been fed during the last 50 years mostly by the expansion in the number of cars in use, will whither when everybody having a license has also a car. A situation almost reached today in Western countries.

The faster means of transportation coming next to the automobile is the airplane. But for the moment being it is far too expensive to make a dent into the time budget. As already said, Americans spend 60 seconds/day, mean, on airplanes (and 50 minutes on cars). Europeans 30 seconds/day. Because the purchasing power of Europeans is comparable to that of Americans, the difference in use may be reduced to a difference in fares, which in the USA in the mean are just about 3 to 4 times lower than in Europe.

Assuming that travel on all transport modes keeps *increasing by 3% per year*, the mean distance traveled per day being today about 40 km/person (the speed of the car which is used one hour per day), travel distance *during the next 30 years will increase to almost 100 km/person/day.* If the extra 60 km were made on airplanes with the present mean speed of about 600 km/h, this would signify *6 minutes/day allocated to airplanes*, mean over the population. The hypothesis of 3% growth which went unabated for 200 years may well hold for another 30 years. Some of the speed can be gained by moving the slower modes faster. Metros are faster than cars in large cities, and they can be made faster by using Maglev technologies now under field testing in Germany and Japan (there is a Maglev line in Berlin). Trains are trying to join the fast league, by the introduction of TGV. Cars were mysteriously stuck to the 40 km/h since Ford's times, and all technical ingenuity poured into new models just compensated the effects of increasing traffic density. The various improvements in speed that we may expect in the future will reallocate customer's choice between modes. Airplanes will snatch a sizable time share out of the traveling hour, and the total km/day on cars may well stay basically constant, as in the previous mode shifts (horse → train, train → car). The trains will take the difference.

The conclusion is that *with the above assumptions during the next 30 years air transport will expand by an order of magnitude in terms of pass-km.*

The logistic problem linked to such an increase in traffic, think of the clogged airports nowadays, appears appalling. *The system has to be rethought from scratch* and we will give some reflections on that. But from the point of view of the individual traveler the hectic is not visible. He will keep traveling one hour per day, but at 100 km mean speed. During the next 30 years his territory will increase by a factor of 2.5 in linear size, or about six times in terms of area. During the last 200 years the territory went from 5×5 km^2 to 40×40 km^2, an increase by about 60 times.

It must be clear that *the airplane will not simply substitute other means of transportation on the same routes. Having a larger Travel Distance Budget (TDB) people reorganize the use of territory* and consequently the points of destination, which will tend to be located farther away. In a sense our mental image of the territory is in terms of traveling *time*, and consequently it will expand more or less homothetically with the transport speed available, like the city of Berlin we discussed before.

The time consumed for long-distance travel will be subtracted to short-distance displacements. One of the consequences, as noted before, will be the *reduced use of cars*, after they will have reached saturation, as it is today for most Western countries.

Most of the previous considerations have been made referring to passenger traffic. It is true that passengers constitute the bulk of air transport both in terms of weight and income from fares; just like when steamboats were introduced and sailships carried the bulk. Cargo has mostly been a sideline, except in the form of mail when airplanes were too small and weak to carry passengers. With the advent of the 747 and its generous cargo bays, freight transport has picked up to the point that a number of planes operate as specialized freighters.

In spite of the fact that the two most successful long-range carriers, the 707 and the 747 were originally born as military freight carriers, they were, in fact, intended as civil planes. A real civil freight carrier has yet to be designed. The level of traffic may justify the expenses in a time horizon of 2020.

It must be clear that good transport technology follows the same rules as for the transport of people. Fig.2-8 clearly parallels Fig.2-1. Both are for France but the features are general. The next medium is faster and more expensive and progressively substitutes the old one when the value of merchandises increases, per unit weight, and the cost of transport decreases, with technical progress and volume. Like in the case of people, light and expensive goods travel by plane (Fig.2-9). This is obvious for electronics of all description, and also for expensive apparel. But raw textiles may do. In fact, it is extraordinary that fruit are routinely carried from South Africa to Europe with mark-ups of 1 or 2 $ per kg. Because the trend is toward larger and cheaper airplanes, possibly of specialized make, the spectrum of goods entering into air transport may grow very fast. On the other hand, the much ventilated idea of "dematerialization" of our society simply means that value-added per unit of weight keeps increasing. More properly one should say that "dematerialization of value added". These two convergent processes may lead to a progressive subtraction of freight from trucks, leading first to a stabilization of their level of business in terms of ton-km (like for rail after 1940) and reducing them to local retailing after 2050.

Because the largest traffic may develop at short distance (1000 to 3000 km), cargo airplanes should be large and light with cargo capacities of perhaps 500 tons, and take-off weight of perhaps 800 tons, roughly the double of a 747. This take-off weight may not constitute a problem for the runways as they are designed today.

Fig.2-1

The penetration of mechanical transport, measured in terms of km/person/day is reported here for France since 1800. The introduction of a new technology first stops the growth of the previous one (train versus horse) absorbing all the growth in mileage, then phases it out. The introduction of new transport technologies has a rate of about 55 years. For the next Kondratiev due to start around 1995, a new technology could be that of the Magnetically Levitated Train (Maglev). The total distance traveled with mechanical transport grew in France by about 3.3% per year.

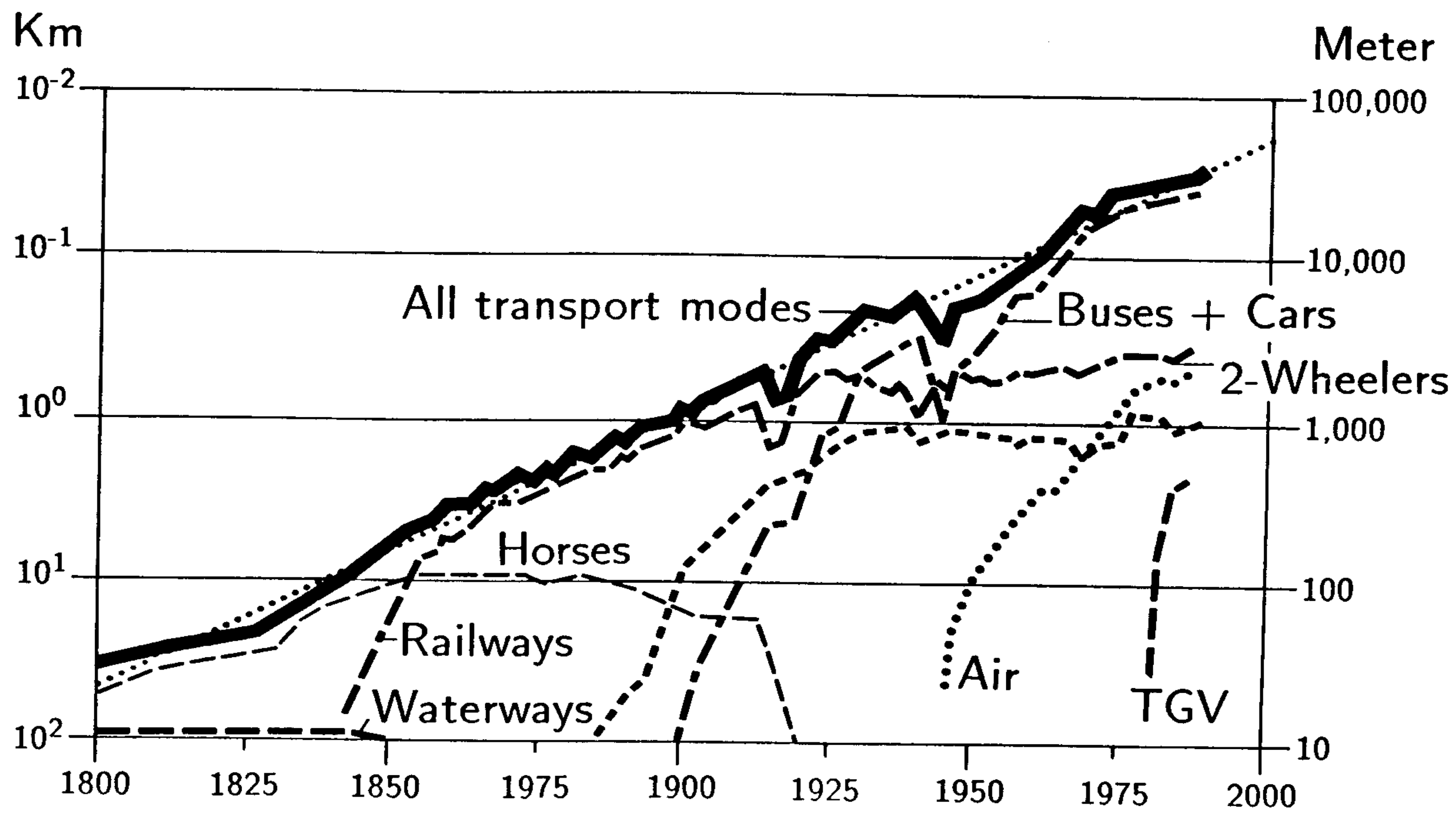

Km
Meter
10-2
10-1
100
101
102
100,000
10,000
1,000
100
10
1800
1825
1850
1975
1900
1925
1950
1975
2000
All transport modes
Buses + Cars
2-Wheelers
Horses
Railways
Waterways
Air
TGV

Fig.2-2

The global picture of Fig.2-1 can be split into a number of local phenomena. Reported here is the case of the substitution of horse-driven vehicles with motor-driven vehicles, for *public transport* in the UK. The complete process of substitution took about 16 years. ΔT=8.1 years refers to the time to go from 10% substitution to 90% substitution.

UK – Public Passenger Transport Fleet

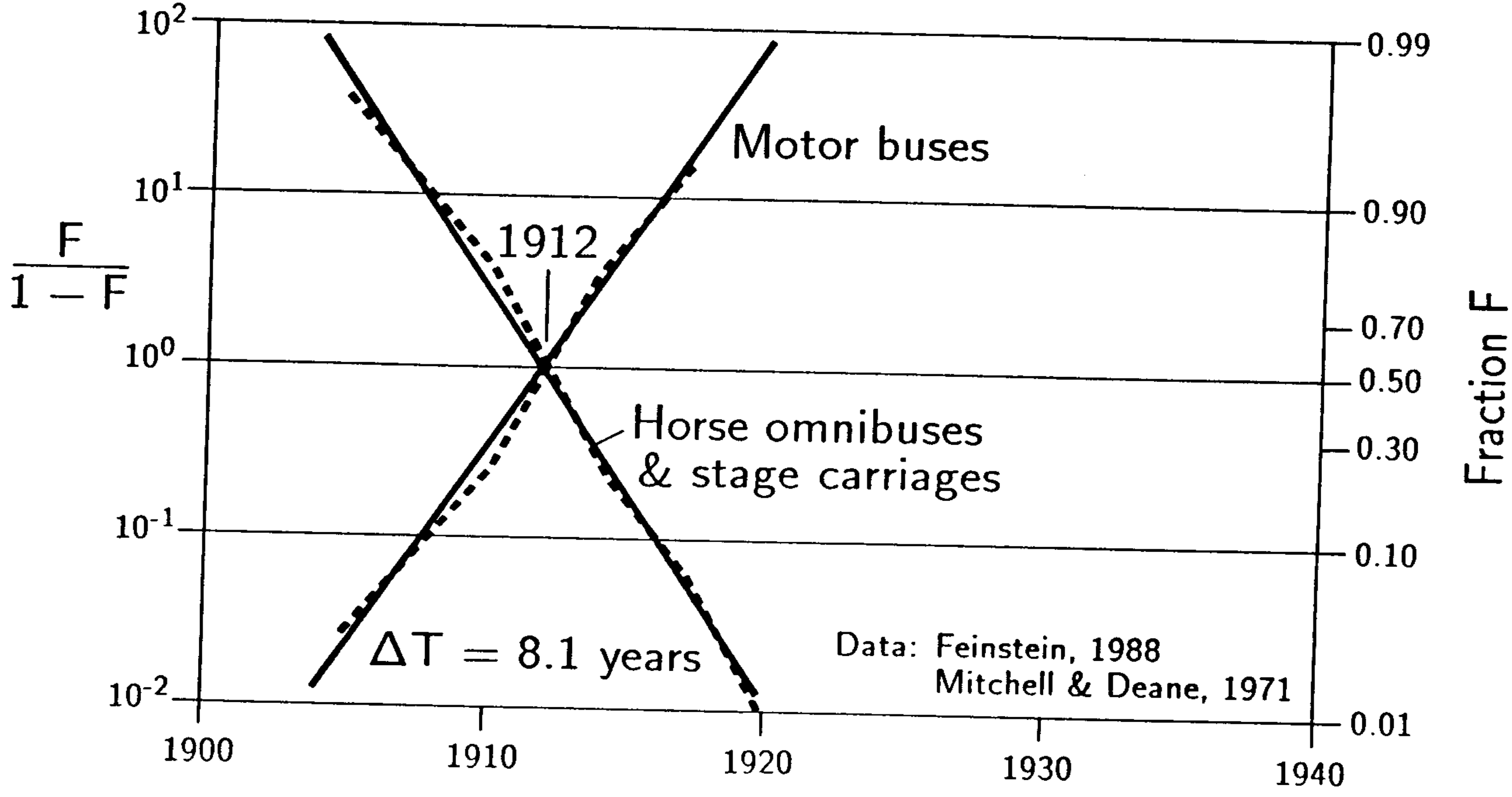


Fig.2-3

Instead of looking at substitution of vehicles, we can look at the growth of the infrastructures that serve them, as an index of their spatial diffusion into the system. We report here the case of the length of canals, railways, and paved roads referred to their final lengths, and fitted with logistic equations. We note that the flexes of the curves where growth is maximum, are 55 years apart.

