Building Bridges and Tunnels: The Effects on the Evolution of Traffic

Cesare Marchetti

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IIASA
International Institute
for Applied Systems Analysis
A-2361 Laxenburg / Austria

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Summary

A general model for the generation of traffic is described. It is based on the assumption that a traveler tries to maximize the territory he can visit and exploit, by properly allocating a travel money budget (TMB) and a travel time budget (TTB) among available transportation modes (Zahavi, 1979). On the other hand, the evolution of *total traffic*, with constant boundary conditions, is assumed to follow the usual dynamics of human activities, described by systems of logistics contained in time boxes of about 55 years or the so-called Kondratiev cycles.

This conceptual frame is applied to a certain number of cases, where boundary conditions have changed because natural barriers have been overcome by bridges and tunnels, in order to grasp the essential modifications in traffic that follow and their mechanisms.

The results of these analyses have been applied to the case of the Messina Bridge, in order to evaluate its effects on traffic in different circumstances. It appears that the greatest impact of such a bridge will be on local traffic, and consequently its greatest potential utility ought to be found there. It may also stimulate the development of a linear metropolis – for instance, along the contiguous coasts of Calabria and Sicily – with decisive consequences for the structure of human settlements in that region.

The first part of this paper is dedicated to assembling an efficient model of traffic generation, including the effects of geographical impediments and their removal. Part II deals with a number of case studies where the model's validity is tested. Part III applies the model and analogical experiences to the case of the Messina Bridge, to assess the consequences of different configurations.

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Part I. The Models

The Territorial Concept of Travel

In order to forecast, we need some theoretical guidelines, and in the area of transport many theories compete for that role. Most of them construct from the grass root and try to interpret, in a quantitative way, the preferences and utilities of potential travelers.

I have somewhat arbitrarily chosen a model originally developed by Zahavi (1979) about 20 years ago, when he was working at the World Bank: the UMOT (Unified Mechanism of Travel) model. My choice is based on the affinity of Zahavi's assumptions with those embodied within my own systems analyses of social behavior, and the fact that UMOT requires only objective inputs with no need for local recalibration.

Because UMOT does not depend on the classical assumption of a Rational Economic Actor, the model has long been opposed by traditional economists. Nevertheless, UMOT permits forecasting of physical variables (e.g., pass-km traveled) through a simple maximization procedure when boundary conditions (such as price and speed of competing transport modes) are changed.

What UMOT essentially asserts is that ***man is a territorial animal*** and, as a consequence, he ***tries to maximize the territory*** he can explore and exploit under certain constraints. The constraints are:

- *Travel Time Budget (TTB)* or the mean time traveled per day by an active adult. Extensive field tests in the USA, Canada, the UK and Germany have shown that this time budget is remarkably constant at least in modern Western societies, averaging slightly more than *one hour per day* (Table 1.1).
- *Travel Money Budget (TMB)* or the money spent for travel, measured in terms of *disposable income* available to the traveler in question. Field tests show that this quantity, expressed in relative terms, is also constant, amounting to about 13% of disposable income (Table 1.2).

Within these constraints the traveler *allocates TTB and TMB* among different transport modes in such a way as to *maximize traveled distance*, i.e., basically the size of his territory.

These concepts do not necessarily contradict the idea of free rational choice. They indicate that such choices are made inside a context, a niche, a budget, which the "free" actor fills by a continuous search for opportunities.

The principles of TTB and TMB, with great conceptual parsimony, organize such complex decisions as the the way people choose their residences along a transportation corridor ending in a center of employment. Take, for example, the case of Washington, DC (Figure 1.1). Because this figure incorporates a cross-income analysis, it shows the *quintessential role of travel time in the structuring of a human settlement.* The effect of income is shown in Figure 1.2.

An important detail is the way people divide their total daily travel distance into *daily trips.* Figure 1.3, which also refers to two of the Washington "corridors", is enlightening: in a given environment the number of trips is independent of the distance traveled, i.e., speed.

Clearly, when people gain speed they use it to travel farther and not to make more trips. In other words, most individuals treat their territory the same way, regardless of its size. The important parameter in the environment that changes the number of trips is the size of the city. A small city (10^5 inhabitants) calls for five or six trips a day, whereas a large city trims the total to three.

Table 1.3 shows that, with some limited variations, the same principles and numbers are valid around the world - an important point, as we will use some of the conclusions to deal with our problem, without local calibrations. This stability suggests that an important pattern of human behavior has been uncovered, related to latent instincts that survive even in our modern age.

Another observation, related to the TTB, leads to a *functional definition of the geographical extension of a city*: the city is that geographical area within which one travels during the day, every day, and returns home. The more or less universal TTB of one hour, then, fairly sharply defines the extent of the city and links it to the speed of the transportation system, public or private. Because the different modes of transport - walking, bicycling, bus, car, subway - have different speeds but also different costs, the possible allocations of TMB makes the city appear to increase in size with increasing income. This effect can be enhanced by providing *fast* and frequent public services, like Metro suburban railways, and by properly pricing them.

Fast transport systems can thus conglomerate strings of preexisting centers into single functional units that provide a much wider range of opportunities for people living there, in terms of jobs, housing, services, and entertainment.

This definition of a city easily accommodates such breakthroughs in transportation technology as that afforded by the airplane. Because available income is increasing, and consequently TMB, and also because cost in real terms of air transport is decreasing, ever-larger strata of users can allocate some part of TTB to this transport mode.

For example, every day about 3000 passengers fly between Milan and Rome. Most of them make a one-day trip. This means a progressive integration of the two cities in what Doxiadis and Papaioannou (1974) calls Eperopolis. Similar phenomena occur in many countries, sometimes linking a string of cities by air shuttles.

An analysis of air corridors - such as Boston–NY–Washington, San Diego–Los Angeles–Sacramento–San Francisco, Tokyo–Osaka, using city rank size maps at a world level – show them emerging as functional single units, even if geographically the human settlements appear as dense, separate clots (Figure 1.4). This shows the central importance of transport systems, and in particular their *speed*, in defining the extension of the functional city and ultimately the geographic evolution of human settlements (Figure 1.5).

The functional limits of a city can be determined *to a point* by the mobility of the elite who can afford to use the fastest and usually most expensive form of transport. For example, the number of day-trippers between Milan and Rome cannot compare to the number of passengers transported daily in Milan's Metro. But money is not the sole constraint, as we have seen.

Other constraints are time and the number of trips per day, which we can assume for simplicity to be about three, as our analysis refers to fairly large conurbations. This means that even making a long trip per day, and two short ones, one cannot allocate much more than 30 minutes to the long one. Consequently, the area of daily use is limited by the distance covered by the fastest means of transport in 15 or 20 minutes.

Thus, time is of quintessential importance in determining the volume of traffic along a transport line, because it discriminates between the population that will take it every day more or less, like the Metro in Milan, and those who will use it only occasionally, like the air commuters between Milan and Rome. The density of traffic differs in the two cases by orders of magnitude, and the switch is clearly visible when prices remain basically the same but transit times change drastically. A typical case is when a slow ferry is replaced by a fast toll bridge, as in Lisbon, Istanbul, and Hong Kong, so that traffic switches from intercity to intracity mode.

UMOT is very useful in perceiving the mechanisms of travel demand formation and interpreting counter-intuitive phenomena, such as the fact that zeroing the cost of public transportation actually increases car traffic in the center of a city. Because the car is perceived as a faster mode than the public service, it is then taken as far as the TMB permits. As public transport prices drop, the money saved will go into purchasing gasoline and extending in time the use of the car.

Perhaps the most important concept introduced by UMOT is that of the fixed TTB. When a manager catches a very expensive plane in order to "save time", he actually hides his natural instinct to expand his territory of action. In fact, the time he saves will be used to catch another plane, his travel time being organized around the best way of spending his TTB of one hour per day.

UMOT, however, is not so efficient for grasping long-term trends because it requires foreknowledge about the speed of future transport modes and user prices. For that reason we will use a complementary model, saying nothing about mechanisms, but giving crisp maps of the evolution of systems over periods as long as a century. Because the lifetime of a modern bridge is of that order of magnitude, at least, this *is the necessary* time frame within which we must work.

Long-Term System Dynamics and the Volterra Model

The Volterra (1931) model states that every human activity develops logistically over time in a diffusive mode filling a certain potential – a market or a niche. This "Darwinian" concept, which uses Volterra–Lotka (1925, 1926) equations as a formal background, was originally applied to map the dynamics of energy markets during the last 100 years (Marchetti and Nakicenovic, 1979). It has been used recently for an extensive mapping and forecasting of transportation systems in Europe for the last 100 years and the next 20 (Marchetti, 1987). Some details of the model are given in the Mathematical Appendix.

To illustrate the Volterra notion, we describe the evolution of the American transport system in terms of its infrastructure growth (Figure 1.6) and passenger use (Figure 1.7). In the two figures the actual value at a given time (e.g., railway track length) is given as a percentage of total infrastructure length (e.g., canals + railways + paved roads), expressed in Fisher–Pry notation (see the Mathematical Appendix). In the case of passenger-km, we represent a modal split, expressed in percentages of total traffic.

We can thus see that, apart from any economic considerations, usually bound to restricted periods of time, the "physics" of a given system evolves with great stability so that surprisingly accurate and long-range forecasts can be made over long periods.

To show that this patterns is universal, and not linked to specific forms of economic and social organizations, the same infrastructure growth analysis is reported for the Soviet Union in Figure 1.8. Unfortunately, data on air pass-km were not available, which in a sense robs the analysis of its look into the future.

The analysis of Figures 1.6 and 1.8 shows a remarkable periodicity in the introduction of new modes of transport and their infrastructures. One wonders whether some new system is now brewing. The question is relevant, because even if introduced in the near future, the influence of a new transport system would be felt during the operation of the Messina bridge, a structure intended to serve for another century, at least.

The analysis can be repeated looking at each infrastructure separately, as if it grew within its own niche, independent of the other system infrastructure. The procedure is not fully defensible, but it gives a clear picture for at least the first stages of a new technology's penetration. As Figure 1.9 shows, a new mode of transport, as mirrored in its related infrastructure, was introduced every 55 years in the USA from 1750 to 1950.

These 55-year or Kondratiev cycles also emerge from the historical introduction of primary energy sources. From the records, one could have predicted the peak of nuclear energy use in 1980 (Marchetti, 1981) and can predict the emergence of fusion energy around 2025.

A new transport mode should enter the market around the year 2000. As I have shown in my analysis on transport systems in Europe (Marchetti, 1987), the number one candidate for this technology is the Magnetically Levitated Train (Maglev), which may play a central role in the potential traffic on the Messina bridge.

Incidentally, Maglevs have reached technological maturity as basic innovations. Prototypes have run up to 600 km/hr, and have been designed both for intercity service, e.g., in the frame of a third 800 km Shinkansen line, and for intracity service, i.e., Metro and suburban lines. Their acceleration, speed, and precision of control, not to speak of the absence of noise and vibrations, make them an inevitable choice for future Metros.

To my knowledge, about 1500 cases of technology diffusion have been analyzed using the Volterra model, mostly by researchers at the International Institute for Applied Systems Analysis (IIASA). The results are so consistent over such a large variety of subjects that we think the model has great descriptive power and universality when properly applied to dynamic social and economic systems. For this reason, it will be used extensively in mapping the evolution of traffic and the effects of "bridges and tunnels" in various test cases.

Table 1.1. Travel expenditures as percentage of disposable income in selected countries and urban areas.

Site	Survey period	% of total household expenditures	
Nationwide:			
US	1963–1975	13.18 ± 0.38	
Canada	1963–1974	13.14 ± 0.43	
UK	1972	11.7	
West Germany	1971–1974	11.28 ± 0.54	
		% of household income in households:	
		With cars	Carless
Urban area:			
Washington, DC	1968	11.0	4.2
Minneapolis–St. Paul	1970	10.1	3.4
Nuremberg	1975	11.8	3.5

[a]Source: Zahavi, 1979.

Table 1.2. Daily travel time (in hours) per motorized traveler for selected cities, correlated with selected variables.

Site	Survey date	Variable		
		High income		Low income
Bogota, Colombia		1.05		1.78
Santiago, Chile		1.09		1.52
Singapore		1.14		1.36
		Car travel		Transit travel
Washington, DC	1955	1.09		1.27
	1968	1.11		1.42
Minneapolis–St. Paul	1958	1.14		1.05
	1970	1.13		1.15
All USA	1970	1.06		0.99
St. Louis	1976		Car availability	
0 car			1.06	
1 car			0.99	
2 cars			1.05	
3+ cars			1.06	
average			1.04	
Nuremberg region	1975	Household size	1 car	0 car
		1	1.22	1.41
		2	1.25	1.42
		3	1.28	1.36
		4+	1.27	1.35
Munich	1976		Survey day	
day 1			1.15	
day 2			1.16	
day 3			1.16	
			Total	
Toronto	1964		1.09	
Calgary	1971		1.11	
Montreal	1971		1.18	

SOURCE: Zahavi, 1979.

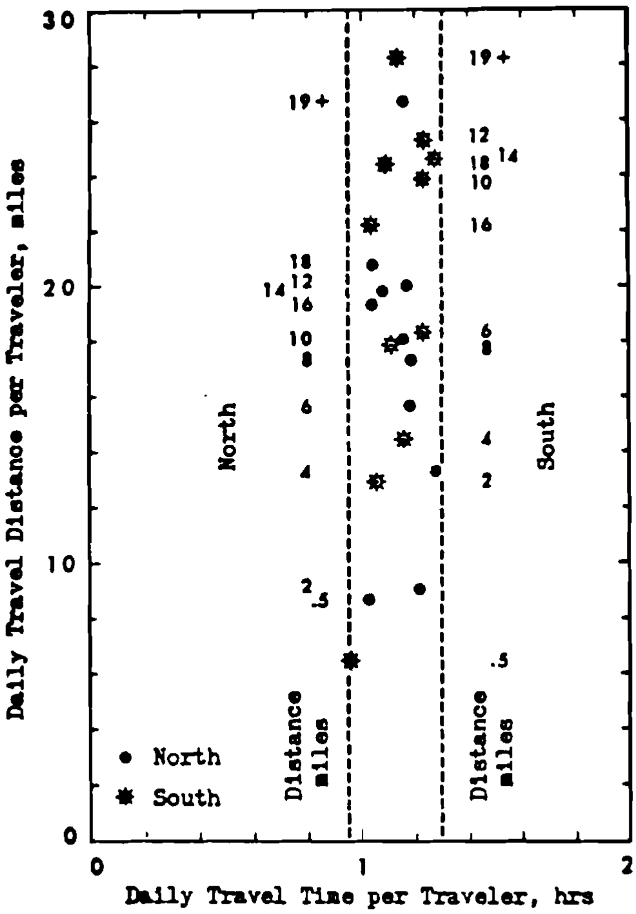


FIGURE 1.1. Daily travel distance versus daily travel time per traveler, by residence distance from the city center, north and south corridors, Washington, DC (1968). (Source: Zahavi, 1981).

