Are markets predictable?

Dr. Cesare Marchetti

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We all live on the shores of the future and all navigational tricks are quintessential to survival. It has always been so for biological systems. Cyrcadian rhythms "forecast" day and night, or the phases of the moon, when mating can be optimal. Birds and insects have weather forecasting mechanisms challenging our computers. Forecasting is the central task of brains, perseverantly selected and improved in all animal lineages. The complex actions of a bird of prey are all organized toward a future meal.

Because cultural constructions with syntactic languages closely mimic the evolution of DNA structures, building models of external world through trial and error procedures, it was inevitable that forecasting would be deeply embedded into any culture, to the point that every religion has forecasting procedures and that fortune tellers in Europe certainly budget more than Saab, Combitech and the whole lot. Being so deep, inevitably leads to ideological wars. Forecasting means in fact limiting the free range of human decisions. And the decision maker is on one side terrorized by uncharted seas, and on the other very jealous of the sense of power he derives from the feeling of being in control.

The battle has gone on for thousands of years, and my results will inevitably kindle the skirmish again. Historically the pendulum swung between the providential determinism where everything is preset down to the least detail, and the boundless freedom of the free will. The voluntarism of Western countries leans strongly on the free-will side. Although with some doubt as the bills of the soothsayers suggest. I must say that the Christian Churches both Catholic and Protestant, never took sides officially.

My rational and illuministic point of view is that the degrees of freedom of the system are almost infinite, and by pruning most of them through careful forecasting, there is always room for bad luck to bring a brilliant decision to dim failure. My honest objective is to reduce probability of failures. The immensely complex brain of our bird of prey is doing just that. On the other hand, my techniques are extremely simple, philosophically and mathematically. This means they are transparent. The central dogma is that: Actions are a consequence of mental images which spread culturally by interpersonal contacts.
Torsten Hägerstrand, Professor at Lund, spent his life studying these diffusion processes, and from him I got the clue for interpreting the astonishing stability over time of the dynamics of so many social and economic phenomena. The mouth-to-ear

networks are stable since time immemorial and are made each of about 100 people in friendly connection. Introducing telephone and fast travel expanded these clubs (or bands: hunter-gatherer bands have about the same size) over a larger space, leaving their functioning intact. The number 100 must derive from our strive and limitations in handling social intercourses.

Because diffusion occurs epidemically in the sense that the number of people who come to know grows according to stochastic infectious contacts, it is natural to deal with the problem using logistic equations which best describe epidemics (Fig 1). Direct experiments in a boys' camp, concerning the diffusion of a certain message, shows precisely this result. Such equations go deep into the working of the system and are at the core of the solutions of Volterra-Lotka equations which describe a competitive biological world under the rule of the survival of the fittest in Darwinian dressing.

That these equations were important for the social and economic system was felt since long ago. In fact, the first practical applications can be traced a century back. They were then abandoned because sometimes they worked sometimes not. A great flurry came, e g, in the thirties. But in the fifties it was clear that they did not work through the troubles of the recession. The work at IIASA covers now about 3 000 cases, and the key to the successful revival is in the precise physical definition of the object to be studied. This has basically eliminated defaulting.

One peculiar case that led our predecessors astray is that of multiple competition, where the dynamics of part of the system is logistic, and part is not. Fig 3 shows the first successfully resolved case of multiple competition for the energy markets. The extended mathematics neatly dresses more than a century of statistical data, with great mathematical economy. Each competitor needs only two parameters to define its complete lifecycle. We were obviously struck by the philosophic revolution incorporated in the chart.

The first thing is that the parameters are only two. This means the system navigates with unsuspected stability over periods of time, a century at least, where every conceivable destablizing feature showed up. Wars and revolutions, political and technological, mineral discoveries, recessions and financial breakdowns. Very little is reflected in the results. Deviations, due presumably to the effects of the above mentioned perturbations, always came back dutifully to the mainline traced by the diffusion-competition process. The most striking fact is the lack of any reference to money and prices.

That money is the fuel of the system we all know. But that the system can be described precisely, and as we shall see, precisely forecast without the use of the measure or even the concept of money, strikes straight at the heart of the Weltanschauung of any economist. I am a physicist by education and I do not really care about the feelings of these colleagues, but for many years I sat on the problem of what is the real, i e, physical, function of money. I did not find any hint yet. However, waiting for the answer, let us pragmatically enjoy the fruits of this rediscovered methodology. As could be expected, we first rambled into the area of energy, zooming down into more details through geographical, technical, and economic delimitations. We analyzed about 300 cases, overconfirming the generality of the first results. Just one chart I report here as it carries the winds of change in powering navigation (Fig 4). I attract again the attention on the stability of change so to speak, in spite of the rough seas. It is this stability which we observed empirically in thousands of cases, the basis for forecasting under appropriate conditions.
The example I usually show is that of Fig 3 reconstructed using only 20 years of data as a data base (Fig 5a, b, c). I will not show the forecasts that in the course of time top level institutions have produced using the best economic models available. Each of them generated a different result. The determinism exuding from Fig 5 may be refreshing after all. Better in the hands of some sort of providence than in those of chaos. The "providence" is in fact the result of ordered and stable societal behaviour, à la Hägerstrand. Energy connects broadly into transportation and for a period of time I worked intensively on the subject. First looking at cars, the big energy guzzlers, and then, for context, into all sorts of transportation technologies, both for people and goods. What comes out here is that Darwin was right, once again, and multiple competition equations reproduce a fine print of what happened during the last two centuries, with a peep into the next one.
We can look at the evolution in transportation systems from various viewpoints: general infrastructure, by measuring, e g, the length of canals, railways, roads, or air connections; machinery by counting ships, locomotives, bicycles, cars, or airplanes; output, by measuring passenger-km or ton-km of goods transported over the various modes.

I will only pick some examples from the mass of cases we have analyzed. The substitution (Darwinian competition) between general infrastructures in the USA is reported in Fig 5. The measure through which they are compared is network length. For air transport this is the sum of the distances between airports served by scheduled airlines. As interest in Eastern countries is at top level nowadays, the same analysis is reported in Fig 7 for the Soviet Union.

Figs 6 and 7 present the competition in relative terms. But it is of obvious interest to look at these infrastructures intrinsically, i e, in absolute terms. This is done for world railways in Fig 8 and in Fig 9 for the European ones. The quality of the fitting is not due to agglomeration. Fig 10 reports the case of Denmark. But one could also zoom into single independent railway companies.

At this point I would like to make two general observations. The coming in pulses is not typical of railway infrastructures. All activities of Western societies are contained in 55 years time-boxes, the Kondratiev cycles modulating everything, from energy consumption to criminality. Second, as the case of Denmark shows, railways are on their phase-out. I am sorry to say that when railways nostalgia is at its top, and so many billion dollars of investment are ready to be poured into them. They will be wasted. Darwin has no nostalgia. The new technology wins and the old one loses. Full stop. To hammer my nail a little deeper I shall show the length of rail for different European countries. But if trains could run at 1 000 km/h, then the situation could change.

Glancing through the car system, we can see the growth of cars in operation in the USA (Fig 12) or Europe (Fig 13) from 1900, or in various states during the present Kondratiev cycle that started around 1940 and will end around 1995. These car populations grow in an utterly selfconsistent manner, permitting precision forecasting. And, for Western countries, they seem to be at a saturation point. A hint in that direction is given by looking at passenger-km intercity for the USA (fig 15) or Europe (Fig 16). The competition is the faster airplane, the last technology in the competition sequence. Curiously, the peak of passenger-km share for cars was in 1960 for the USA. Just when cars masqueraded as airplanes with winglets, "after burners" rear lights, and tricky cockpits: Exorcism.

Because winners are usually the most interesting, let us look into the progress of the air system. The unrelented progress in passenger-km world-wide is reported in Fig 17. It amounts to a factor of 50 in just one Kondratiev cycle. But it is just the beginning. In the USA, where air travel has penetrated most, the time spent on planes per day and per person over the total population is about one minute. They spend 50 minutes/day in cars. The increase in traffic has been curiously managed by a substantially constant number of planes, at least if we measure them through the IIATA fleet (Fig 18). This requires airplanes of increasing productivity (passenger-km/h). Successful airplanes in fact always matched this requirement (Fig 19). One of the weak points of Concorde was that its productivity as a first level machine was too small (by a factor of 3) when it came into operation.

Larger planes mean larger engines and the race is depicted in Fig 20. The exhaustion of the potential of piston engines in the fifties seems to be paralleled by a similar situation and the end of the eighties for jet engines. A jump in technology, presumably via hypersonic planes is to be expected. They would neatly solve it for the first level.

All this competition comes from newcomers which in Darwinian sense are more endowed with inclusive fitness. Evolution is associated with mutations, i e, with basically stochastic events. Perhaps noise brings some freedom in the sense of quintessential unpredictability also in the socio-economic realm. Helas, not really. Spurred by a friend organizing a congress on innovation, I tried to model through the data on invention and innovation that G Mensch had collected in the seventies and published in 1975 in a book: "Das Technologische Patt". The result is business as usual in my realm: The invention-innovation business is more tightly regulated than country fairs. Also the strikes of geniuses are, as further research did show. Because The System keeps turning their noses in the appropriate directions.

The quintessential result of the innovation analysis is that the system is fractal. This means an innovation is a product for a market asking for innovation, in the same sense as a car is a product for a market asking for cars. And, in analogy, new innovation markets open up every Kondratiev cycle. A bit out of phase because their centrepoints coincide with the end of the recession, i e, with the end of the cycle. So the end of the last Kondratiev was in 1940 and the centrepoint of the last innovation wave in 1937. The end of this Kondratiev will be in 1995 and the centre of our innovation wave will be in 1993. Previous innovation waves were centred in 1880 and 1882. All this comes from the analysis of the data in Mensch's book, except for the present wave which was forecast on the basis of the striking regularities of the previous waves. Also the inventions that finally went into innovations, i e, successful applications, are organized much the same way. In logistic waves with strictly defined centerpoints and time constants. All the argument is reported in Figs 21 to 24 where the analysis is condensed in form of logistic waves.

So before trying to inject something new into the system, The System has to be interrogated with perseverance and humility. Here a Shaman can be very useful, also because The System is a Moloch. The case of car manufacturing companies entering the market in the USA is reported in Fig 25, solid line. The number, as usual, is cumulative and fitted with a logistic. The cumulative number of companies eaten by the Moloch is represented by the dotted line; they are the quitters. They sum up to the same number. The final survivors, a dozen, are hidden in the computing errors. The mean lifetime of these companies, i e, the distance between the two lines is four years. Molochs like little children as the story goes. A similar analysis done for the computer industry shows similar results. I could not collect a list of quits, but one can work by inference. The cumulative number of mainframe makers is given in Fig 26; that of mainframe models put into the market in Fig 27. In the mean each maker will produce four models. But the big ten, shown in Fig 28, will produce one third of these models. Most makers then will produce one or two and disappear. That's life, right as Darwin saw it.

Once an invention becomes an innovation, i e, a product, it will start filling its own niche, i e, its market. We have seen that with cars, in various geographical contexts, and during two Kondratiev cycles. The most notable characteristic is the sturdy stability of the process. If derailing forces are excessive it will come out of the track and then back like an expert rally driver. Obviously people market-oriented as you are, would like to know more, e g, the size of future markets and the time constants, i e, the speed to saturation. I can give only hints because our research was not centred on commercial services, we only stumbled on interesting clues in the course of other pursuits. One thing that hits the eye looking e g at car penetration in Fig 14 is that all the lines lean together toward their end, although their starts are far apart. This is a fairly general rule, and the relation can be even quantified (Fig 29). The log of the time constants is linear with the start-ups (1 %) time. The wall against which the line pile up is the end of the Kondratiev cycle.

A colleague of mine looked also at the size of the market as a function of the start-up date. In the same mood of the time constants, this size decreases logarithmically with start-up date. This means latecomers will fill smaller and smaller markets, faster and faster. If the penetration already started then best fit with a logistic, all precautions taken, is the best point to start. I report here a trick-film prepared by a colleague, M Gruber, on comparative predictions for a very specific case: that of production of ethylene in Western Europe. Because neither Saab nor Combitech produce ethylene, the game is on neutral ground. CEFIC is the European Federation of Chemical Industries, the ones who should best know about ethylene industry and forecasting in that area. The starting point statistical data are reported with a heavy line until 1972. The forecasts by CEFIC are presented with dotted lines.

Our first logistic best fit (1972) is given in Fig 32. It depicts a future much different with a saturation around 10.5 million tons. Turbulent zone means that near saturation the subsystem finds its way by violent excursions above and below the mean values which correspond to the logistic. The situation is reviewed again in 1986, 14 years later, looking at what the system has done (thick line) and what CEFIC has again forecast in 1977 and in 1980. Evidently CEFIC people have not yet absorbed the lesson (from the last 200 years) that the world ends (i e saturates) with the end of a Kondratiev cycle. To start again with the next cycle. The cost of not knowing that, reflected on all industry overdimensioning its capacity since the end (1968) of the boom side of the cycle is hard to evaluate, but might be in the trillion dollars ballpark. It must be absolutely clear that the same thing happened during the second part of the three preceding Kondratiev cycles. So we have not been more stupid than our fathers and forefathers. It is sad that we have not been wiser.

Let us now glance at the world of robotic. Much romance has been spent around that word. After all, robots are amplifiers and specifiers of our gestures and in that sense they existed since tools were invented. They are becoming more and more sophisticated, expanding our outputs with more or less constant input from our side. Looking at the problem in such a very general way, all quantitative analysis becomes very specific. I shall report here in any case the evolution of the number of robots in Japan, according to a naive classification: simple-task and complex-task robots. The results are given in Figs 34 and 35. There is nothing striking in the result. Business as usual. The system seems to come to a standstill in the next few years. The real message, as usual, is that the market will revive in a few years and with niches probably orders of magnitude larger. This can be calculated going to higher level in the fractal hierarchy of the system, where time constants are larger than a Kondratiev cycle, so that the structures beyond can be calculated and forecast. From them we can then construct the structures below. As my presentation should be in form of a basic stimulus, I leave the solution of the problem to you. It is solvable!

Back to square one, I think I gave you some glimpses of the fact that the future has many unknowns but that the system is so well organized that, like a ship or plane, it will arrive at destination in due time. We are basically predictable because we are running our destinies. And by acting we give out our intentions.

Fig 1 A very simple formalization of the stochastic contacts between individuals leads to a diffusion function for a plaque. The function is an S-curve, a logistic here represented in the Fisher-Pry transform. The number of people who caught it (here the ones who actually died) is measured as fraction F of the total number of people that will finally die due to the plague. The course of mortality can be represented bz log F/1-F = at+b, where t is time and a, b are constants usually calculated bz best fitting of data. The number in parentheses represents the niche, i e, the saturation point of the logistic.. In this case the total number of people actually died due to this particular wave of pestilence. Next plague, new logistic.

Fig 2 Just like viruses, information packets can flow from individual to individual with an "epidemic" process. Here is a certain piece of new that psychologists monitored to assess the characteristics of the diffusion. Two things should be observed: first the perfect matching between the empirical data and the mathematical function. Second the existence of a residual. Few boys were in a sense isolated and never caught the information. This gives a feeling for the concept of niche. In this case it is not the total number of boys, but the number of infectable ones. The "delta" represents the dynamics of the process. "delta" T is the time for F to go from 10 % to 90 %.

Fig 3 The cases of Figs 1 and 2 are limiting ones, in the sense that normally diffusion is multiple and appears in the light of Darwinian competition between different species of technologies, fighting for growth inside the same niche. In this case the competition between primary energies for the world energy market is reported. The mathematics is a computer package derived from the general Volterra-Lotka equations for ecological dynamics. However, the straight segments in the chart care logistics. When a newcomer successfully competes, for a while his progress can be mapped with a logistic equation even in presence of other competitors. At a certain point this is not true any more to the deception of early users of this model in the thirties. The deceptions finally led to the abandonment thereof.

Fig 4 As a sideline of competition in the energy area we studied the competition between prime movers in shipping. Sail, steam engines, internal combustion engines. Each competitor can be characterized by only two parameters which define, interactively with the competitors, the complete life cycle of the technology. To note the great stability of the process of competition over long periods of time. To note also that money indicators are not present as in the case of primary energy substitution.

Fig 5 The stability of the process of substitution which we observed in thousand of cases is a compelling stimulus to try to use the descriptive algorithm in a predictive mode. Real forecast must be made in the real future, but a rapid test of the techniques is permitted, even in the hare s sciences, to split the past into two pieces and reconstruct one of them from information extracted from the other. In this case the "trick-film" gives the data base (1990 - 1920) for primary energy substitution in Fig 5a. The fitting of the substitution e equations is given in Fig 5b. The real world outside the data base is reported in Fig 5c. Market share of oil in 1970 could have been predicted in 1920 with a precision of about 2 %. A very encouraging result.

Fig 6 A continental transportation system is seen here through the lense of its infrastructures. The parameter taken for measure is length: of canals, railways, roads, or distance between scheduled airports. The substitution is very smooth and long term. The forecast is for more air transport. We shall see later on a parallel analysis on passenger-km or ton-km performed on these infrastructures.

Fig 7 Not only money can be absent from the parametrization, but also the type of political and economic organization. This is true for all subjects we have in time analyzed. Here we analyze the parallel case of evolution of transportation in the USSR.

Fig 8 The analyses of Figs 6 and 7 are made in relative terms. But we can also do the intrinsic analysis of the evolution of a system. Here the case of railway track length worldwide. They come in two logistic waves of growth. This shows explicitly the effect of Kondratiev cycles on economic activity. These cycles are very pervasive and need to be taken into account for a correct use of substitution analysis.

Fig 9 The same as for Fig 8, but for Europe. The final length is the sum of the tow pulses (250 000 km + 150 000 km). The build-down of the system has started after World War 2. The competing technology are basically road vehicles.

Fig 10 Zooming into a small country we have here the case of railway length in Denmark. Two growth pulses and the initiation of the phase-out pulse (or pulses). Railways seem to be in the final branch of their product life cycle. According to my analysis because they cannot provide competitive speed. In my opinion also the TGV is doomed to lose for distances above 200 - 300 km.

Fig 11 The detection of the end of product life cycle for railways in Denmark is confirmed by similar trends in other countries.

Fig 12 Car population, i e, registered cars in the USA. WE can observe tow waves of growth, one ending before 1940 and the second in its final phase now. As we shall see later, there are signs for the product car having reached the top of its life cycle. The competitor here is the airplane taking increasing chunks of intercity traffic. Very fast Maglev may take other parts of the niche.

Fig 13 The case of car penetration in Europe is reported as pendant to the US case to show the strict similarity of the two processes. Incidentally the final number in 1995 will turn out to be almost the same. As the car can be considered as a personal prothesis, their number will finally correspond to the number of people with driving licences. The usage time will decrease from the present mean of 55 minutes per day when airplanes (or Maglevs) will absorb more of the travel budget. Just to take myself as an example, I use airplanes about 30 minutes a day mean over the year, and cars about 25 minutes. Although I own 5 cars.

Fig 14 To show the selfconsistency and predictability of car population (not sales!) even at lower special scale, we report here synthetically the case of a number of nations for the period after World War 2 (present Kondratiev cycle).

Fig 15 Up to now we have shown infrastructure an machinery. But the gist is performance, i e, passenger-km or ton-km transported. The chart shows the competition between intercity modes in the USA in terms of passenger-km transported. The car reached its maximum share in 1960, and in losing ground to air transport which already covers 15 % of the total.

Fig 16 The model distribution of intercity passenger-km in Europe shows similar trends as in the USA, if with perhaps 20 years delay. To notice the stability of road transport, preluding to a fall, and the vigorous growth of air transport.

Fig 17 Air transport analyzed in isolation shows a perfect logistic growth during the present Kondratiev. Passenger-km (or ton-km) are the business end that the system tries desperately to preserve, even in the fact of sudden increases in the price of jet fuel as it happened in 1974 and in 1976. Life inside operating companies was not so smooth in these times. But the system was successful in "expelling" the perturbation in less than one year. Yearly statistics show no trace of the fights.

Fig 18 IIATA fleet was curiously stable at around 4 200 airplanes for almost 40 years, when traffic increased by almost two orders of magnitude. The reasons for this magic number are not clear, but incidentally oil tankers are in the same ballpark. The stability in number put precise constraints on the productivity (passenger-km/h) of the machines.

