggressive weapons. To see the dynamics of this struggle, I plotted market shares for the *dominant* companies in the United States and Japan. As Figures 11 and 12 show, these shares keep fluctuating but remain basically constant in the long run. As the Red Queen said to Alice, "Now *here* you see, it takes all the running *you* can do to keep in the same place." Actually there is some life at the lower levels and smaller companies come and go. Much of the penetration of Japanese cars in the United

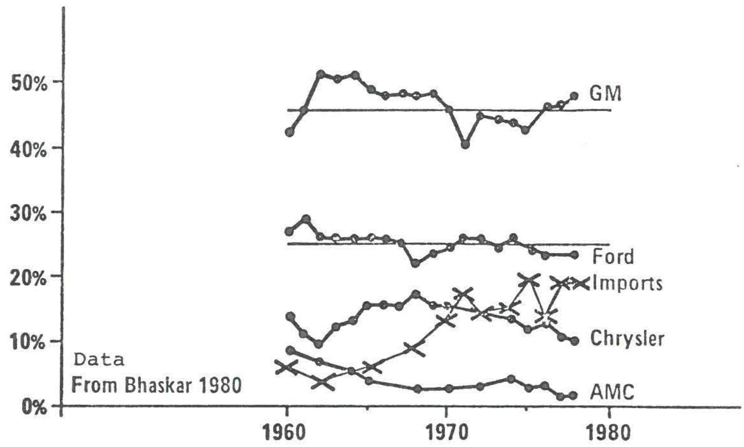

Fig. 11. Cars: United States market shares (volume). Analysis of market share of major firms shows a great stability in time. Innovation and promotion do not seem to provide an edge, but they are probably part of the elbowing mechanisms.

States, for example, can be seen as a replacement for market losses by Chrysler, American Motors, and other smaller companies.

Last Come, First Served

Figures 1 to 10 have been ordered according to the time when car penetration reached 1% of the final saturation level. It is clear that the penetration rate, expressed by the time constant ΔT, i.e., the time to go from 1%–50% penetration, or from 10%–90%, (which may be more appealing because it deals with riper structures), keeps decreasing. Dr. Ed Schmidt [8] suggested plotting ΔT vs the 1% penetration rate, and obtained Figure 13. Not only does ΔT keep decreasing, but it does so in a very regular way.

I have no hint to explain the decrease nor the regularity. It seems, however, that the process should stop. If not, absurdly short penetration time will be reached in the near

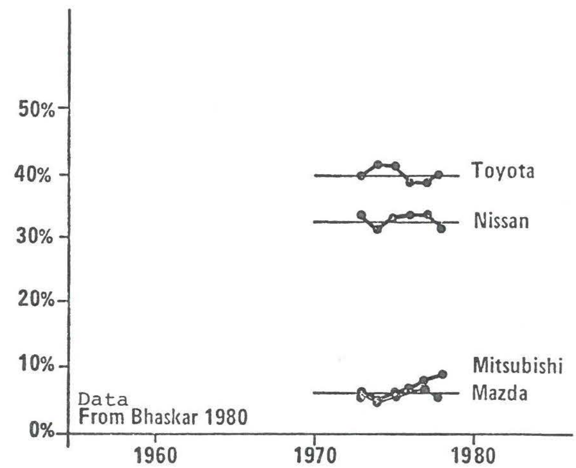

Fig. 12. Cars: Japan's inland market shares (volume). (For an explanation see Figure 11.)

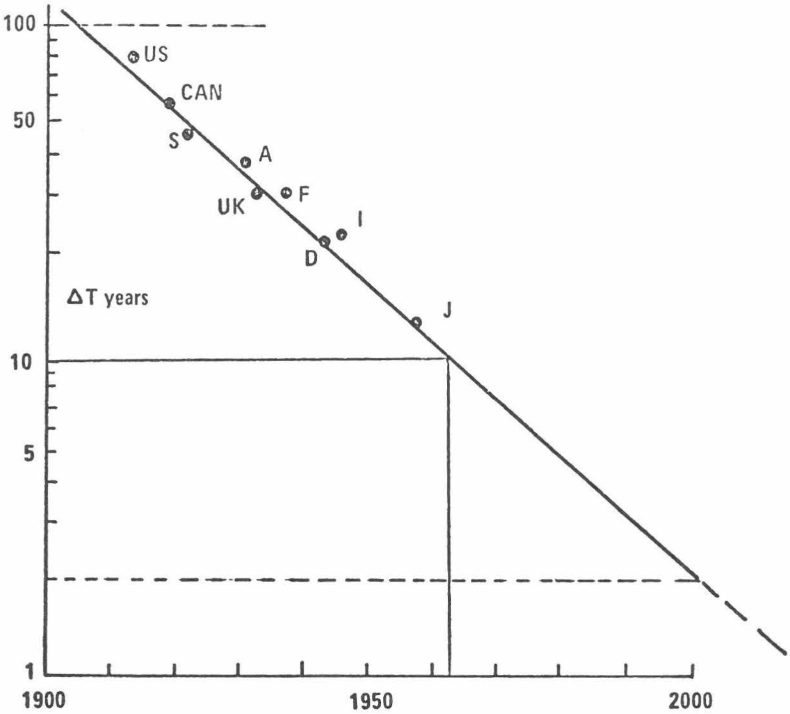

Fig. 13. Relation between ΔT and time when the car population was 1% of saturation. The time constant of car penetration in various countries is here reported vs. the date when the car population reached 1% of saturation level, which is considered as the starting point of massive penetration. The precise time trend $\log T = at + b$ appears to be well matched. No explanation is available.

future. Japan has already the extraordinarily short ΔT of 12 years, and I cannot really imagine what the 2 years ΔT in the year 2000 could really mean. Can a country be motorized to saturation in four years? Improbable. Perhaps, as in the case of inventions and innovations [1] the function is a see-saw one.