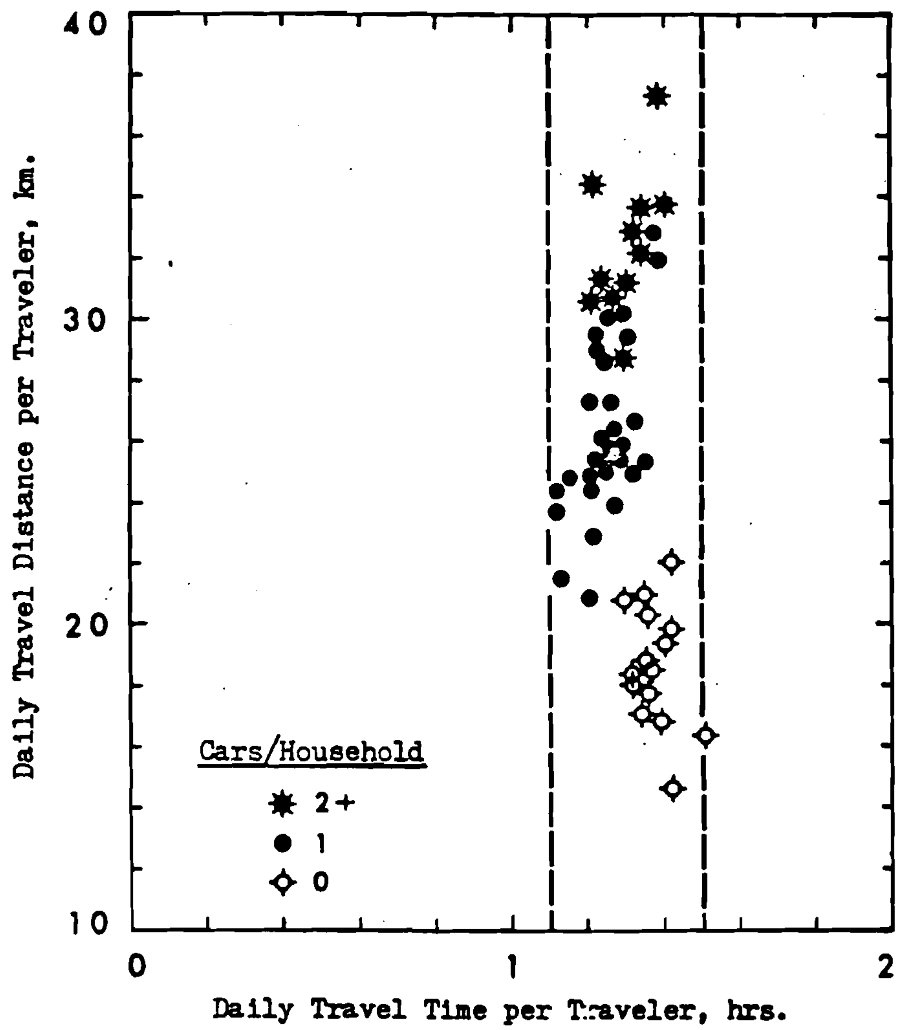


FIGURE 1.2. Daily travel distance versus daily travel time per traveler, by household car availability, Nuremberg Region, 1975. (Source: Zahavi, 1981.)

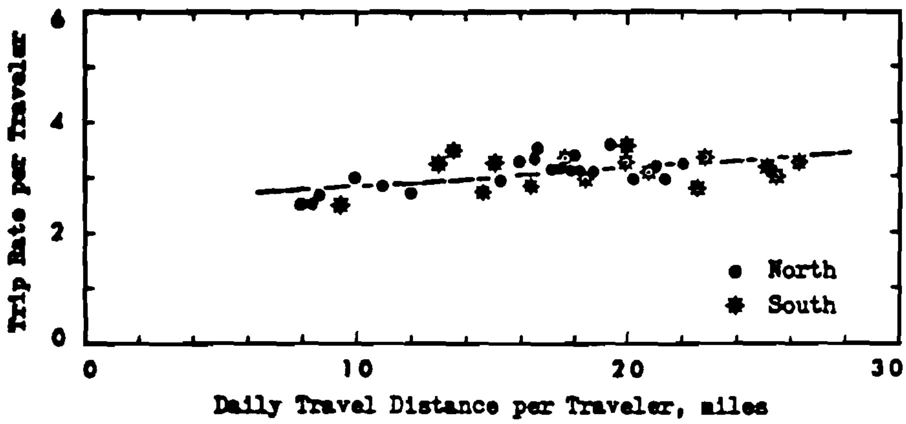


FIGURE 1.3. Daily trip rate versus daily travel distance per traveler, by income and residence distance from the city center, north and south corridors, Washington, DC (1968). (Source: Zahavi, 1981).

Table 1.3. The use of time in 12 countries (in hours).

	Time per Person Spent on Activity								
						Travel			
Country/city	Work	House-Work	Household, Child & Personal Care	Sleep	Total Leisure	Work	Non-work	Total	Grand Total
Belgium	4.38	2.42	3.23	8.35	4.73	0.40	0.50	0.93	24.04
Bulgaria, Kazanlik	6.05	1.67	4.37	6.97	3.55	0.68	0.70	1.48	24.09
Czechoslovakia, Olomouc	5.07	2.87	3.47	7.80	3.77	0.55	0.45	1.03	24.01
France, 6 cities	4.25	2.70	4.03	8.30	3.85	0.37	0.52	0.97	24.10
Fed. Rep. Germany	3.88	2.95	3.92	8.50	4.18	0.30	0.28	0.65	24.08
Fed. Rep. Germany, Osnabruck	3.63	2.78	3.82	8.34	4.68	0.27	0.42	0.97	24.26
German Dem. Rep., Hoyerswerda	4.63	3.43	3.38	7.90	3.70	0.53	0.43	1.00	24.04
Hungary, Györ	5.55	2.73	3.57	7.88	3.10	0.68	0.50	1.23	24.06
Peru, Lima–Callao	3.57	2.87	3.10	8.28	4.68	0.62	0.87	1.50	24.00
Poland, Torun	4.97	2.67	3.25	7.78	4.10	0.62	0.63	1.30	24.07
USA, 44 cities	4.03	2.37	3.78	7.83	4.75	0.42	0.83	1.30	24.06
USSR, Pskow	5.65	2.18	3.25	7.70	3.77	0.55	0.92	1.47	24.02
Yugoslavia, Kragujevac	4.00	2.80	3.28	7.87	4.87	0.45	0.80	1.28	24.01

SOURCE: Szalai, 1972.

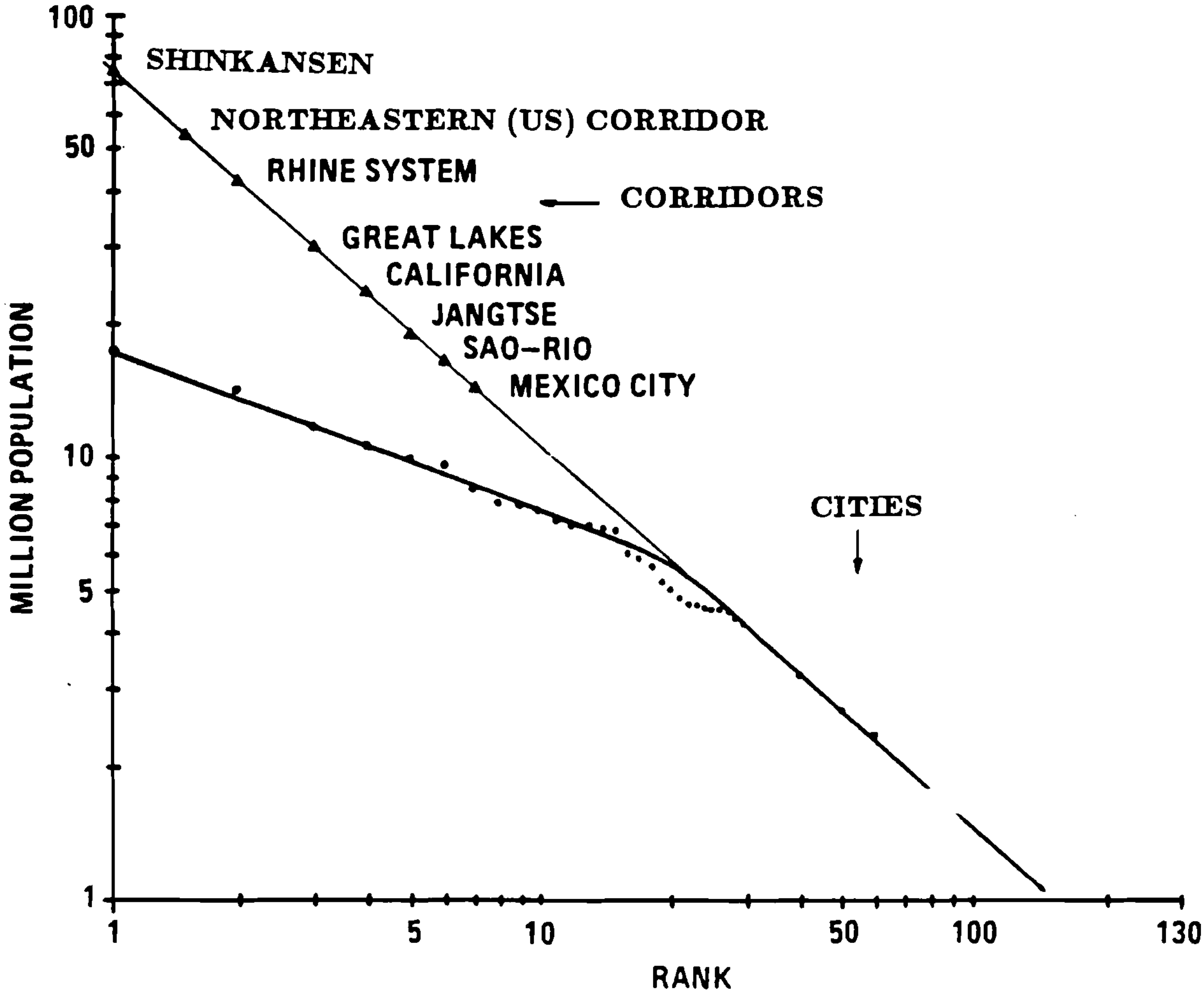


FIGURE 1.4. Rank size distribution of world cities and corridors.

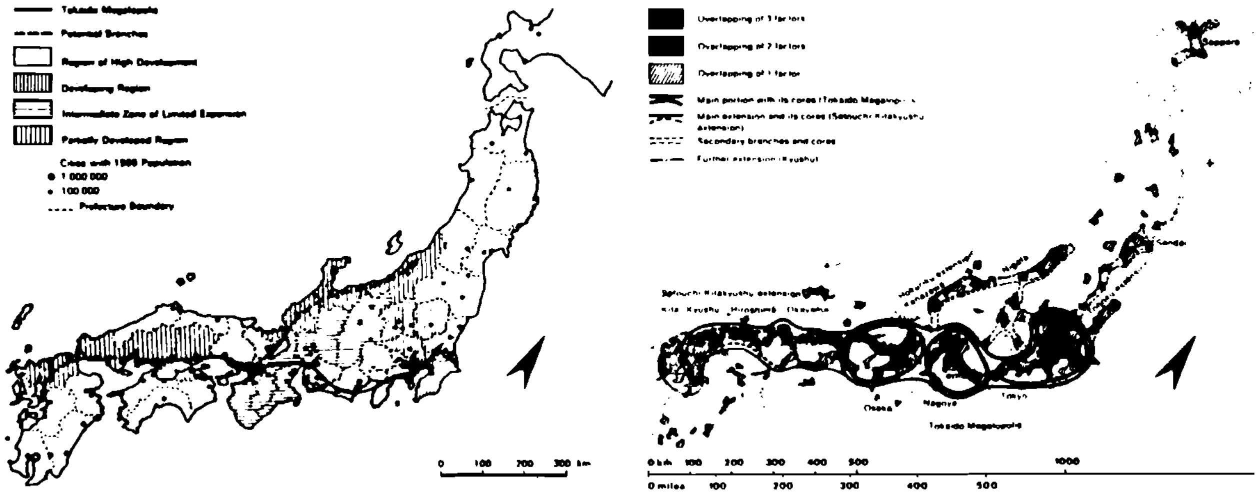


FIGURE 1.5. The coagulation of a corridor into a megalopolis. (Source: Doxiadis and Papaioannou, 1974).