USA – Length of Infrastructures

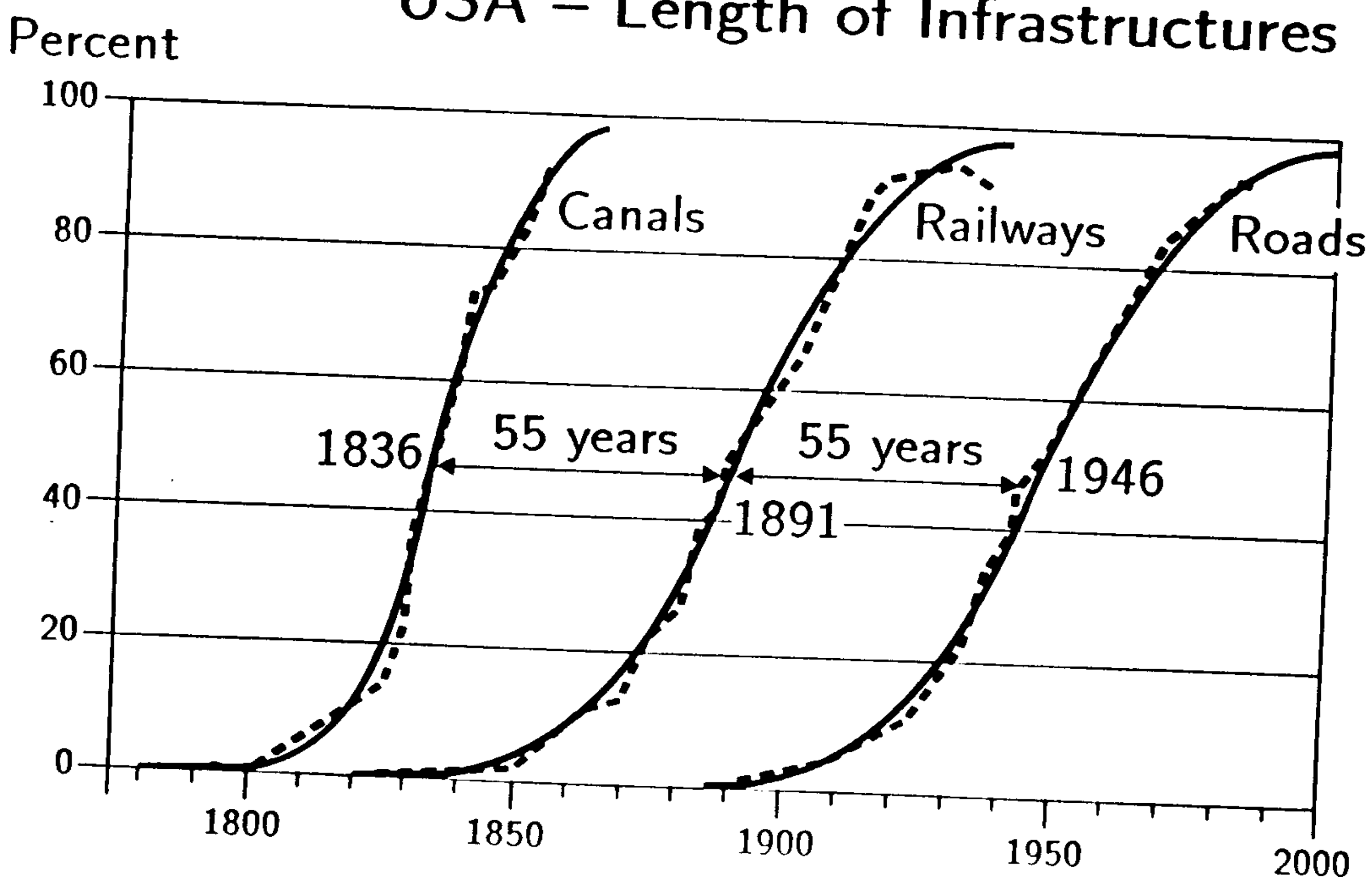
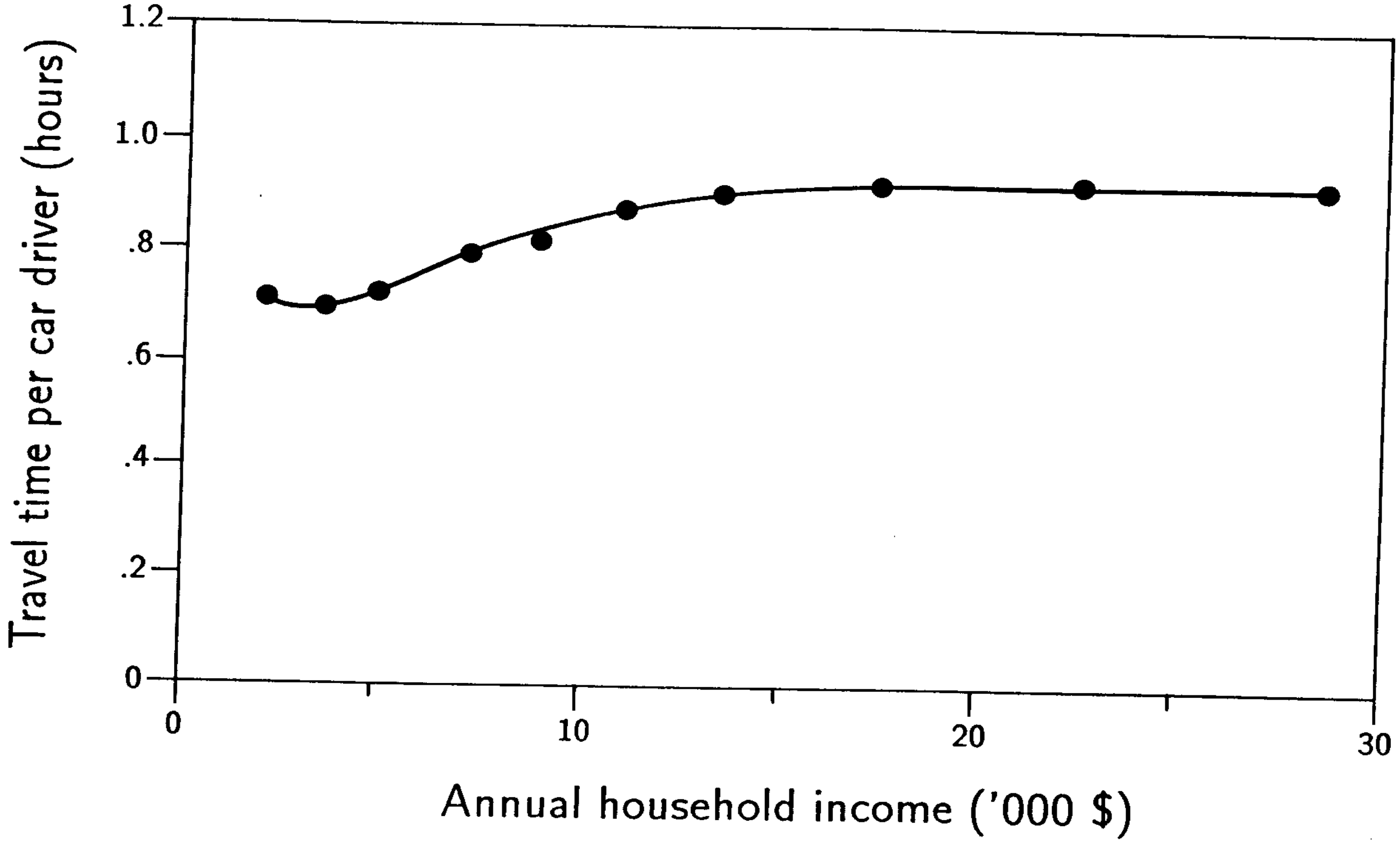


Fig.2-4.

When a person can dispose of a car, most of his traveling hour will be spent driving. Cars are the fastest means of transport with the exception of the airplane. Operating costs of cars are acceptable into the TMB of a large stratum of family incomes. Airplanes are decidedly too expensive, particularly in Europe. A round trip Vienna–Rome to give an example, costs the equivalent of one month worker's salary, for two flights of roughly one hour each. The $ for the household income in the chart are 1968$.



Travel time per car driver (hours)
1.2
1.0
.8
.6
.4
.2
0
0
10
20
30
Annual household income ('000 $)

Fig.2-5

Because cars are used basically one hour per day, mileage traveled over the year divided by 365 gives the mean speed. This mean speed of about 40 km/h is remarkably constant since Ford's times. This is also the diameter of Berlin. We did not find any plausible mechanism to interpret why all innovations in the mechanics of cars just compensated the hindrances created by their crowding. No more, no less.

USA – Passenger Vehicles (Miles/Year)

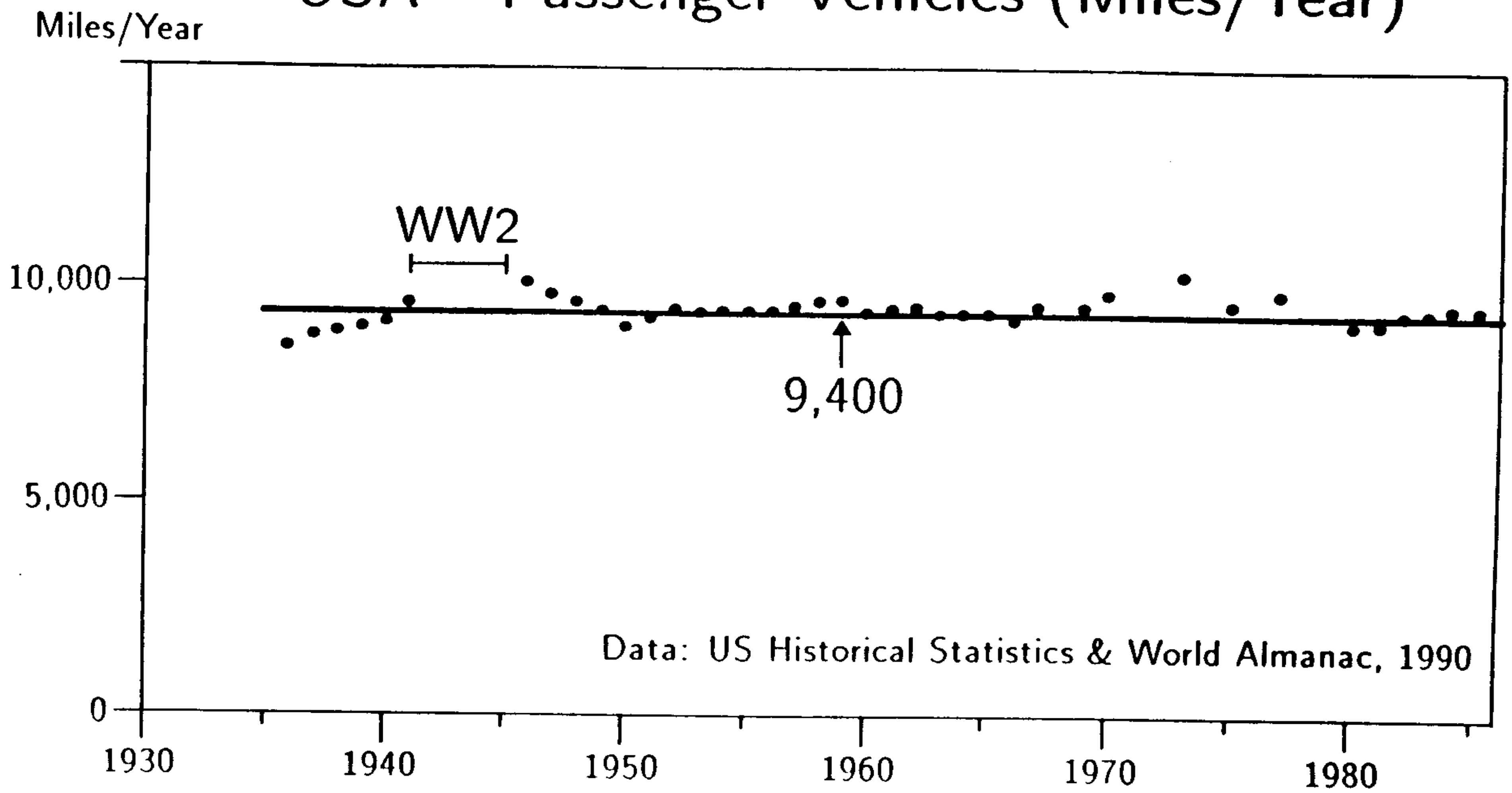


Fig.2-6

For the transport of goods we can construct a chart like that for the mechanical transport of people of Fig.2-3. Also this one is for France and shows strict taxonomic relationships. We see air transport coming up in two waves, the first one probably referring to mail. For expensive goods air transport is now a must (Fig.2-7). But air transport is conquering shares on the market of perishable goods of not so high specific value, like fruits, competing with trucks. We may expect planes specially designed for cargo during the next Kondratiev, as the ton-km transport will soon be comparable to that of passengers.