A further comment on Figures 1 and 2: Contrary to current intuition, the United States and Canada appear far away from saturation, and more or less in a similar position in the penetration curve. Formally, this is happening because, being early adopters of the car, the U.S./Canada time constant is so long, but as stated before, it is not clear why this should be so. Zahavi [2] has formulated a highly convincing "mechanical statistics" style theory linking time, money, and road network to produce car usage, but I have not been able to distill from it a simple concept clarifying such behavior.

The other developed nations studied so far appear, on the contrary, to be very near to saturation point; the car industry is then at the mercy of more whimsical replacement markets. The practice of subsuming one's neighbor will be the only mechanism to continue healthy growth. This is tacit warfare, and here innovation may play a major role in determining the victor. Competition analysis shows that normally the youngest contestant, *if* already successful, will be the winner (for a while). Success is sealed when a market has been penetrated by a few percent [3]. This is good news for the Japanese industry, which may well finally win through an uninhibited use of innovation.

Why the younger wins is complex to explain. In older minds, e.g., decisional reflexes are linked to past successes and may not be efficient in strongly modified environments. Furthermore, only in rapidly expanding industries does the workforce have a vested interest in increasing productivity, as it favors high salaries and does not lead to a reduction of occupational levels.

The penetration of Japan in the international markets is shown in Figure 14, and the phase out of such historically aggressive exporters as Germany and Italy, in Figure 15. These early exporters are also invaded by foreign cars themselves (with a measure of swapping), and a hint in that direction is given in Figure 16 showing the progressive dilution of the car population in Italy with foreign brands. This is also a consequence of the progressive internationalization of the car market as shown in Figure 25.

Unless new competitors, e.g., Korea, pop up in the next few years, it appears that Japan will become the dominator of these international markets before the end of the century. It already controls about 50% of it.

Keeping the guidelines in mind, I also looked at competition between classes of cars. This is reported for Europe in Figure 26. Contrary to much advertisement and newspaper theories, the market appears stable and the rush to smallish cars nonexistent. In fact, the market shares for all classes of cars appear to remain constant (if with considerable noise), and the only movement is that of medium class cars eroding the market of very small cars.

The Robotized Buyer

The central issue in the car industry is forecasting demand, for next year first, and then for the following five. A key element in that forecasting is the mortality rate. This rate is difficult to assess in clean form because explicit statistics are generally lacking. The

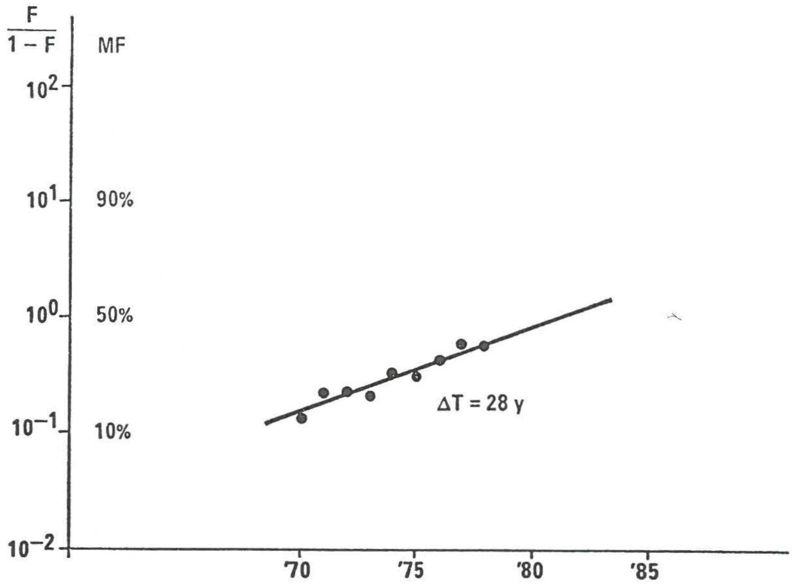

Fig. 14. Cars: Japan in world export market. Japan appears to be progressing steadily in the penetration of the world export market, about half of it should already have done so in 1982 and if no newcomers challenge her progress, this figure will increase to 90% by 1996.

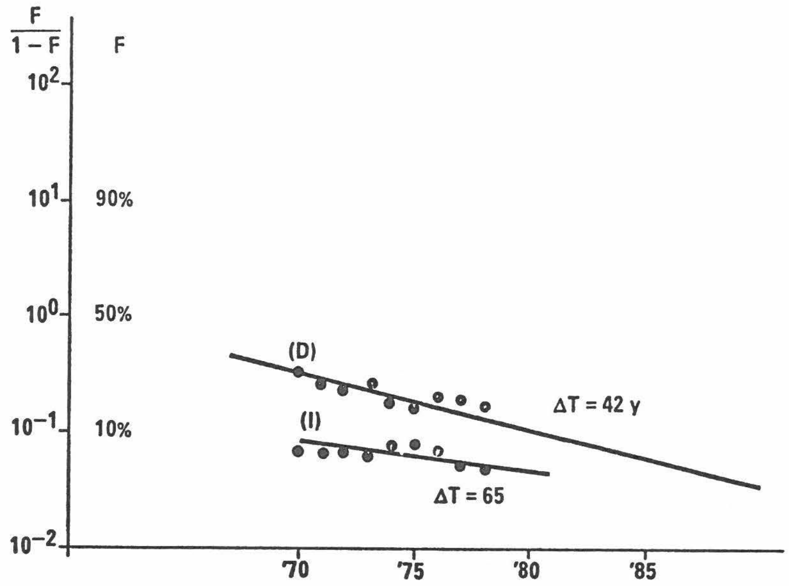

Fig. 15. Cars: Germany and Italy in the world export market. Two aggressive exporters, Germany and Italy, see their positions in the international market slowly but progressively eroded.