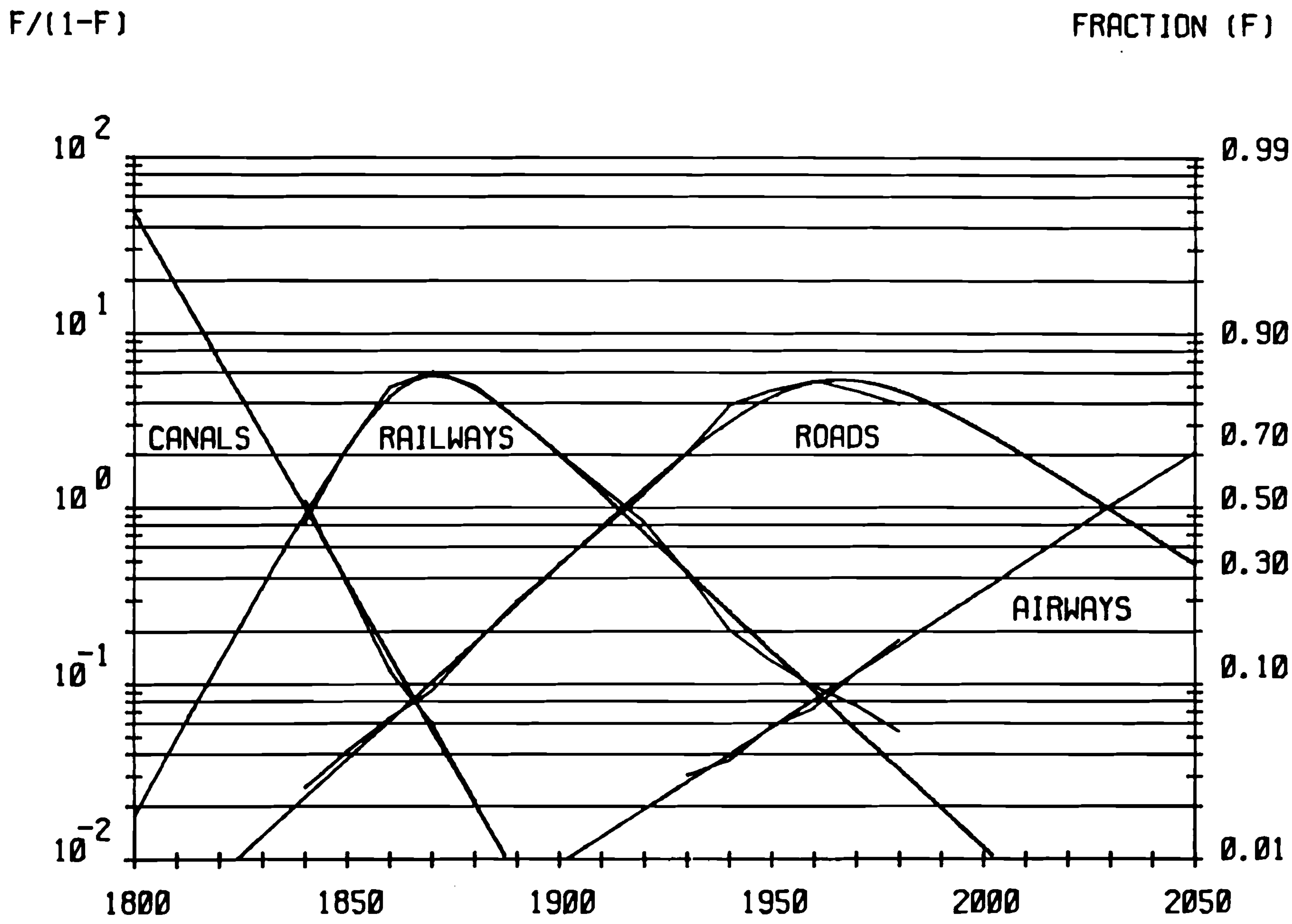


FIGURE 1.6. USA – transport infrastructures substitution, 1800–2050. (Source: Nakicenovic, 1986).

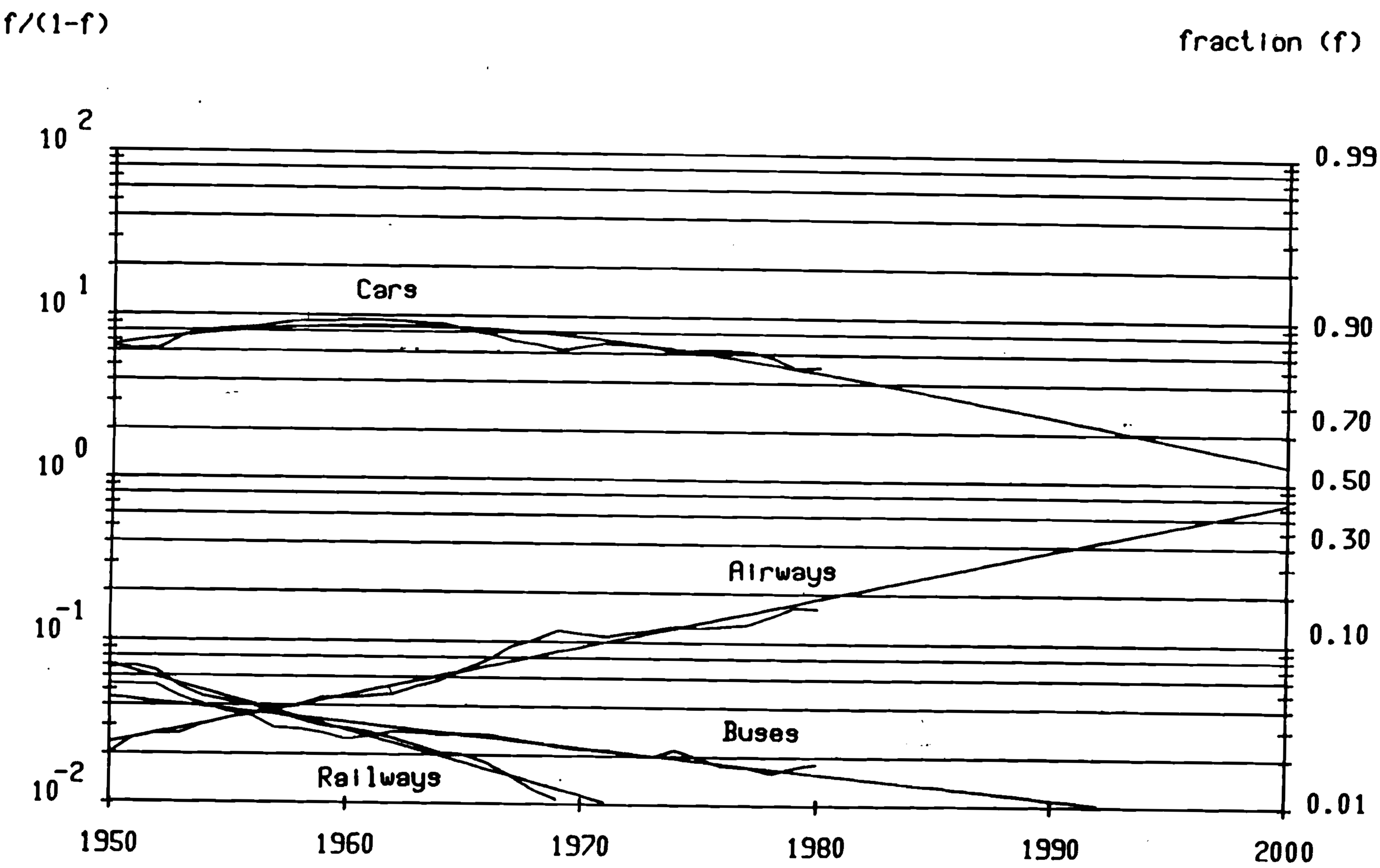


FIGURE 1.7. USA – intercity passenger traffic substitution (in passenger-km). (Source: Nakicenovic, 1987).

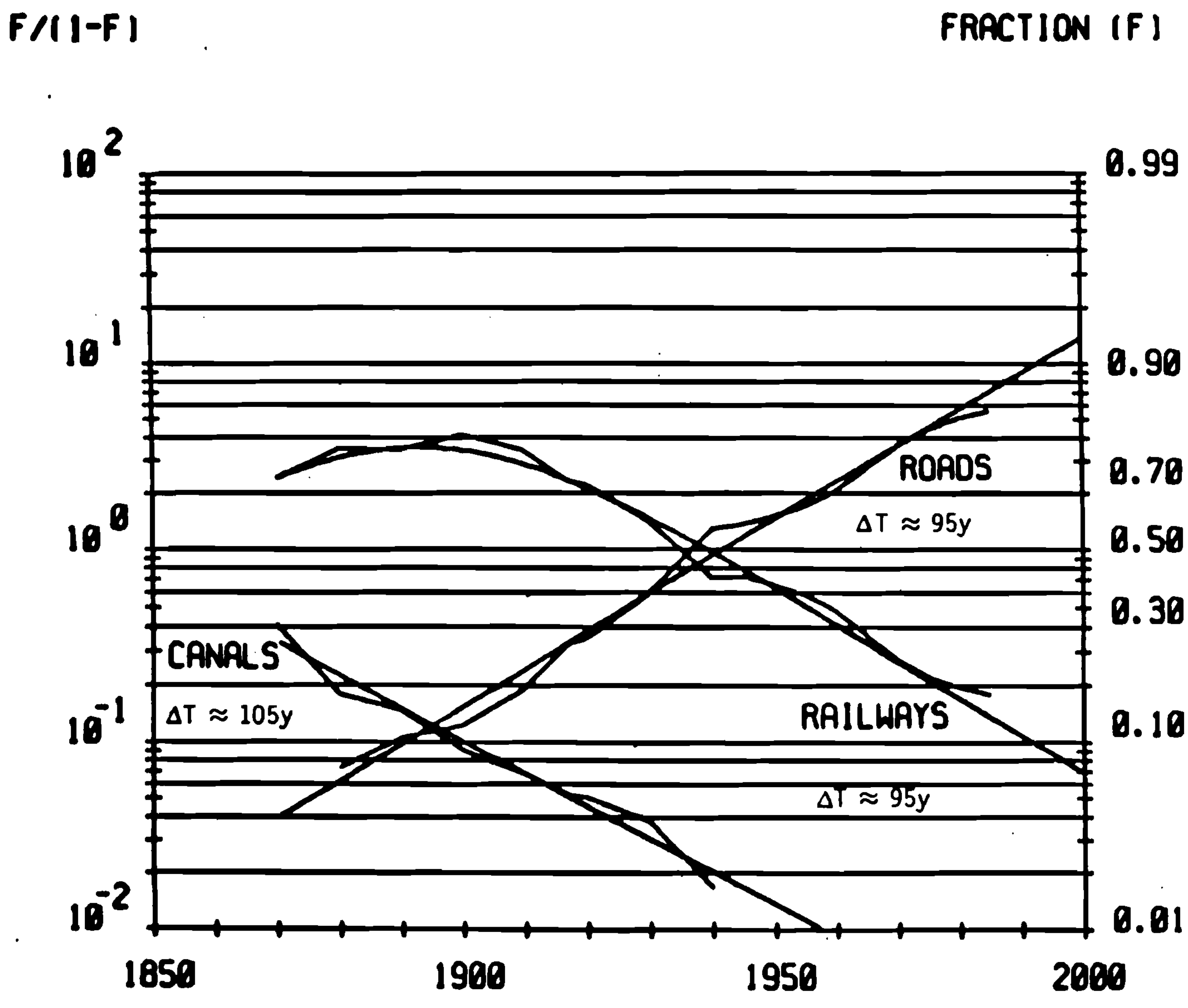


FIGURE 1.8. USSR – transport infrastructure substitution. (Source: Grübler, 1987).

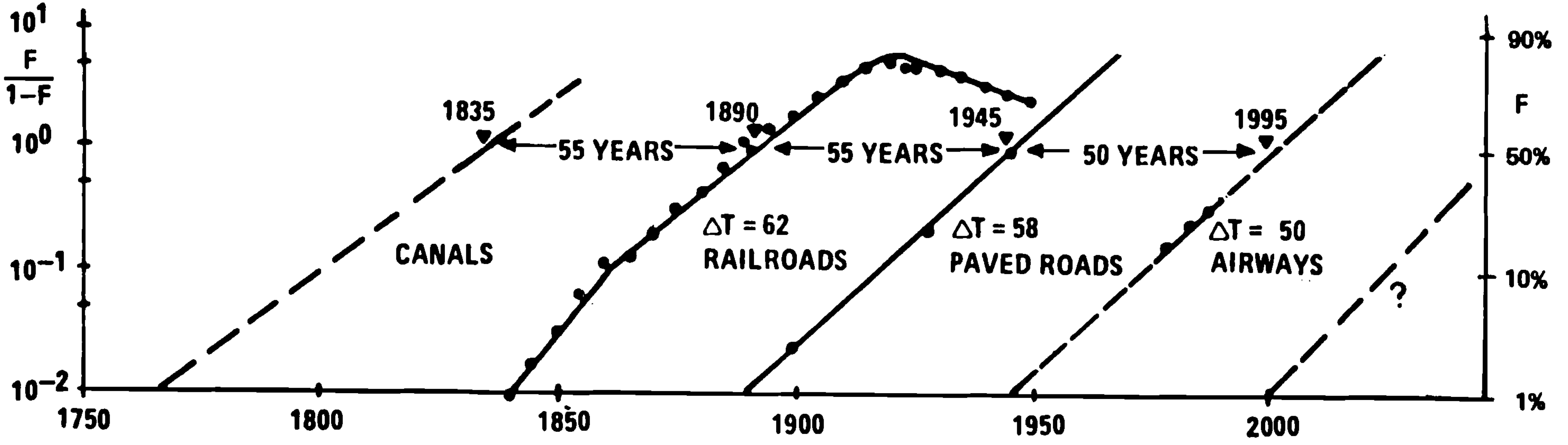


FIGURE 1.9. US transport infrastructure. Perceived saturations: railroads (3 x 10^5 miles), paved roads (3.4 x 10^6 miles), airways (3.2 x 10^6 miles). (Source: (Marchetti, 1987).

Part II: Case Histories

Overcoming Natural Barriers

The two models delineated in Part I will now be used to analyze and interpret what happened in a number of places analogous to the Messina case. Basically we will look at the evolution of traffic through barriers of a certain permeability and at the effects of a sudden increase of permeability by the opening of a bridge or a tunnel.

Barriers to the exchange of people, goods, and messages have always attracted the interest of physical geographers and I summarize here their relevant findings.

The effect of a river on the development of a city is perhaps the most common example, as shown schematically in Figure 2.1. The city on the left side of the river, where the original settlement was located, systematically grows larger than the city on the other side. Four North American cities demonstrate the validity of this finding: Detroit–Windsor, Cincinnati–Covington, Philadelphia–Camden, St. Louis–East St. Louis (Figure 2.2). A river is a strong enough barrier for the two parts of a "natural" city to develop strong separate identities and different names. In our case studies, we examine Lisbon–Almade, Istanbul–Üsküdan, and Kowloon–Victoria, among others of this type. Winnipeg's expansion across the Red River is shown in Figure 2.3 at four different dates, between 1884 and 1948, with arrows indicating the actual thrust of growth.

Human settlements interact not only through the movement of people and goods, but also through information transfer. Telephone calls and letters are easier to measure than people's movements and can be used as proxies.

The effect of a barrier of some sort is shown schematically in Figure 2.4, where the width of the bars represents density of telephone conversations, based on a gravitational model in a homogeneous system, from Gossipville to its environs and other cities, and divided by an appropriate factor linked to the permeability of the barrier.