Fig 19 Putting together the chart for the traffic (dashed line) and that of the productivity of airplanes reported at the time when they were put on the market, we find this precious relation: they are proportional. First level airplanes all fall in a line parallel to the traffic line. The only exception is the DC-10 which classifies with second level airplanes as th A-300. Also Concorde, whose small productivity was perhaps one of the reasons of its very limited success.

Fig 20 As Fig 19 shows more traffic (at world level!) means larger planes and consequently larger engines. The rush to power is here neatly modelled with two logistics, one for pistons and the other for jet engines. The switch was done precisely when piston engines were out of breath, and jets could satisfy the demand for more power. Their introduction could be predicted, as we now predict the introduction of hypersonic airplanes (and engines) in order to face the increase in demand for productivity. Until the year 2000, however, 747s stretched to 1000 seats can hold the market.

Figs 21 - 24 Basic innovation waves (and the inventions that preceded them) can be modelled as products filling a market, with the usual market penetration logistics. This permits a fine taxonomy of the process over 200 years, which reveals unexpected regularities and the possibility of forecasting, which is done in Fig 24. According to this forecast we are now in the middle of an innovation wave that will have its peak in 1992. Previous innovation waves had their peaks near the end of recession, i e, of Kondratiev cycles. The present cycle ends around 1995.

Fig 25 "Innovations" in Fig 21 - 24 are the dates when they were first put on the market. For their diffusion they have to find entrepreneurs to manufacture them, if they are manufactured products. The process of starting a new business in the face of many uncertainties is the source of vigour of Western economies, but it is also a form of carnage. The solid line reports the cumulative number of new companies to manufacture cars opened in the USA. The dashed lines represent the cumulative number of companies that did not make it (quits). The saturation point calculated by fitting the statistical data comes out to be the same (1400). The survivors are "hidden" into the computing imprecision. The high mortality is not specific of the car industry.

Fig 26 We report here the cumulative number of companies which took a go in the area of mainframe computers. Fitting the data leads to a final number of 700. We are now halfway the process.

Fig 27 The cumulative number of new mainframe computer models can be again fitted with a logistic saturating at 3 000. This means every company will produce a mean of about 4 models during its lifetime. Because the big ten (Fig 28) will produce almost one third of the total, the others will produce two and disappear.

Fig 28 Zooming into the "big tens" activity, we find the cumulative number of new mainframe models can be fitted with logistics. The first number after the company name is the saturation point and the second the time constant. All these time constants fall into the same ballpark and come to saturation around the end of the Kondratiev cycle. Only IBM seems to span two cycles.

Fig 29 Regularities in the penetration processes of products are interesting as they reveal the architecture of the system, and as they may make forecasting possible when data are very scant. The relation between the time when penetration has started and the time constant it proceeds is reported here for cars. A good relationship is obtained by plotting log (time constant) vs time when penetration was 1 % of saturation.

Fig 30 Fig 29 shows the latest, the fastest. A similar relation be obtained by plotting the log of relative saturation level vs the time when penetration started (1 %. The relative saturation level is here given in relation to a limited saturation level for cars (population x .5). Putting together the results of Figs 29 and 30 one can construct a band of values for the actual saturation levels and time constants in relation to starting times, even before any activity has been started.

Figs 31 - 33 The quality of a methodology has to be assessed by comparing it with the best competitors (Darwin again). For this example I choose the forecasts for European ethylene production done by CEFIC, the Association of European Chemical Industries, in 1972, 1977 and 1980. They are compared with our forecast done using data up of 1972, as for the first CEFIC case (Fig 31). The fitting can be done with a simple logistic, as our internal checks had shown and is reported in Fig 32. As our experience with these simple logistic fitting points out, real systems have problems in detecting the saturation level, and do so by exploring the environment, i e, they oscillate around this saturation value (Turbulence zone). CEFIC attempts in 1977 and 1980 are reported with dashed lines. Our 1972 forecast stands the facts. The other obviously not and the reasoning behind, of economistic nature, can be easily reconstructed.

Figs 34 - 35a Industrial robots all together penetrate the Japanese industry with the smoothest logistic course one could imagine. Inside however there is a fight, between primitive and sophisticated machines which we call first and second generation. This internal competition is described in Fig 35 and shows again a perfectly smooth way to victory of sophisticated machines. The same analysis is reported in Fig 35a, in absolute terms (actual number of machines in operation vs time).

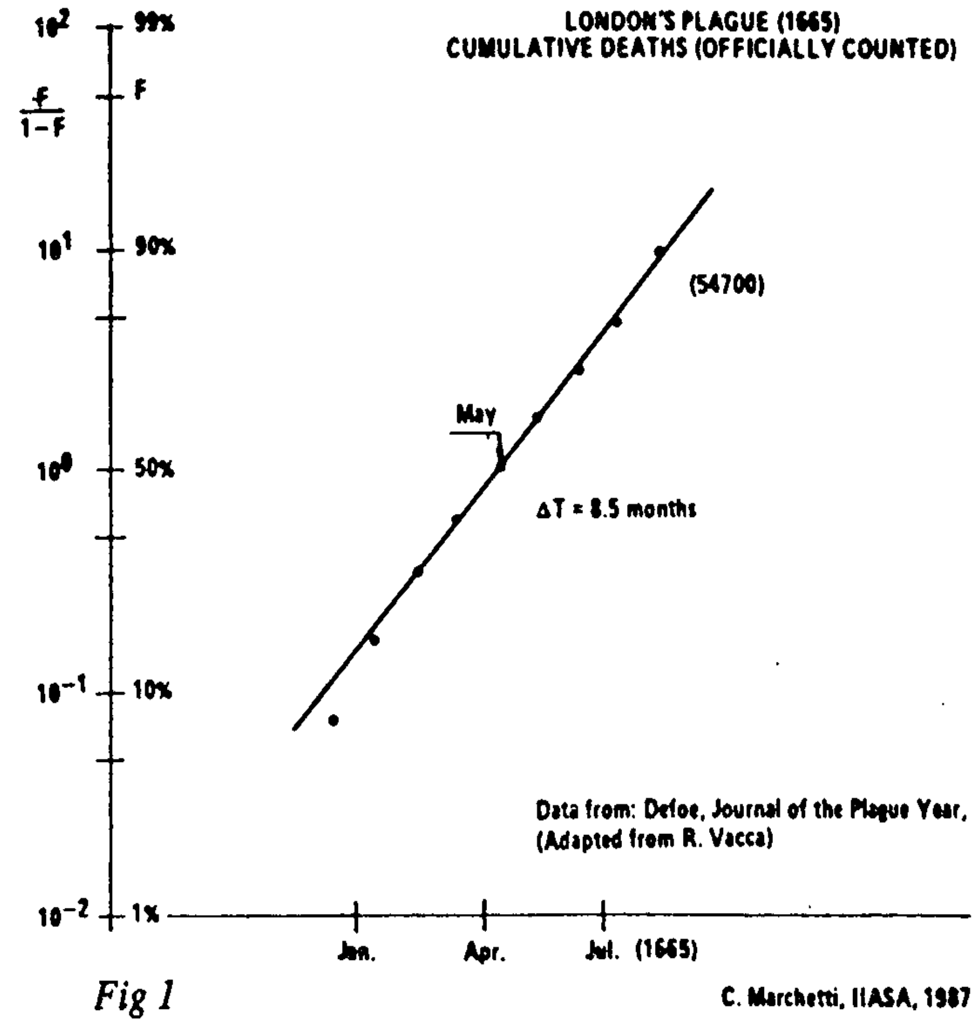

LONDON'S PLAGUE (1665)
CUMULATIVE DEATHS (OFFICIALLY COUNTED)
10^2
99%
F/(1-F)
F
10^1
90%
(54700)
May
10^0
50%
ΔT = 8.5 months
10^-1
10%
Data from: Defoe, Journal of the Plague Year,
(Adapted from R. Vacca)
10^-2
1%
Jan.
Apr.
Jul. (1665)
C. Marchetti, IIASA, 1987

Fig 1

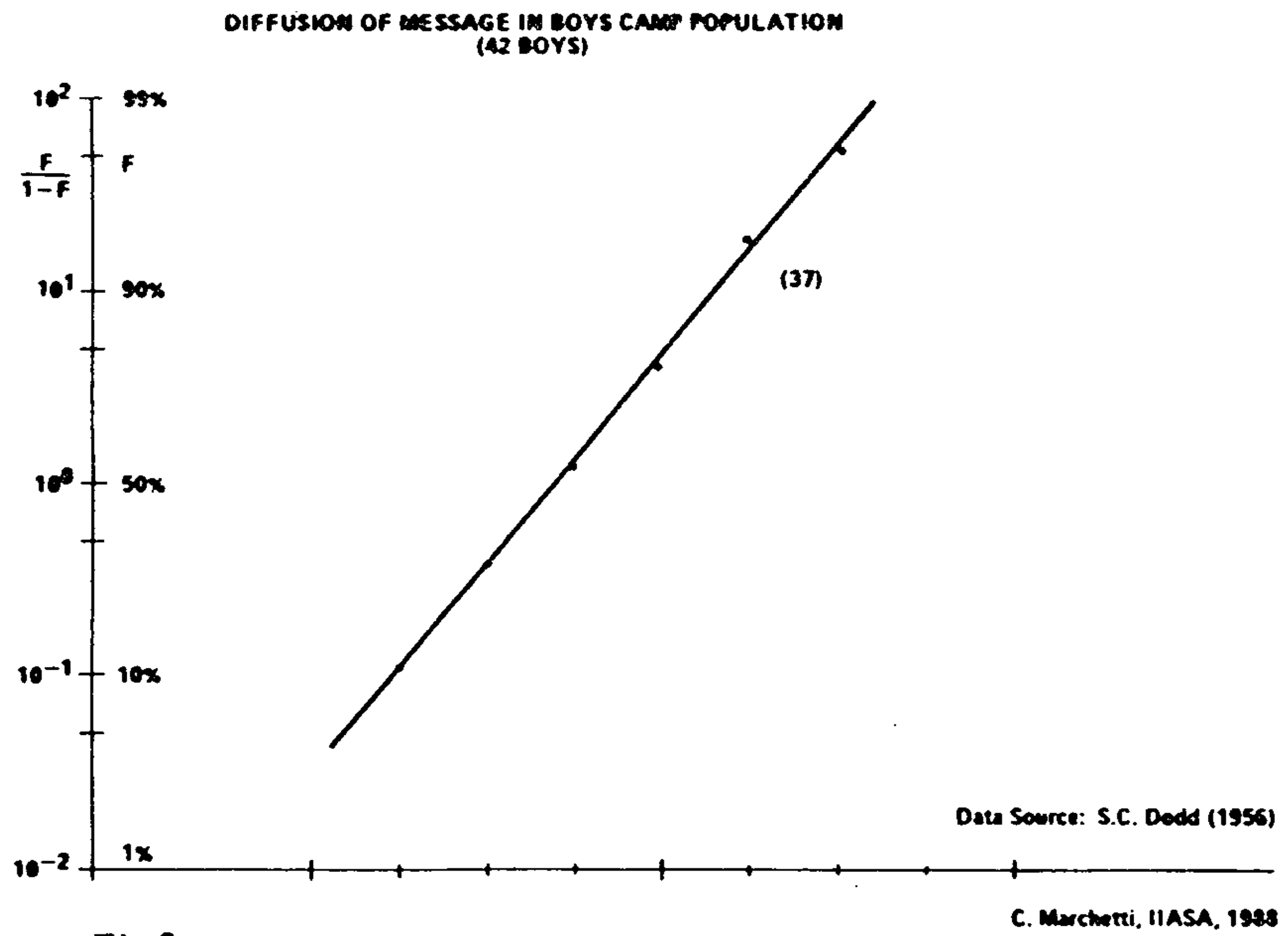

DIFFUSION OF MESSAGE IN BOYS CAMP POPULATION
(42 BOYS)
10^2
$\frac{F}{1-F}$
10^1
10^0
10^{-1}
10^{-2}
99%
F
90%
50%
10%
1%
(37)
Data Source: S.C. Dodd (1956)
C. Marchetti, IIASA, 1988

Fig 2

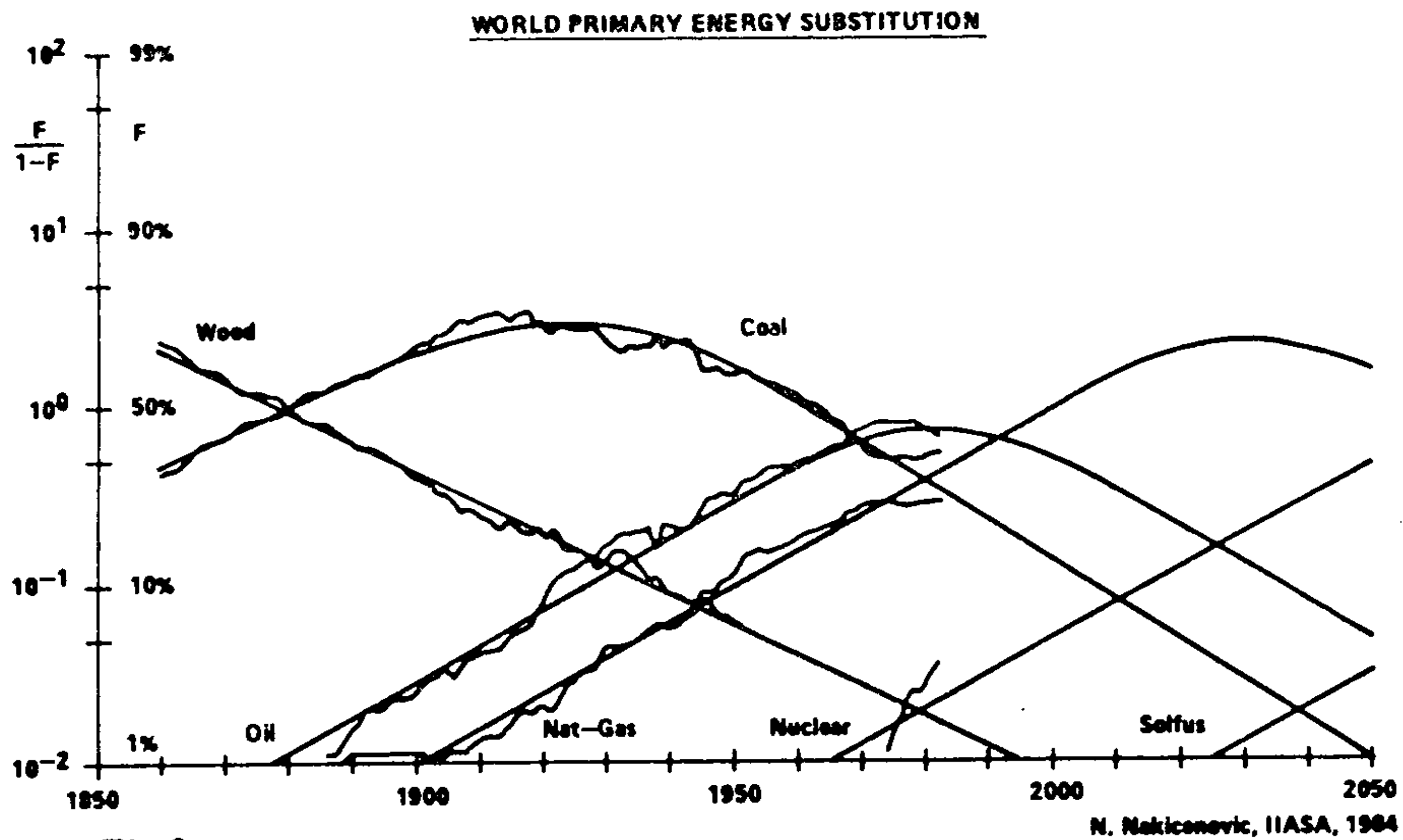

WORLD PRIMARY ENERGY SUBSTITUTION
10^2
99%
F
$\frac{F}{1-F}$
10^1
90%
10^0
50%
10^{-1}
10%
10^{-2}
1%
Wood
Coal
Oil
Nat–Gas
Nuclear
Solfus
1850
1900
1950
2000
2050
N. Nakicenovic, IIASA, 1984

Fig 3

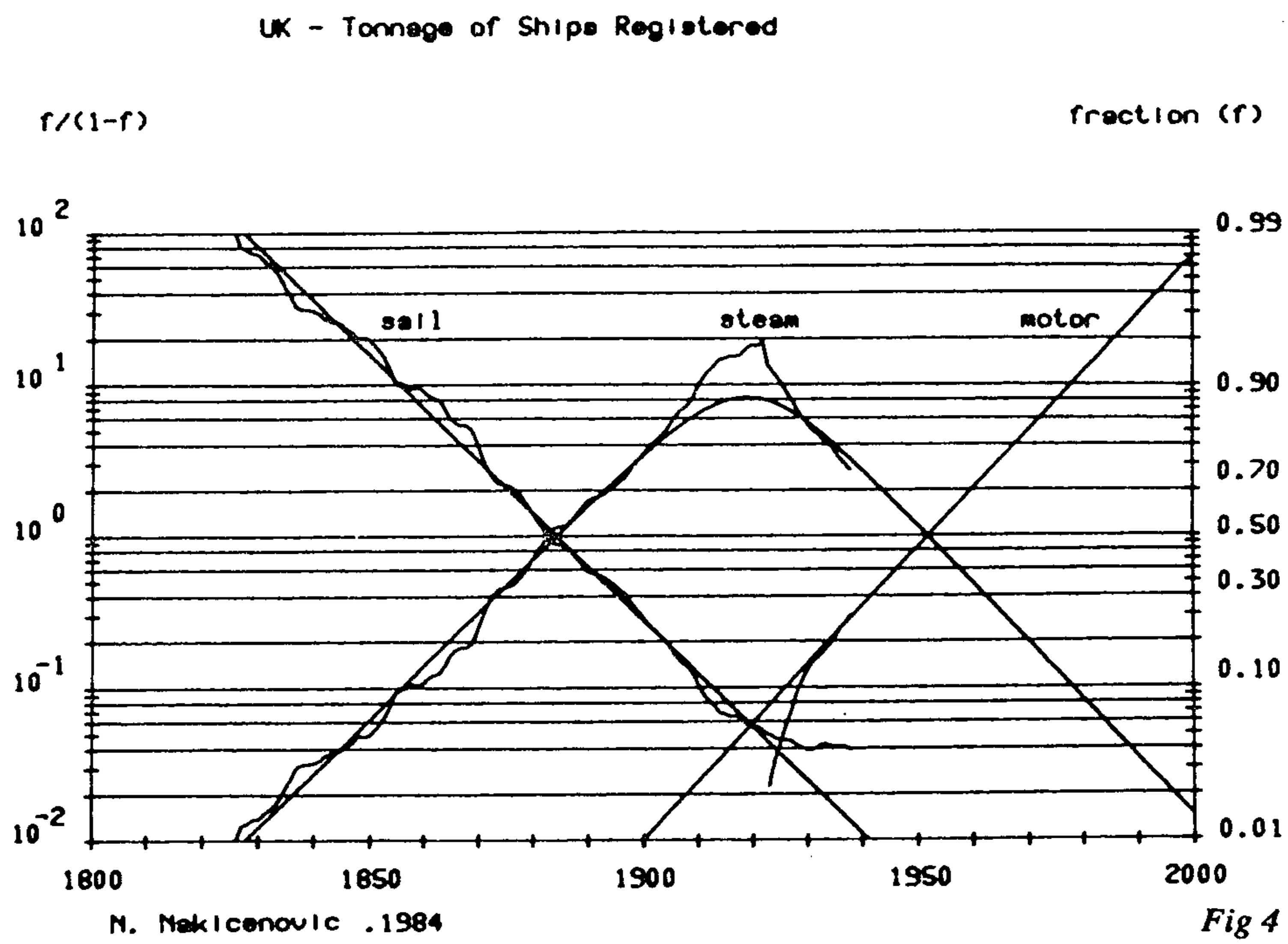
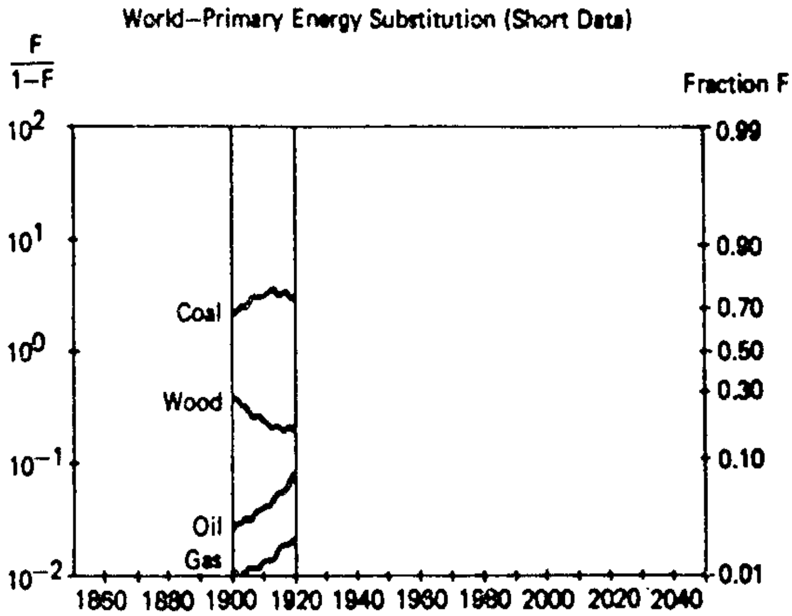
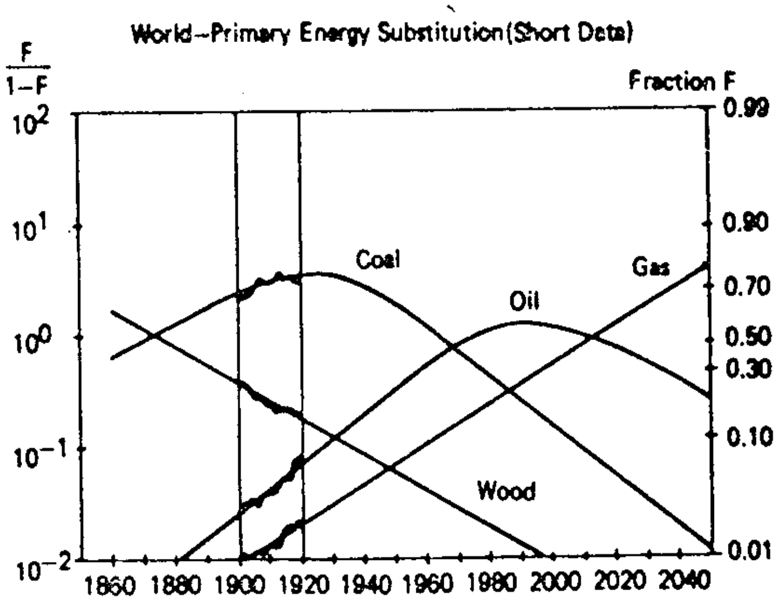