United States has something usable, and I tried to plot the survivors of a certain cohort (year, make) over time as shown in Figure 17. It is a point experiment, but very encouraging. In fact, the survivor's numbers are neatly fitted again by a logistic. With a little poetry incorporated, one could say that death competes with life and finally wins. As for any other competition between "structures," progress should be described by a logistic.

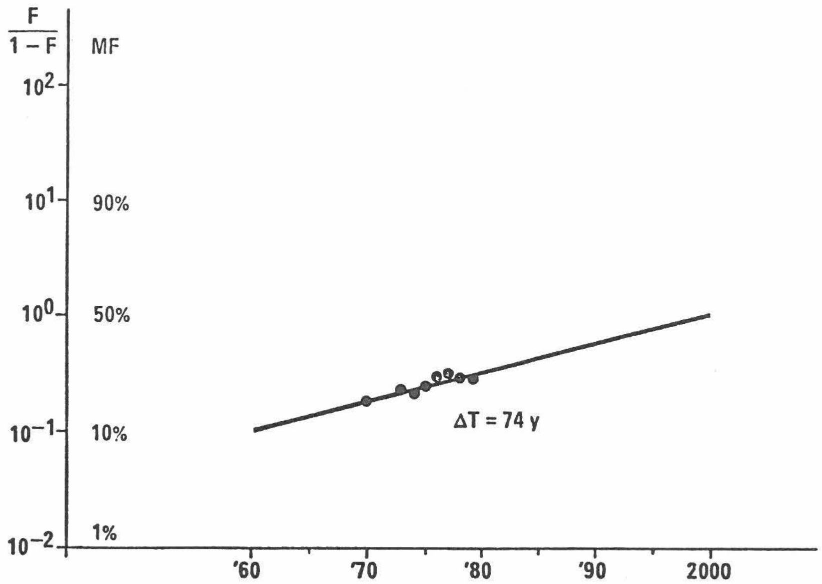

Fig. 16. Foreign vs. Italian car population. The analysis of car population mix in a certain country shows spreading of foreign "genes."

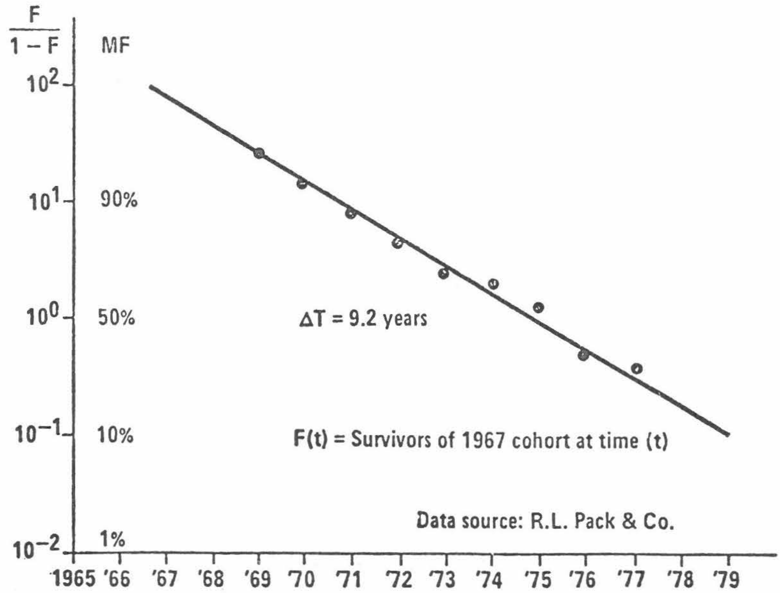

Fig. 17. United States mortality curve. Survivors curve appears to fit a logistic trend neatly. Curiously death curves and birth curves have the same functional expression pointing perhaps to a deep symmetry in the two processes.

Assuming that mortality rates are stable (apart from noise), or predictable from the incipient mortalities of new makes, then a logical procedure to *forecast demand* for new cars can be generated *on a purely physical basis, i.e., without any knowledge of economics or consumer behavior.*

The derivative of car populations, as they are shown in Figures 1–10, is defined as first wave. The definition can be considered as arbitrary, or perhaps linked to the concept of the first car. I will use it in a purely formal way. Applying the death function (derivative of the survivor's curve) to first wave cars, one obtains the second wave, because the number of cars at saturation being constant, any death produces a birth. The process is repeated to get a third wave and so on. The sum of the waves gives the demand. The results of this exercise are given in Figures 18 and 19 for the case of Japan. It is obviously a zero approximation, but promising.

How Safe is Safe?

Much interest and many emotional responses are usually raised by the problem of car safety. After all, cars kill approximately 2.10^5 people/year and maim about ten times as many. Many efforts are made to render cars safer in case of accident, and to encourage caution when driving. It may be interesting to look at the effects with a sense of detachment.

Speaking of risks, my opinion is that society feels them globally and tries to keep them under control. Consequently, instead of looking at accidents per mile or per car, I looked at accidents per unit of population. The very interesting result, reported for the United States first because time series are good and available down to about 1900, is shown in Figure 20. Deaths are taken as an indicator, as they are best interpreted and recorded.