When a lake is the barrier, the communication effect is sketched in Figure 2.5 to visualize the process. The barrier can also be linguistic and cultural, as for the French–English boundary in Canada, or political as for Canada–USA. The last cases were studied by Ross Mackay (1968), using the gravity model for calibration and are reported in Figure 2.6. These figures show amazing results. Calls between Montreal and *English-speaking* Canadian cities are roughly *ten times* more frequent than for gravitationally equivalent US cities. So much for cultural solidarity across political barriers! As might be expected, however, calls between Montreal and French-speaking cities were more frequent than for English-speaking cities in Canada, varying by a factor up to ten for small cities, but almost equal for large cities.

Viewing wedlock as a more intensive form of information transfer, Figure 2.7 reports on marriages between one town (Spring Mills) and its neighboring communities in a mountain region of Pennsylvania. Valleys are in white here, and it is clear that the tendency for marriages is along the valley, mountain ridges acting as quite impermeable barriers.

The same pattern occurs in the microenvironment of a city, noted by Zipf (1972) (Figure 2.8), who counted residential blocks between the prior home addresses of newlyweds. The relation is perfectly gravitational. (In two dimensions gravity forces appear as 1/distance and not as the inverse squares as in three dimensions.)

These examples emphasize the importance of objective forces (such as physical geography) in shaping human behavior – an important reason for choosing objective models to help map and forecast traffic flows.

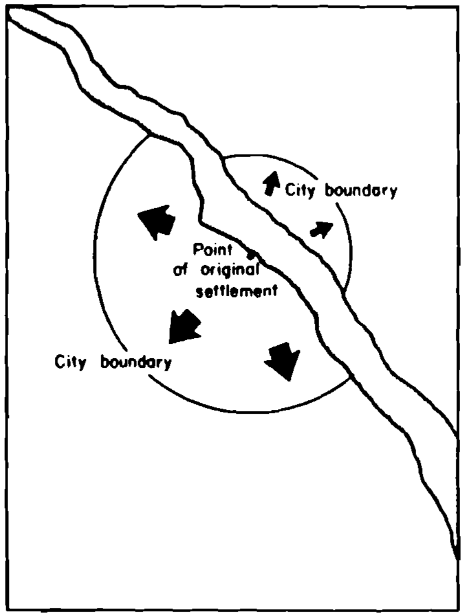


FIGURE 2.1. Effect of a permeable river barrier on the diffusion of a city. (Source: Abler et al., 1972).

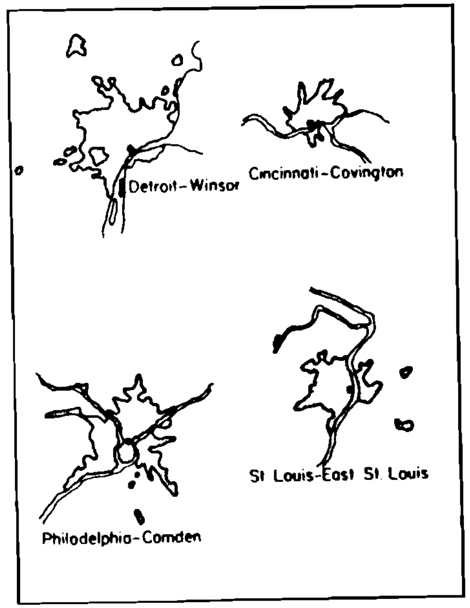


FIGURE 2.2. Barrier effects of rivers on four pairs North American cities. (Source: Abler et al., 1972).

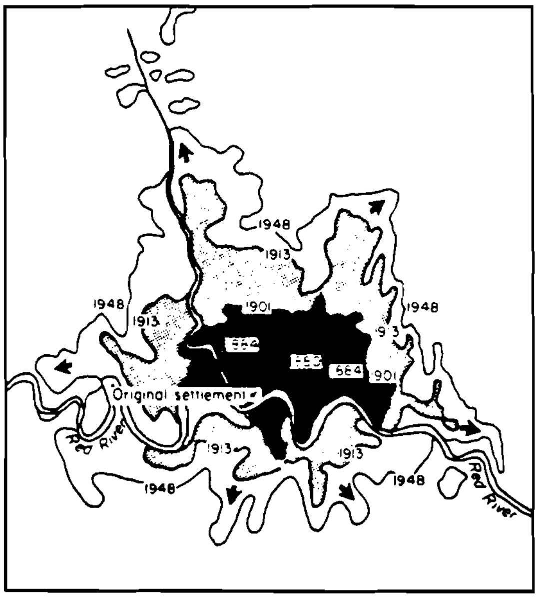


FIGURE 2.3. Diffusion on Winnipeg from site of original settlement on the Red River, 1884–1948. (Source: Abler at al., 1972).

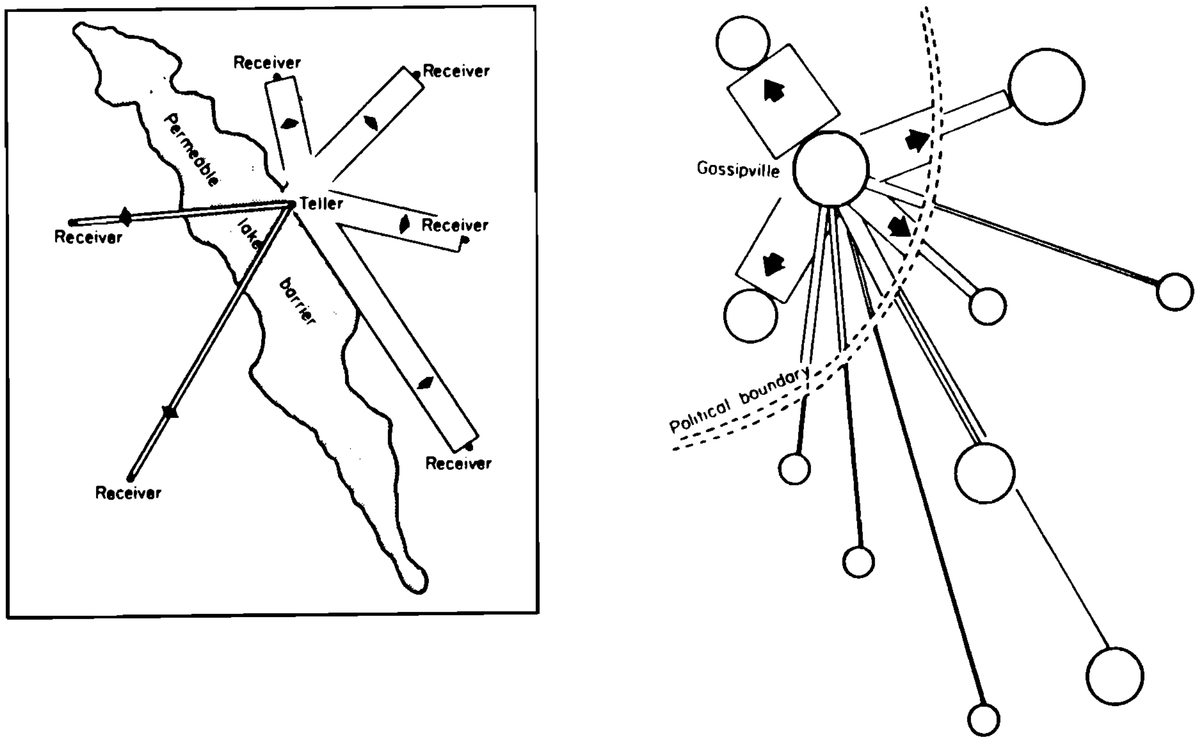


FIGURE 2.4. Schematic representations of the effect of barriers in telephone interchange between cities represented as circles.' Calls in a certain direction are strongly reduced when a barrier is introduced. (Source: Abler et al., 1972).

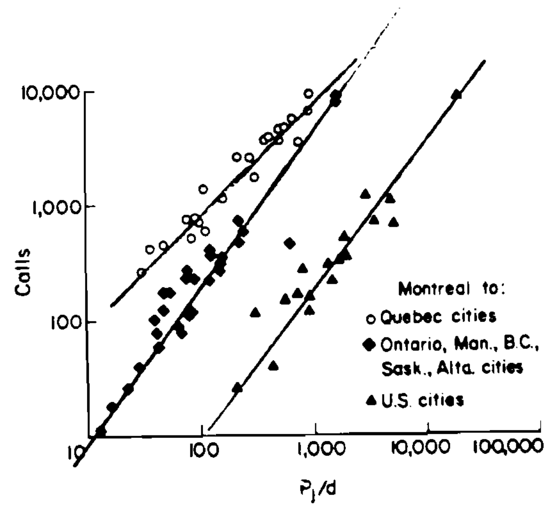


FIGURE 2.5. Gravitational plot of telephone calls between cities in French speaking Canada, English speaking Canada and the US (calls $= \frac{\text{pop}(1) \times \text{pop}(2)}{\text{distance}(1-2)}$).

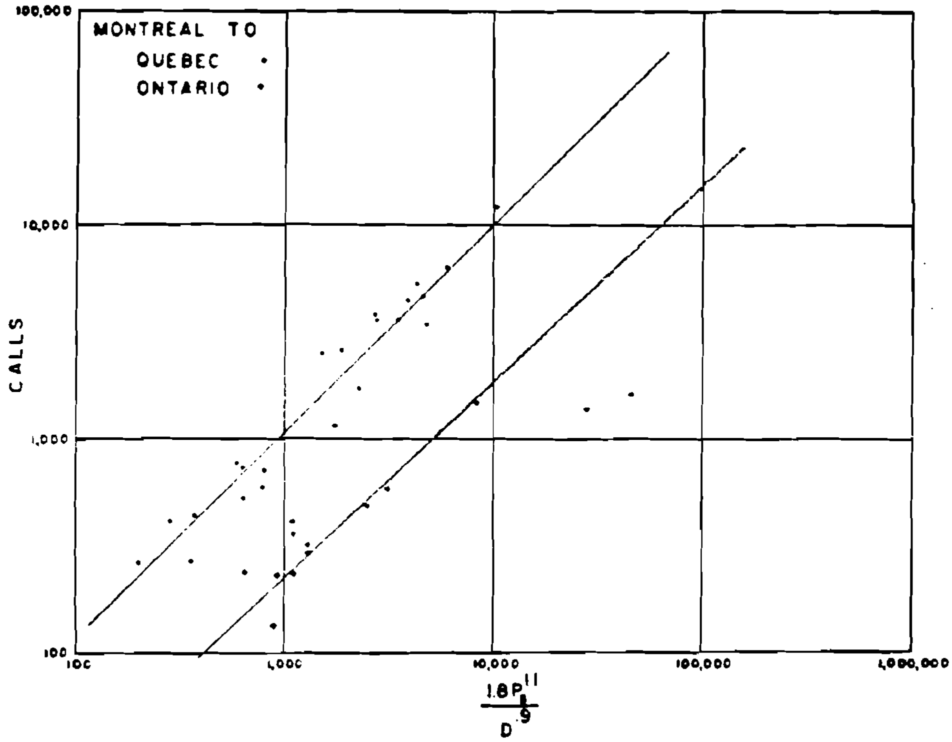


FIGURE 2.6. Quasi gravitational plot of telephone calls from Montreal to Quebec cities (upper line) and Ontario cities (lower line).

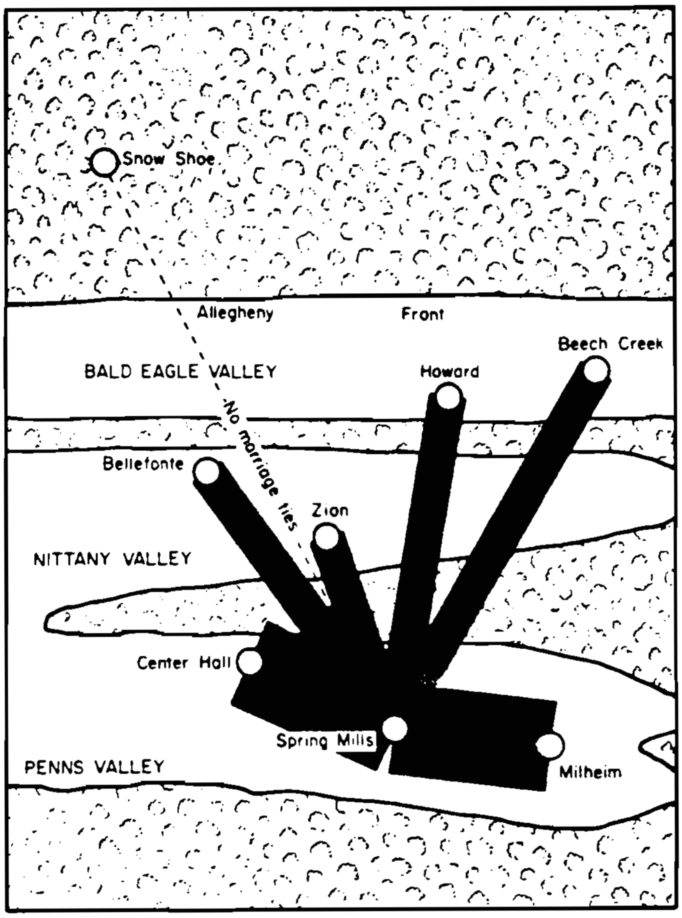


FIGURE 2.7. Marriage ties between Spring Mills, Pennsylvania, and neighboring communities: valleys are white; mountain areas are shaded. (Source: Abler et al., 1972).

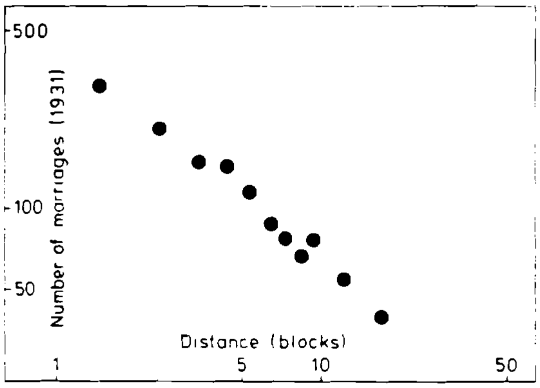


FIGURE 2.8. Number of marriages in a city as a function of distance between the partners' prior residences. (Source: Zipf, 1972).

The Bosphorus

A bridge built across the Bosphorus in 1974 exemplifies the general principles discussed above and has direct relevance to the Messina bridge case. The first Bosphorus bridge was originally conceived as part of an Asia/Europe Motorway, and its location was chosen on purely technical grounds - in particular, the fact that the Bosphorus is narrowest at that point (Figure 2.9). The motorway basically carries trucks and lorries, moving goods between Asian Turkey and the Middle East and Europe.