UK - Tonnage of Ships Registered
f/(1-f)
fraction (f)
10 2
10 1
10 0
10-1
10-2
0.99
0.90
0.70
0.50
0.30
0.10
0.01
sail
steam
motor
1800
1850
1900
1950
2000
N. Nakicenovic .1984

Fig 4



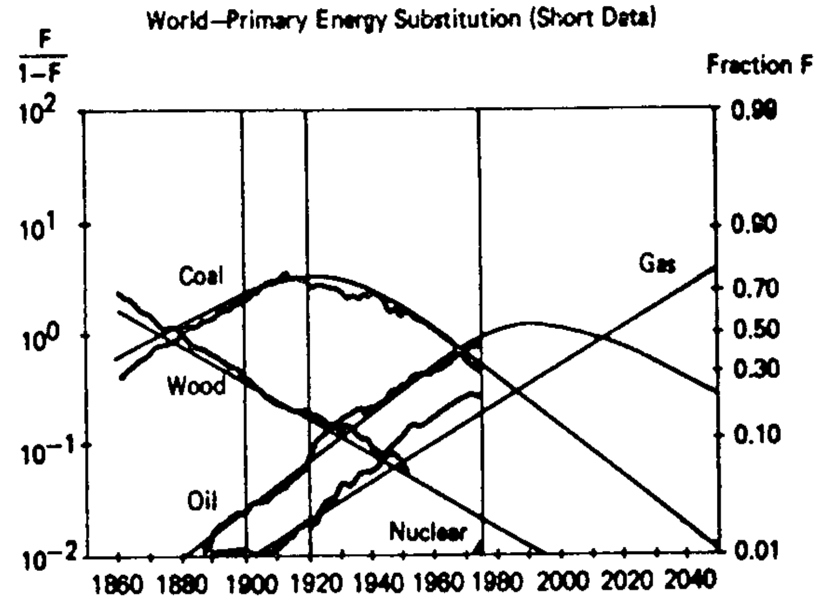
World–Primary Energy Substitution (Short Data)
F/1–F
Fraction F
10^2
10^1
10^0
10^−1
10^−2
0.99
0.90
0.70
0.50
0.30
0.10
0.01
Coal
Wood
Oil
Gas
1860 1880 1900 1920 1940 1960 1980 2000 2020 2040

Fig 5



World–Primary Energy Substitution(Short Data)
F/1–F
Fraction F
10^2
10^1
10^0
10^−1
10^−2
0.99
0.90
0.70
0.50
0.30
0.10
0.01
Coal
Oil
Gas
Wood
1860 1880 1900 1920 1940 1960 1980 2000 2020 2040

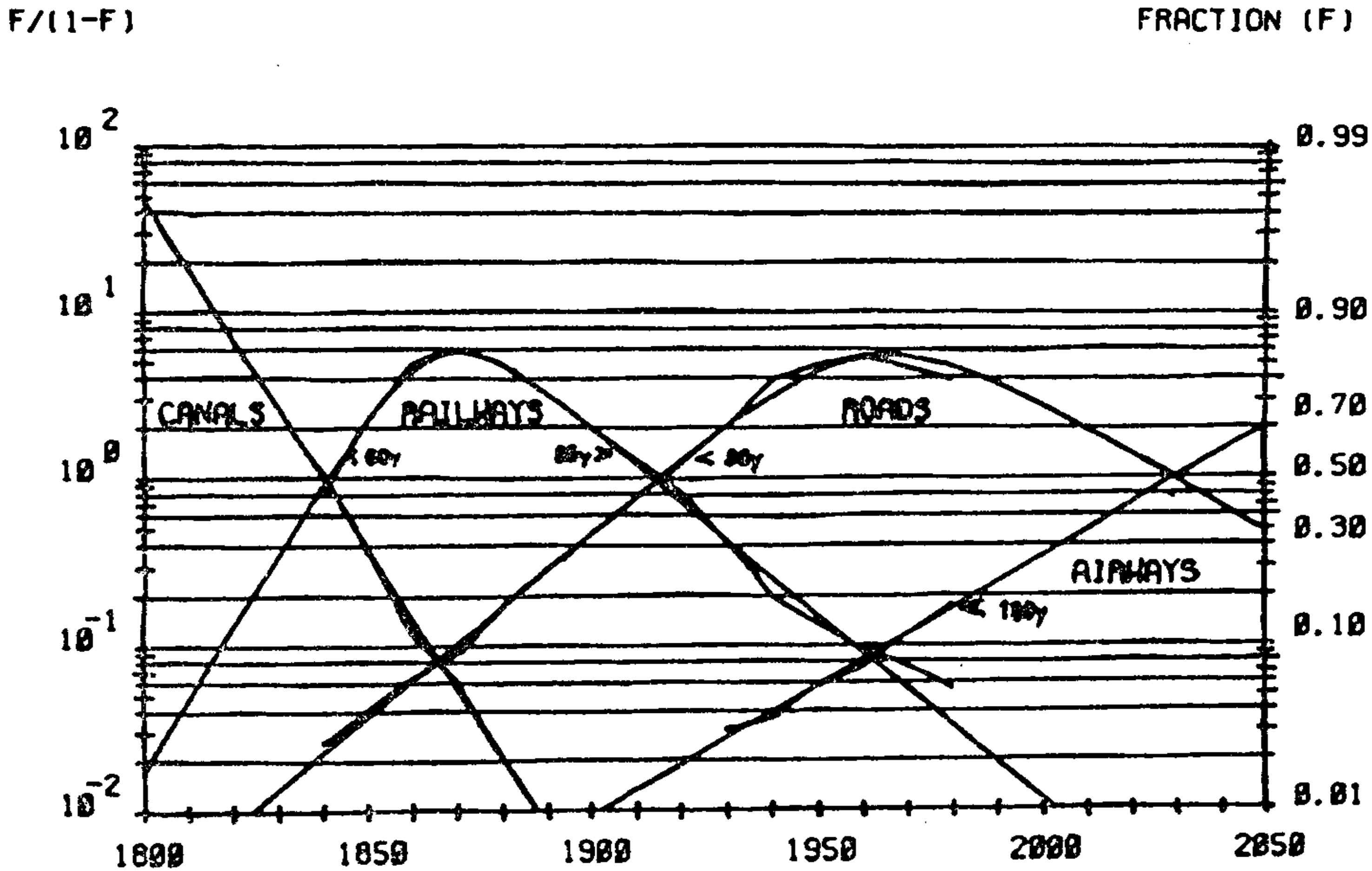
Fig 6



World–Primary Energy Substitution (Short Data)
F/(1−F)
Fraction F
10^2
10^1
10^0
10^−1
10^−2
0.99
0.90
0.70
0.50
0.30
0.10
0.01
Coal
Wood
Oil
Gas
Nuclear
1860 1880 1900 1920 1940 1960 1980 2000 2020 2040

Fig 7

USA - SUBSTITUTION OF TRANSPORT INFRASTRUCTURES



N. NAKICENOVIC, 1986

Fig 8

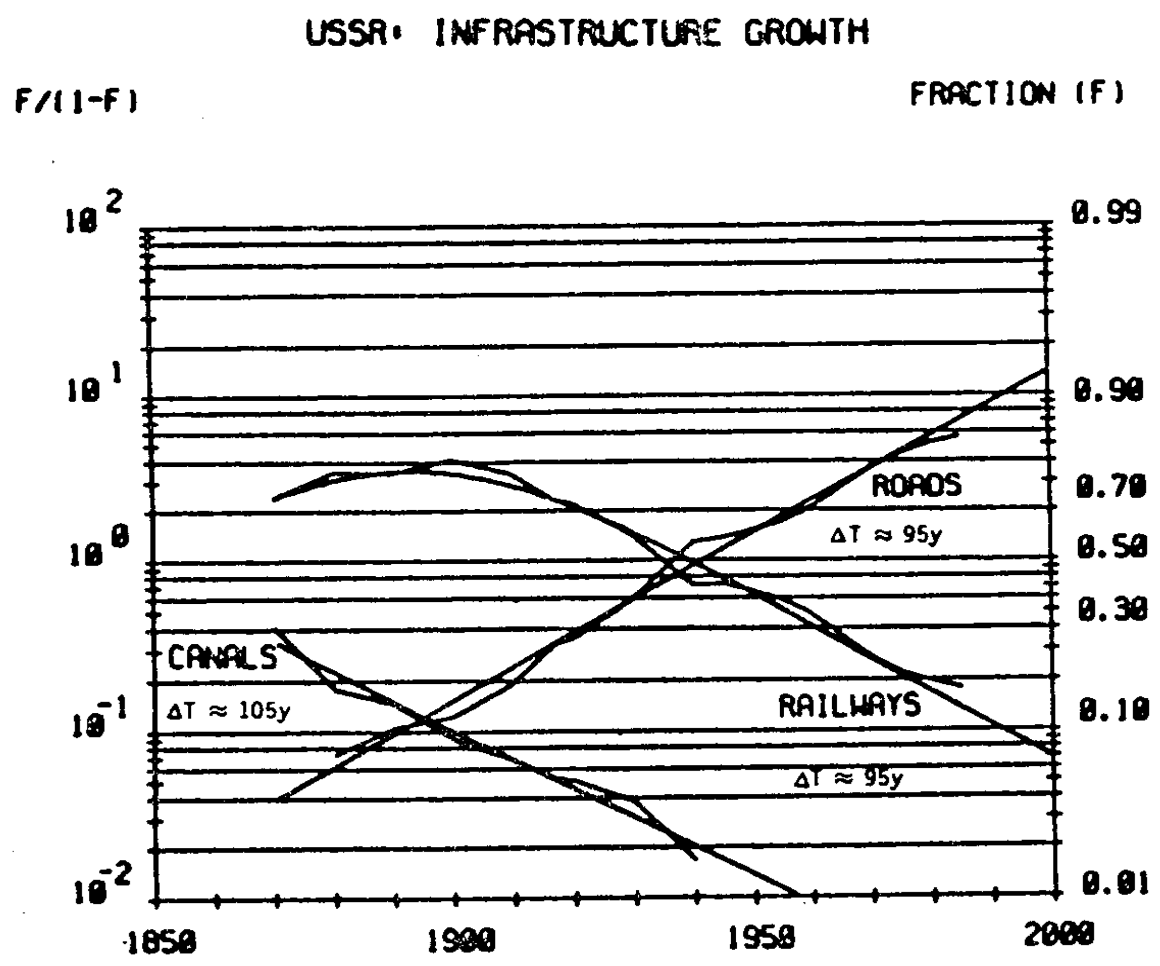
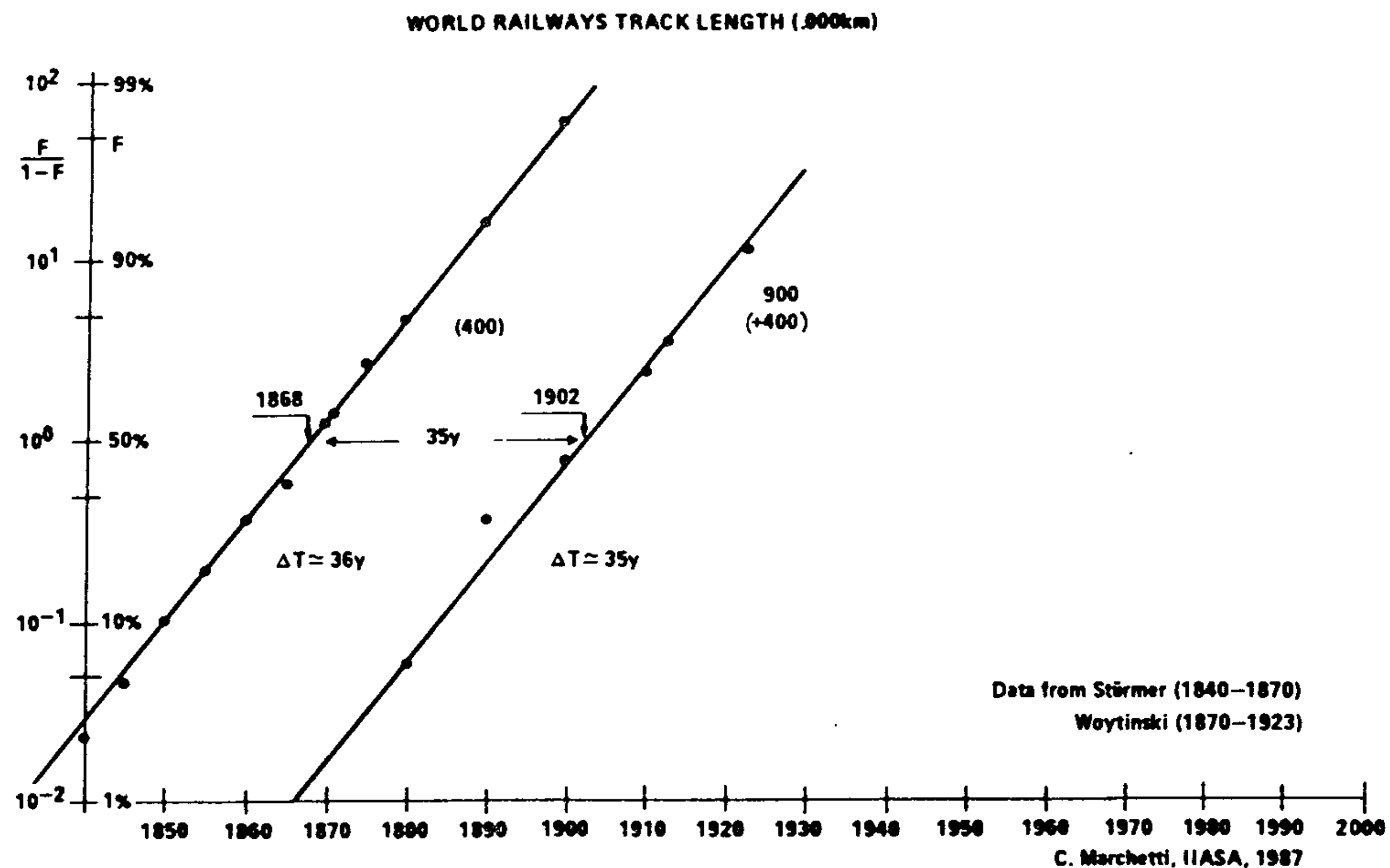

USSR: INFRASTRUCTURE GROWTH
F/(1-F)
FRACTION (F)
10^2
10^1
10^0
10^-1
10^-2
0.99
0.90
0.70
0.50
0.30
0.10
0.01
1850
1900
1950
2000
CANALS
ΔT ≈ 105y
ROADS
ΔT ≈ 95y
RAILWAYS
ΔT ≈ 95y
A. GRUEBLER, 1987

Fig 9



WORLD RAILWAYS TRACK LENGTH (.000km)
10²
F/(1−F)
10¹
10⁰
10⁻¹
10⁻²
99%
F
90%
50%
10%
1%
1868
1902
35y
(400)
900
(+400)
ΔT ≃ 36y
ΔT ≃ 35y
Data from Stürmer (1840–1870)
Woytinski (1870–1923)
1850
1860
1870
1880
1890
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
C. Marchetti, IIASA, 1987

Fig 10

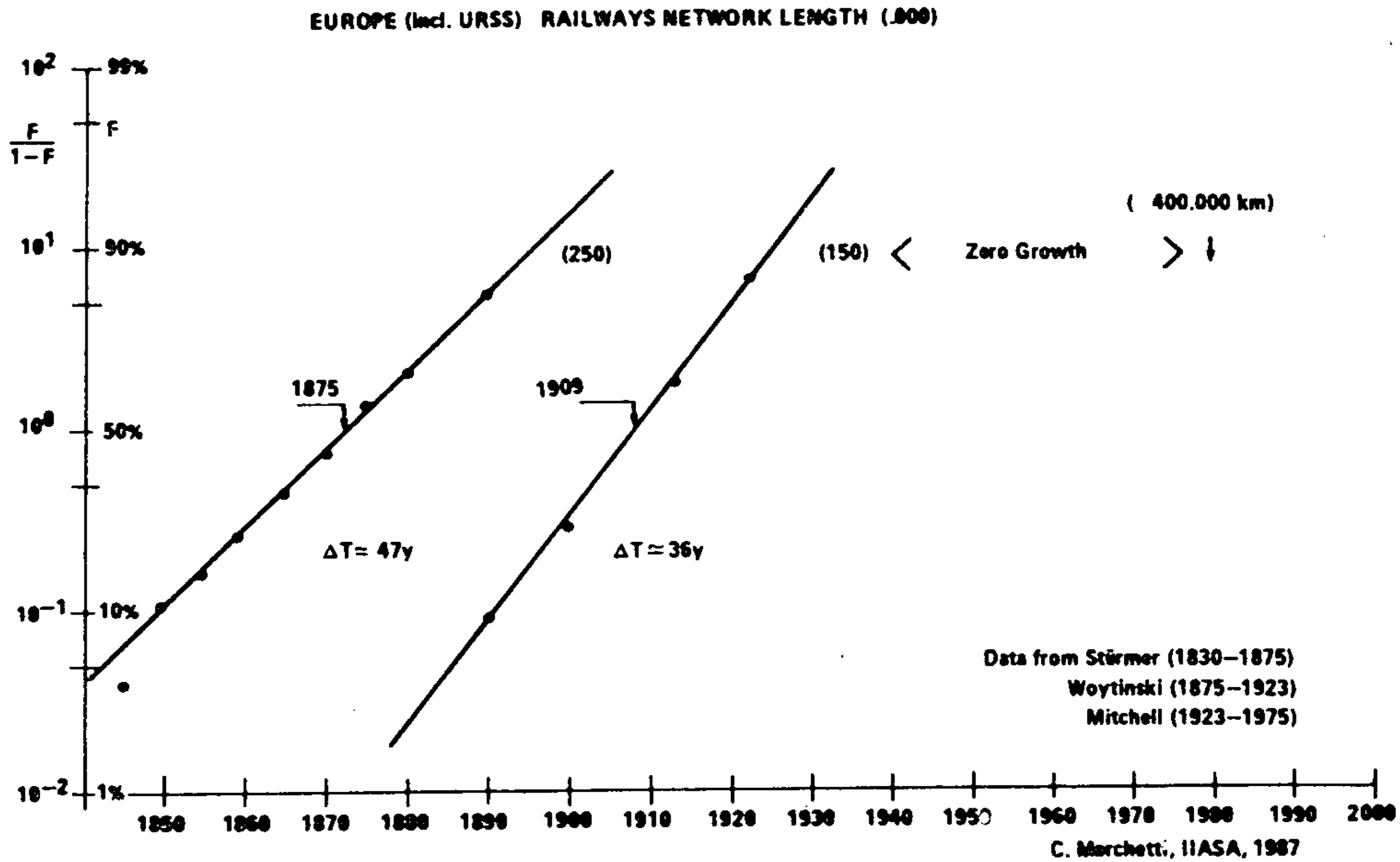

EUROPE (incl. URSS) RAILWAYS NETWORK LENGTH (.000)
F/(1−F)
10^2
10^1
10^0
10^−1
10^−2
99%
F
90%
50%
10%
1%
(250)
(150)
Zero Growth
(400.000 km)
1875
1909
ΔT= 47y
ΔT ≃ 36y
Data from Stürmer (1830–1875)
Woytinski (1875–1923)
Mitchell (1923–1975)
1850
1860
1870
1880
1890
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
C. Marchetti, IIASA, 1987