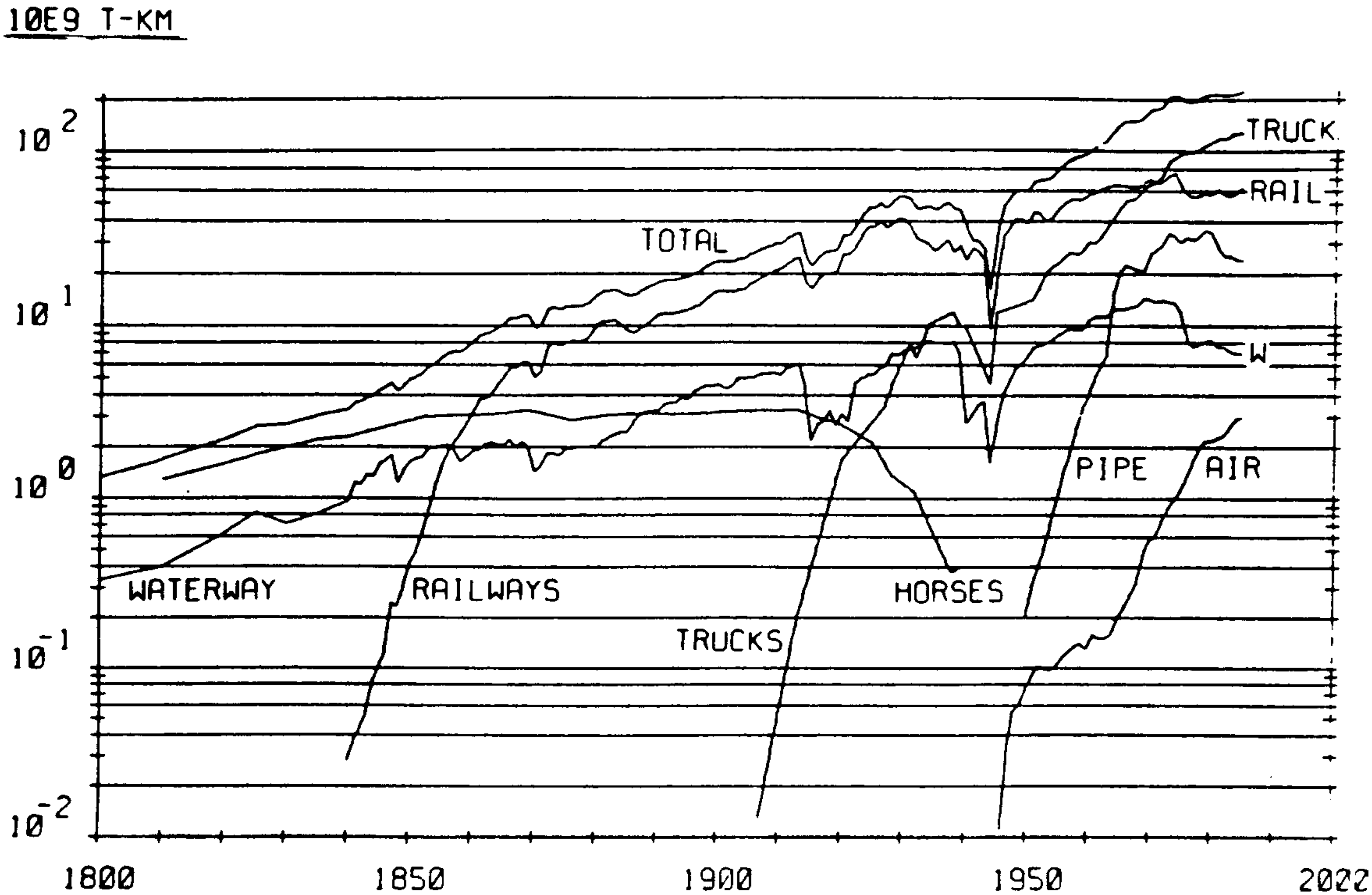
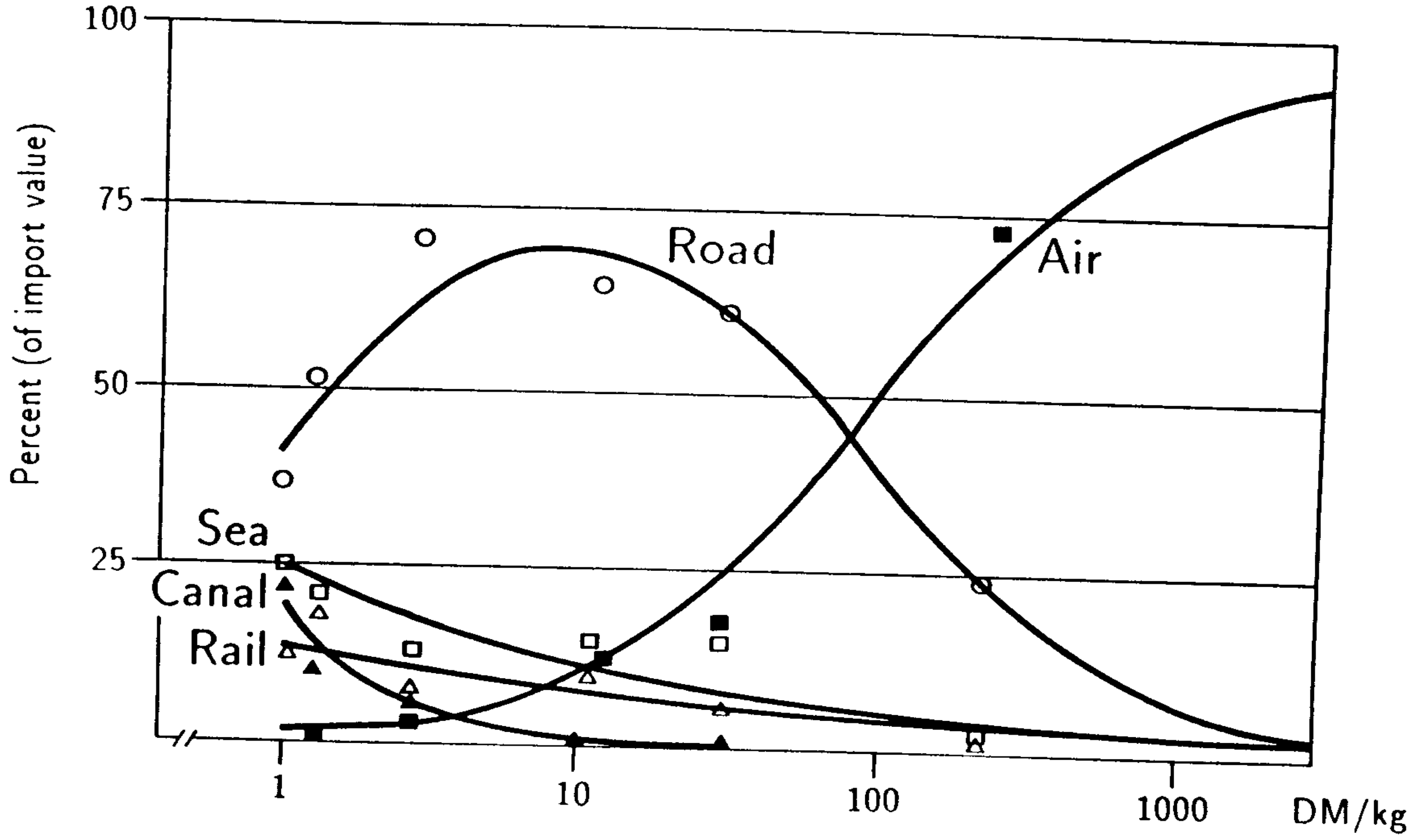

10E9 T-KM
10^2
10^1
10^0
10^-1
10^-2
1800
1850
1900
1950
2022
TRUCK
RAIL
TOTAL
W
PIPE
AIR
WATERWAY
RAILWAYS
HORSES
TRUCKS

Fig.2-7

The importance of the value of goods on the mode chosen for their transport is shown in this chart. It refers to goods imported in Germany. The shares of transport modes are given as a function of the specific value of the goods (DM/kg). (From Grübler.)

FRG – Imports of Manufactured Goods



3. On the Taxonomy of Change: The Kondratiev Cycles

The analysis of the development of infrastructures in the USA reported in Fig.2-3 gives us a first hint of the fact that the system may have high levels of invisible order (see, for example, the perfect self-consistency of the growth process) and a rhythm in the process of absorbing innovation. If we look at the introduction of basic innovations as described by Mensch, we find, in fact, that they come in pulses spaced again about 55 years (Fig.3-1). New transport modes are basic innovations and should stay in the ranks. In fact, each of the three historical waves yielded a new transport mode: train, car, and plane. In the case of energy, the waves yielded coal, oil, and gas. The present wave yielded nuclear energy. For transport a likely candidate is the Maglev.

Once introduced, the new technology has to penetrate the market, and also this is done in pulses, We can report the case of car penetration in the USA and in Europe, just to illustrate the paradigm (Fig.3-2 and Fig.3-3). We can also look at very synoptic indicators like total energy consumption and electricity consumption to reveal the pulses as a continuous signal. An analysis on the deviation from the secular trend for total energy and electricity was done by Stewart (Fig.3-4), showing very neatly the effect of the pulses. We have adopted this chart as an "activity clock", to measure the situations in terms of their phase by respect to the cycle. An example is reported in Fig.3-5, where the center points of the innovation waves of Fig.3-1 are located on the clock chart, where they appear to occupy exactly the same phase position, for these three Kondratievs. We found convenient to take the *lowest points in the chart* of Fig.3-4, as the *starts and ends of the cycles.* These low points are approximately 1830, 1885, 1940, *1995.*

One of the observations that will be important for our logic is that penetration may start at any point along the cycle, but almost invariably saturates at its end. See, for example, the first pulse of growth for cars in the USA and in Europe. Civil aviation started in the thirties, at the level of aerotaxis, if seen from today's technology, but with a well defined network of city connections, reproducing the core of today's intense traffic routes. Civil aviation as an industry really started with the DC-3, and developed along a logistic (Fig.3-6) almost perfectly encased into the present Kondratiev (1940–1995). The pulse saturates in this decade at 290 10^9 ton-km transported. It was 260 10^9 ton-km in 1990. The figure includes Russia and nonscheduled services. The analysis was originally done using data up to 1985. It happens, however, that after this date there is a sizable divergence between the actual values of air transport and the fitting equation. This might be due to "instabilities" that often occur near the saturation point, where actual values oscillate around the asymptote of the logistic. But it also could have been possible that this was due to a second pulse, very fast and again saturating around 1995.