The consequences of two very important elements seem to have escaped the bridge planners and Freeman Fox-Botek Construction Engineers, who gathered traffic data before and after completion of the project:

(1) The average ferry crossing, including some waiting time (15 minutes), takes about one hour.

(2) On the Asian side of the Bosphorus, a conglomerate of human settlements holds perhaps one million people.

The one-hour barrier of the Bosphorus kept the settlements on the two shores operating as two separate cities, following the TTB principle. Reducing this travel time, using a car or a dolmush (taxi van), to presumably ten minutes or less, the two cities have tended to merge, with all the *internal* traffic characteristics of a megalopolis. The same phenomenon applies to Lisbon and Hong Kong.

Transit time reduction triggered a quantum jump in cross-Bosphorus traffic, owing to the preexistence of a poorly connected, but structured settlement ready to exploit the removal of a natural (time) barrier. The effects are due to appear relatively quickly, as compared with opening a fast link between Istanbul and an empty Asian territory, which could have fostered new urbanization.

For cost-conscious long-distance truckers, the difference between the bridge toll and the ferry fare is more important than saving half an hour or so. Consequently, we should not expect great changes in the number of trucks carried by ferries, *nor* in the trends of truck traffic.

The dynamic trend of the situation is shown in Figure 2.10, where truck crossings over the Bosphorus by bridge *and* ferry are reported and estimated. According to the logistic saturation point traffic will be 4.5 million crossings per year around 1995. The time constant of 24 years shows the effect of a Kondratiev wave. To be more orthodox, the exercise should be repeated subtracting the 1940 saturation of ferry traffic, but it is likely to have been very small in comparison to the 4.5 million to be reached in 1995.

What comes out clearly from this analysis, imperfect in many ways, is that the opening of the bridge has not influenced truck traffic much during the last ten years. The increase can be completely attributed to normal economic development and evolution of the motorway interchange.

We can cross-check this finding by observing that a time constant of 24 years means a growth by a factor of ten in 24 years, which amounts to a *mean growth* of 10% per year. Looking at Turkey as a whole, truck traffic (ton-km) increased during the same period by a *mean* of about 9% per year. Thanks to the inevitable imprecision of these statistics, the coincidence is strikingly good.

With respect to total vehicular traffic over the bridge, we have a completely different picture (Figure 2.11). Traffic rushed onto it from its opening and saturated at 29 million vehicles per year in just five years. Part of this traffic came out of the ferries – about 4.5 million vehicles (Figure 2.12). *The rest was "created"*.

In 1974 the bridge carried 11.8 million vehicles of which only 3.75 million were taken from the ferries (projected minus actual traffic). The traffic created was then 8.0 *million vehicular transit* in a year and a half of operation. Four years after its opening, the bridge was technically saturated. The trucks that had motivated its construction can use the bridge only at night, with no great advantage over ferry transport.

At saturation around 1978, the traffic created can be estimated by subtracting the saturation point of the ferries from that of the bridge, i.e., *23 million vehicular transits*. This happened in only four years.

The most important observation here is that cost reduction was not the motivating force. Ferries are cheaper than this tolled bridge. But traffic on them has reduced from a little above 5.0 million transits in 1972 to something around 0.8 million in 1976, and it is now oscillating around 0.6 million. Moreover, the ferries land near densely populated areas and should thus, in principle, be more convenient for truck deliveries.

The fact the bridge saturated before the end of the Kondratiev cycle in 1995 points to an explanation outside the general development trend, no doubt merely of technical origin. Demand for more capacity is, in fact, so evident that a second bridge has already been constructed, and the construction of a third one should start soon.

It would have been very interesting to analyze also passenger traffic, on vehicles and on foot, but data were not available. As in Hong Kong, where such analysis could be done, the next successful infrastructure would be a Metro line, providing fast transit between Istanbul city center and the area of Üsküdar–Kadiköy, at the moment connected only by slow ferries. Using the rule-of-thumb method described later, this Metro line could shuffle across the Bosphorus *half a billion passengers* a year.

FIGURE 2.9. Location of the Bosphorus bridge (1974) and ferry routes between European and Asian shores of Istanbul.

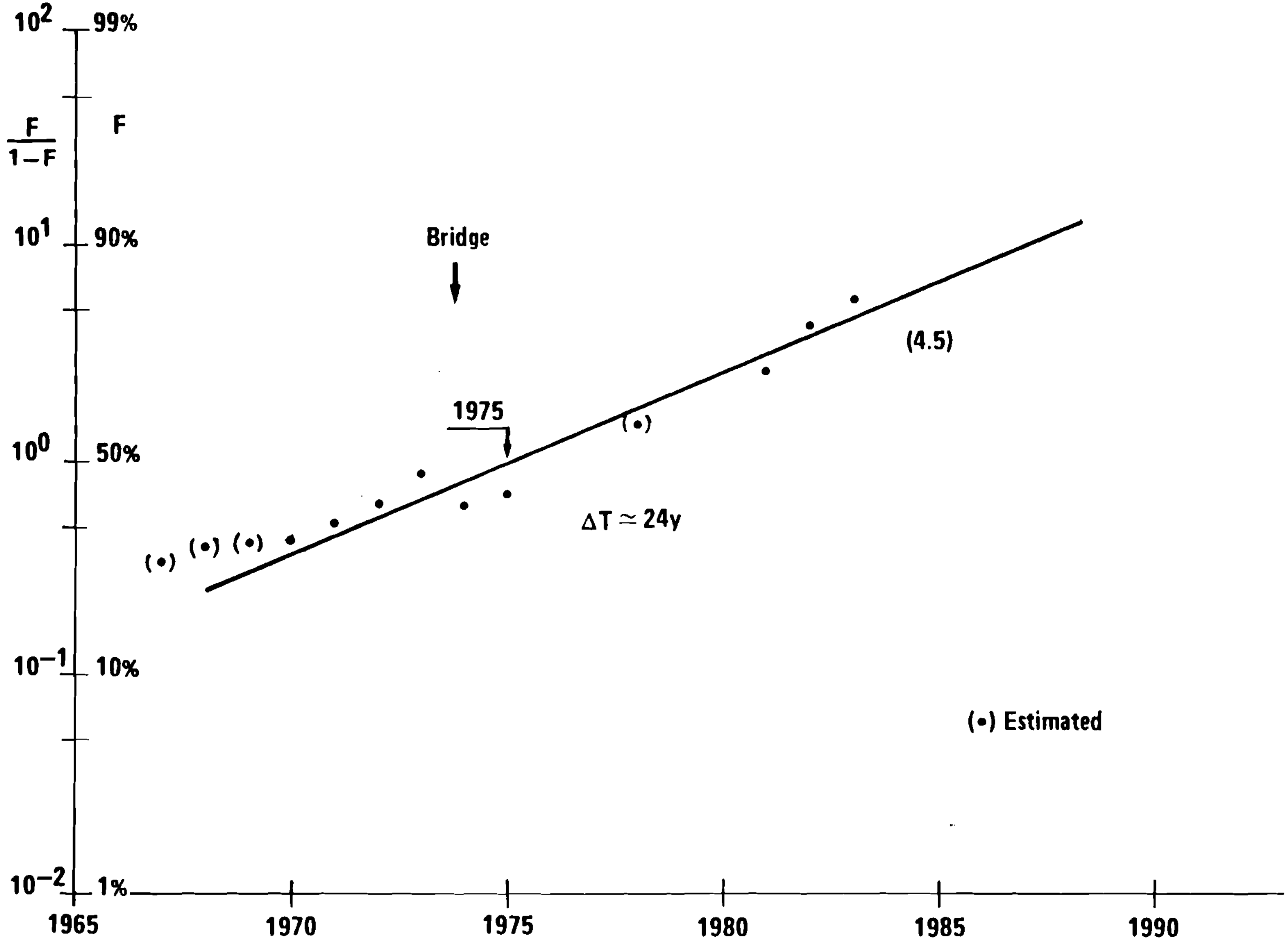


FIGURE 2.10. Trend in total trucks (10^6) crossing the Bosphorus, by ferry and bridge, 1966–1990. (Based on data from Freeman Fox-Botek, 1985).

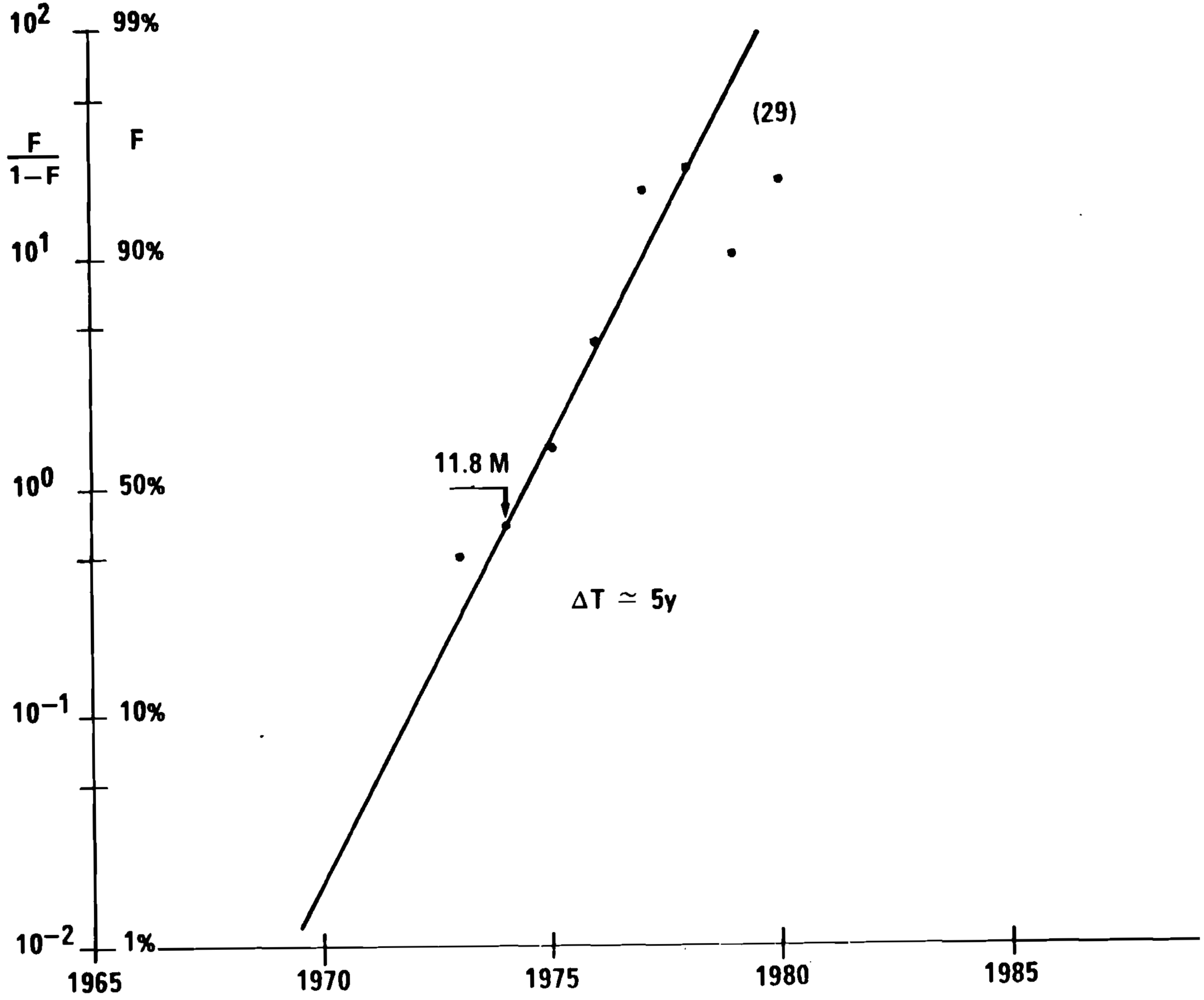


FIGURE 2.11. Trend in total vehicles (10^6) crossing the Bosphorus, 1989–1980. (Based on data from Freeman Fox-Botek, 1985).

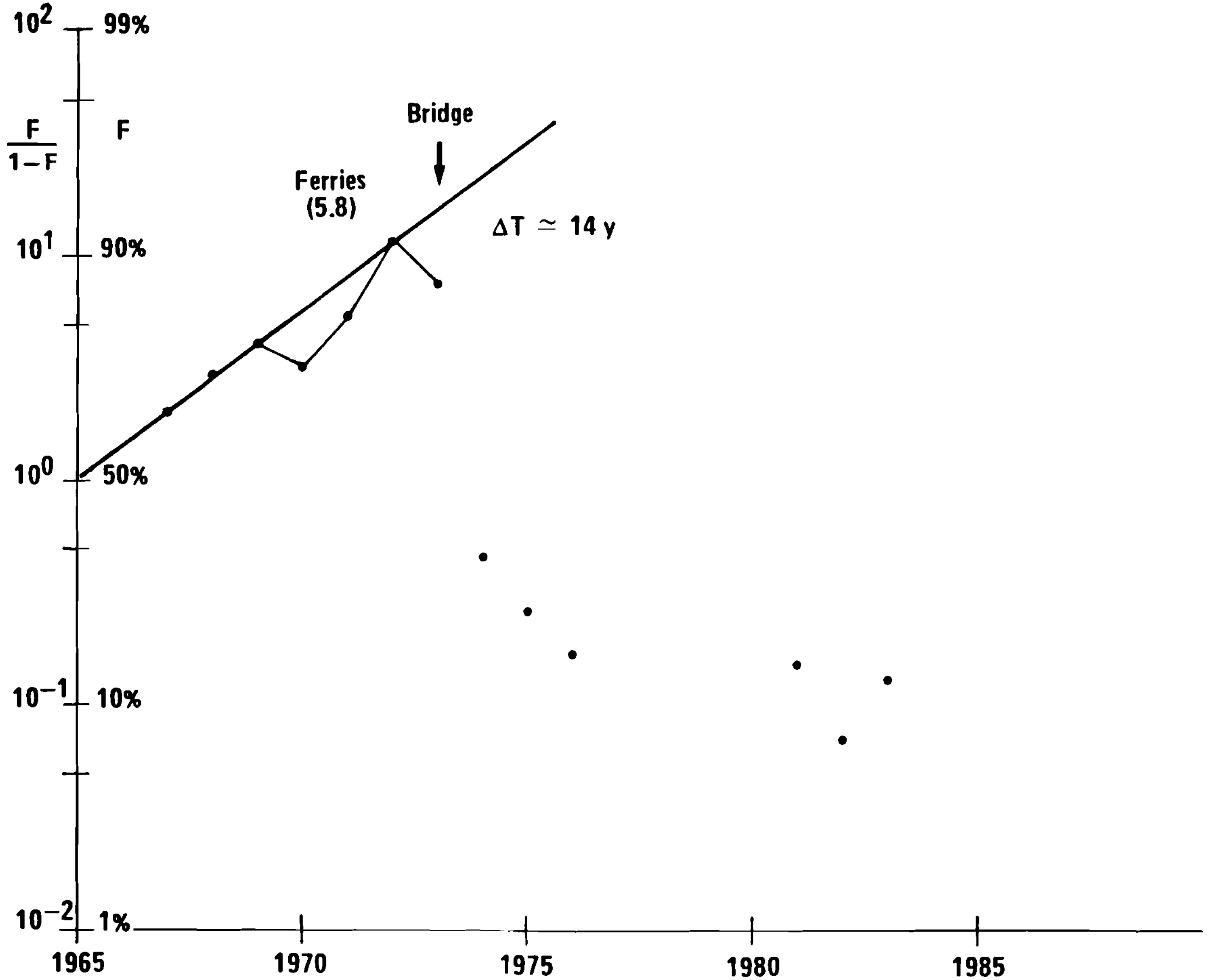


FIGURE 2.12. Trend in total vehicles (10^6) crossing the Bosphorus by ferry, 1965–1984. (Based on data from Freeman Fox-Botek, 1985).