Fig 11

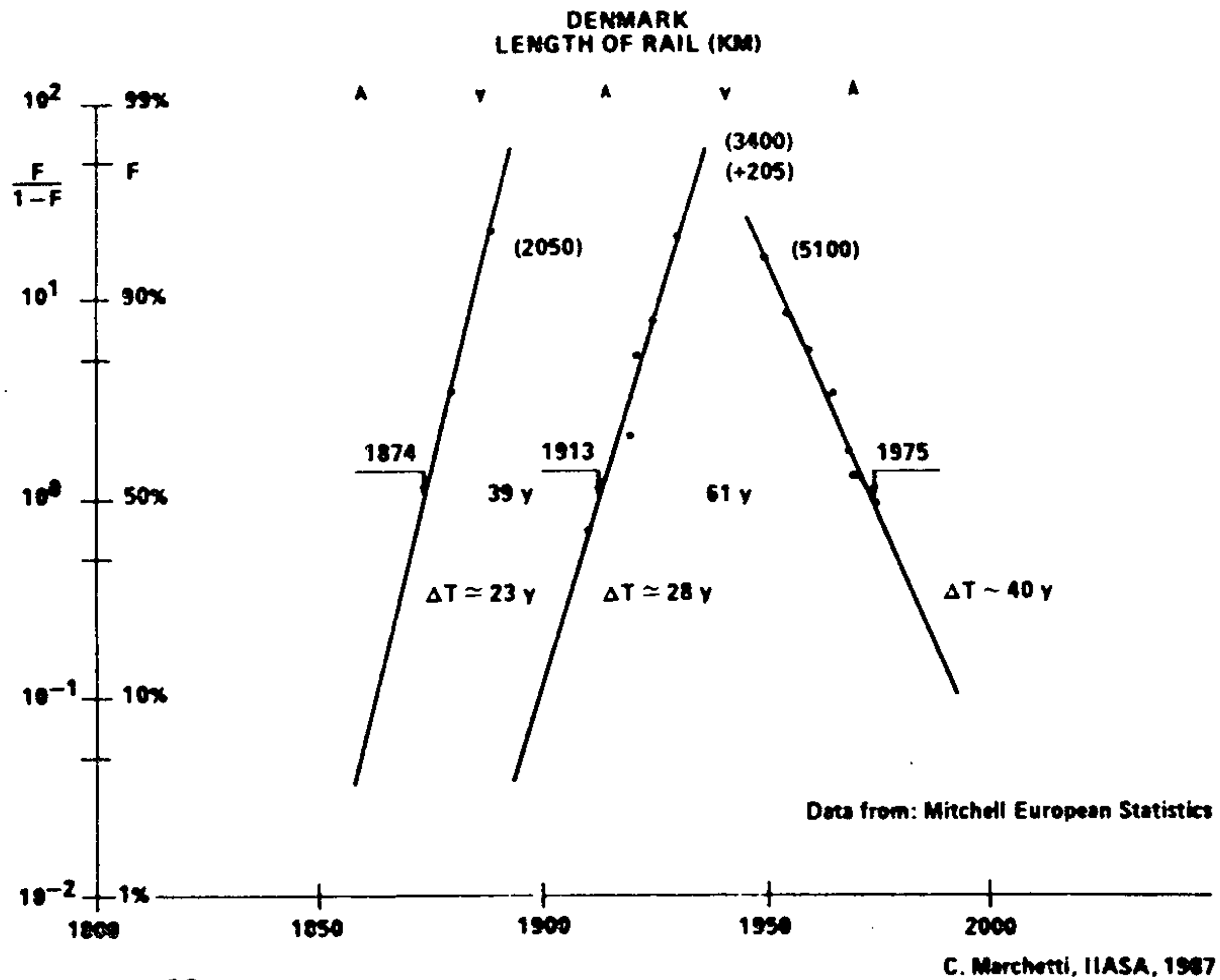
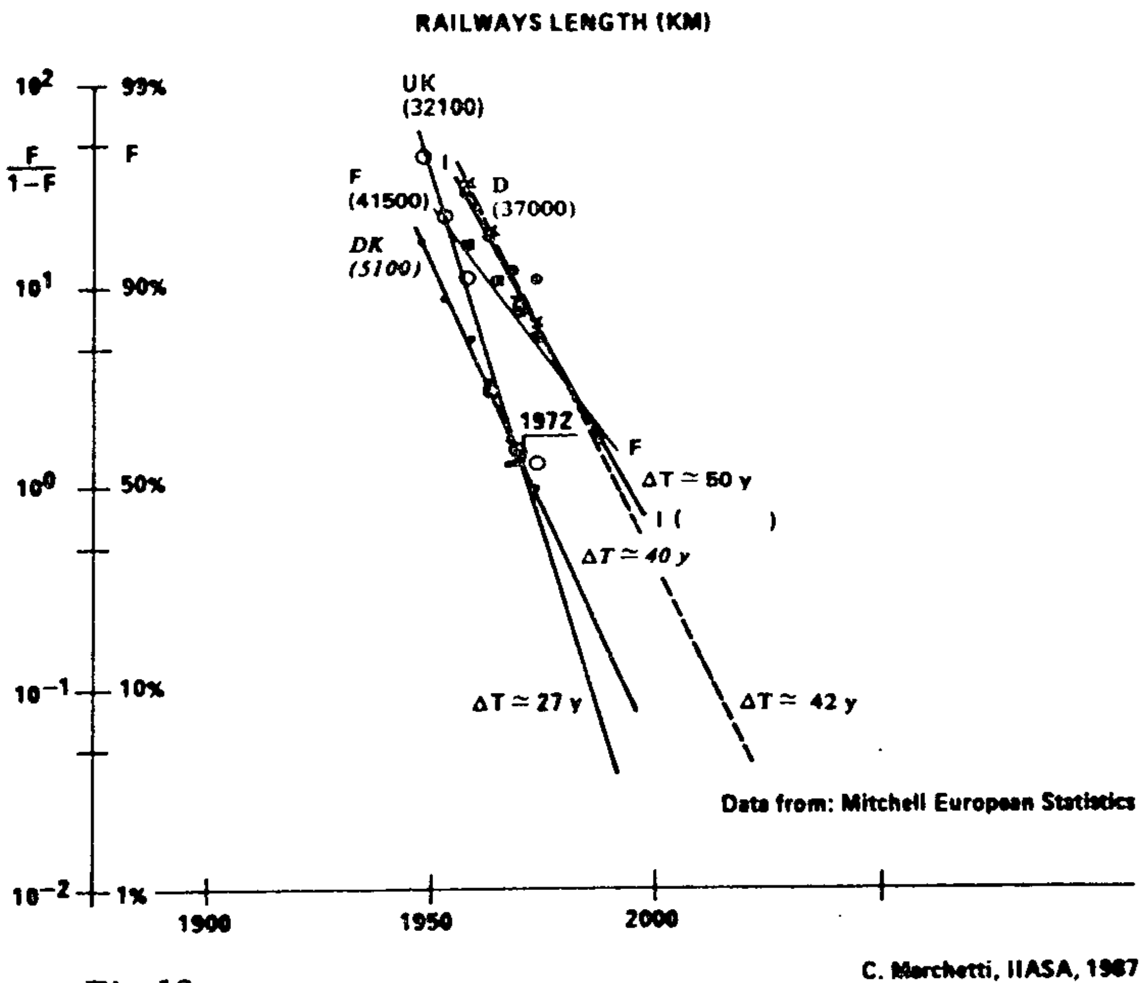
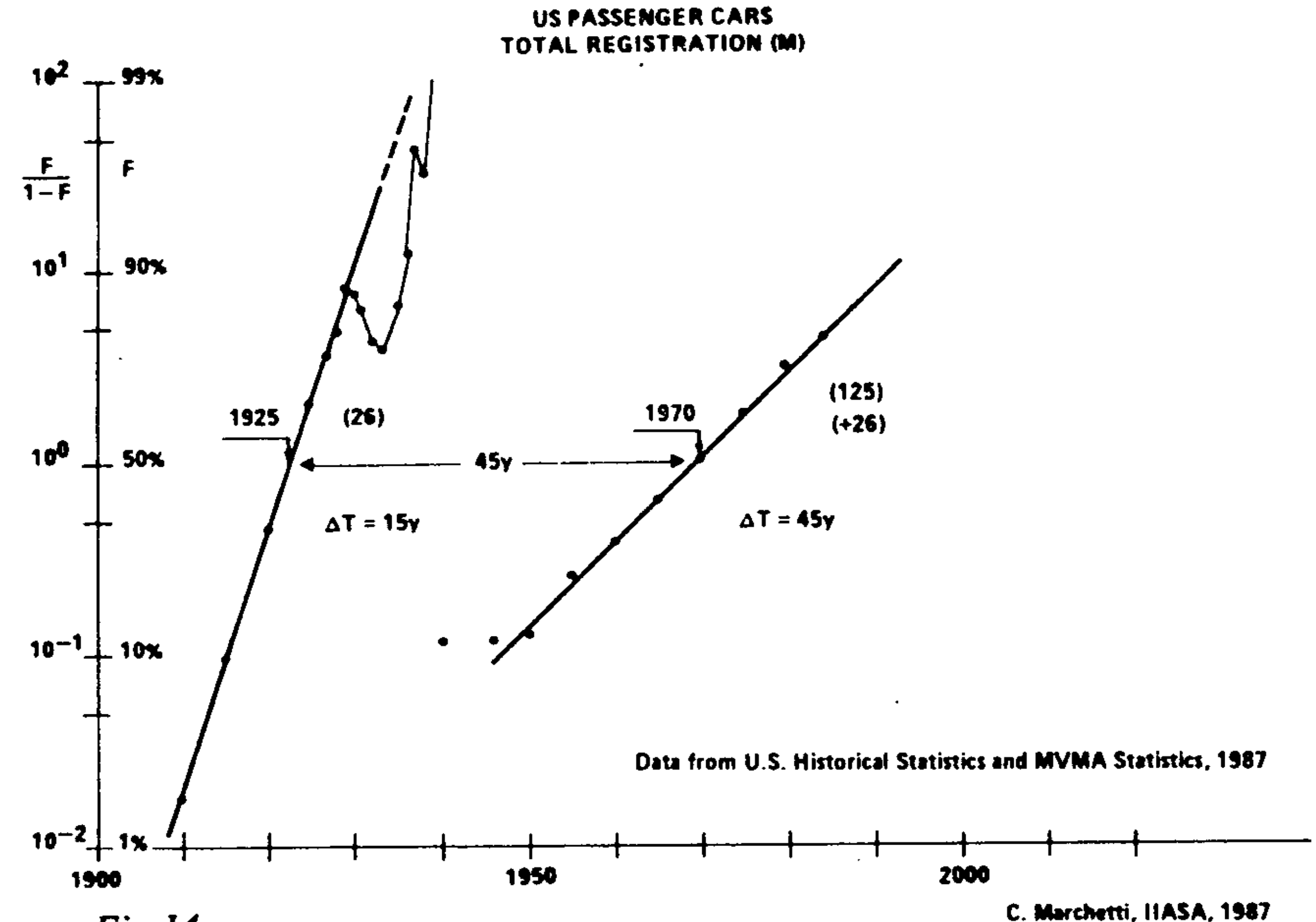

DENMARK
LENGTH OF RAIL (KM)
10^2
99%
$\frac{F}{1-F}$
F
10^1
90%
10^0
50%
10^{-1}
10%
10^{-2}
1%
1800
1850
1900
1950
2000
(2050)
(3400)
(+205)
(5100)
1874
1913
1975
39 y
61 y
$\Delta T \simeq 23$ y
$\Delta T \simeq 28$ y
$\Delta T \sim 40$ y
Data from: Mitchell European Statistics
C. Marchetti, IIASA, 1987

Fig 12



RAILWAYS LENGTH (KM)
10²
F/(1−F)
10¹
10⁰
10⁻¹
10⁻²
99%
F
90%
50%
10%
1%
1900
1950
2000
UK
(32100)
F
(41500)
DK
(5100)
D
(37000)
1972
F
ΔT ≃ 50 y
I (   )
ΔT ≃ 40 y
ΔT ≃ 27 y
ΔT ≃ 42 y
Data from: Mitchell European Statistics
C. Marchetti, IIASA, 1987

Fig 13



US PASSENGER CARS
TOTAL REGISTRATION (M)
10^2
99%
$\frac{F}{1-F}$
F
10^1
90%
10^0
50%
10^{-1}
10%
10^{-2}
1%
1925
(26)
45y
1970
(125)
(+26)
ΔT = 15y
ΔT = 45y
Data from U.S. Historical Statistics and MVMA Statistics, 1987
1900
1950
2000
C. Marchetti, IIASA, 1987

Fig 14

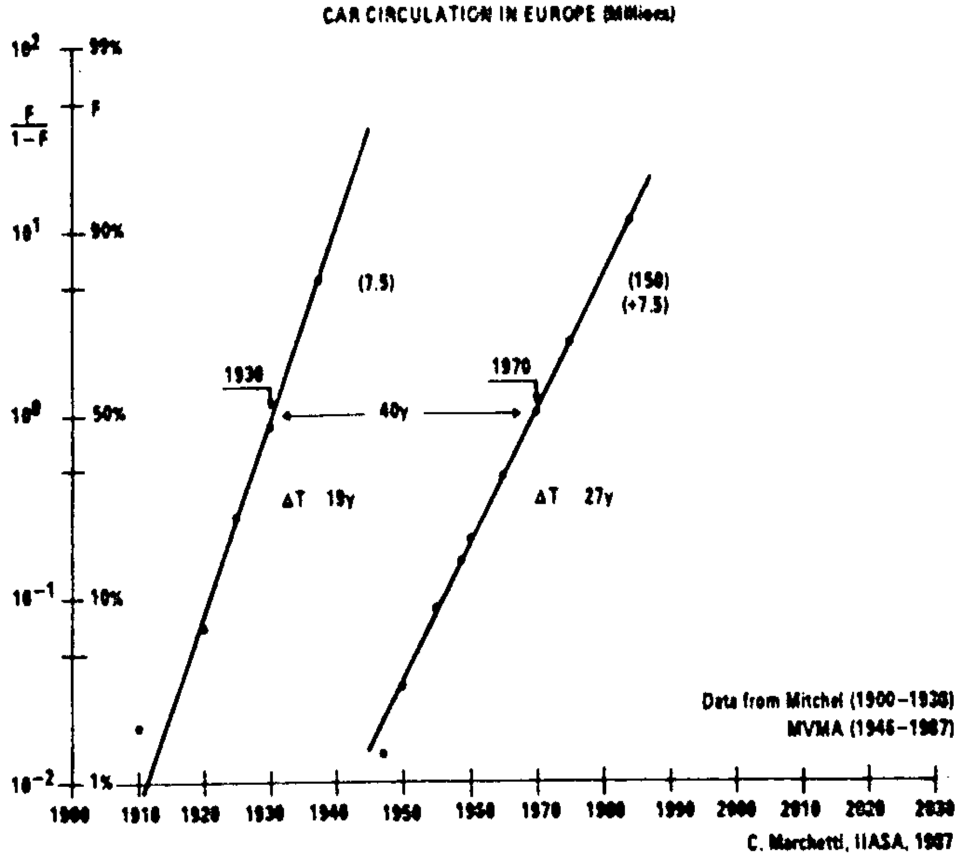

CAR CIRCULATION IN EUROPE (Millions)
F/(1−F)
F
99%
90%
50%
10%
1%
(7.5)
(150)
(+7.5)
1930
1970
40y
ΔT 19y
ΔT 27y
Data from Mitchel (1900−1930)
MVMA (1946−1987)
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020
2030
C. Marchetti, IIASA, 1987

Fig 15

CAR POPULATION IN SIX DIFFERENT COUNTRIES AS PERCENTAGE OF SATURATION LEVEL

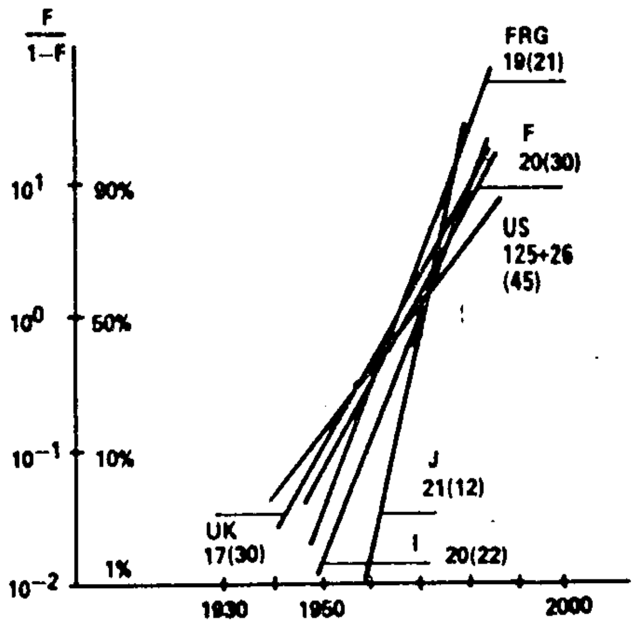


Fig 16

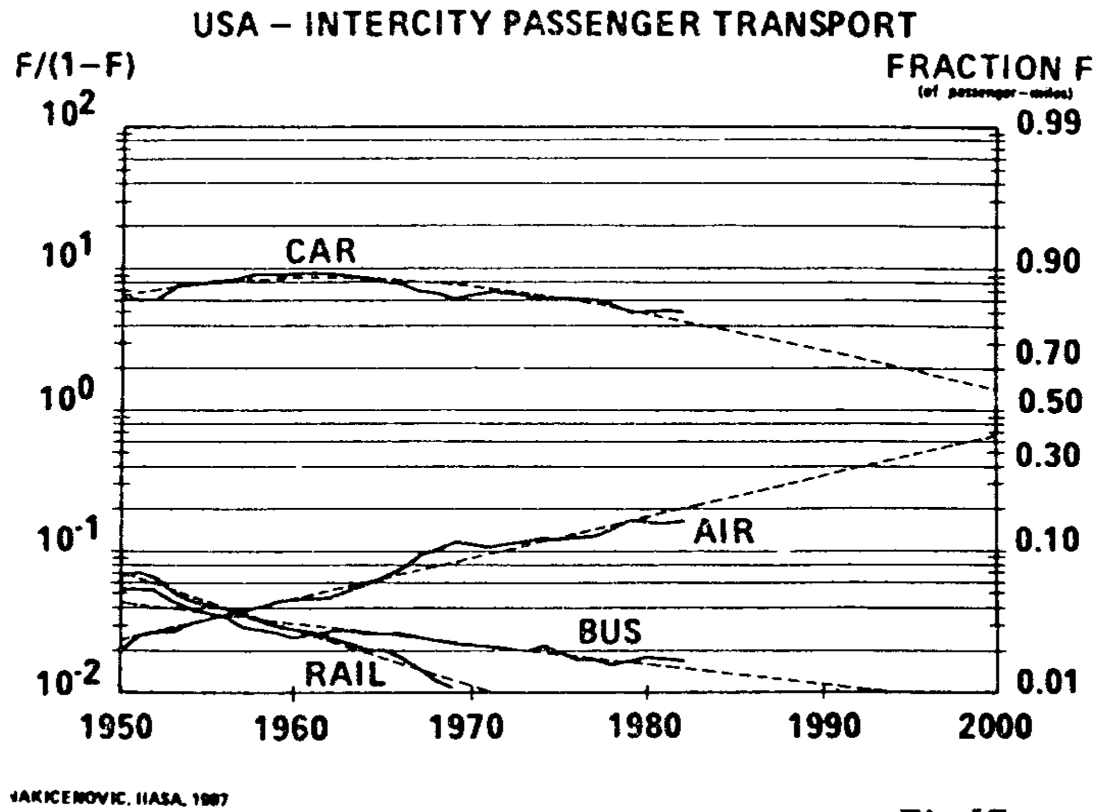

USA – INTERCITY PASSENGER TRANSPORT
F/(1–F)
FRACTION F
(of passenger-miles)
10^2
10^1
10^0
10^-1
10^-2
0.99
0.90
0.70
0.50
0.30
0.10
0.01
CAR
AIR
BUS
RAIL
1950
1960
1970
1980
1990
2000
NAKICENOVIC, IIASA, 1987