Another way of looking at the pulsations in energy consumption is to decompose energy consumption worldwide into a sequence of logistic pulses, in sequence, one on top of the other. The exercise is reported in Fig.3-7. The pulses are clearly contained in the Kondratiev cycles. The second one with its extreme irregularities shows what historians have slowly come to realize, that the "World War" was a 30-year war (1914–

1945) and the economy of the peaceful interval has war characteristics. (We have many other indicators naturally, pointing to that). By making some assumptions we have also constructed the evolution of the total distance between ticketed points for US airports, calling that *network length* in the same sense as the length of paved roads. The exercise is reported in Fig.3-8, using the Fisher-Pry transform (see Fig.2-5 for the first three pulses in linear form). The "Kondratiev-invariant" position of the flex has been used to fix the maximum rate of growth for the air network in 1995+7 or in 2002. As the interconnections between large cities are already in place, the expansion may come by linking small cities to hubs, or by introducing selfcontained commuter lines. The expansion of the purchasing power, and the reduction in air travel cost, will finally come to the popularization of air commuting.

Fig.3-8 contains also a fifth line, marked *Maglevs*. The logic for introducing a new technology of transport in our charts is that a new Kondratiev wave usually calls for a new technology. The logic for putting Maglevs in such a wave is that the new technology must be superior to the previous one in some essential characteristics and available when the wave begins. Maglevs can have the same speed of airplanes, sub- and supersonic, *but on shorter distances.* A Constant Acceleration Maglev (CAM) could cover the distance Bonn–Berlin in about 10 minutes with accelerations-decelerations of 5m/sec^2 (0.5 G). Only a hypersonic plane could do that, but certainly not over a distance of 500 km . The Maglev in question should move in an evacuated tunnel with equivalent air pressure of 15.000 meters, as a Hypersonic. Maglevs are developed in Germany and Japan but this particular technology is studied in Switzerland (project Swissmetro). The second point where Maglevs are superior is *capacity*. The vehicles are completely passive, under control of the computer that regulates the magnetic fields on the track, supporting and pulling the vehicle. This means launching a vehicle every 20 seconds appears possible. The distance at start between vehicles would be 1 km with 0.5 G acceleration. With trains carrying 500–1000 people, peak capacity can be above 100.000 persons/h on a single line between two stops. Maglevs, like airplanes, must carry people basically between two points with no intermediate stop, otherwise their time advantages would be reduced or lost. Maglevs are then perfectly suited to *take over* from planes the *routes most heavily trafficked.* Like where air shuttles are in operation, to start with. They can also create high density routes by providing "hypersonic" service over short distances, like the quoted example of Bonn–Berlin. This route, operated with a transit time of 10 to 20 minutes, could finally generate at regime about 0.5 million trips per direction *per day* by functionally fusing the two cities.

Coming to the extension of the networks, such sequences of logistics for single technologies can be integrated in a superlogistic referring to the collective purpose (network length of *infrastructures for transport*) (Fig.3-9). On purely taxonomic grounds one can forecast to a point the characteristics of networks to come. For example, length grew from canals in the USA (sat. 7 10^3 km) to railways (sat. 5 10^5 km) to paved roads (sat. 6 10^6 km) which reached the maximum. Air transport *network* will finally double with respect to the present one (in the USA) but will be much shorter than paved roads. Maglevs may come in the same ballpark as canals, linking only very intense corridors.

Fig.3-1

Schumpeter observed that technological innovations come in bunches spaced about 55 years. Mensch put together the bunches by dating the innovations. We showed that the bunches are almost perfectly organized by fitting them with logistic equations. The exercise is reported here, and confirms beyond doubt the intuition of Schumpeter. New technologies for transport are also innovations, and each wave carries a new transport technology. The last one started commercial airplanes. For the present one we assume Maglevs will be the winning technology, starting their penetration in the next century. (Data from Mensch, 1975.)

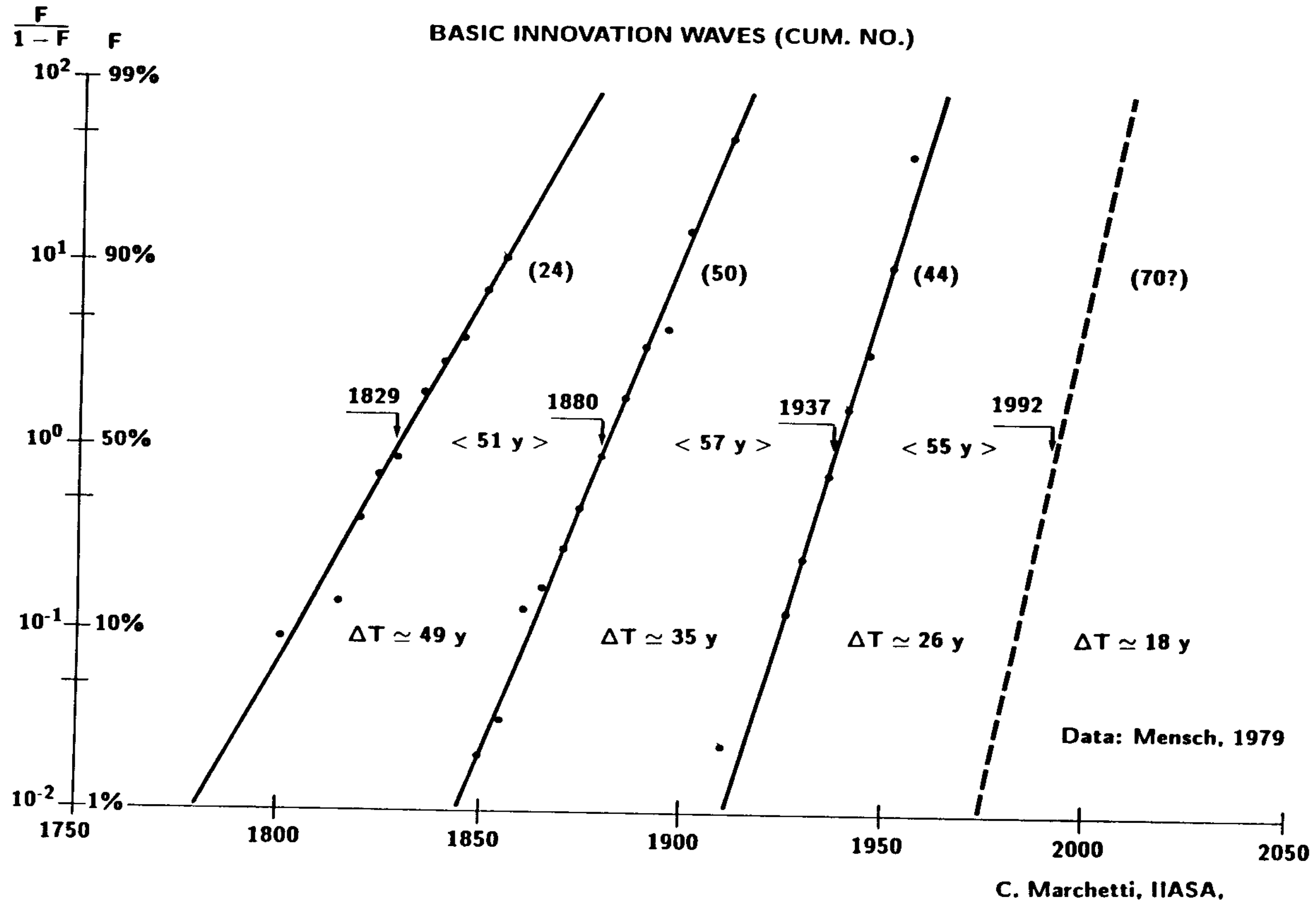
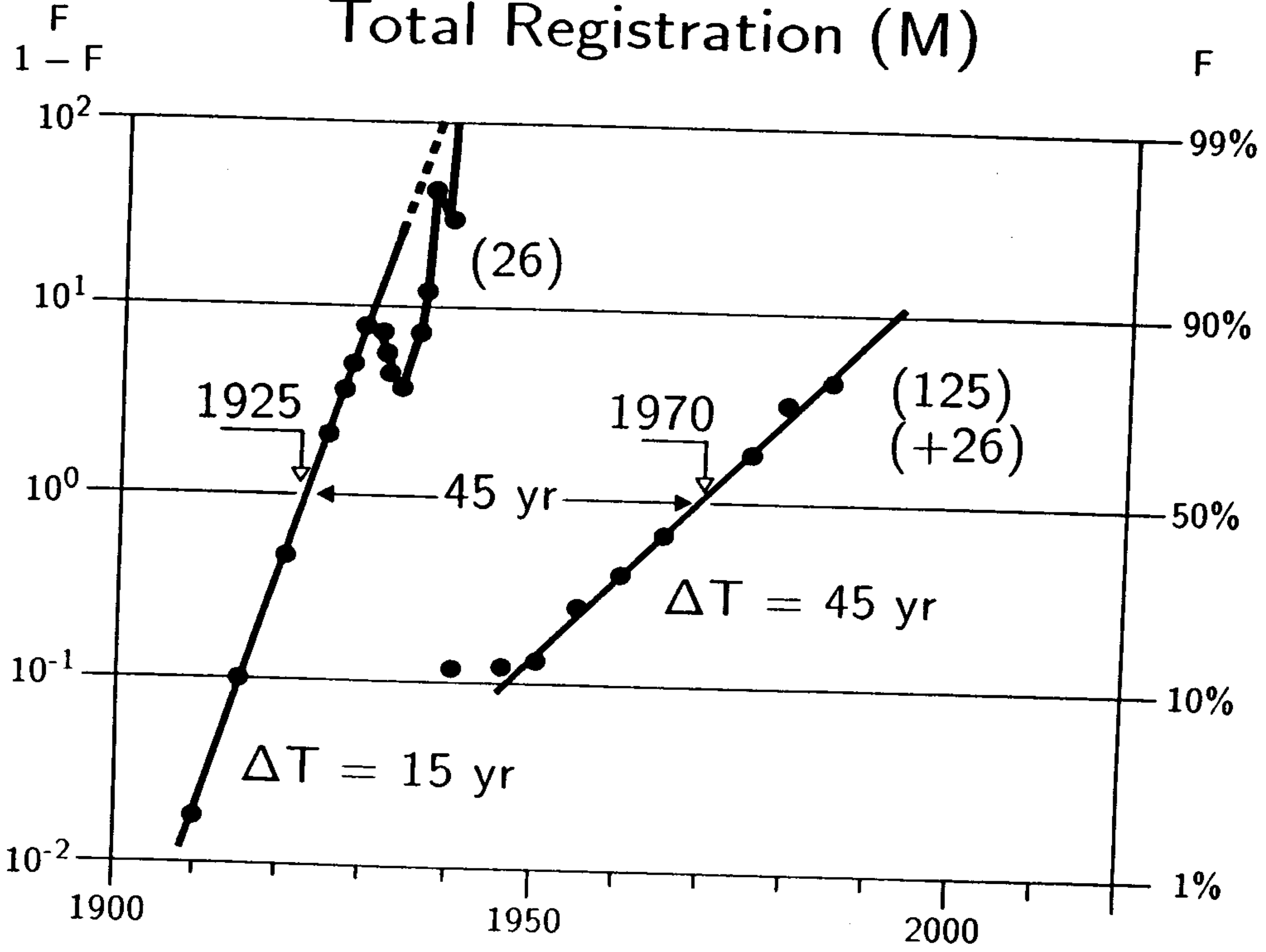

BASIC INNOVATION WAVES (CUM. NO.)
F/(1 − F)
F
10^2
99%
10^1
90%
10^0
50%
10^-1
10%
10^-2
1%
1750
1800
1850
1900
1950
2000
2050
(24)
(50)
(44)
(70?)
1829
1880
1937
1992
< 51 y >
< 57 y >
< 55 y >
ΔT ≃ 49 y
ΔT ≃ 35 y
ΔT ≃ 26 y
ΔT ≃ 18 y
Data: Mensch, 1979
C. Marchetti, IIASA,

Fig.3-2

An innovation does not saturate its markets in a single Kondratiev cycle. We have here the case of cars penetrating in two cycles in the case of the USA. The saturation points are in both cases near the end of Kondratiev cycles (1940, 1995).

USA – Passenger Cars
Total Registration (M)



Data: US Historical Statistics & MVMA Statistics, 1987

Fig.3-3

An innovation does not saturate its markets in a single Kondratiev cycle. We have here the case of cars penetrating in two cycles in the case of Europe. The saturation points are in both cases near the end of Kondratiev cycles (1940, 1995).