Hong Kong

Hong Kong is an especially interesting case because it has many analogies with the Messina–Reggio problem, although on a much larger scale. As in Italy, two cities are separated by a stretch of water – in this case, the Hong Kong harbor channel, which separates the Kowloon Peninsula (Kowloon) from Hong Kong Island (Victoria). The channel or harbor separating them is a couple of kilometers wide. Of the total population (around 6.0 million) about 1.5 million live on Hong Kong Island, about 2.0 million in Kowloon proper, and the rest on Kowloon Peninsula, islets and in the New Territories (Figure 2.13).

Until 1972, all traffic between Hong Kong Island and the mainland was by sea, through a network of very efficient ferries. A road tunnel was then constructed under the harbor channel with the intention of facilitating the transport of *goods*, a motivation curiously similar to that behind the construction of the Bosphorus bridge. With two large cities facing each other, this fast connecting infrastructure, as in the case of Istanbul, was rapidly invaded by passenger traffic using cars, informal vehicles similar to Turkish collective dolmushes, and (franchised) buses.

In order to relieve the pressure of this passenger traffic, a second tunnel was opened in 1980, incorporating a mass transit railway, with ramifications on both sides of the territory – essentially, a Metro system.

Let us look first at the vehicular traffic. Figure 2.14 shows its evolution before the construction of the first tunnel, when ferries were the only means of transport. The saturation point can be estimated to be 13 million vehicles per year, around 1990. It appears then to have followed a normal development, ***under existing constraints***, with an appropriate 26-year time constant and saturation around the end of the Kondratiev cycle.

The first tunnel took about 3.0 million vehicles away from (the natural logistic evolution of) ferry traffic within a couple of years (Figures 2.15 and 2.16), and it *created additional traffic of about 11 million vehicles.* The time constant for the traffic expansion in the tunnel is very short – 12 years – and is estimated to reach saturation at the beginning of the 1990s.

If we compare the saturation point of the evolution of vehicular traffic in ferries (13 million vehicles per year) and that of the tunnel (45 million vehicles per year), we can conclude that the *tunnel-created traffic totals 32 million vehicles per year*, and that peak tunnel traffic will be about 41 million as the ferries seem to have stabilized at about 4.0 million.

The situation changes somewhat if we look at passenger, rather than vehicular, traffic. Taking all the harbor-crossing modes together (Figure 2.17), one could say that traffic did follow its natural trend, and that the opening of the two tunnels was only a technical means to accommodate this increase. Incidentally, the saturation point is about 800 million transits annually, or more than *two million crossings per day*, which gives an idea of the size of the harbor-transit operations.

Figure 2.17 is flawed in that the traffic in 1940 should have been subtracted, but this figure was not available. Projecting the line back to 1940 suggests, however, that this traffic was probably only a small percentage ($\approx 5\%$) of the present volume. This omission has a slight influence in the determination of the time constant, which in fact appears a little too high (40 years). However, the data correctly estimate saturation around the year 1995.

It is useful to examine the details of the whole operation to better understand the mechanisms at play. First, we can look at the *substitution* process whereby sea links are replaced by land links (Figure 2.18). This evolution unfolds according to the prescriptives of Darwinian substitution. Already during the first year of opening, the road tunnel captured 50% of the ferry passengers, who now travel by private car, minibus and franchised bus.

The time constant of the substitution is 24 years and the share of the ferries, which was 100% of the total traffic in 1971, will be reduced to about 10% in 1989. The substitution is perfectly smooth, even in reaction to the opening of the Mass Transit Railway, which in my opinion indicates a natural and timely response to the qualitative and quantitative increase in the demand.

That quality of service (i.e., transit time) was involved comes from a finer analysis of the situation. The ferries operate at about 30% of their capacity, and in rush hours their frequency is measured in terms of minutes. To give another glimpse of the intensity of intracity traffic in this area, the tramways of Victoria, established in 1900 and still running some original cars, have frequencies of 30 seconds.

Looking at the "winning" transit technologies, we see that the road tunnel opened in 1975 and expanded its traffic with great *elan*, the time constant being only nine years, and the perceived saturation point 450 million passengers per year (Figure 2.19). The opening of the Mass Transit Railway in 1980 (Figure 2.20), when the calculated traffic should have been 410 million passengers, wooed 78 million road tunnel passengers, most of them from franchised buses.

This is shown in Figure 2.21, where ground traffic on public services, i.e., franchised buses plus Mass Transit Railway, follows a good logistic growth path with no perturbation when the Mass Transit Railway was introduced. Incidentally, a time constant of 18 years, with 1981 as middle point, will bring also this system to saturation around 1995.

It must be clear that these saturation points around the end of a Kondratiev cycle are functional and are not necessarily related to technical capacity, which can be very large – e.g., in the case of the underutilized ferries.

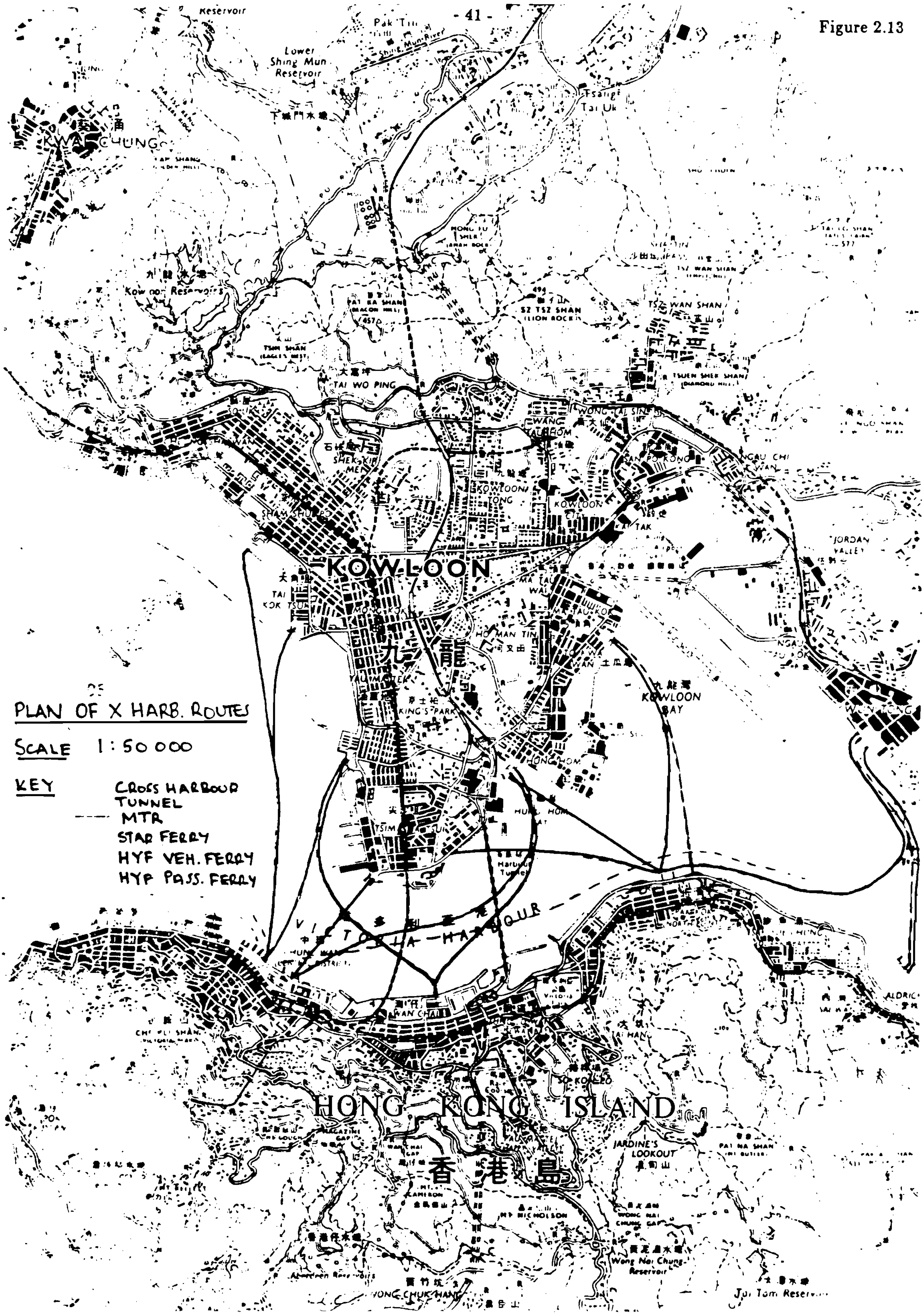
Looking into the pace of the "losing" technology, Hong Kong Yaumati Ferries, the larger company, follows a normal evolution in terms of passengers carried, with a virtual saturation point of 350 million passengers per year (Figure 2.22). The opening of the tunnel deducted 100 million passengers from the expected 215, as early as 1975, less than three years after the opening. The Mass Transit Railway bled away more passengers such that the total in 1986 was only 20% of what one could have expected from a logistic growth of Yaumati's service.

The case of Star Ferries, the smaller company, is slightly different (Figure 2.23). The company seemed near saturation (62 million passengers per year) in the second half of the 1960s, oscillating around 90% of saturation, as some times happens. The tunnel had no drastic effect, merely leveling off of the passengers carried. The Mass Transit Railway, on the contrary, drained away 12 million passengers in one year, and apparently in a stable form.

It is noteworthy that the sum of the passengers carried by both lines and compared with the total traffic (Figure 2.18) declines in a perfectly smooth fashion.

The Hong Kong case, with its impeccable documentation, permits an insight into the mechanisms of traffic evolution and substitution of unparallel quality that is invaluable when applied to the Messina case.

Figure 2.13


PLAN OF X HARB. ROUTES
SCALE 1:50 000
KEY
CROSS HARBOUR TUNNEL
MTR
STAR FERRY
HYF VEH. FERRY
HYF PASS. FERRY
KOWLOON
九龍
VICTORIA HARBOUR
HONG KONG ISLAND
香港島
KWAI CHUNG
SHAM SHUI PO
MONG KOK
YAU MA TEI
KING'S PARK
HO MAN TIN
HUNG HOM
KOWLOON TONG
KOWLOON CITY
TSIM SHA TSUI
KOWLOON BAY
JORDAN VALLEY
WANG TAU HOM
WONG TAI SIN
SAN PO KONG
NGAU CHI WAN
TSZ WAN SHAN
TAI WO PING
SHEK KIP MEI
TAI KOK TSUI
MA TAU KOK
WAN CHAI
Lower Shing Mun Reservoir
Kowloon Reservoirs
JARDINE'S LOOKOUT
Wong Nai Chung Reservoir

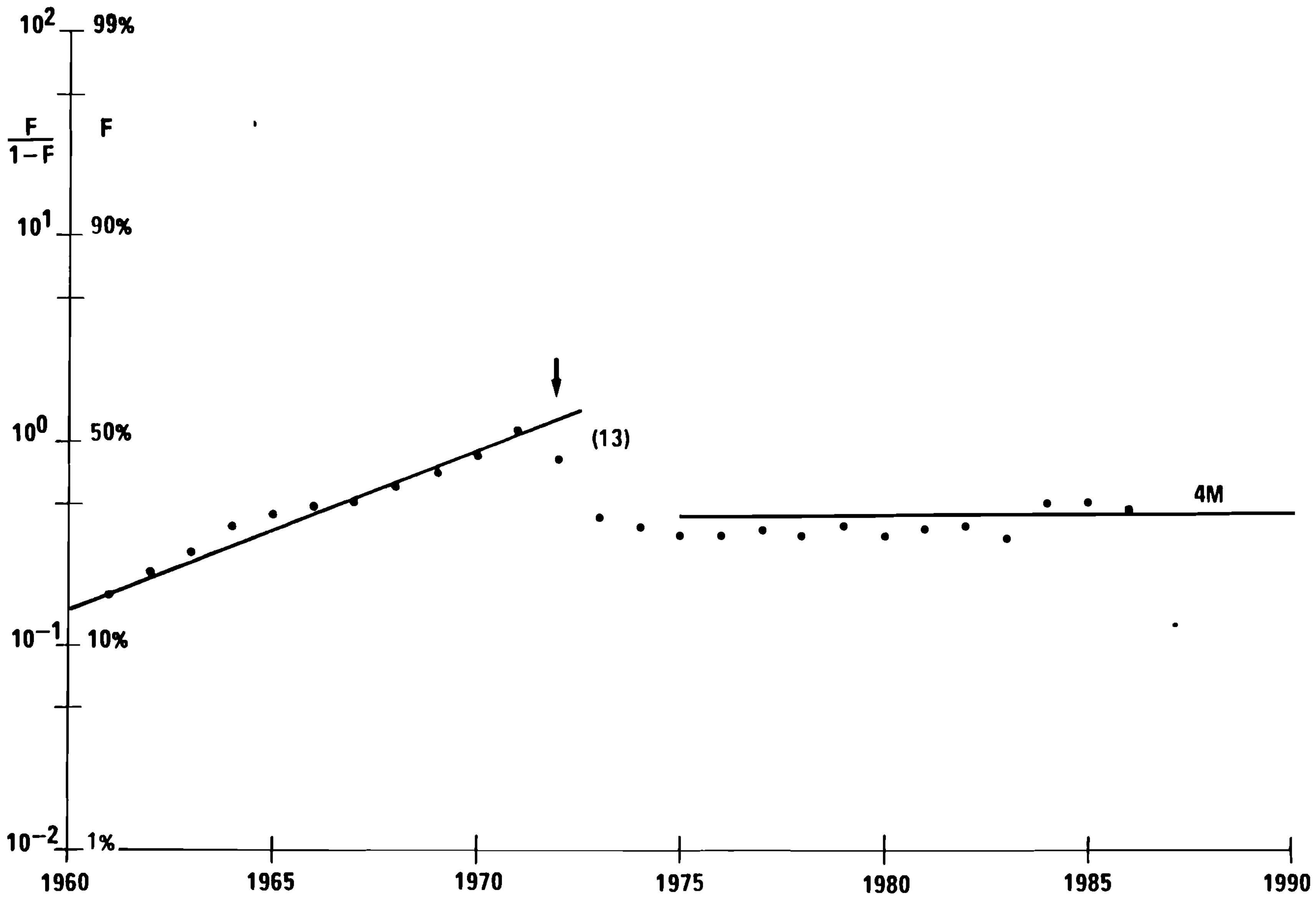


FIGURE 2.14. Trend in total vehicles (10^6) crossing Hong Kong Harbor by ferry, 1960–1990. (Based on data provided by the Hong Kong Government Transport Department, 1987).