Fig 17

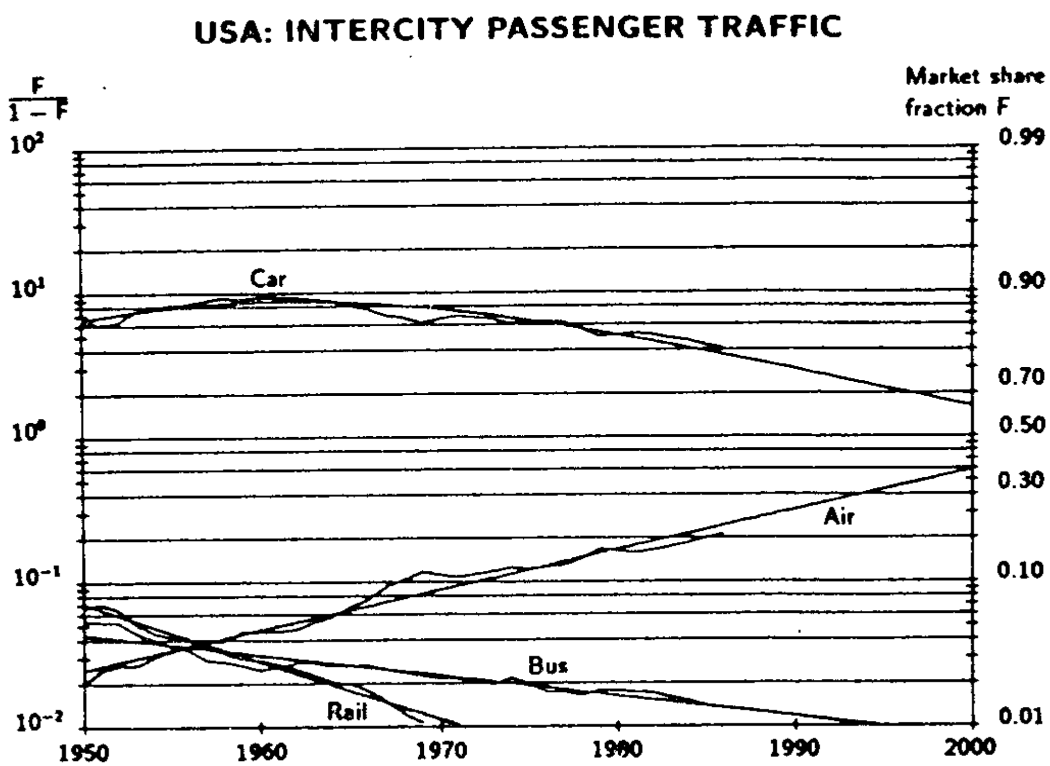
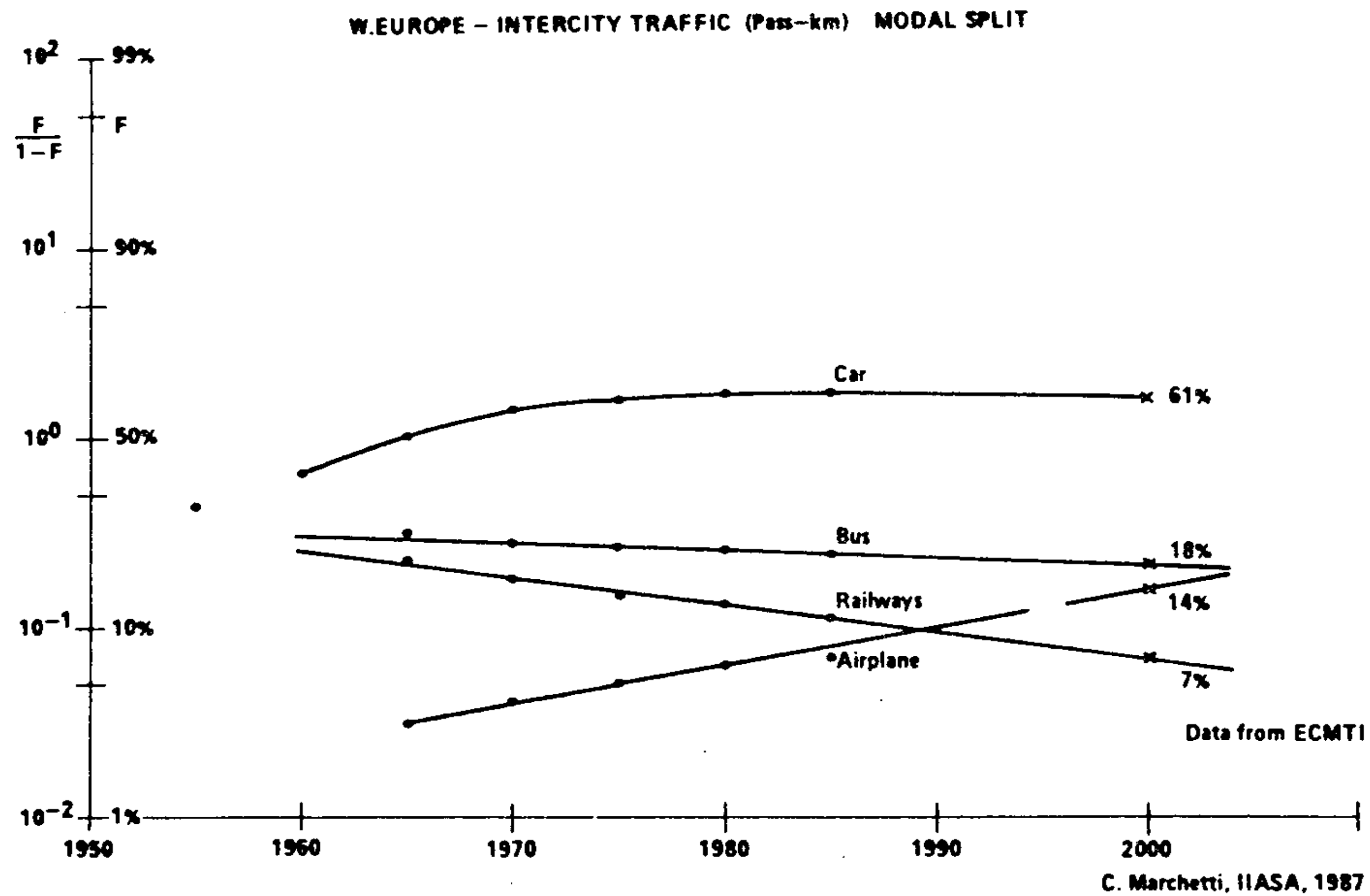

USA: INTERCITY PASSENGER TRAFFIC
F/(1 − F)
10²
10¹
10⁰
10⁻¹
10⁻²
Market share
fraction F
0.99
0.90
0.70
0.50
0.30
0.10
0.01
Car
Air
Bus
Rail
1950
1960
1970
1980
1990
2000

Fig 18



W.EUROPE – INTERCITY TRAFFIC (Pass–km) MODAL SPLIT
10²
99%
F/1−F
F
10¹
90%
10⁰
50%
10⁻¹
10%
10⁻²
1%
1950
1960
1970
1980
1990
2000
Car
61%
Bus
18%
Railways
14%
Airplane
7%
Data from ECMTI
C. Marchetti, IIASA, 1987

Fig 19

WORLD AIR TRANSPORT – ALL OPERATIONS
(10^6 Passenger – km/h)

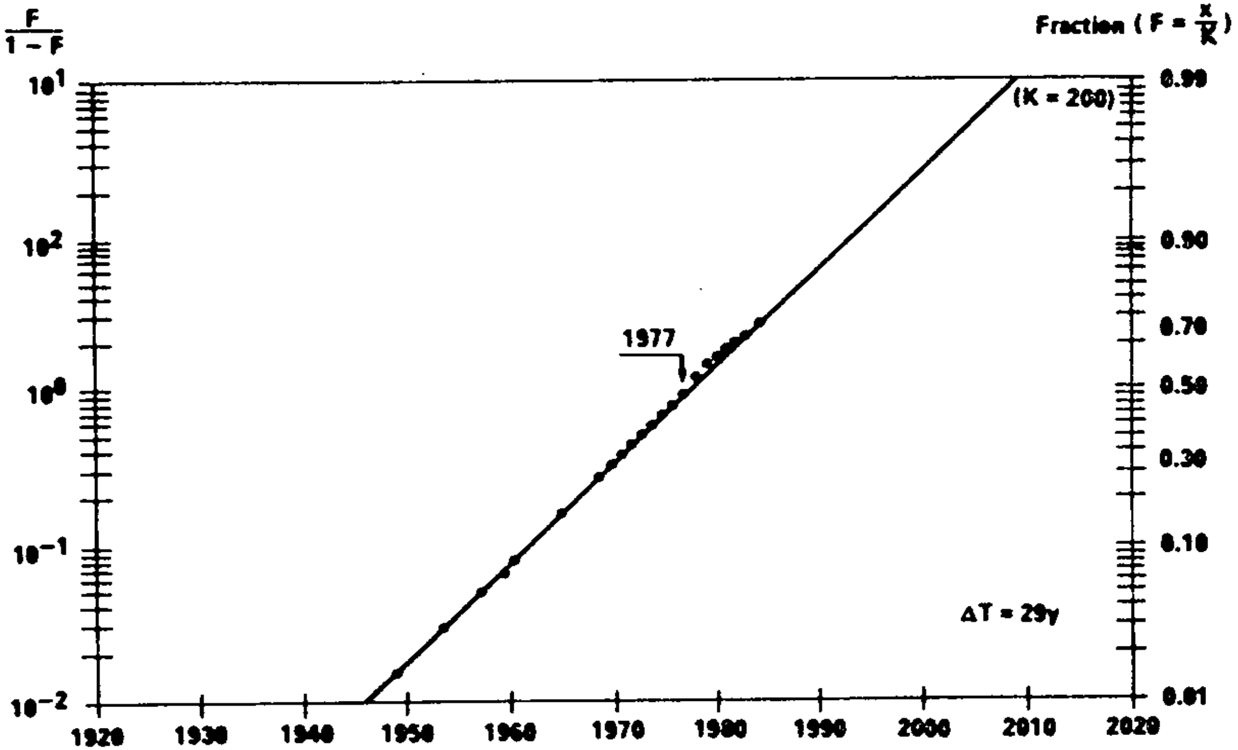


Fig 20

N. Nakicenovic, 1986

IATA FLEET – GRAND TOTALS

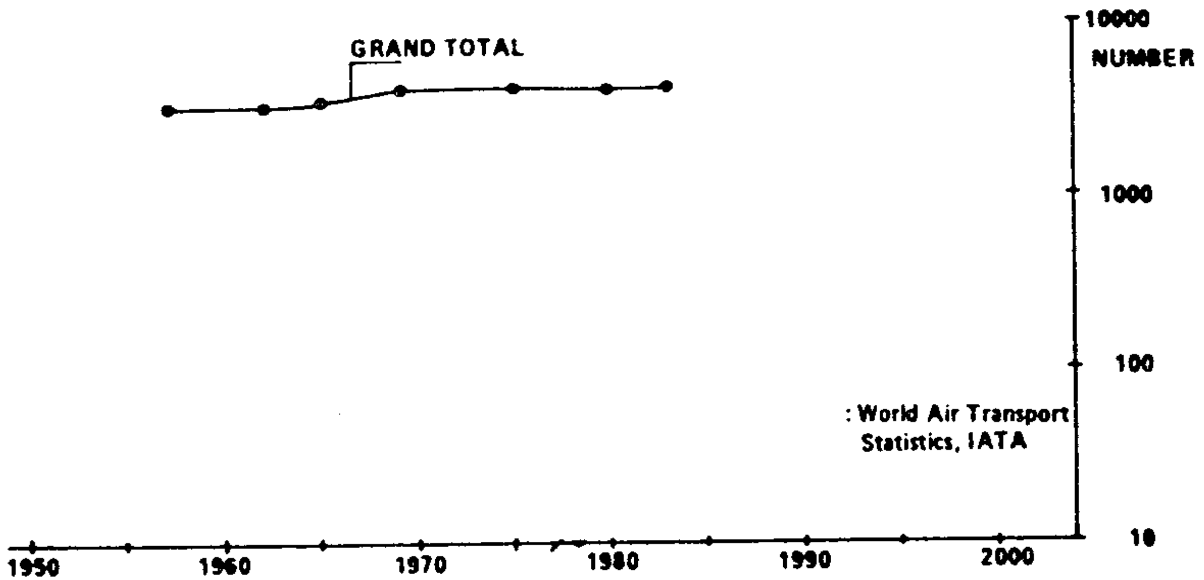


Fig 21

PASSENGER AIRCRAFT PERFORMANCE
(1000 Passenger – km/h)