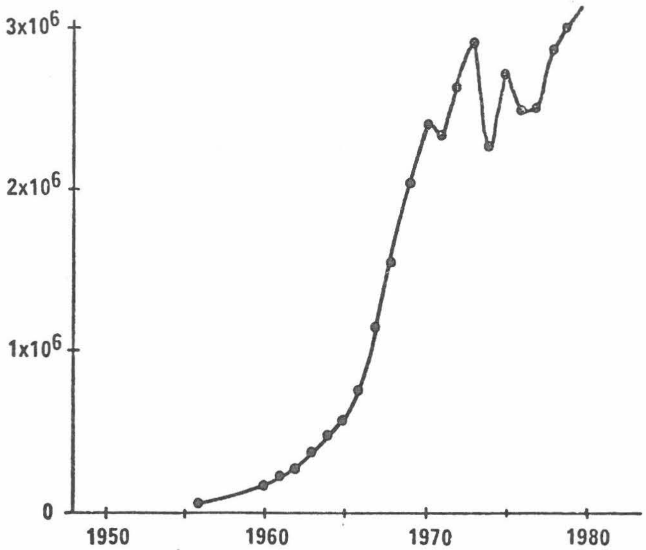

Fig. 18. New registrations in Japan are reported here. Figure 19 will show an attempt to calculate them using birth and death functions.

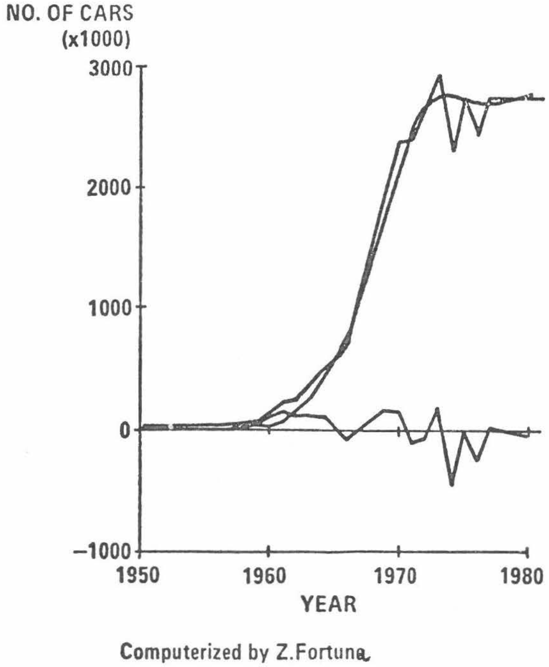

Fig. 19. New registration (Japan) vs. assumed mean life (8 years). "Synthetic" demand reconstruction using only "physical" principles: birth and death functions, calculated for a car mean life of eight years. The difference between calculated values and actual ones is given at the bottom of the figure.

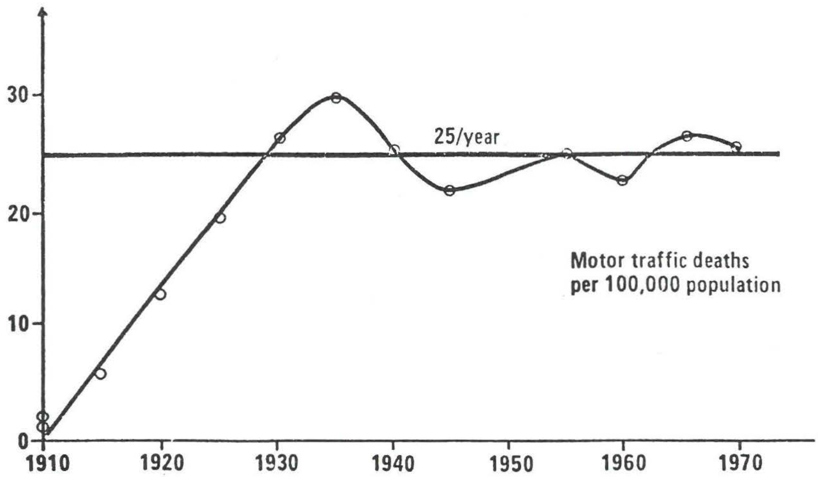

Fig. 20. Safety in cars in the United States. Traffic deaths expressed in terms of population grow first with the number of cars (but at a lower rate) and finally stabilize around a "set point" of about 25/year per 100,000 population. This suggests a very strong societal homeostasis imposing restrictions when deaths go above the set point. What is almost incredible is the stability of the set point over time and the strength of the hold.

What we observe is that deaths grow with the car population, but to a saturation point of about 25 per 10^5 people/year. From then on they become independent of the number of cars. It seems obvious that a social homeostatic mechanism enters into action when this "set point" of 25 is reached. Why it should be 25 and not 35 is not clear to me, so I looked to other nations to see whether a similar set point exists and is culturally linked.

The case of 10 nations is reported in Figure 21 where deaths are reported for the year 1975 (with some corrections to account for different methods of recording deaths following an accident). For seven cases, the set point appears to be about 25, which is extraordinary if we think of all differences, physical and cultural. Three cases, however, have set points almost half of that, and the analysis of why this is so may yield interesting results. Are left hand drivers less risk prone?

Cars for Moving

Another curious observation (Figure 22) is that, at least for the United States, mileage per car is basically independent of the number of cars on the road and is about 15,000 km/year. This stability suggests homeostatic linkages between personal traveling time budgets, road network, and disposable income, as studied in depth by Zahavi [2]. Gas consumption should not then be too difficult to forecast.