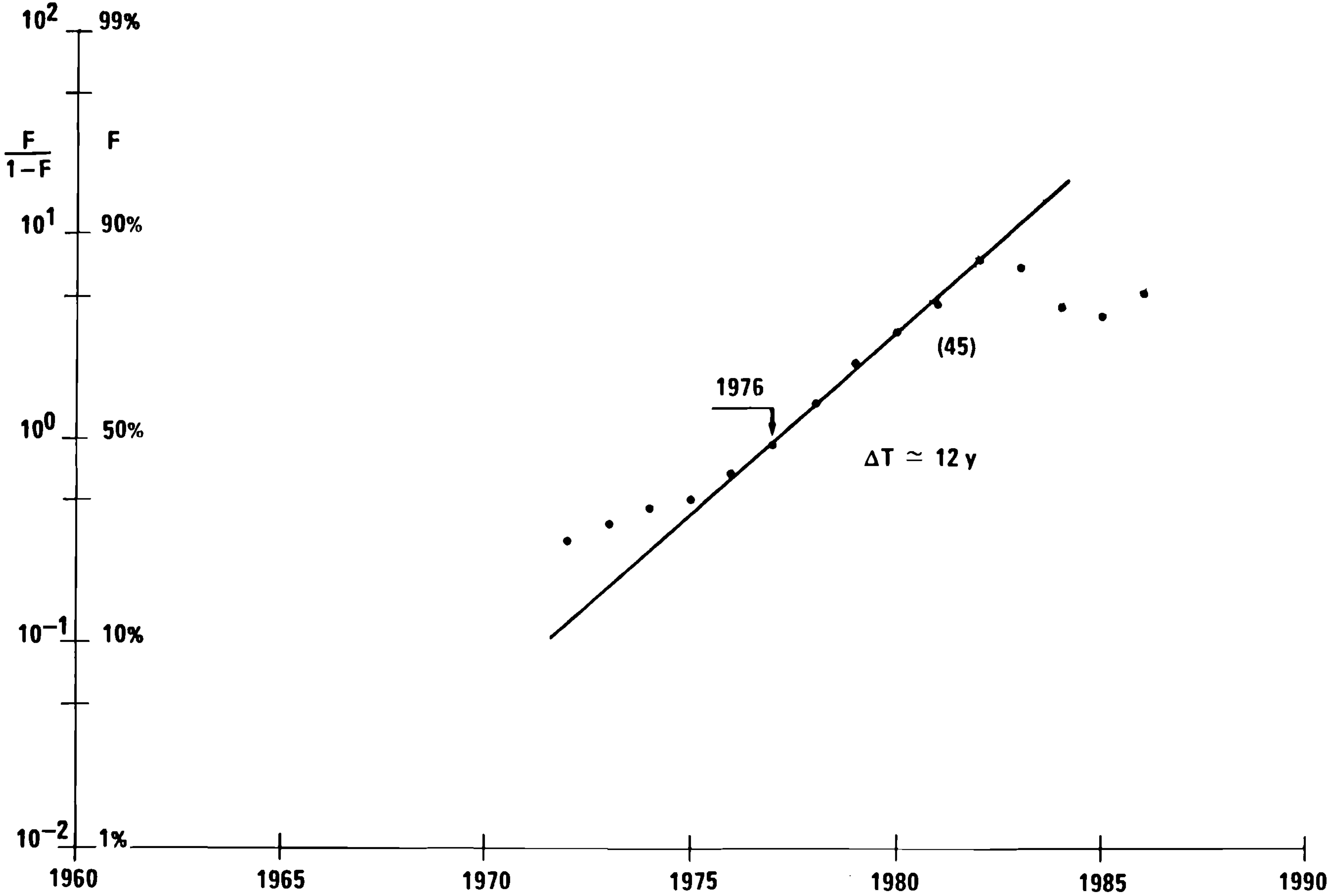


FIGURE 2.15. Trend in total vehicles (10^6) crossing Hong Kong Harbor by ferry and the first tunnel, 1971–1985. (Source: see Figure 2.14).

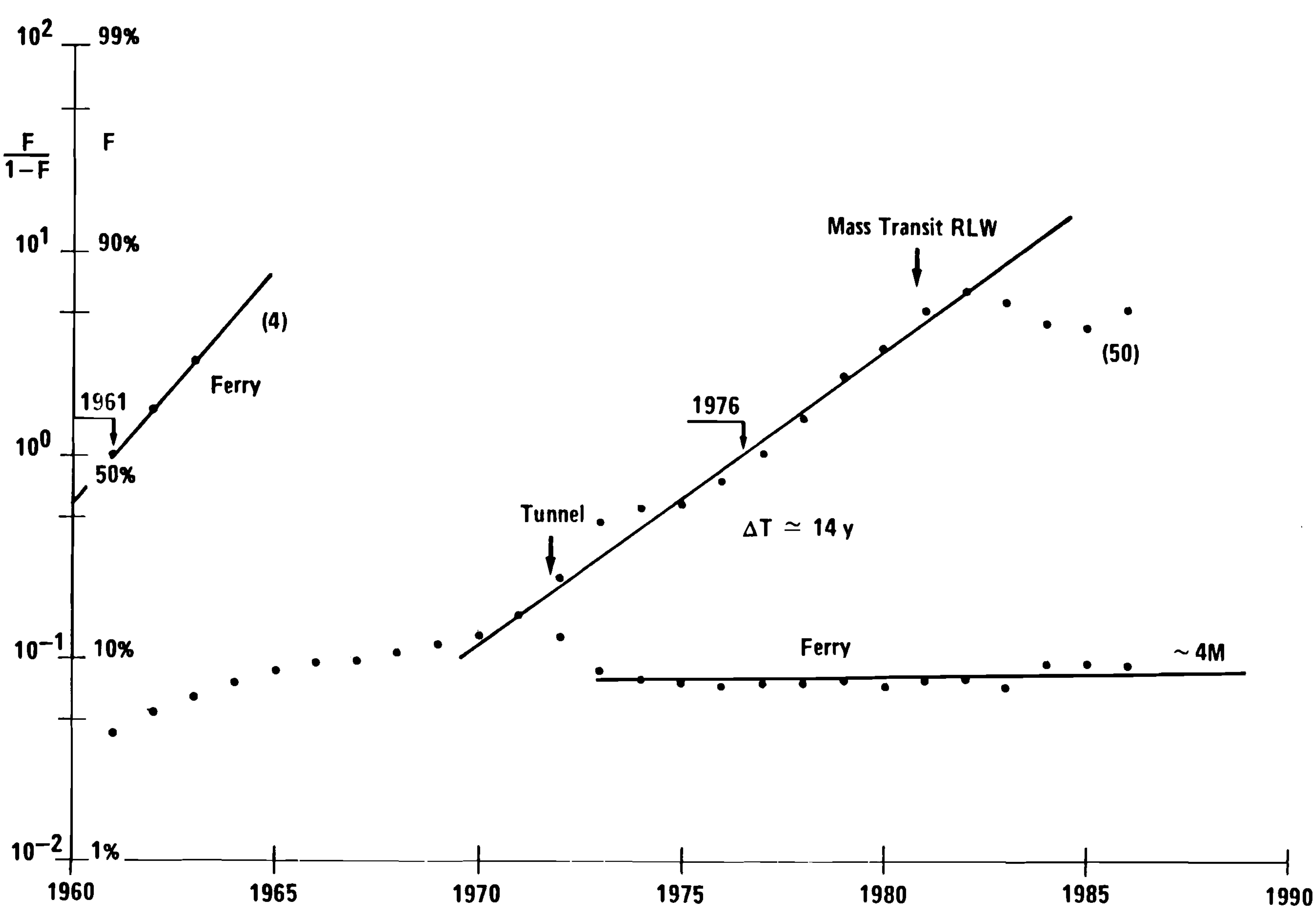


FIGURE 2.16. Trend in total vehicles (10^6) crossing Hong Kong Harbor by ferry and two tunnels, 1961–1990. (Source: see Figure 2.14.)

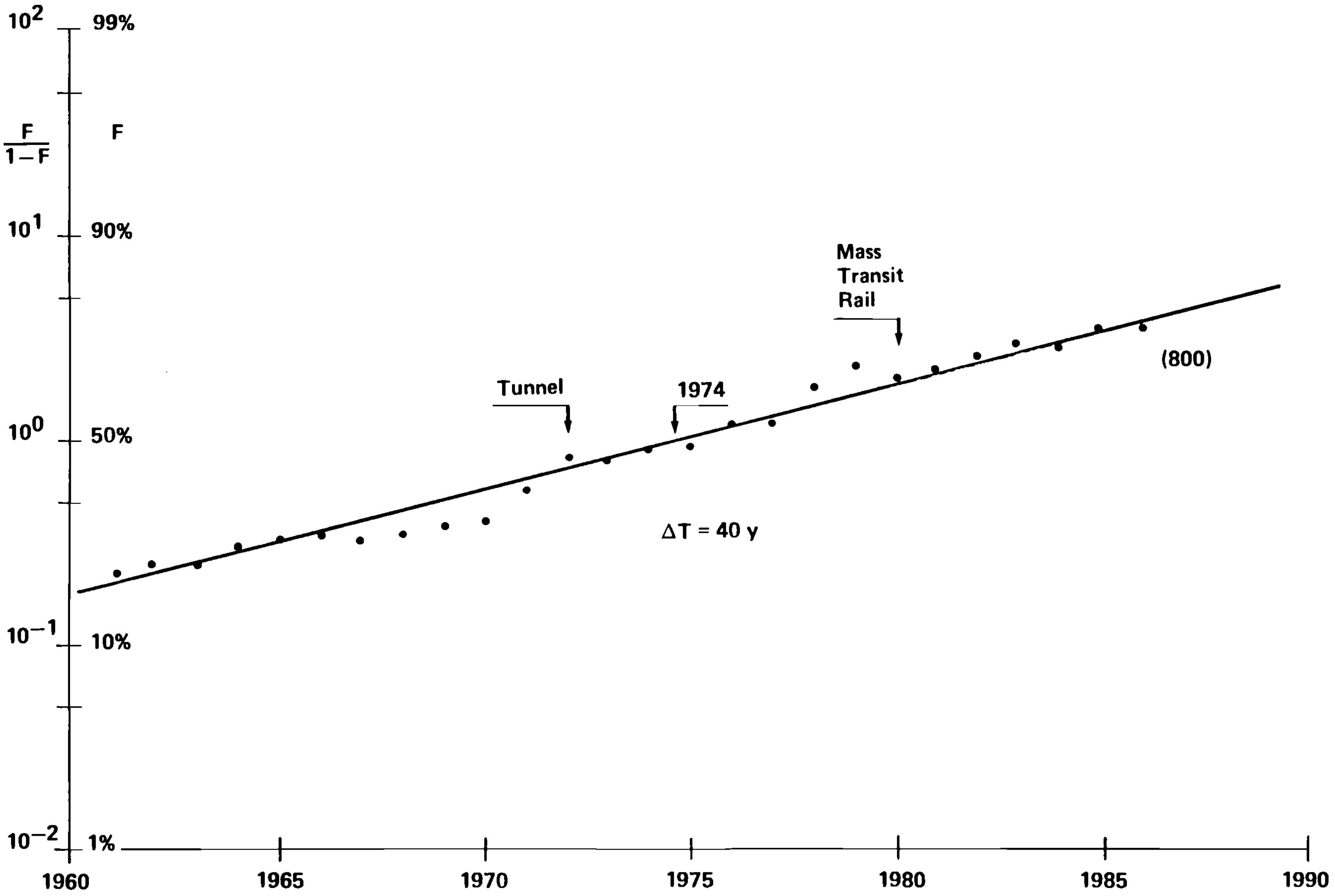


FIGURE 2.17. Trend in total number of passengers crossing Hong Kong Harbor by all transit means. (Source: see Figure 2.14.)