Car Circulation in Europe (Millions)

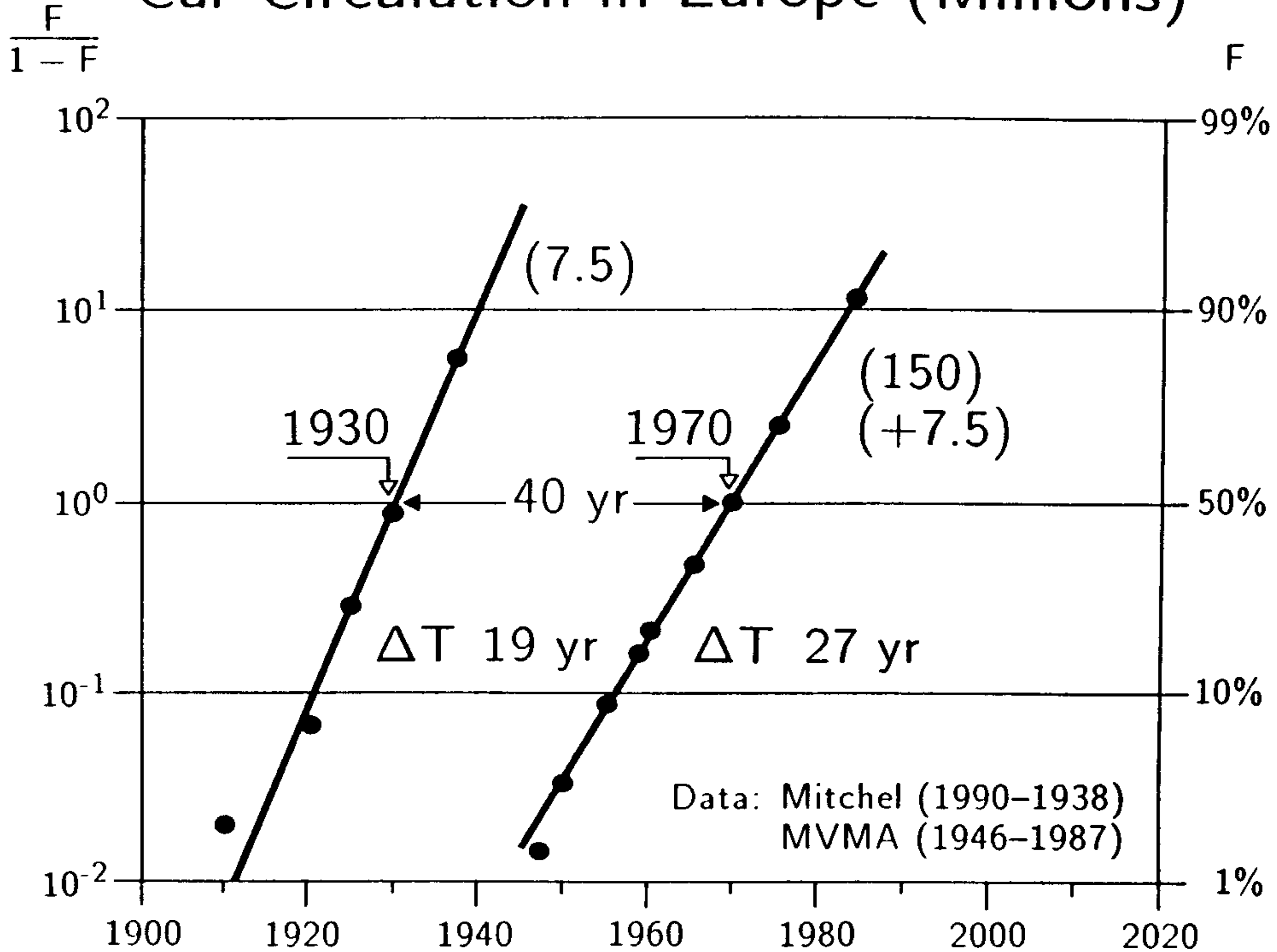
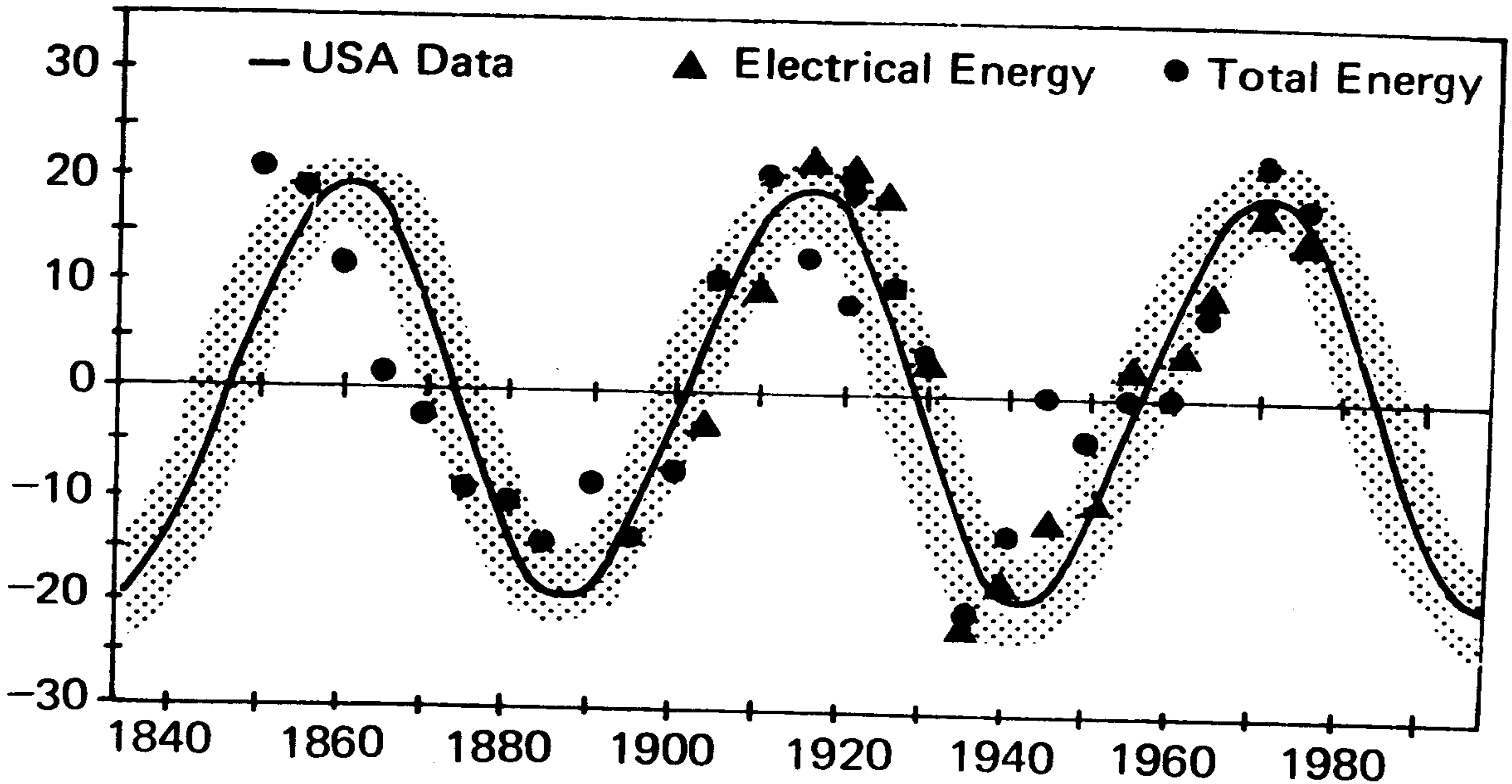


Fig.3-4

Stewart observed that the growth of primary energy and of electricity for the USA can be approximated by exponentials. The deviations from these long-term trends can be represented as a sinusoid with a period of about 55 years. The open circles represent total energy and the triangles electricity. (From Stewart, 1982.)



— USA Data
▲ Electrical Energy
● Total Energy
30
20
10
0
−10
−20
−30
1840
1860
1880
1900
1920
1940
1960
1980

Fig.3-5

If we position on Stewart's cycles the centers of the innovation waves of Fig.3-1, we find that they are always precisely located a little before the lower end of the cycle (1993 of the present innovation wave). The message is that if we want to introduce innovations in the transport industry in general, and in air transport in particular, *the time is now.*

CENTER OF INVENTION AND INNOVATION WAVES
LOCATED ON ENERGY INDICATOR

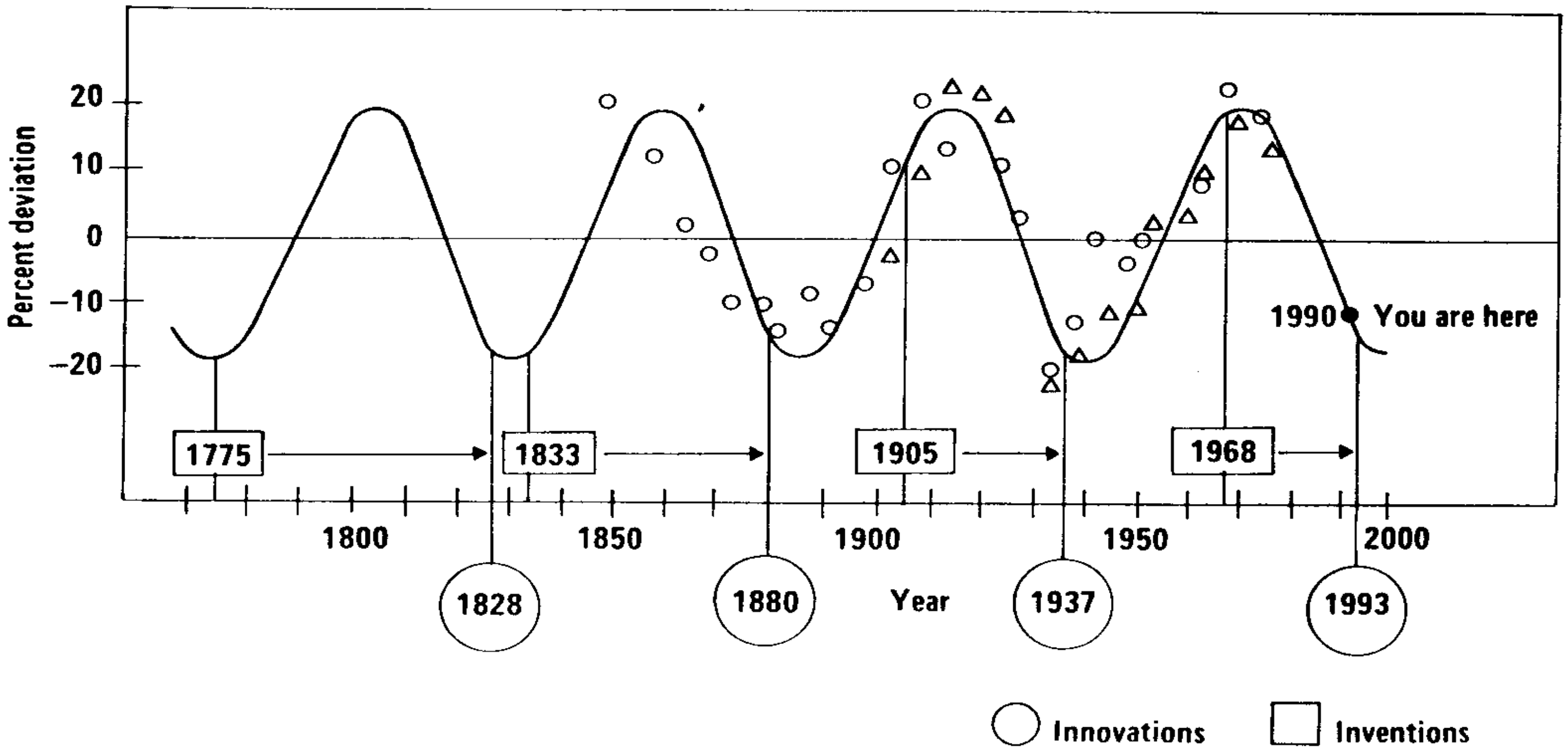


Fig.3-6

All ton-km transported by the air system including the Soviet Union can be well approximated by a logistic equation from 1955 to 1985. This logistic would saturate at about 300 10^9 ton-km (passengers are counted at 90 kg including baggage). During the last few years, however, a new logistic appears saturating at about 30% of the old one, more or less at the same time. These "second pulses" inside a Kondratiev are possible and they saturate at the same time as the first pulse. They may testify the rapid opening up of a new niche (e.g., charter). In this case we did not search yet for a definition of a new niche (it could also be a transient to be reabsorbed later on).