Concerning road network, Figure 23 reports that the deployment of paved roads in the United States curiously preceded, at least in relative terms, the upsurge in auto production, and was not at all affected when numerous cars were on the road. In a chicken and egg logic, one could argue that the stimulus to the introduction of the car came from the development of paved roads, a slightly queer suggestion that Zahavi could support with his UMOT model [2].

A car is one of the possible means of transportation and if we look at the transportation market the various modes should darwinially compete among them. I performed this analysis in a previous study on air transportation [4], and the result for the United States is

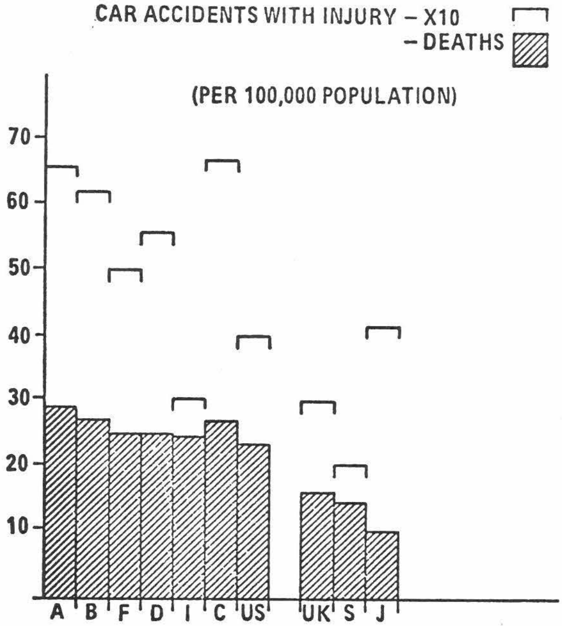

Fig. 21. Set points are given for 1975, and for a number of countries. Most of them seem to be locked to the magic figure of 25. The United Kingdom, Sweden, and Japan are a curious and unexplained exception.

reported in Figure 24. For reasons of homogeneity, the market was separated in intracity, intercity, and commuting. The graph refers to intercity travel. As supposed, the three modes under consideration, train, car, and plane, fit Volterra equations for ecological competition, with the car reaching maximum penetration in 1958. Curiously enough, at that date cars did masquerade as airplanes with Mach 0.8 aerodynamics, ailerons, tails, and "cockpit" instrument panels. The competitor is the devil—in this case the airplane—

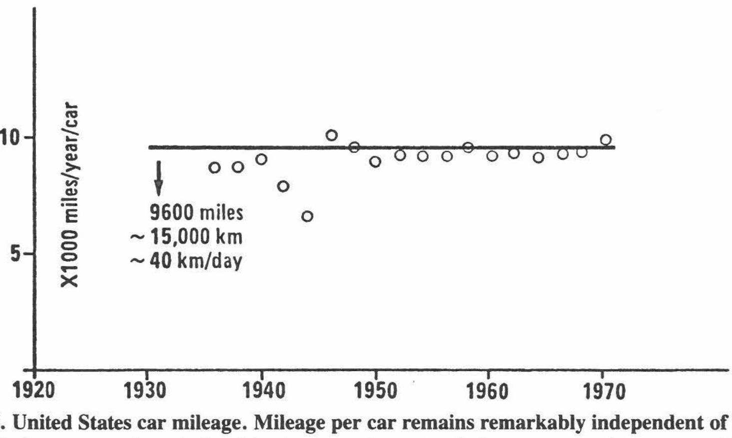

Fig. 22. United States car mileage. Mileage per car remains remarkably independent of time and car number, pointing to complex relationships between the car and the transportation system. Data for other countries are not much different.

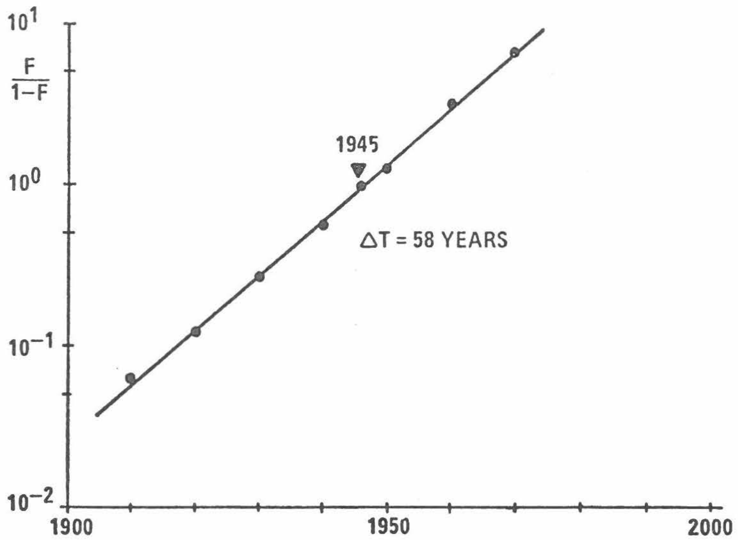

Fig. 23. United States surfaced roads—saturation point 3.4 × 10⁶ miles. A common statement in the literature, that the development of the paved road net is a consequence of the introduction of the car, should be taken with caution. Certainly cars and paved roads show a symbiotic relationship, but the fact that paved roads preceded the introduction of the car by a good 30 years in the US, and the fact that their rate of deployment was not modified when the car appeared, strongly points to a reverse causality.