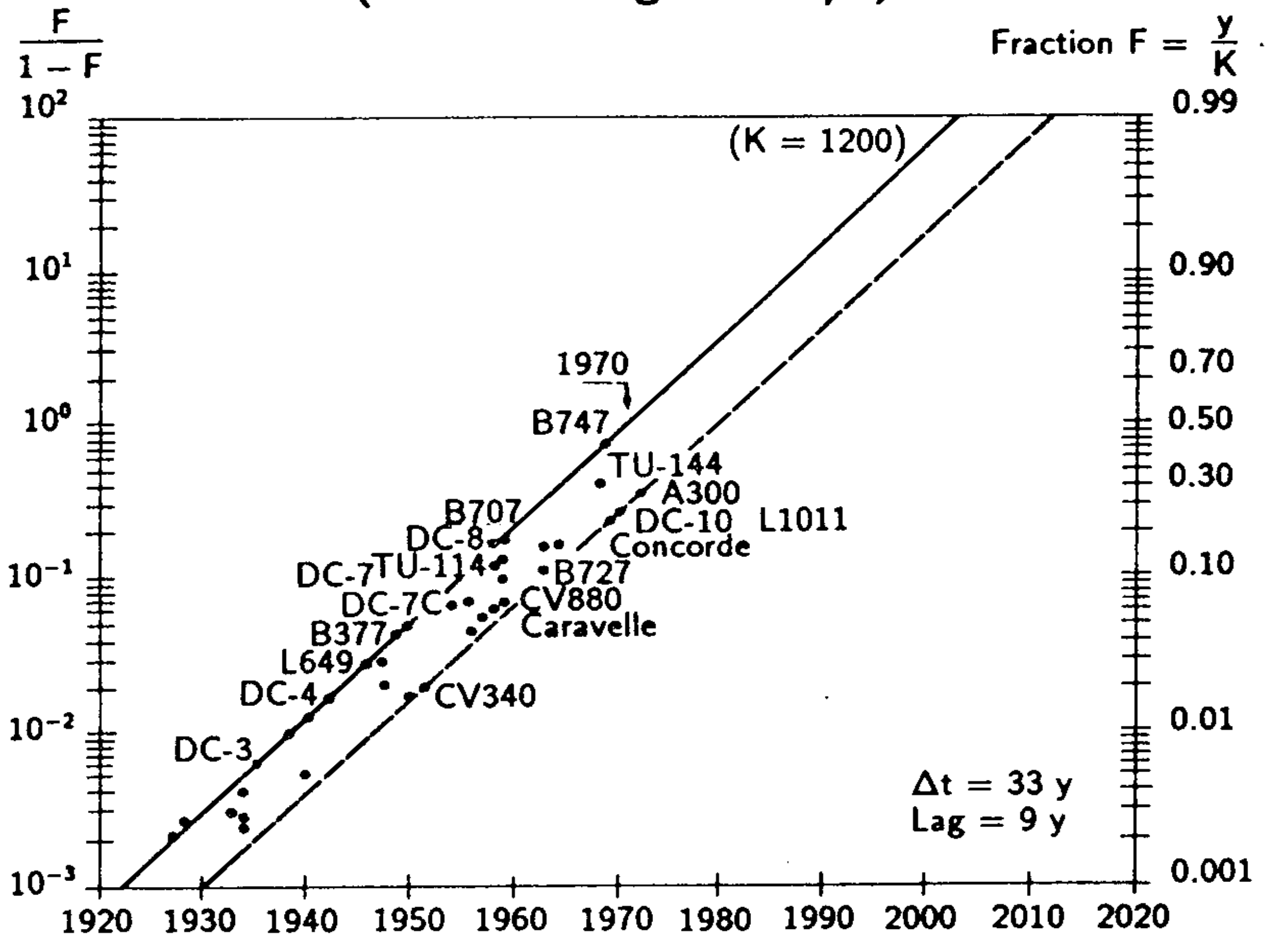


Fig 22

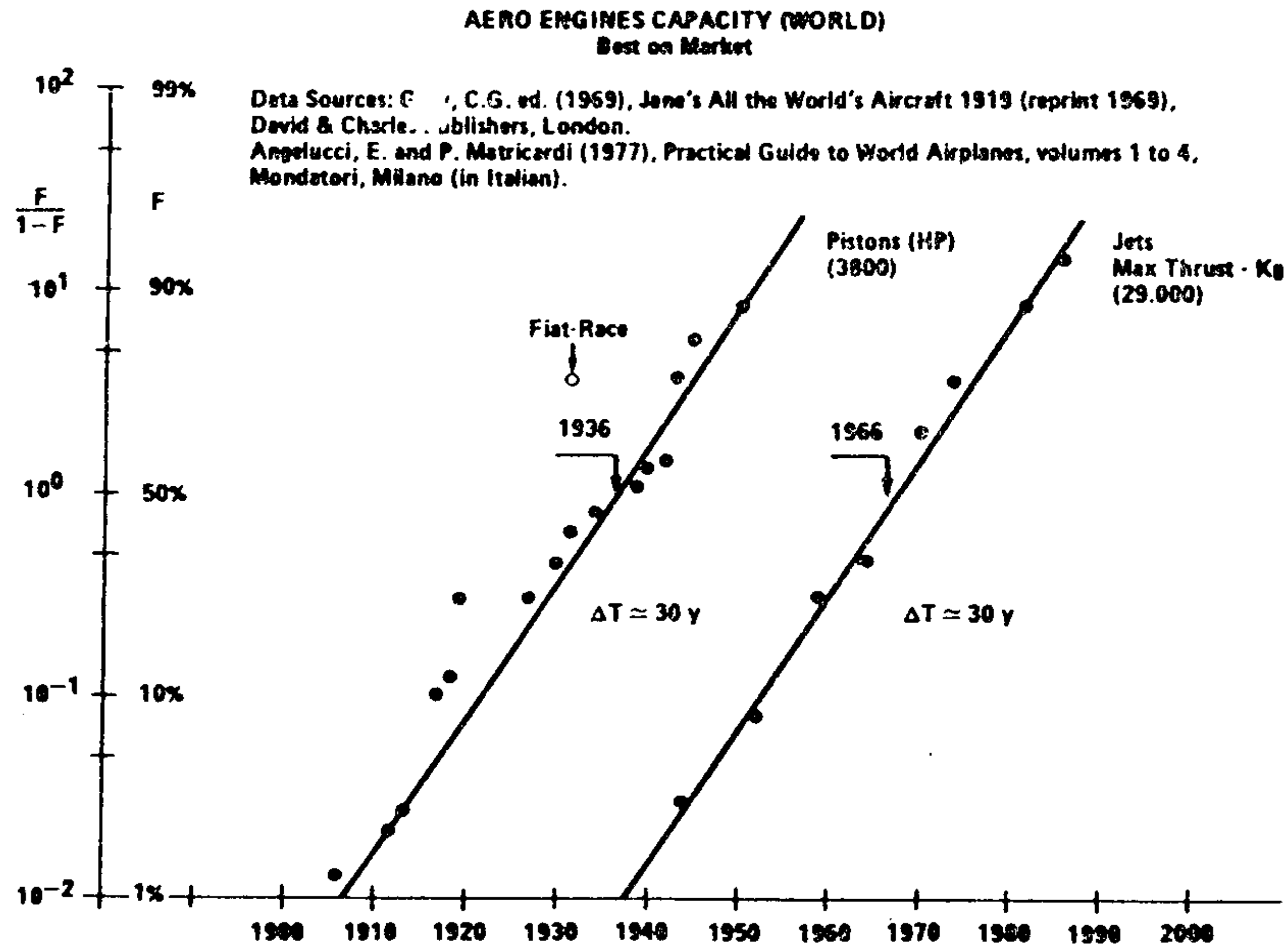
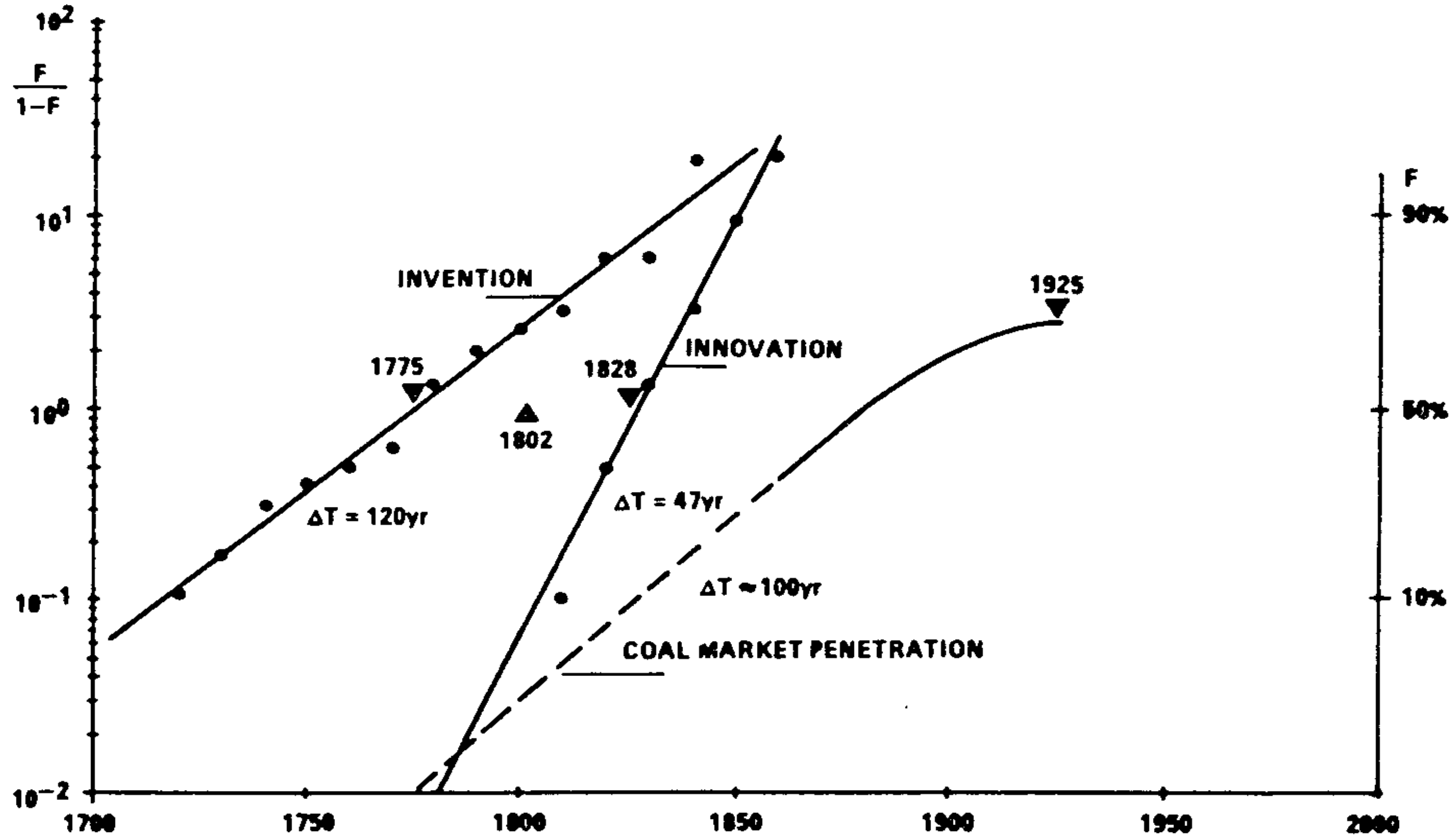

AERO ENGINES CAPACITY (WORLD)
Best on Market
Data Sources: C , C.G. ed. (1969), Jane's All the World's Aircraft 1919 (reprint 1969), David & Charle. . ublishers, London.
Angelucci, E. and P. Matricardi (1977), Practical Guide to World Airplanes, volumes 1 to 4, Mondatori, Milano (in Italian).
$\frac{F}{1-F}$
F
10^2
10^1
10^0
10^{-1}
10^{-2}
99%
90%
50%
10%
1%
Pistons (HP)
(3800)
Jets
Max Thrust - Kg
(29.000)
Fiat-Race
1936
1966
$\Delta T \simeq 30$ y
$\Delta T \simeq 30$ y
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
A. Grübler – IIASA, 1986

Fig 23



10^2
$\frac{F}{1-F}$
10^1
10^0
10^{-1}
10^{-2}
INVENTION
INNOVATION
1775
1802
1828
1925
$\Delta T = 120yr$
$\Delta T = 47yr$
$\Delta T \approx 100yr$
COAL MARKET PENETRATION
F
90%
50%
10%
1700
1750
1800
1850
1900
1950
2000

Fig 24

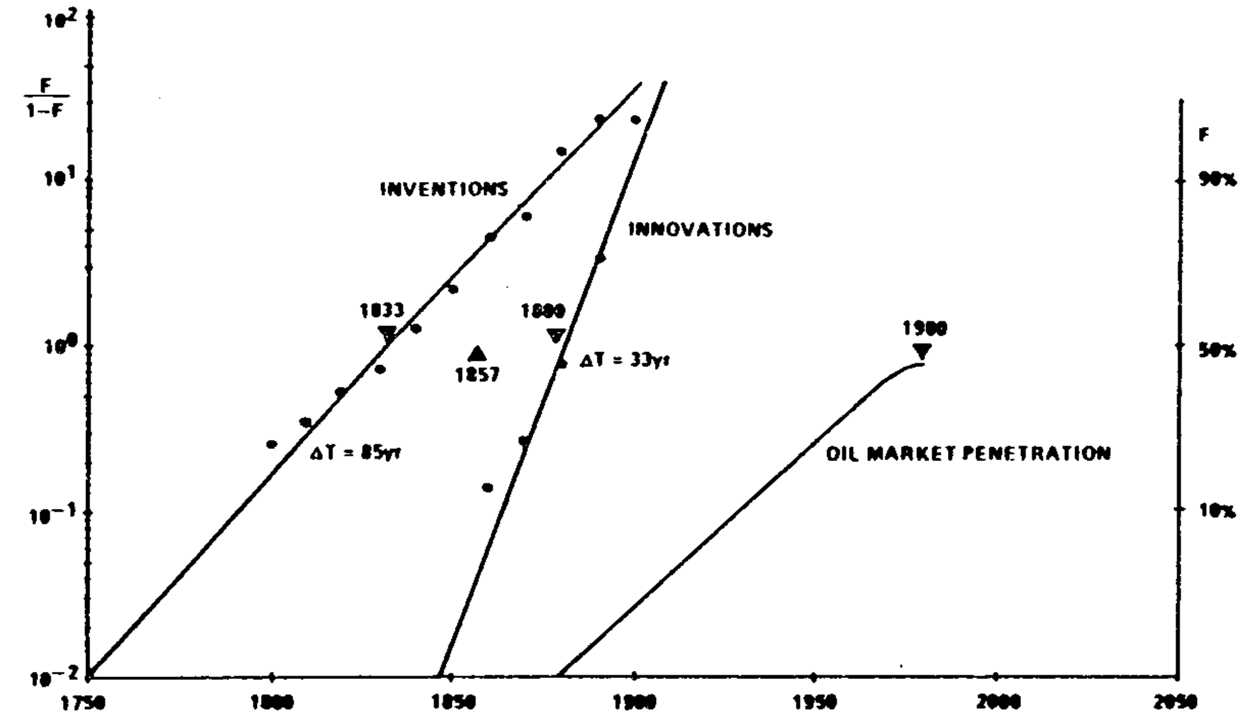

10^2
$\frac{F}{1-F}$
10^1
10^0
10^{-1}
10^{-2}
1750
1800
1850
1900
1950
2000
2050
F
90%
50%
10%
INVENTIONS
INNOVATIONS
OIL MARKET PENETRATION
1833
1857
1880
1980
ΔT = 85yr
ΔT = 33yr

Fig 25

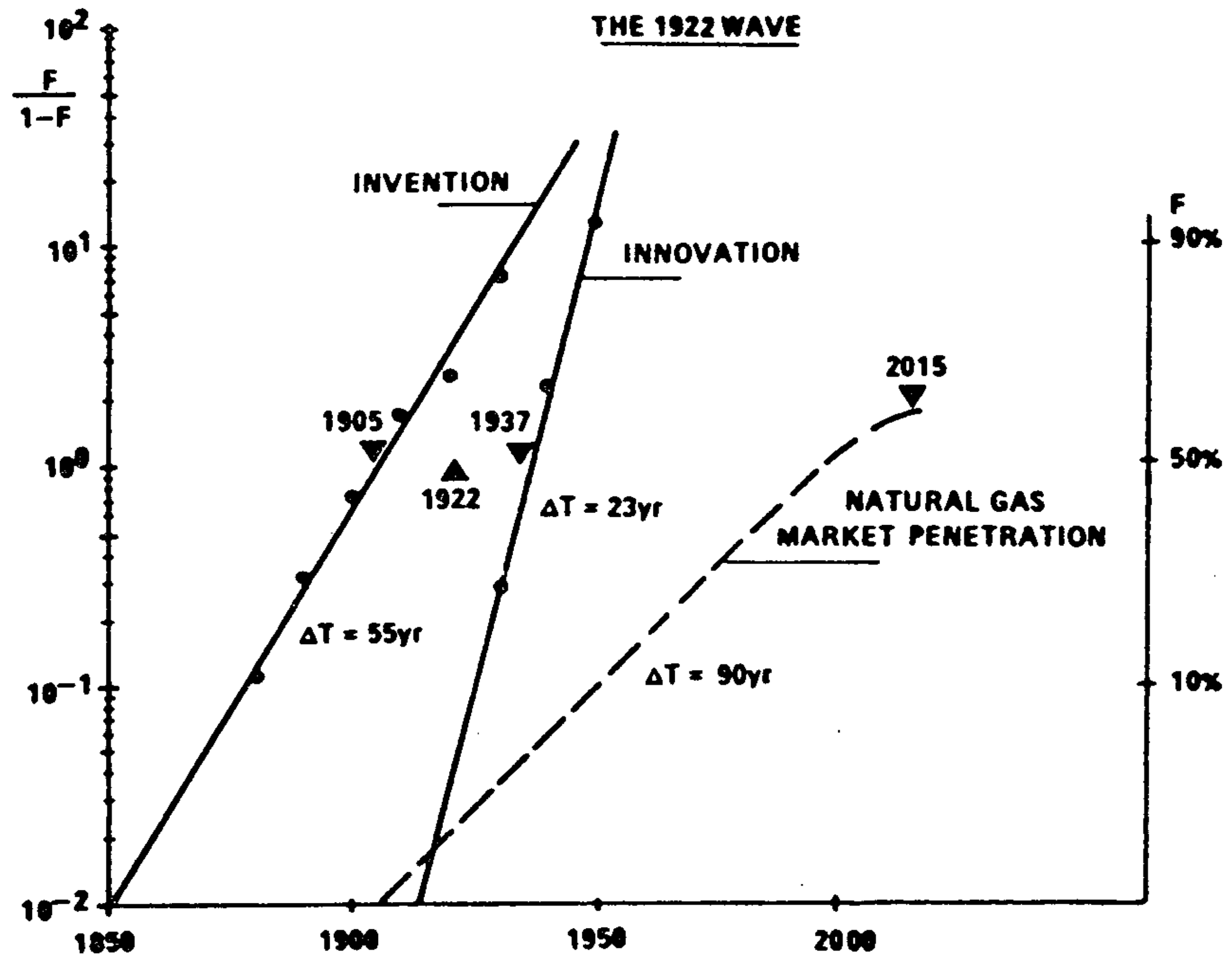

THE 1922 WAVE
F/1-F
10^2
10^1
10^0
10^-1
10^-2
INVENTION
INNOVATION
1905
1922
1937
2015
ΔT = 55yr
ΔT = 23yr
ΔT = 90yr
NATURAL GAS
MARKET PENETRATION
F
90%
50%
10%
1850
1900
1950
2000

Fig 26

POPULATION OF NEW COMPUTER MANUFACTURES

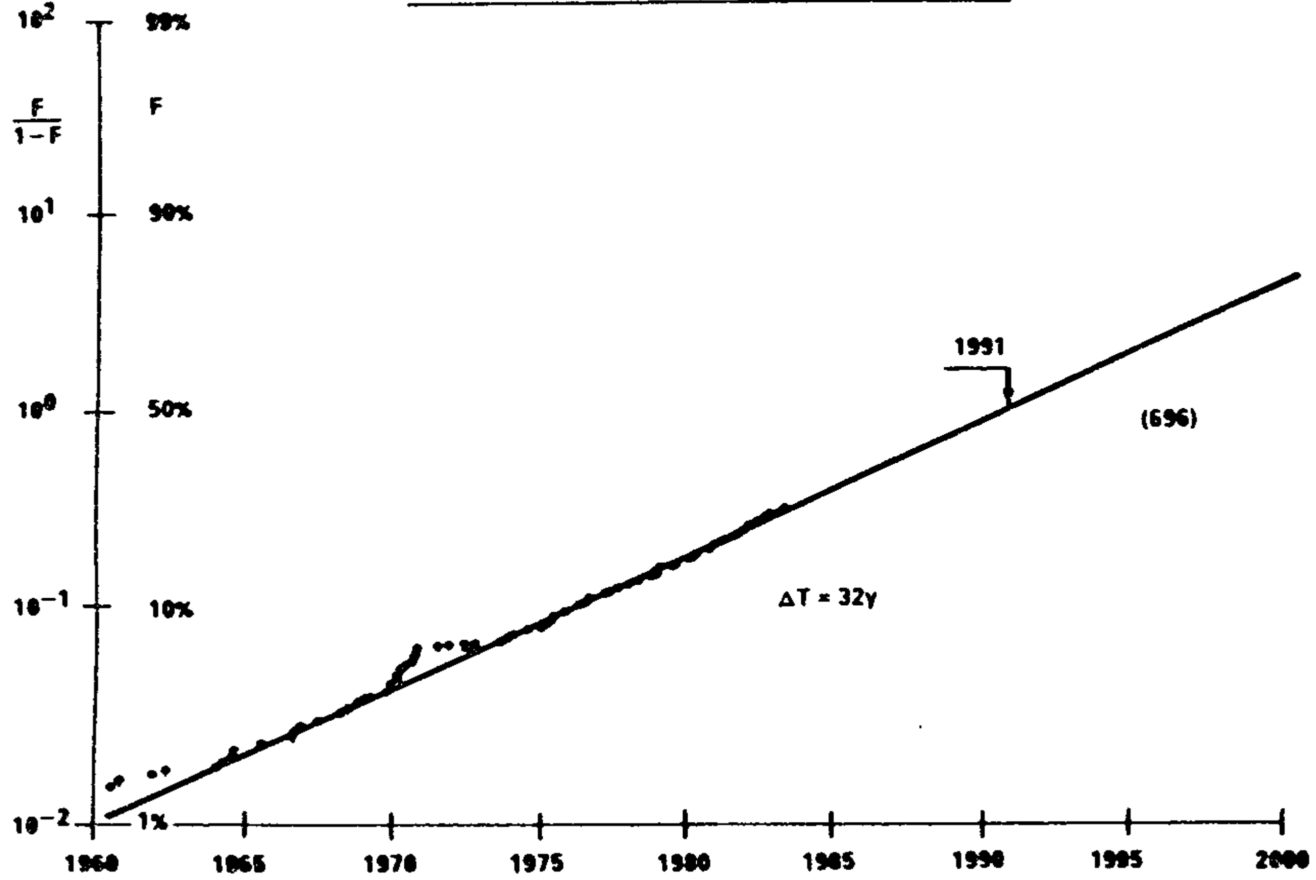


Fig 27

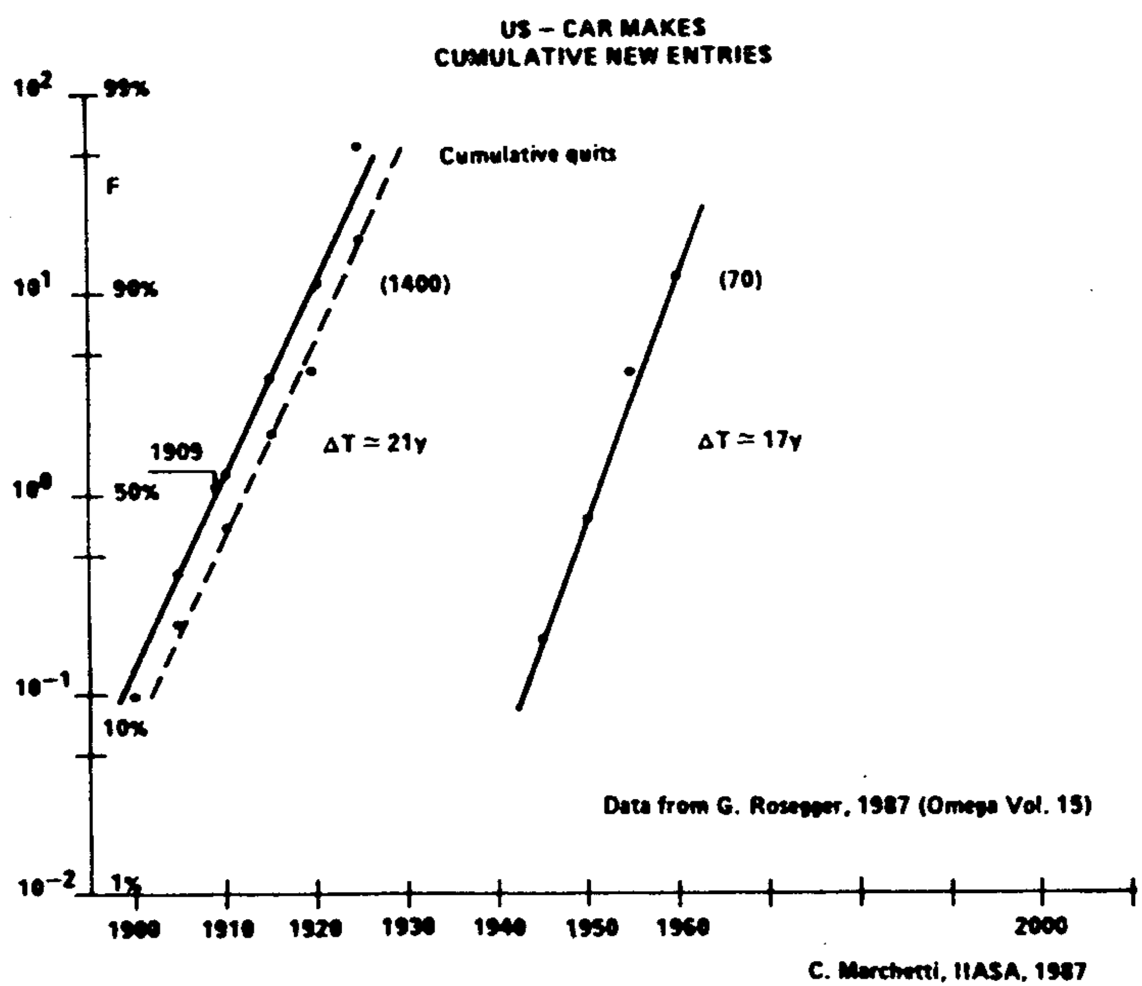

US – CAR MAKES
CUMULATIVE NEW ENTRIES
Cumulative quits
F
99%
90%
50%
10%
1%
10^2
10^1
10^0
10^{-1}
10^{-2}
1909
(1400)
$\Delta T \simeq 21y$
(70)
$\Delta T \simeq 17y$
Data from G. Rosegger, 1987 (Omega Vol. 15)
1900
1910
1920
1930
1940
1950
1960
2000
C. Marchetti, IIASA, 1987