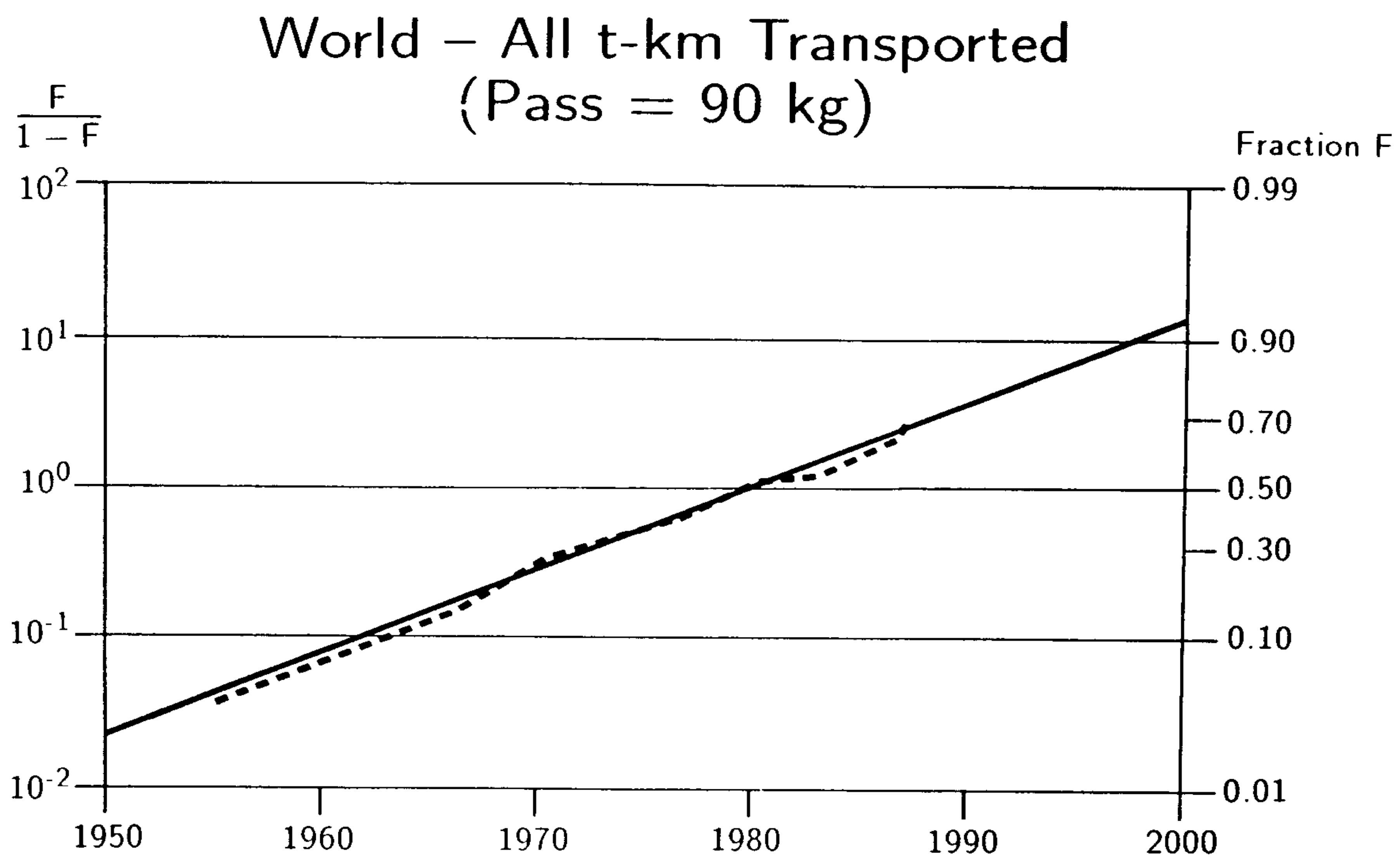
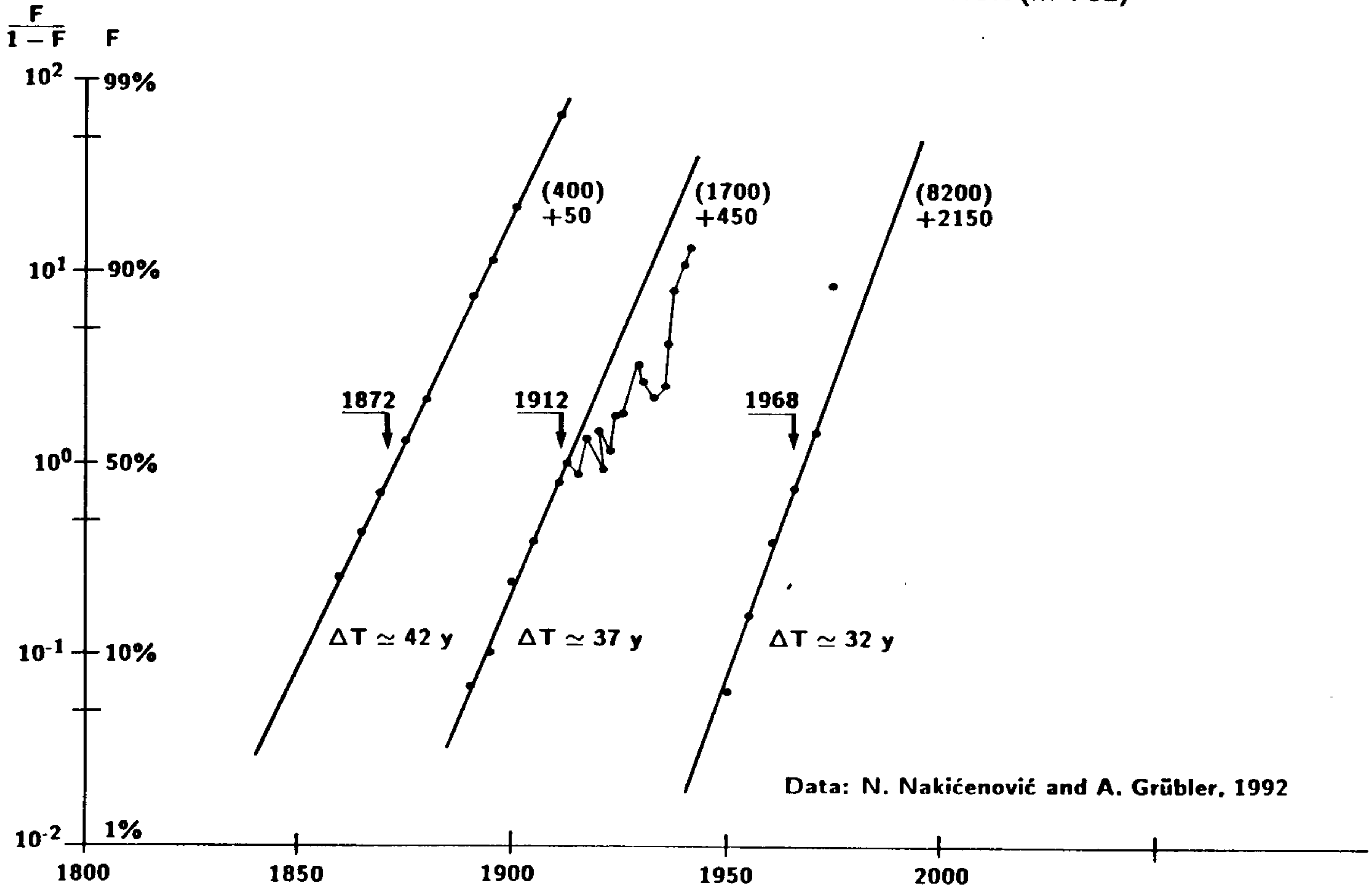

World – All t-km Transported
(Pass = 90 kg)
F / 1 – F
Fraction F
10^2
10^1
10^0
10^-1
10^-2
0.99
0.90
0.70
0.50
0.30
0.10
0.01
1950
1960
1970
1980
1990
2000

Fig.3-7

Energy consumption enjoys good statistics, being such an important parameter in the working of Western societies. We took advantage for plotting it since 1850 in terms of three growth pulses. They are in good synchronization with Kondratiev. The deviations of the second can be attributed to the warlike situation in the period between World War I and World War II. Historians now put them together into a 30-year war.

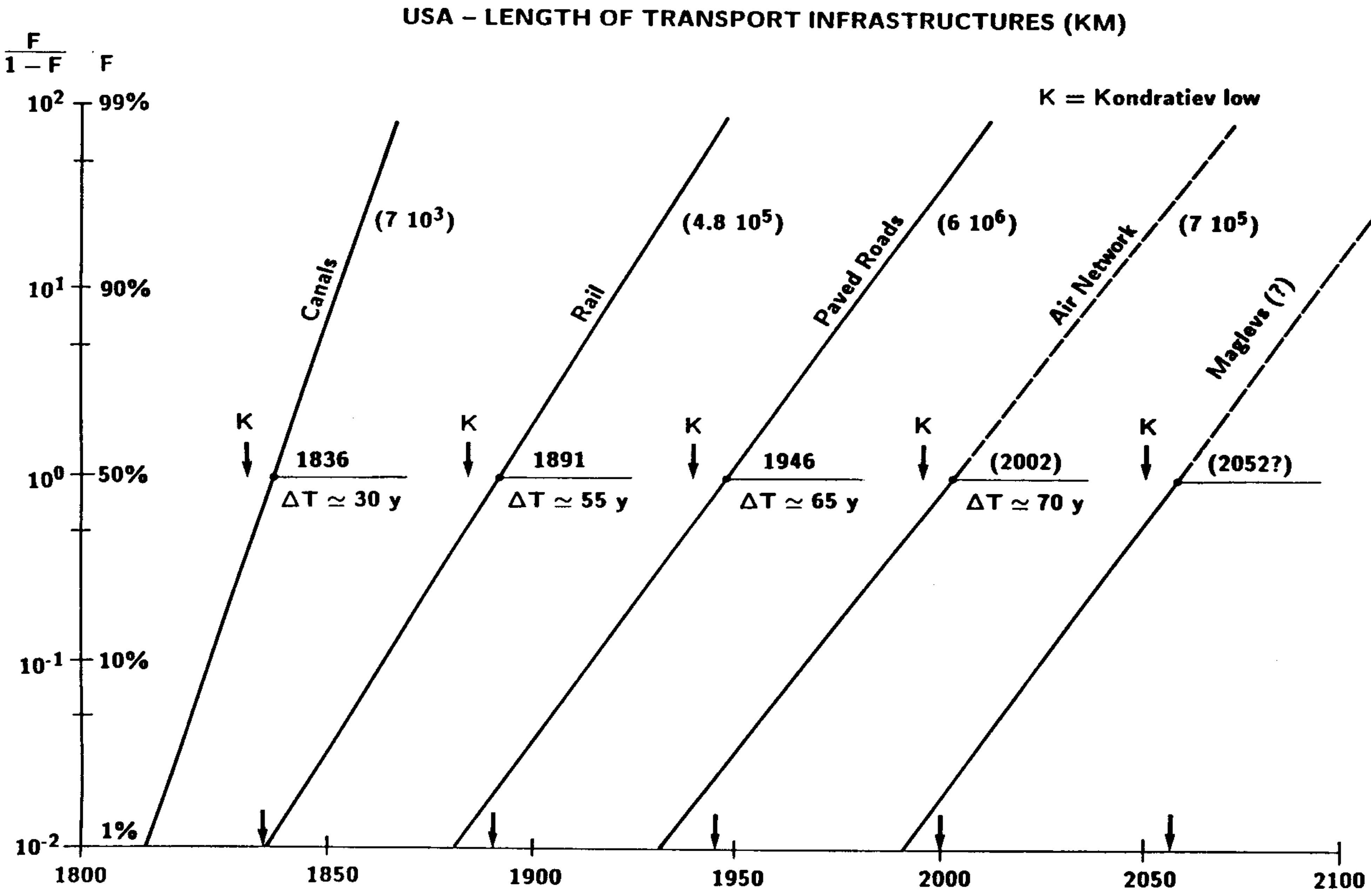
WORLD COMMERCIAL ENERGY CONSUMPTION (M-TCE)



C. Marchetti, IIASA, 1992

Fig.3-8

The penetration of transportation infrastructures of Fig.2-3 can be expressed in terms of the Fisher-Pry transform and expanded to include the air network (the sum of the distance between ticketed points) and a new transport infrastructure, presumably Maglevs. The line for Maglevs is constructed assuming certain taxonomic constraints extracted from the analysis of previous pulses. There is an obvious similarity between Fig.3-7 and Fig.3-8. Both refer to market penetration of new technologies.