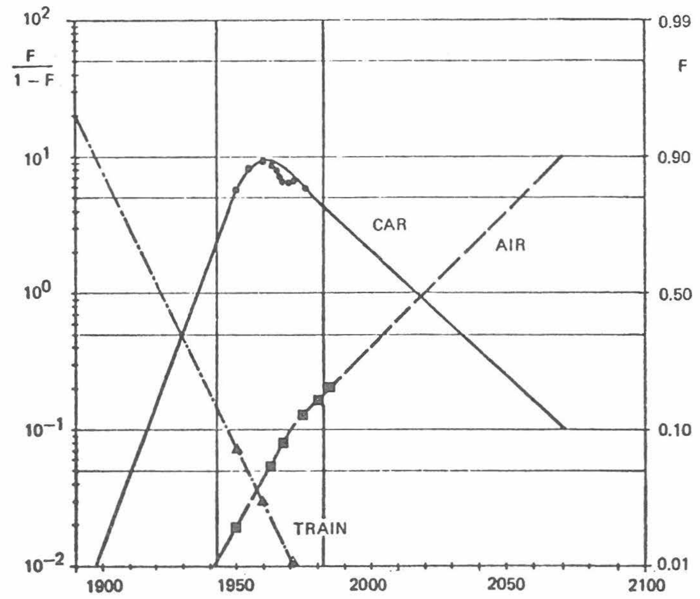

Fig. 24. Intercity passenger-km in the United States. Train, car, and plane compete for passenger-km in a neatly darwinian way. Curiously, US cars displayed airplane secondary characteristics when reaching, in 1959, the top of their penetration, and initiated the inexorable fall. Mimicry of the fight?

and as peasants still do in the Austrian Alps, to scare the devil one has to dress like the devil. It appears that planes will overtake cars in 2025, for intercity travel, a process requiring much capillarization.

Some Final Thoughts

This search was exploratory and we left many leads still unexploited: in particular, the fact that *this form of analysis is not linked to a particular type of commodity,* but has a general character. Even at this point a certain number of conclusions can be drawn:

- *The deployment of the car population* in a certain area appears *to be dominated by an internal dynamic* that does not appear to be determined by decisions taken inside the industry, and vehiculated through innovation and marketing.
- *Innovation and publicity do not seem able even to change the relative market positions of large manufacturers.* One may perhaps interpret them as manifestations of vitality to insure territorial respect, in the sense of posturing by territorial animals.
- Concerning the future, the top down analysis I used gives an extremely simple, if simplified, picture of the state of the system and its evolutionary lines. *The car industry appears to become more and more internationally oriented (Figure 25), and Japan appears to dominate that market (Figure 14).*
- *Car safety appears to be controlled by societal set points and feedbacks.* Trying to increase it on purely technical grounds may be disappointing if societal homeostasis is not taken into account. Strapped drivers seem ready to release their

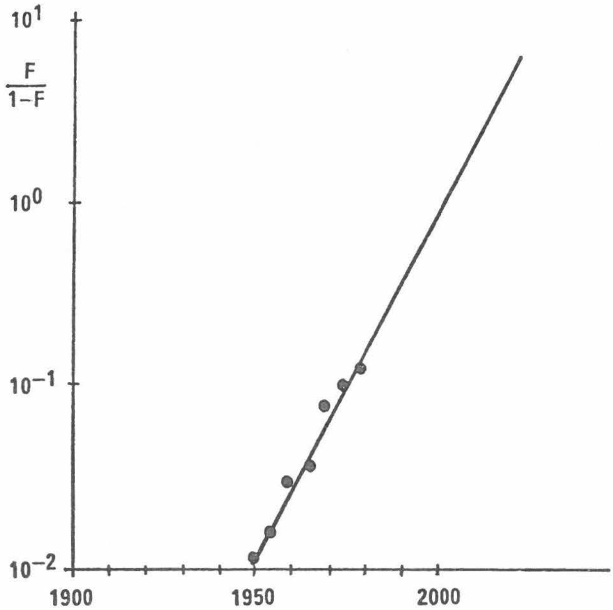

Fig. 25. Import–export production, worldwide. The car industry is rapidly going international as the data show. Only the United States appears to be actually nationally contained, but this may only be an optical effect, as the international operation is taken by overseas daughter companies.

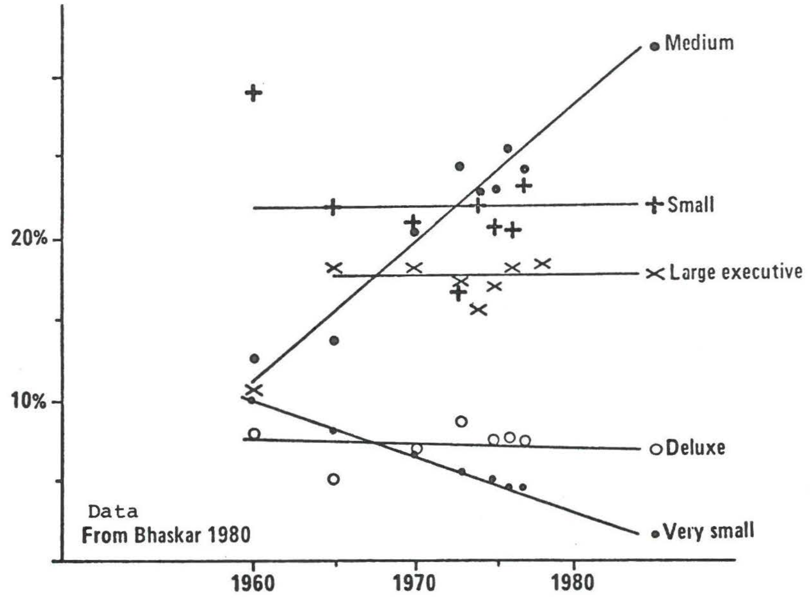

Fig. 26. Car by size in Western Europe. With ups and downs, most car categorizations seem to hold their market share in time with the exception of "medium" cars eroding the niche of the very small ones, and nibbling that of the others.

inhibitions to the very point at which they can meet their alloted quota of killing.