Fig 28

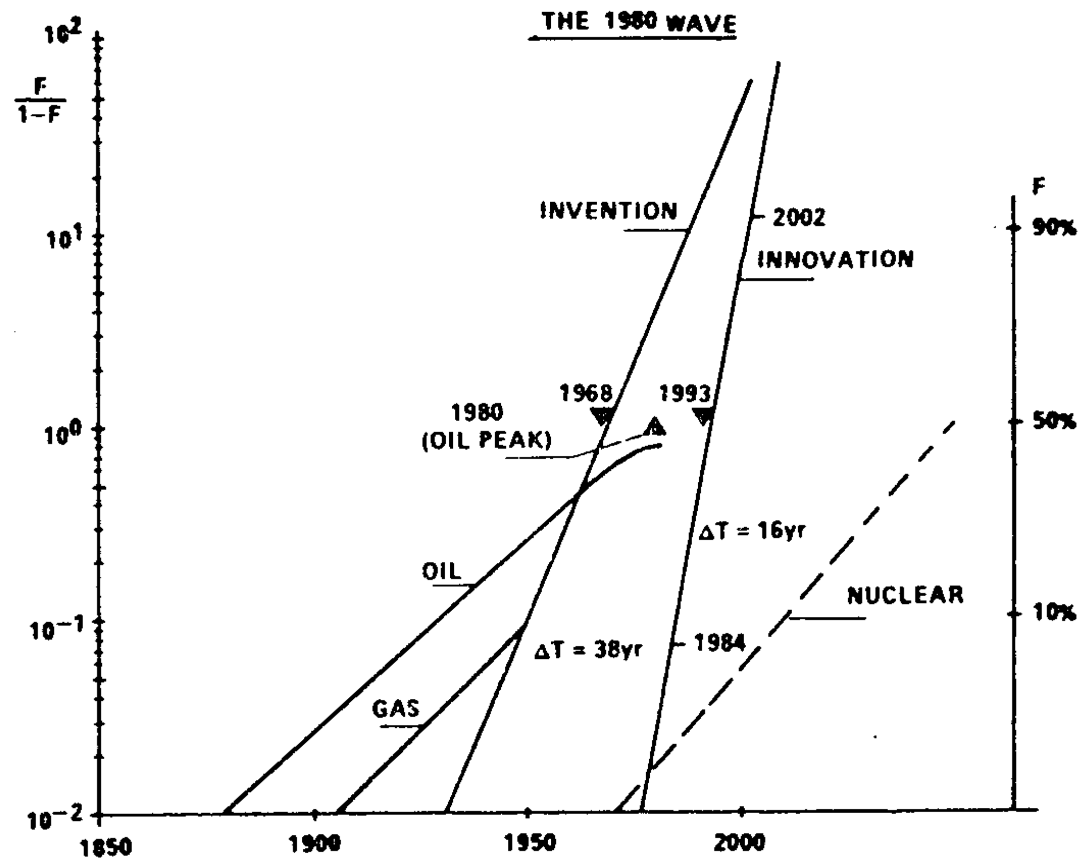

THE 1980 WAVE
F/(1−F)
10^2
10^1
10^0
10^−1
10^−2
1850
1900
1950
2000
F
90%
50%
10%
INVENTION
INNOVATION
2002
1968
1993
1980
(OIL PEAK)
OIL
GAS
ΔT = 16yr
ΔT = 38yr
1984
NUCLEAR

Fig 29

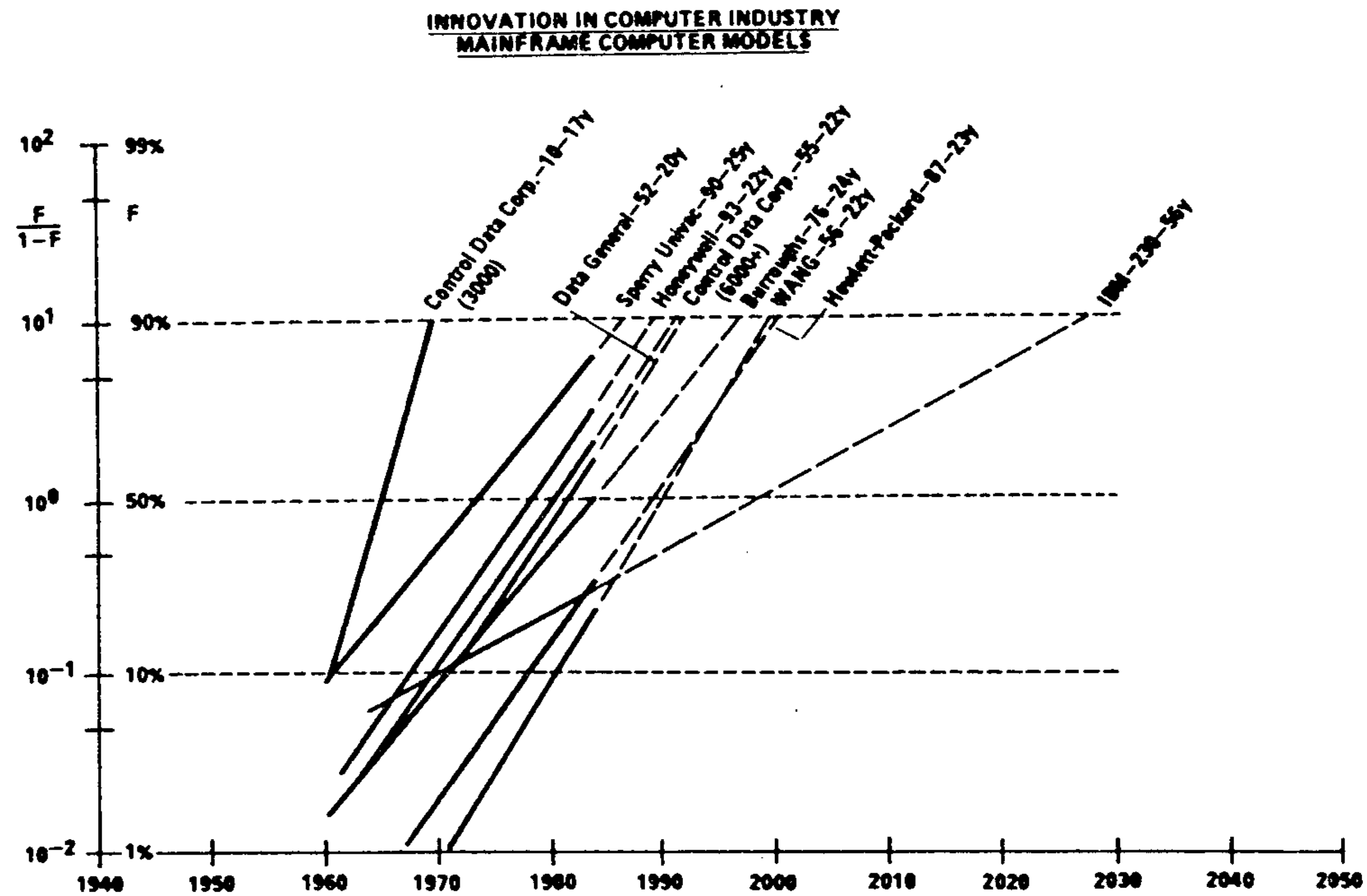

INNOVATION IN COMPUTER INDUSTRY
MAINFRAME COMPUTER MODELS
Control Data Corp.–18–17y (3000)
Data General–52–20y
Sperry Univac–90–25y
Honeywell–93–22y
Control Data Corp.–55–22y (6000+)
Burroughs–76–24y
WANG–56–22y
Hewlett-Packard–87–23y
IBM–230–56y
10^2
$\frac{F}{1-F}$
10^1
10^0
10^{-1}
10^{-2}
99%
F
90%
50%
10%
1%
1940
1950
1960
1970
1980
1990
2000
2010
2020
2030
2040
2050