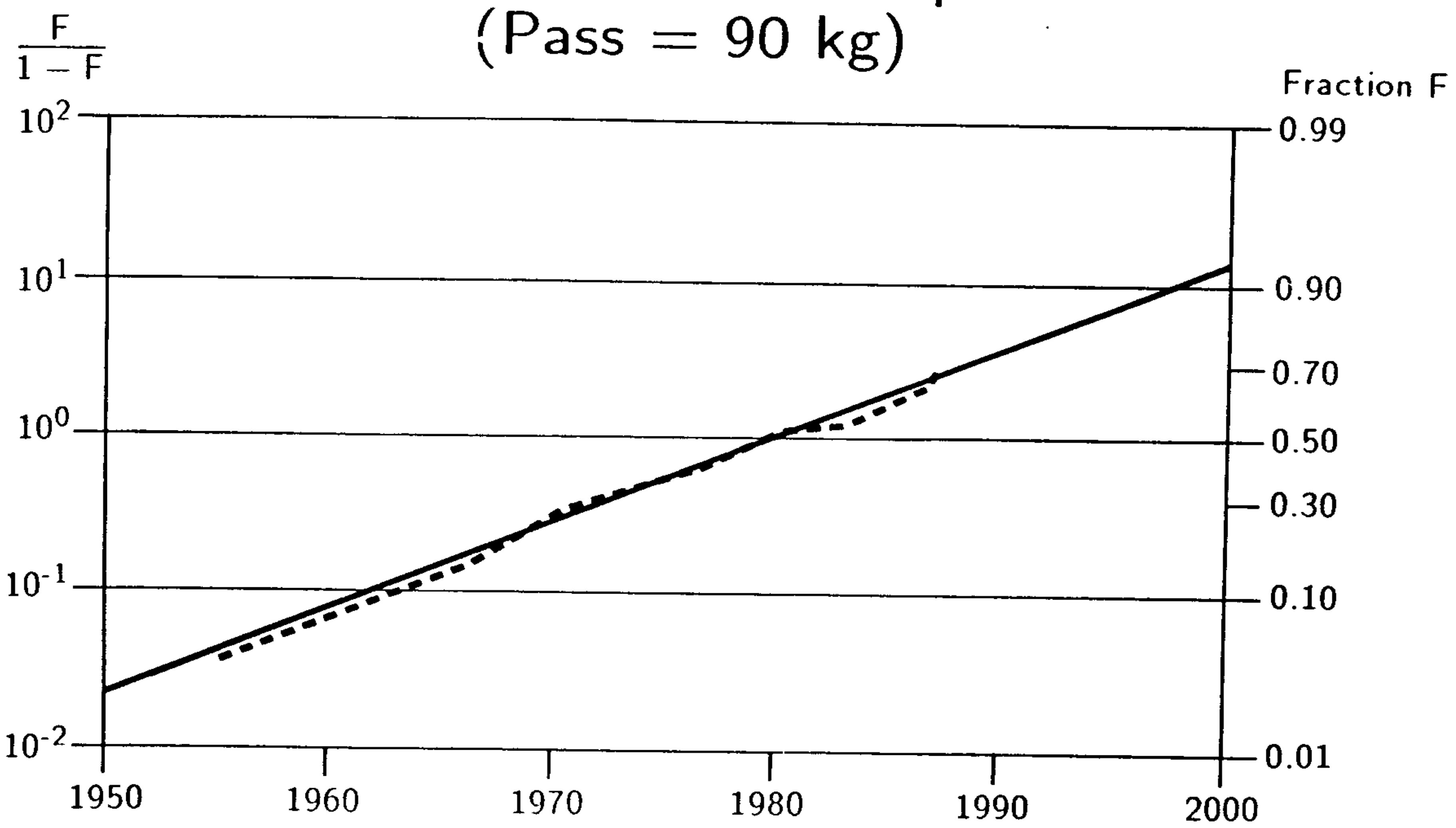


C. Marchetti, IIASA, 1992

Fig.3-9

Summing up transport infrastructure lengths of Fig.2-1 and presenting them according to a Fisher–Pry transform, we get a new logistic reported here.

World – All t-km Transported (Pass = 90 kg)



4. On Air Traffic

When a new mode of transport enters the market, its penetration in functional terms is logistic. Normally these logistics are encased into Kondratiev cycles. Our cycle is located between 1940 and 1995. As the chart in Fig.4-1 shows, this is the case for world air transport measured in pass-km performed. We see a wave of growth saturating 1.5 10^{12} pass-km, centered in 1976, which is perfectly normal. Unexpected because rare is a second fast wave of growth during the last part of the Kondratiev bringing to saturation *another* 0.9 10^{12} pass-km. The double-shot increase in pass-km appears both in domestic (Fig.4-2) and international flights (Fig.4-3), although with different characteristics. For domestic flights the second shot was earlier (centerpoint 1985) and faster (time constant 6 years) than for international flights (centerpoint 1988 and time constant 10 years). The time constants were too short for the air companies to react in a robust way. They rushed in a purchasing spree (Fig.4-4) where airframe companies could not produce what was demanded in terms of size and number. Consequently the companies went out of balance in terms of fleets. They kept over-aged and small planes, *faute de mieux*, and were (and still are) loaded with fleets too fragmented and too large. The situation is well shown in Fig.4-5 where, in correspondence with the second pulse of growth the fleet of IATA members more than doubled. In the previous 30 years it had remained almost constant in spite of an increase in traffic of almost two orders of magnitude, simply by keeping airplanes productivity proportional to traffic (Fig.5-1). This would have requested the availability of Jumbo-1000 that Boeing had considered (and to a point designed), but that overloaded air companies did not have the courage to request. This lack of foresight puts air companies in a dire situation nowadays, where most of them are more or less deep in red. But also the time available was very short, due to the abrupt nature of the second pulse.

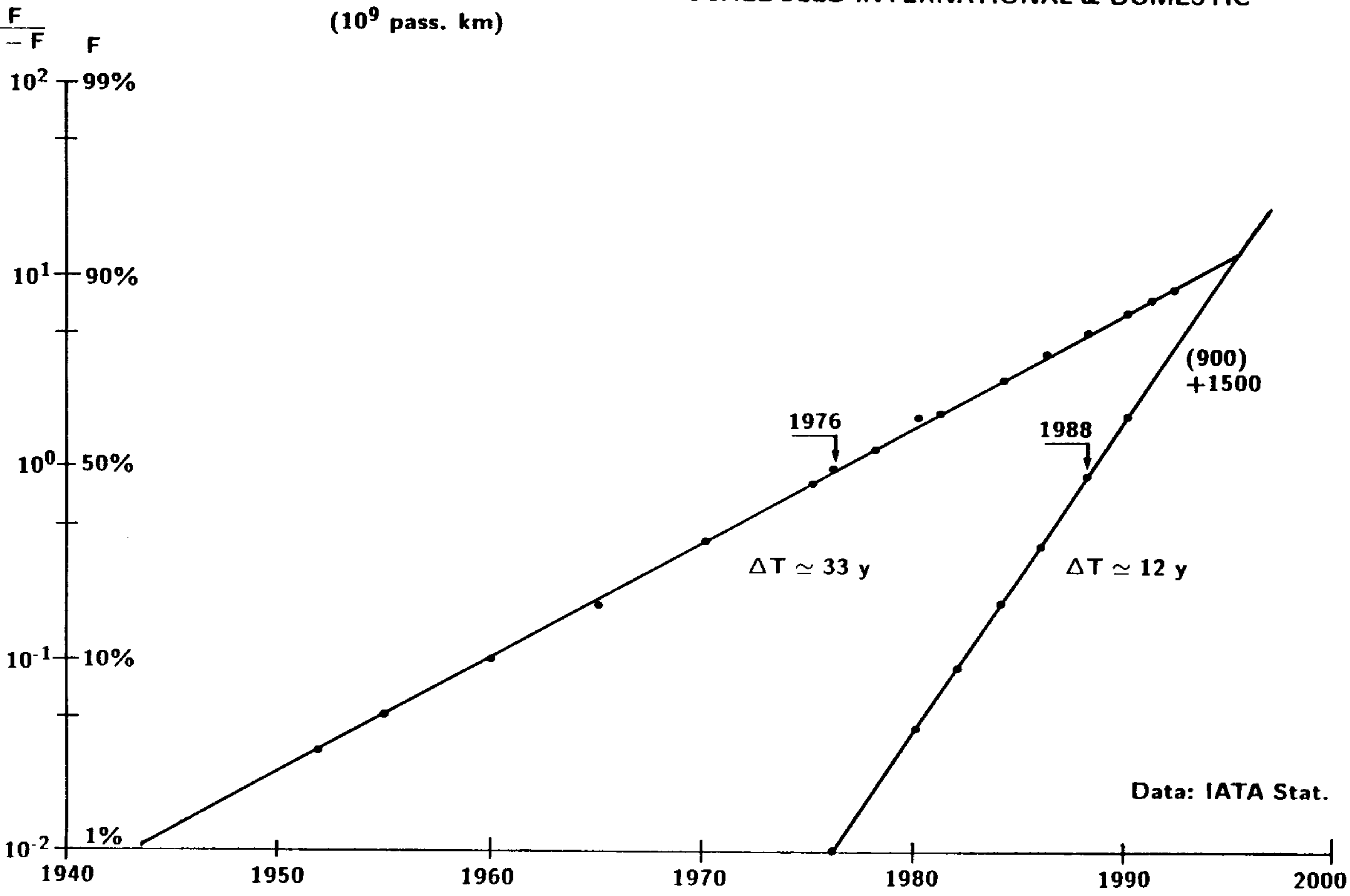
The logistic analysis of the growth of the fleet is reported in Fig.4-6. The evolution of the size of airplanes for the IATA fleet is reported in Fig.4-7 and a logistic analysis of its evolution is reported in Fig.4-8. Also speed is important as it is a factor in the productivity, and its evolution is reported in Fig.4-9.

To conclude, the operators seem now to be loaded with an *excessive number of planes* (on top of an excessive capacity). This is expensive *per se* and tends to clog airports and airlanes. Incidentally, a 1000-seat at the top range would call a 620-seat at second level, a 390-seat at the third and so on, as the ratio of size between rungs tends toward the golden mean. The optimality of this structure and the possibility of holding a six-level hierarchy (to provide 90-seaters for regional and feed-line traffic) could be a very interesting research subject *per se*.

Fig.4-1

Air passenger transport (scheduled) is analyzed in this chart. A first logistic wave, centered in 1976, leads to a saturation point of 1500×10^9 pass-km toward the end of the century, well in time with the present Kondratiev (1940–1985). However, a second logistic wave started at the end of the 1970s, with the very short time constant of 12 years, saturating again toward the end of this decade, with a remarkable value of the saturation point of 900 10^9 pass-km. We had no tools for forecasting this wave, which incidentally upset the organization and the budgets of air transport companies and plane manufacturers.