- *Car demand appears predictable on "physical" grounds:* penetration rate and death rate. A reference curve based on that could in any case greatly help to separate the superimposed noise and try to spot its causes. For car types, the often discussed whims of the public do not appear to be valid in retrospect. For Europe at least, (Figure 26), the consequence was a substitution of medium for very small cars, all the others remaining impervious in the extent of their market shares. With the wisdom of hindsight, one gets the impression that Ford's famous statement about his model T, "They can have it in any color, provided it is black," may not be a pure witticism, and styling might be, at least in part, a selfpreserving game.

I hope that hindsight may help insight and wise planning for the troubled years ahead.

And Afterthoughts

One of the objections almost inevitably popping up when presenting these results to learned societies or to interested bodies, is that the excessive determinism is unpalatable to a voluntaristic society such as ours.

My first line of defense is that what I am showing are basically facts, if in a different light and perspective. My second line is that this determinism is behavioral and intrinsically generated, having nothing to do with external and metaphysical "fate."

However, to break the lucent carapace a bit and start a new line of research, (evolutionary potential is of necessity linked to imperfection), I will describe here two cases where I zoomed into details in search of misbehavior.

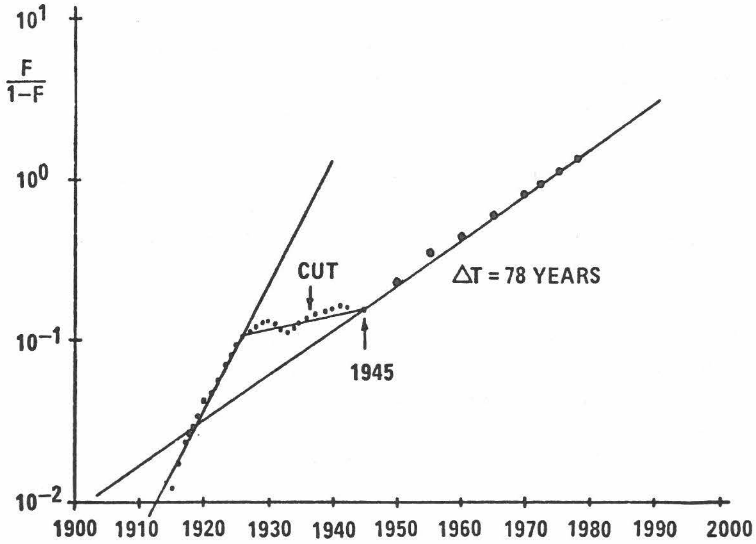

Fig. 27. Total car registrations in the United States from the beginning of car introduction. The dash at the start to the point indicated by CUT has been analyzed independently in Figure 28.

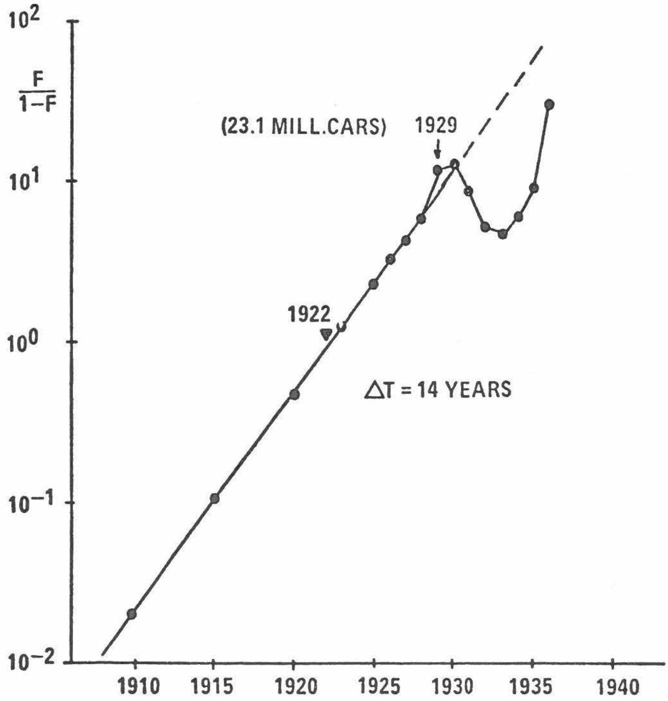

Fig. 28. If I had analyzed car penetration in the United States in 1935, the result would have been this one, with 25 million cars as the *perceived* saturation point and ΔT = 14 years, a situation not much different from that of Japan today.

Figure 1 describes the evolution of US car population between 1950 and 1977. I had, in fact, data as early as 1900 from [5], but I did not use them in order to have a homogeneous data base [6] for all cases under study.

With the data from [5], one gets the result shown in Figure 27. The curve is good, but has a funny kink with twists in the '20s. My question then was whether during the first rush of expansion the car system did not "perceive" a different saturation point and behave accordingly. An analysis of this period taken in isolation (Figure 28) shows that the hypothesis is worth a further exploration. My friends in the car industry actually pray for a multilayer niche that could accommodate their brand new dreams, e.g., a car that parks in $2m^2$ by sitting on its back.