Fig 30

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

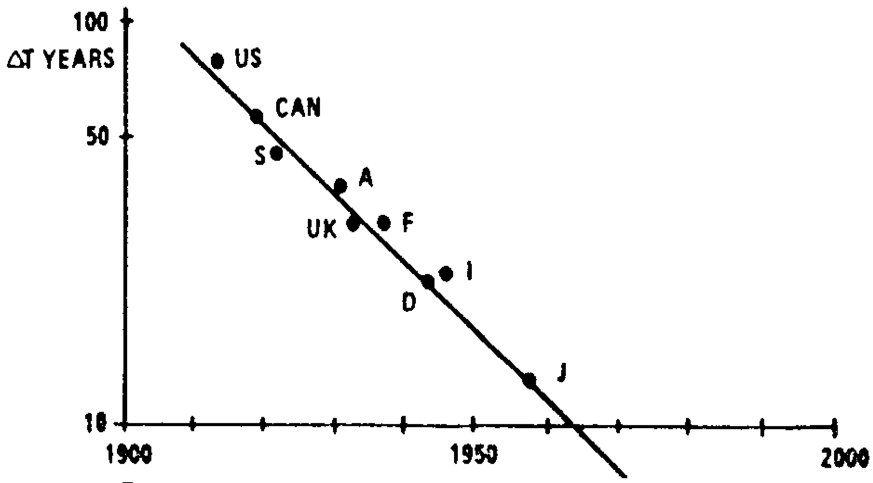


Fig 31

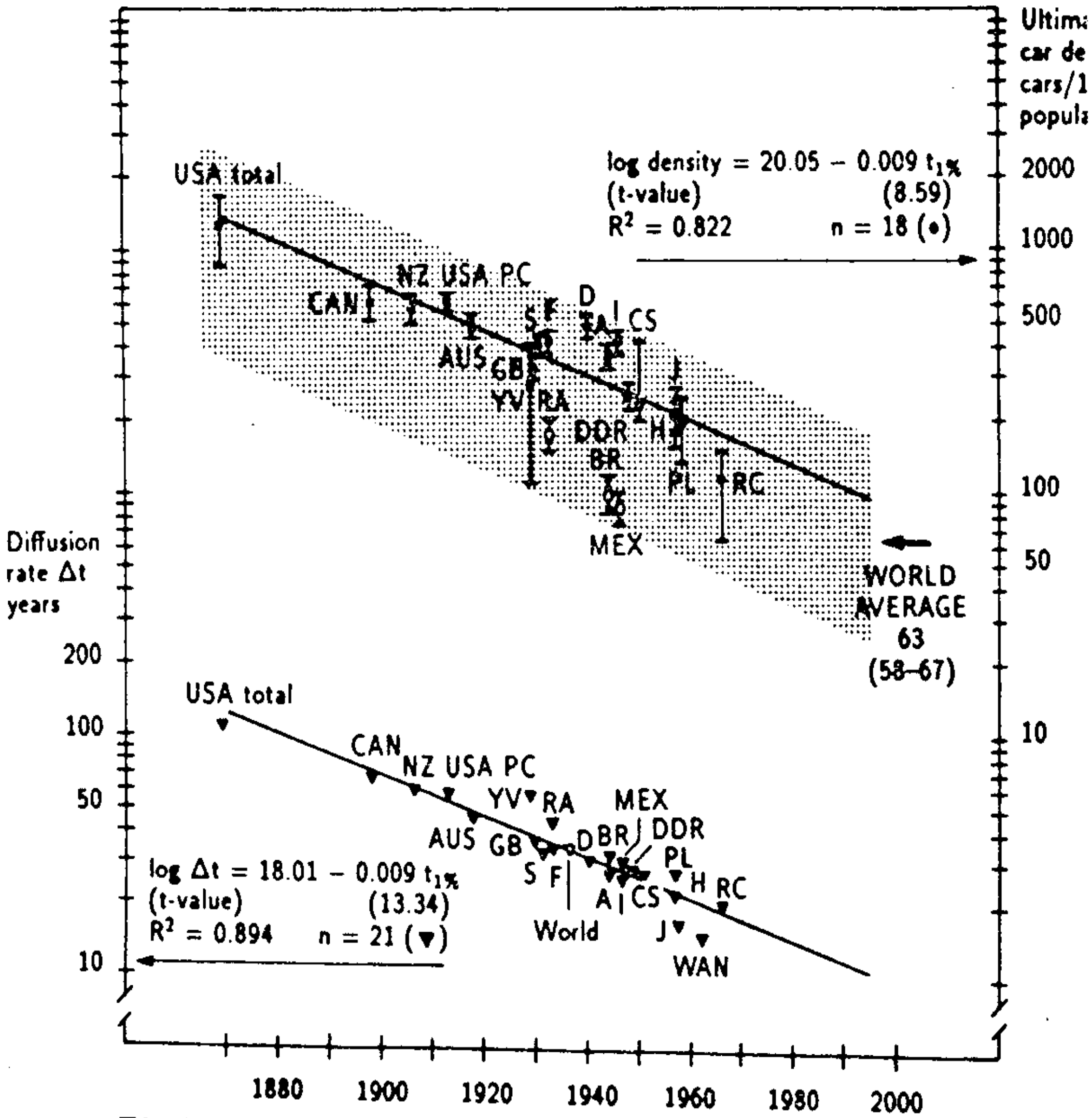


Fig 32

W. EUROPE ETHYLENE

1972: SITUATION AND CONVENTIONAL FORECAST

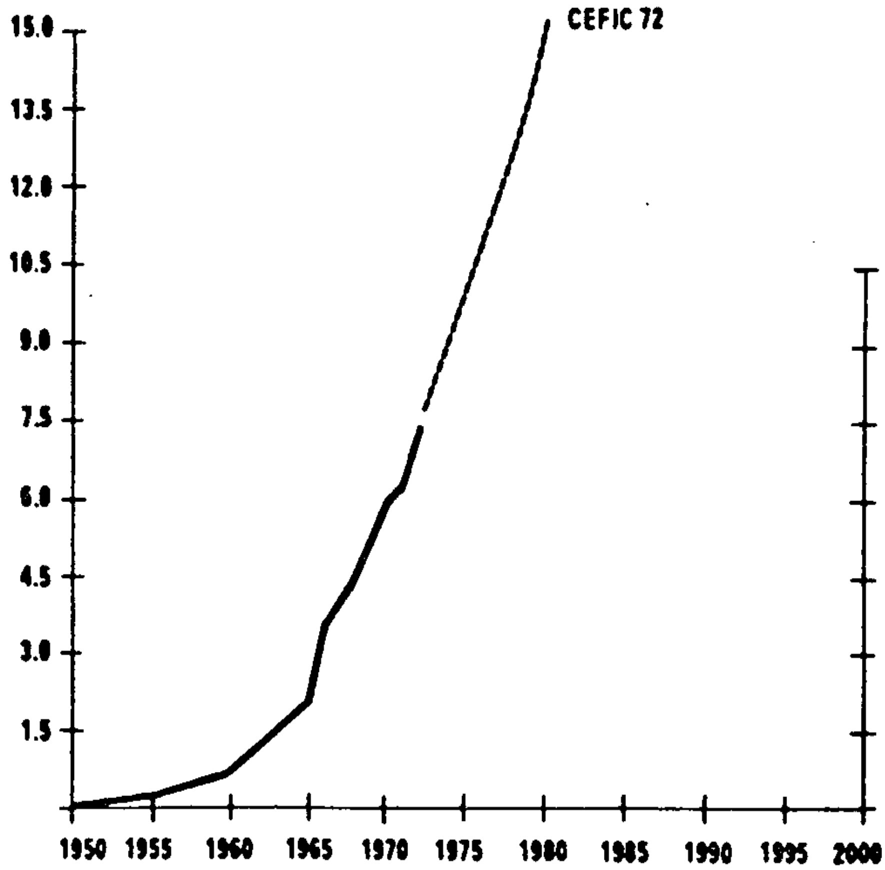


Fig 33

A. GRÜBLER, IIASA, 1988

W. EUROPE ETHYLENE

1972: ANTICIPATING SATURATION AT 10.3 MT

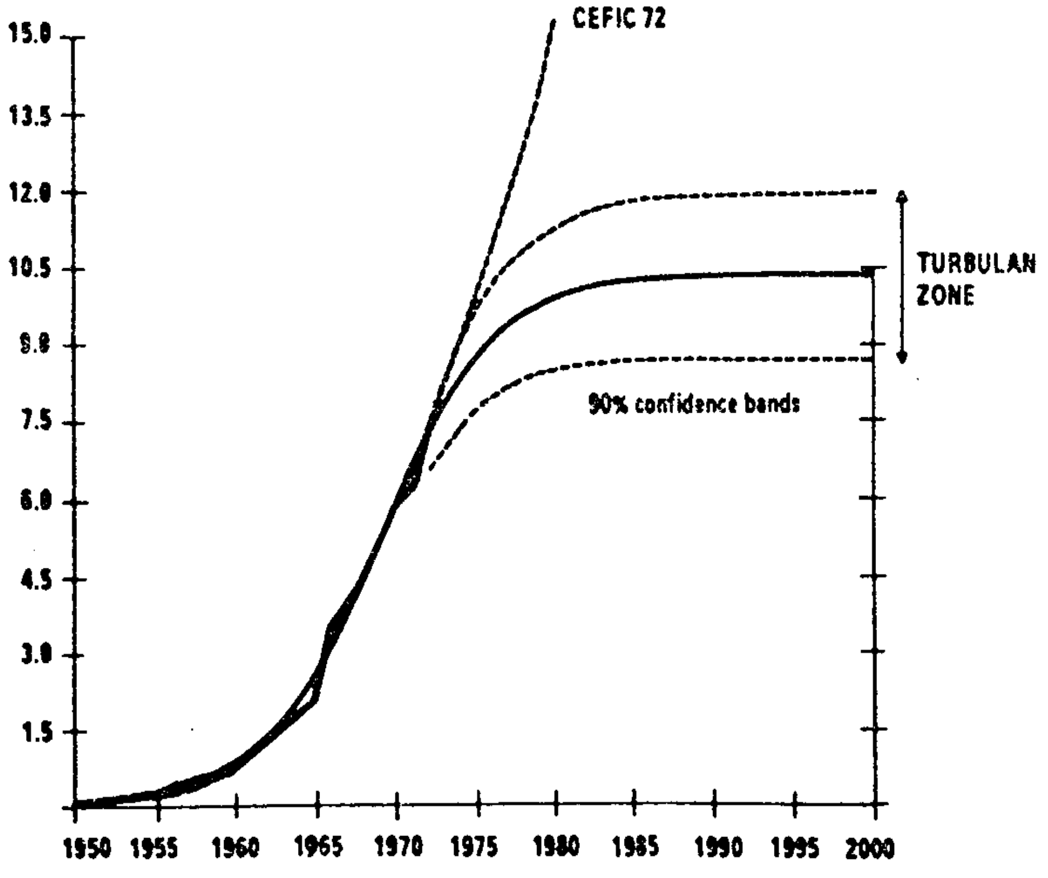


Fig 34

A. GRÜBLER, IIASA, 1988

W. EUROPE ETHYLENE

1988: A HISTORY OF FORECASTS

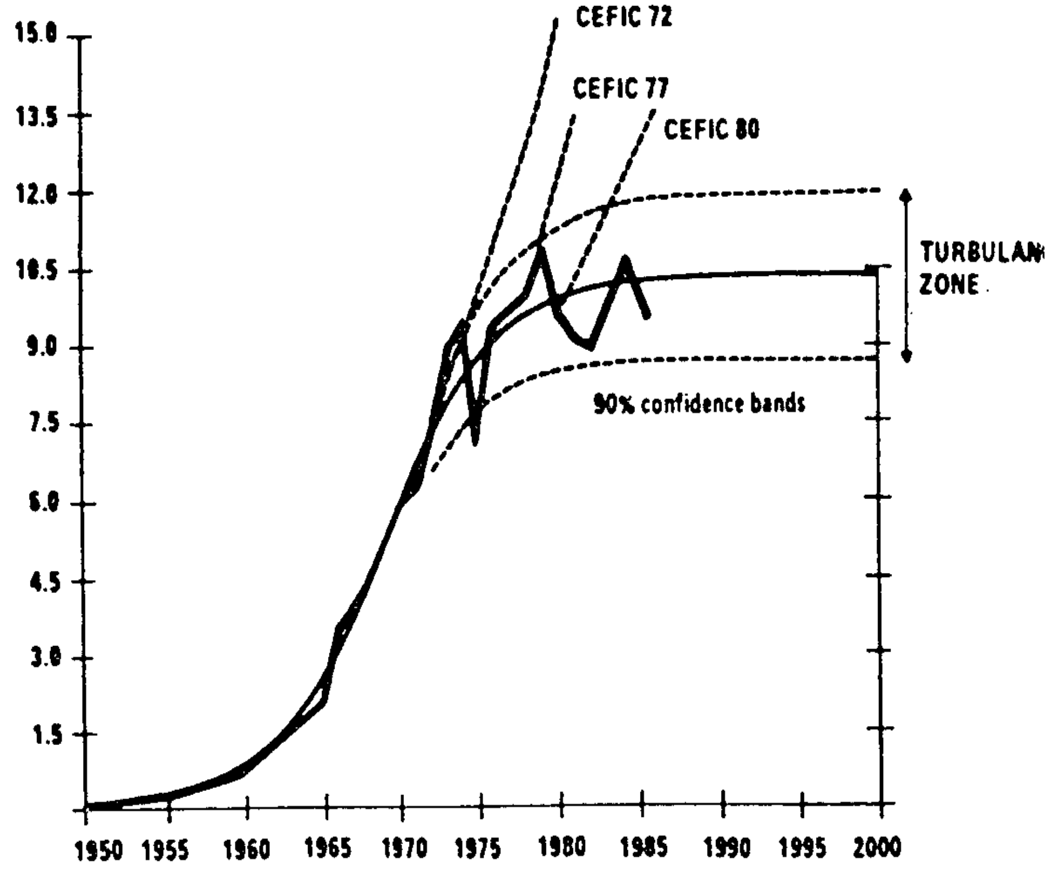


Fig 35

A. GROBLER, IIASA, 1988

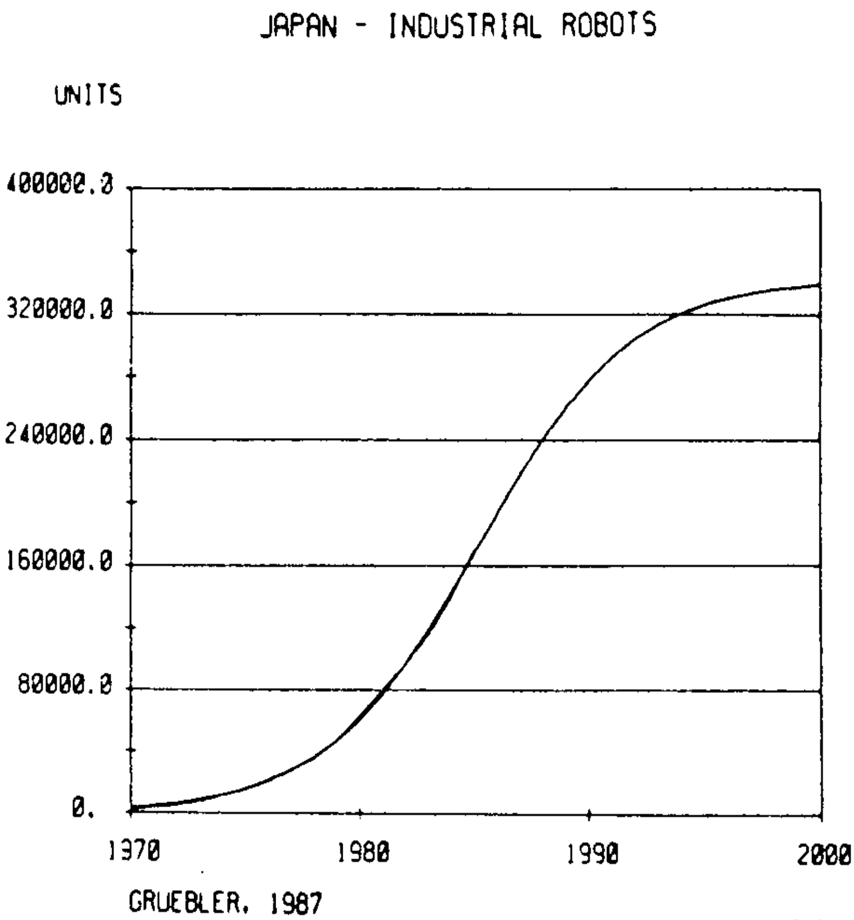
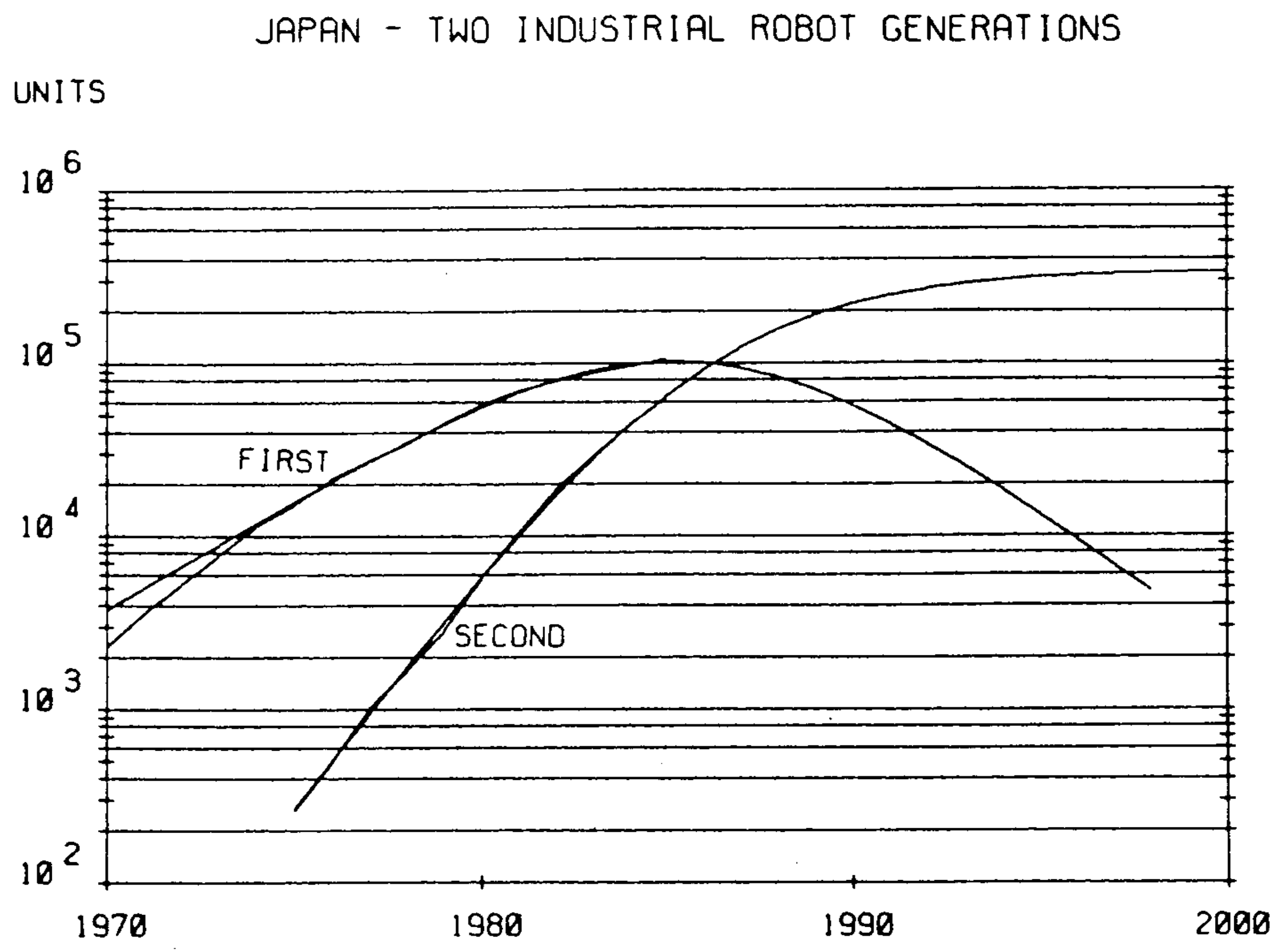

JAPAN - INDUSTRIAL ROBOTS
UNITS
400000.0
320000.0
240000.0
160000.0
80000.0
0.
1970
1980
1990
2000
GRUEBLER, 1987

Fig 36



JAPAN - TWO INDUSTRIAL ROBOT GENERATIONS
UNITS
10 6
10 5
10 4
10 3
10 2
FIRST
SECOND
1970
1980
1990
2000

Fig 37

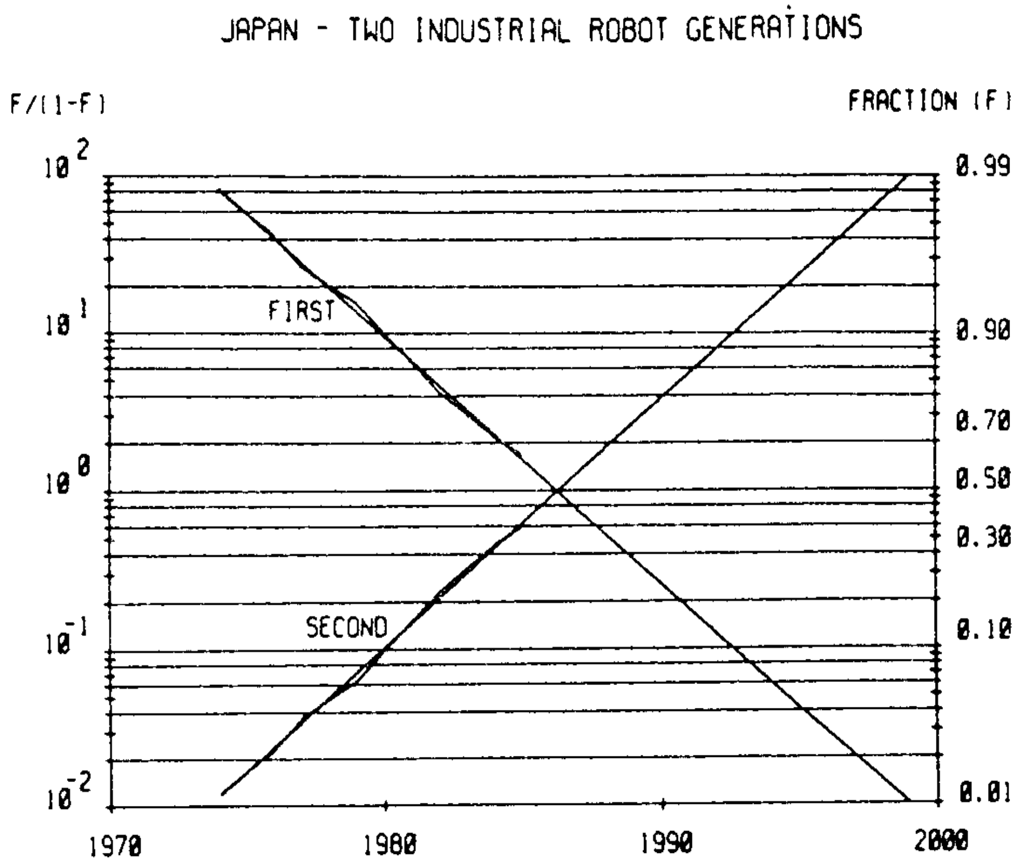

JAPAN - TWO INDUSTRIAL ROBOT GENERATIONS
F/(1-F)
FRACTION (F)
10^2
10^1
10^0
10^{-1}
10^{-2}
0.99
0.90
0.70
0.50
0.30
0.10
0.01
FIRST
SECOND
1970
1980
1990
2000

Fig 38

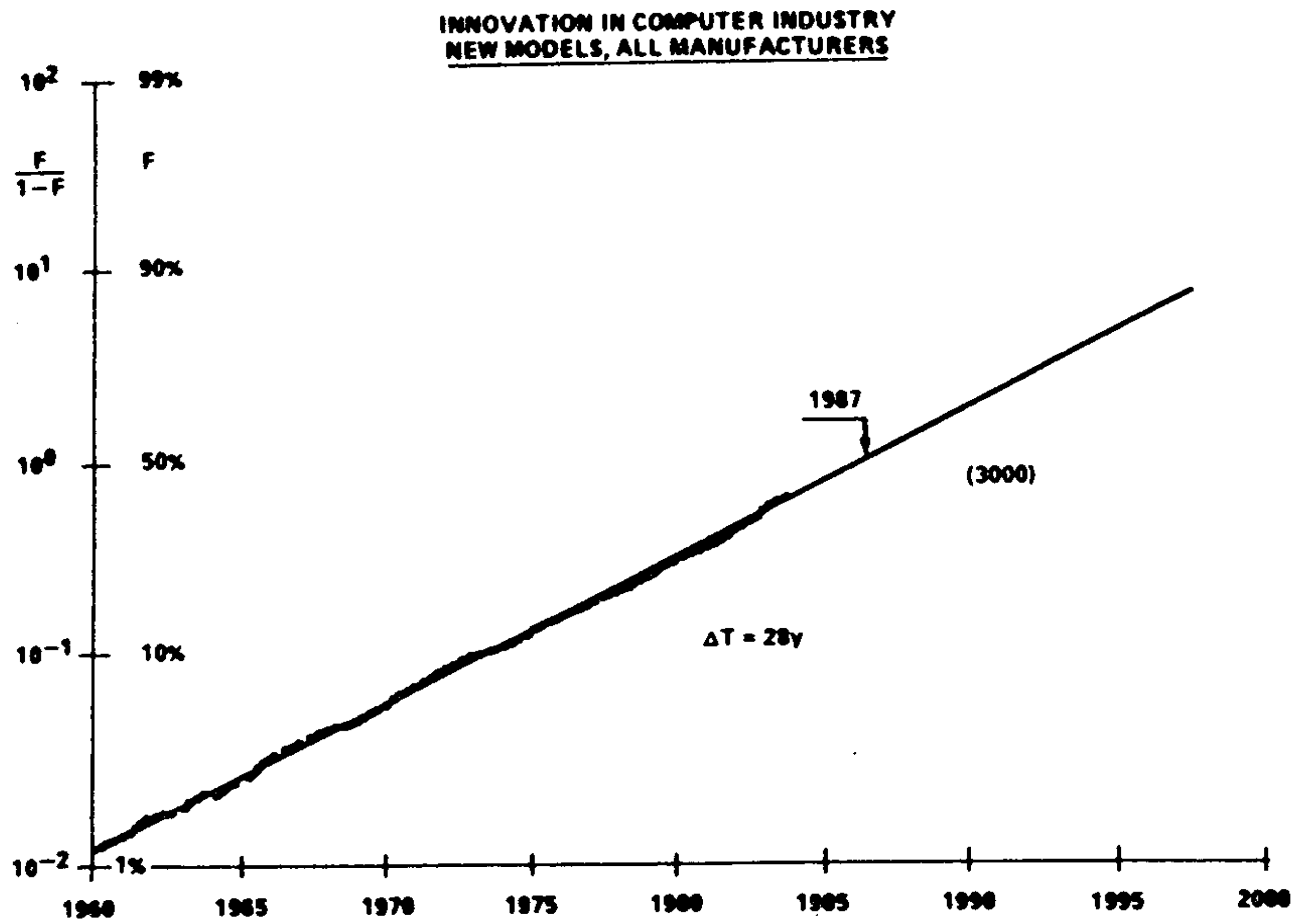
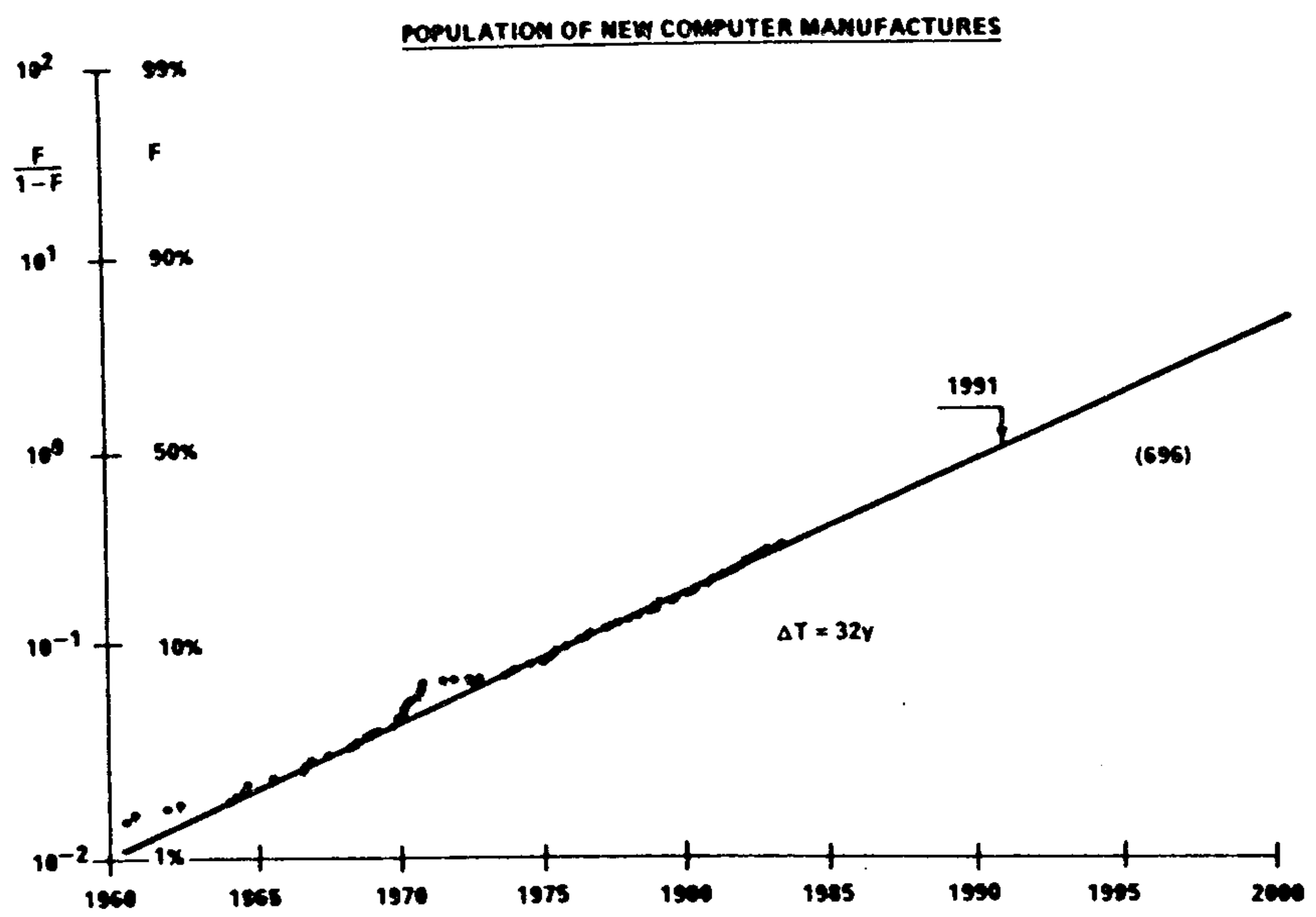

INNOVATION IN COMPUTER INDUSTRY
NEW MODELS, ALL MANUFACTURERS
10^2
99%
$\frac{F}{1-F}$
F
10^1
90%
10^0
50%
10^{-1}
10%
10^{-2}
1%
1987
(3000)
$\Delta T = 28y$
1960
1965
1970
1975
1980
1985
1990
1995
2000

Fig 39



POPULATION OF NEW COMPUTER MANUFACTURES
10^2
$\frac{F}{1-F}$
10^1
10^0
10^{-1}
10^{-2}
99%
F
90%
50%
10%
1%
1991
(696)
ΔT = 32y
1960
1965
1970
1975
1980
1985
1990
1995
2000

Fig 40