WORLD AIR TRANSPORT – SCHEDULED INTERNATIONAL & DOMESTIC
(10^9 pass. km)

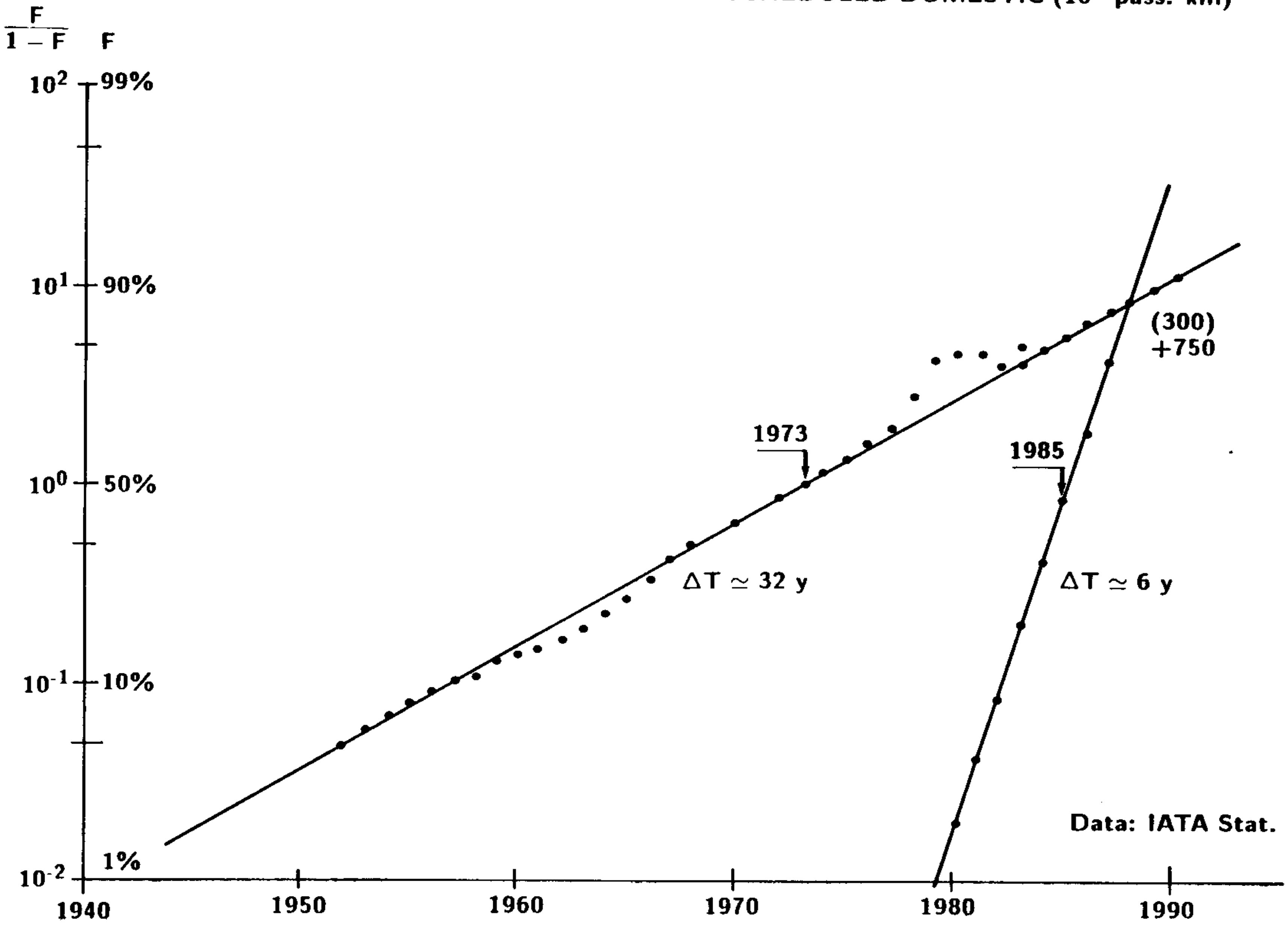


C. Marchetti, IIASA, 1992

Fig.4-2

In order to get more insight into the double-pulse phenomenon of Fig.3-1, we analyzed separately the cases of domestic and international transport. Also here, the two pulses are evident, and for the case of domestic transport the second pulse is extremely fast with a time constant of only 6 years. It appears to have saturated already in 1990. The second pulse is also smaller by respect to the first one, in comparison with the totals of Fig.3-1. However, it remains importnat adding 300 10^9 pass-km to the 750 10^9 pass-km of the first pulse (+40%).

WORLD AIR TRANSPORT – SCHEDULED DOMESTIC (10^9 pass. km)

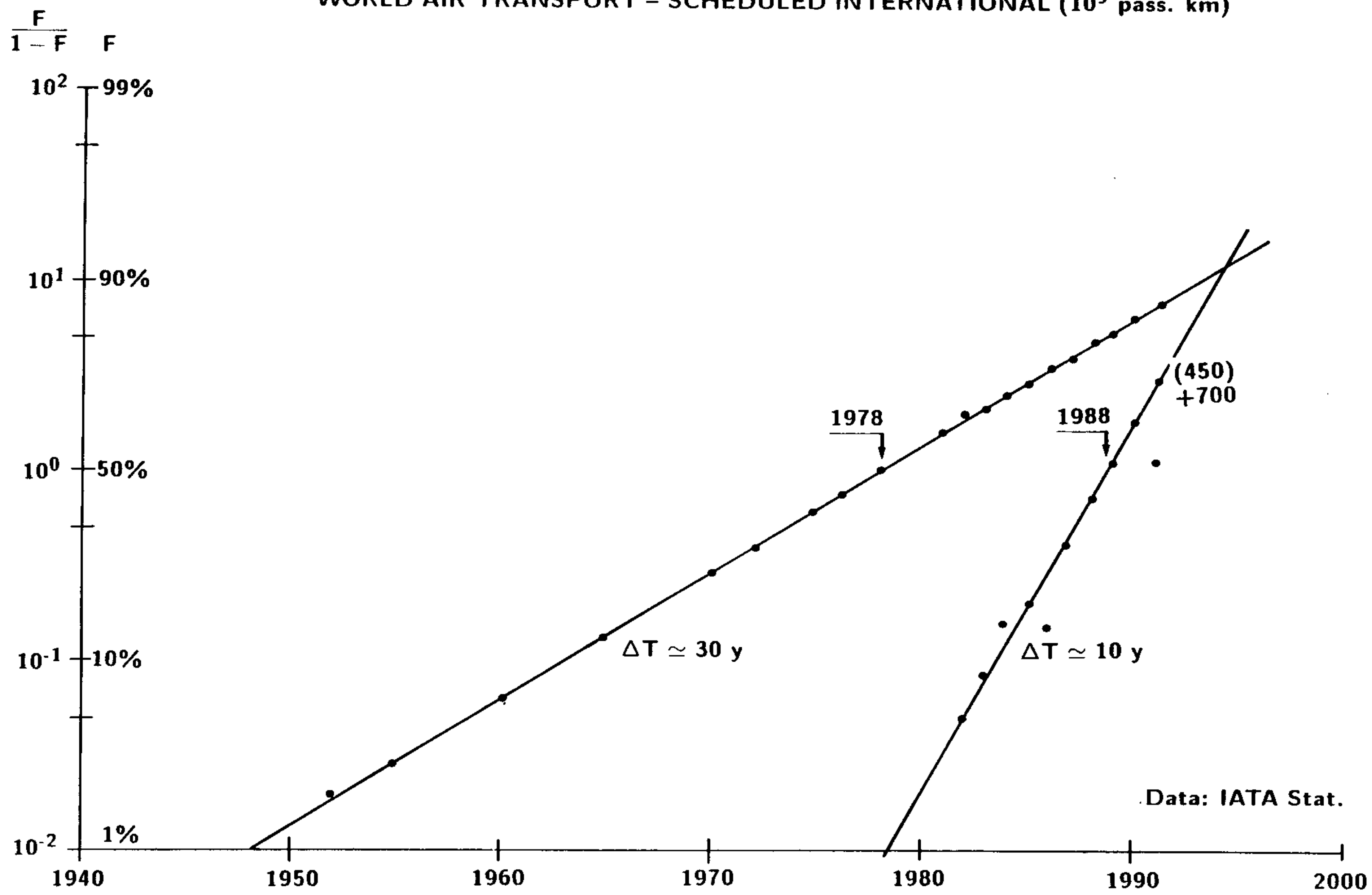


C. Marchetti, IIASA, 1992

Fig.4-3

The case of international, scheduled world air transport is analyzed here. The second pulse is very large, adding 65% to the saturation level of the first one. The suggestion that the "explosion" in domestic traffic expanded into international traffic is suggestive, but should be supported by more arguments.

WORLD AIR TRANSPORT – SCHEDULED INTERNATIONAL (10^9 pass. km)



C. Marchetti, IIASA, 1992

Fig.4-4

The hush and rush of the air transport companies under the pressure of the second wave of expansion of air traffic is well revealed by the orders–deliveries book. Until 1983 the order book followed a routine course with order bulges preceding deliveries by a few years. But in 1989 the order book reached the quota of almost 2000 planes. The manufacturers increased production but not beyond the levels they reached in boom years around 1965 and 1978. Order books are shrinking now, also because air companies in distress are cancelling orders.

Commercial jet aircraft history

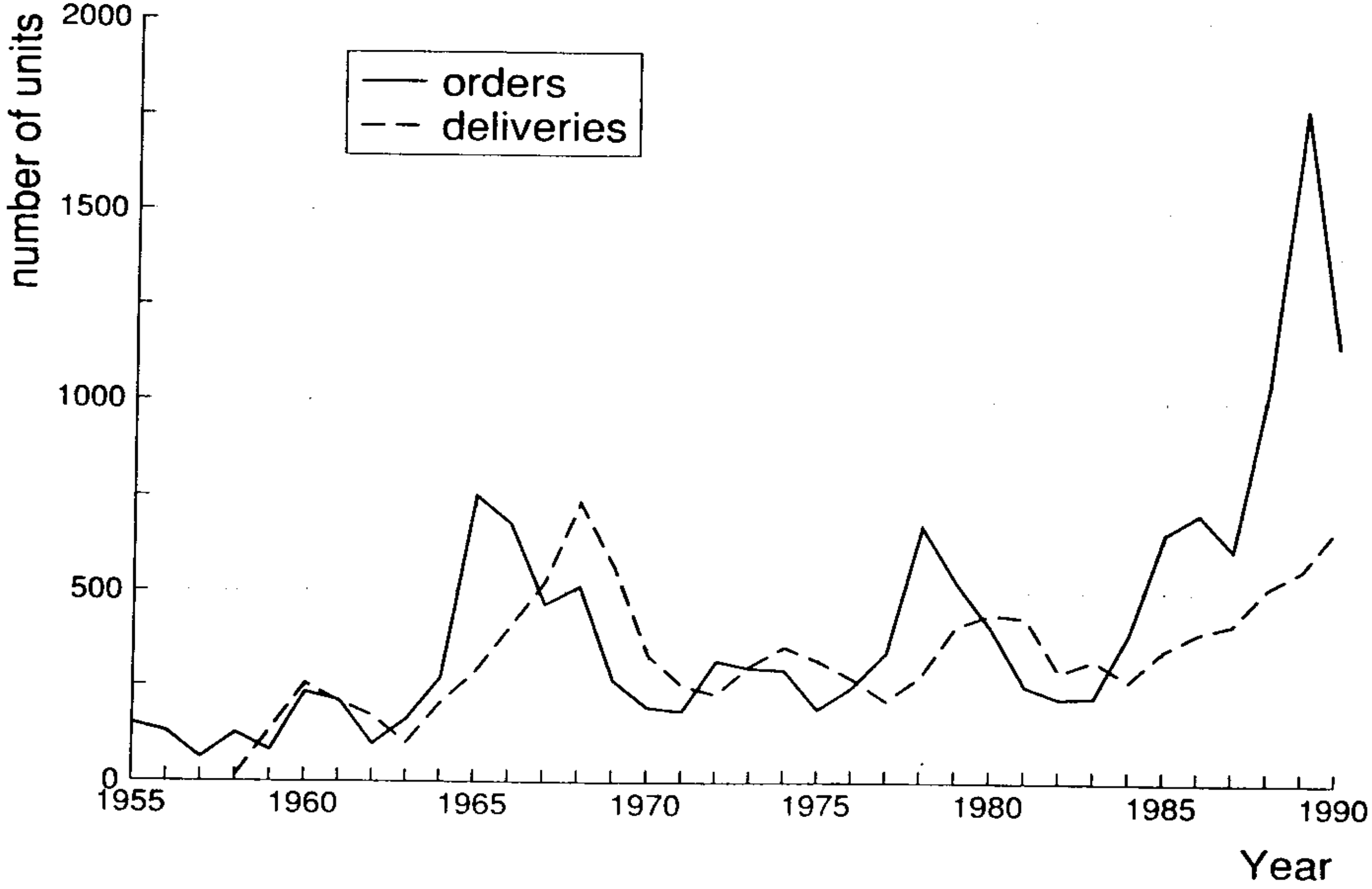


Fig.4-5

In previous analyses, based on the period 1950–1980, we had observed that productivity (pass-km) of first level planes followed the trend of pass-km growth at world level. Assuming that second-, third-, and fourth-level planes would follow, this would bring to a substantial stability in the number of planes in operation. This was in fact the case. The difference between 3200 and 4000 in the figure is in good part due to the fact that the IATA members to which the data refer increased in the period 1965–1970.

However, the second pulse of growth in the 1980s (Fig.1) was covered by a disproportioned increase in the number of planes without any increase in their mean capacity (and productivity, as most of them are jets with substantially equal speeds). We attribute this situation to a sudden pulse of demand that could not be satisfied with airplanes of appropriate capacity. The pulse of growth in traffic was also very fast and companies rushed to buy available models (that could not be delivered, however!).