Another objection was that the saturation number of 19 *M*, which I had given for Western Germany, had already been overtaken. This is not unexpected. As Figure 29 shows for three cases taken from the mining industry in the United States, these logistics or quasilogistics can become oscillatory when approaching saturation (a possible solution of Volterra equations often appearing in ecological contexts). However, I was very curious and examined in detail the last six years, separating them from the rest (Figure 30). It appears here, too, that the overshooting can be interpreted as a change in maximum level

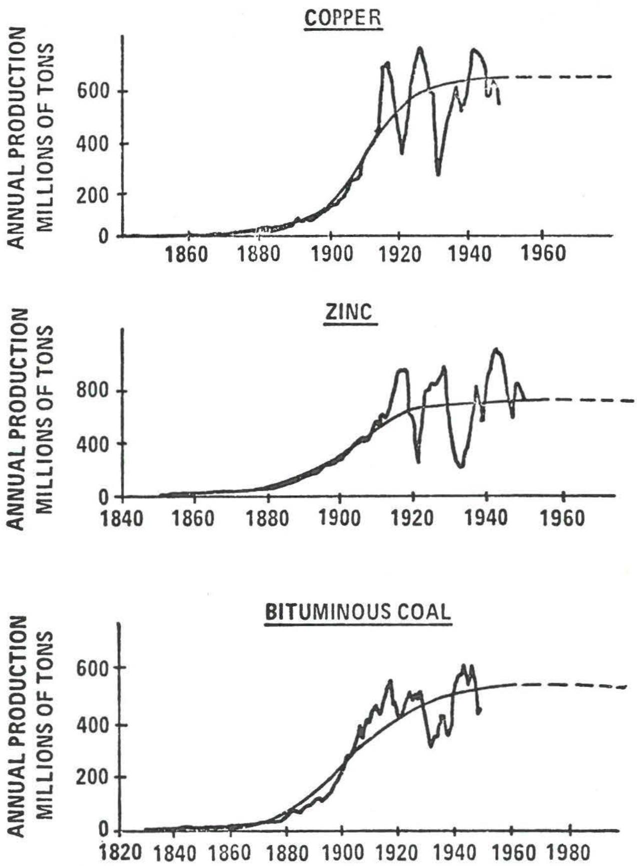

Fig. 29. These three examples from the mining industry in the United States show how a very regular logistic progression can develop instabilities when the saturation point is approached.

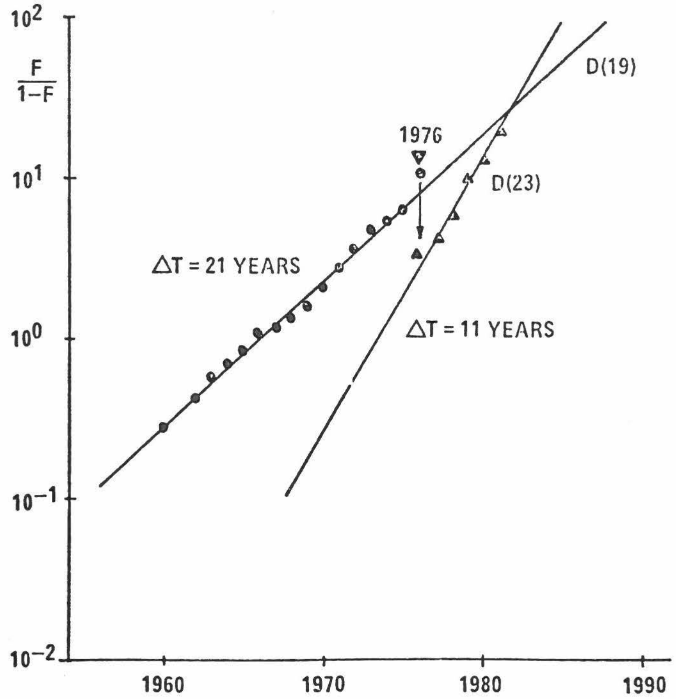

Fig. 30. The instability occurring with the West German car park has been analyzed separately, reaching for the new perceived saturation point (23 million), and time constant. I cannot say at this point whether this instability will resolve in an oscillatory behavior as in the three cases presented in Figure 29, although I think it very probable.

perception and rate of approach, the functional relationship being held. So the castle has back doors—and trap doors too, as any serious castle must have in order to make life a little challenging, if only at the perception level.

References

1. Marchetti, C., Society as a Learning System: Discovery, Invention, and Innovation Cycles Revisited, *Technol. Forecast. Soc. Change* 18, 267–282 (1980). Also reprinted as RR-81-29. International Institute for Applied Systems Analysis, Laxenburg, Austria (November 1981).
2. Zahavi, Y., The UMOT—Urban Interactions. DOT-RSPA-DPB, 10/7. U.S. Department of Transportation, Washington, D.C. (January 1981).
3. Marchetti, C., and Nakicenovic, N., The Dynamics of Energy Systems and the Logistic Substitution Model, RR-79-13, International Institute for Applied Systems Analysis, Laxenburg, Austria (December 1979).
4. Marchetti, C., The Evolution of the Energy Systems and the Aircraft Industry, *Chemical Economy & Engineering Review* 7–13 (May 1980).
5. U.S. Bureau of the Census, Historical Statistics of the United States, Colonial Times to 1970, Bicentennial Edition, Part 2. Washington, D.C. (1975).
6. Motor Vehicle Manufacturers Association of the United States, Inc. World Motor Vehicle Data, Detroit (1976).
7. Bhaskar, K., *The Future of the World Motor Industry*, Kogan-Page, 1980.
8. Schmidt, E., Private Communication.

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