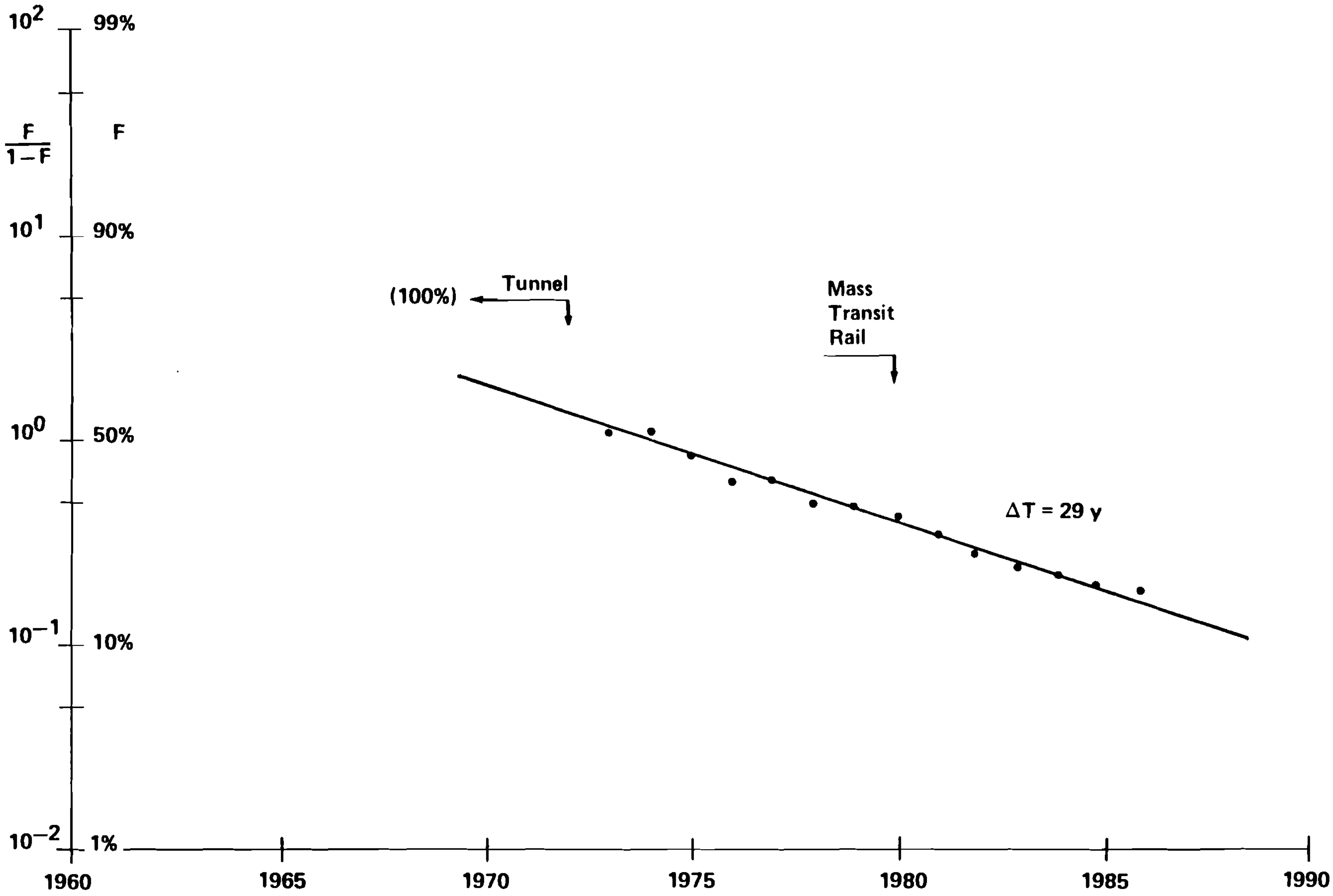


FIGURE 2.18. Trend in ferries' share of total passengers (10^6). (Source: see Figure 2.14.)

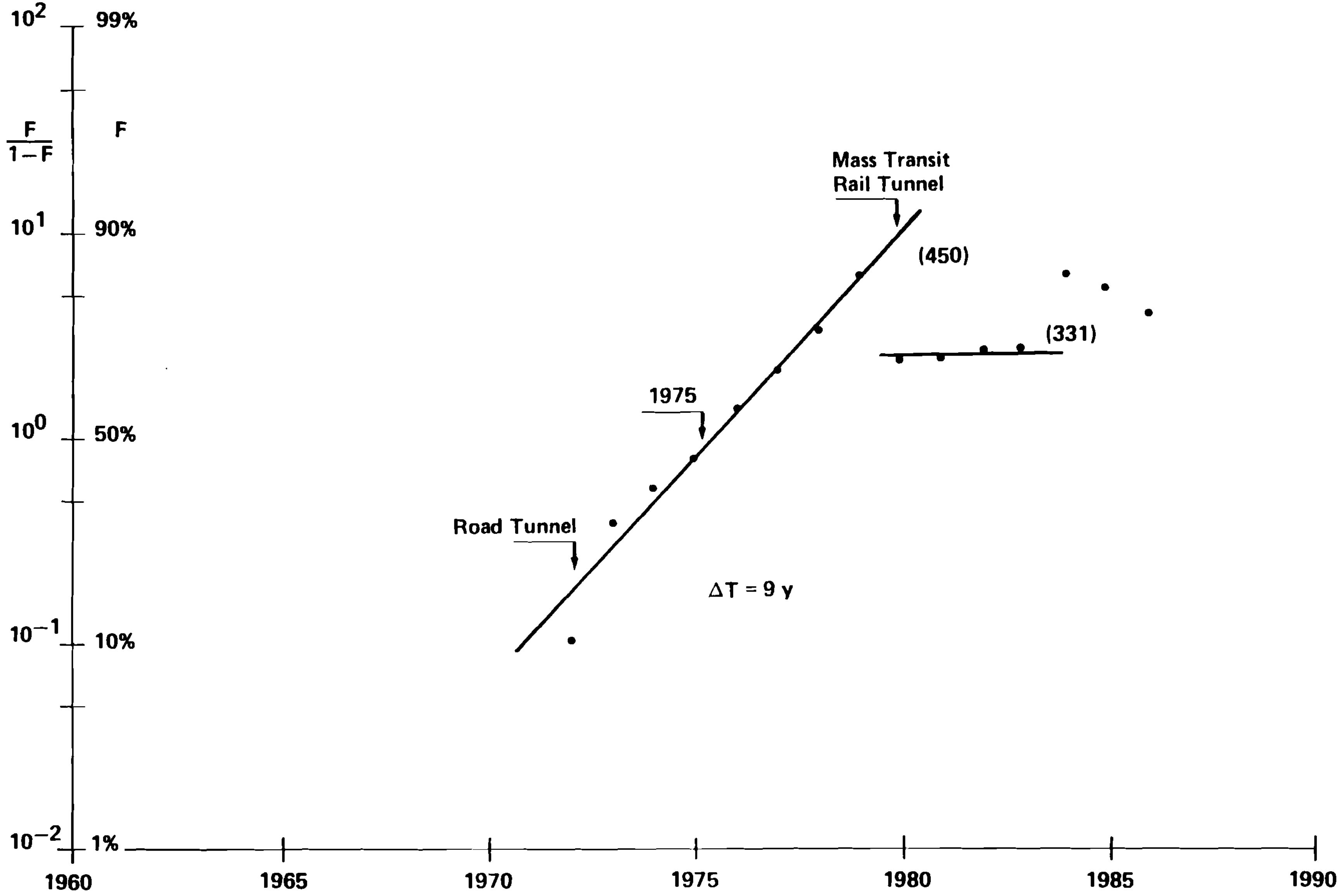


FIGURE 2.19. Trend in total passengers (10^6) crossing Hong Kong Harbor by road tunnel. (Source: see Figure 2.14.)

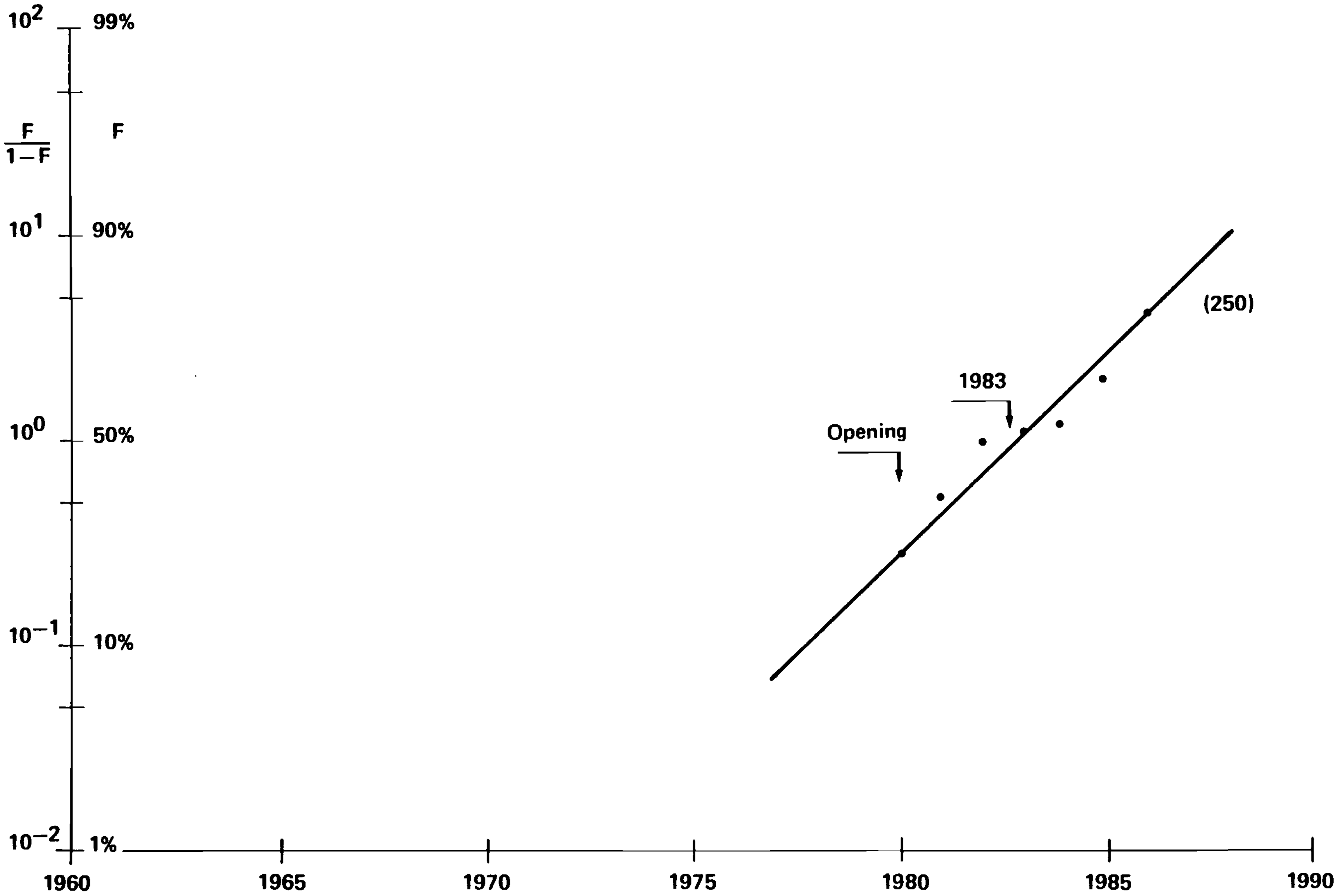


FIGURE 2.20. Trend in total passengers (10^6) crossing Hong Kong Harbor by Mass Transit Railway. (Source: see Figure 2.14).

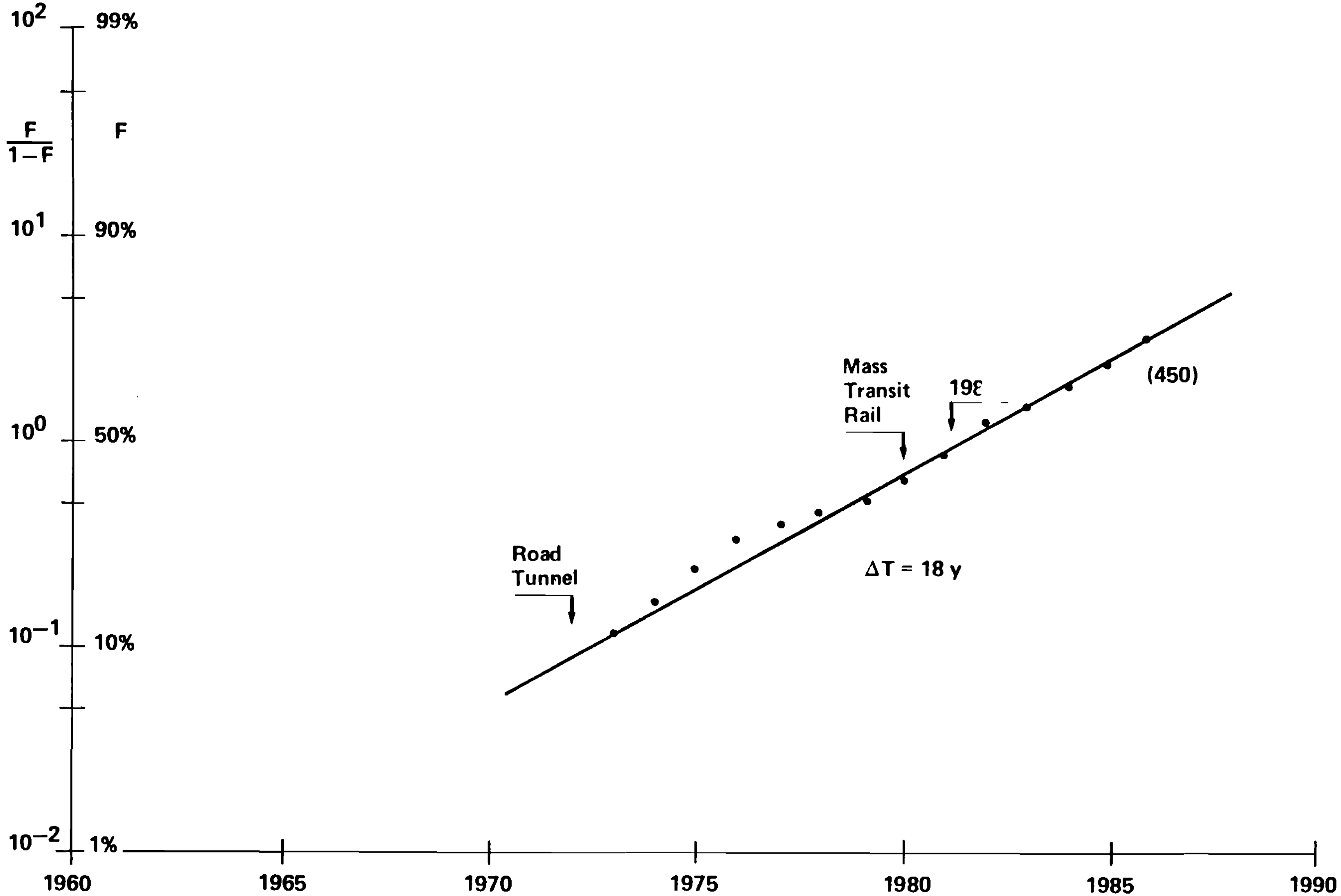


FIGURE 2.21. Trend in total passengers (10^6) crossing Hong Kong Harbor by public ground services (franchised buses and Mass Transit Railway). (Source: see Figure 2.14.)

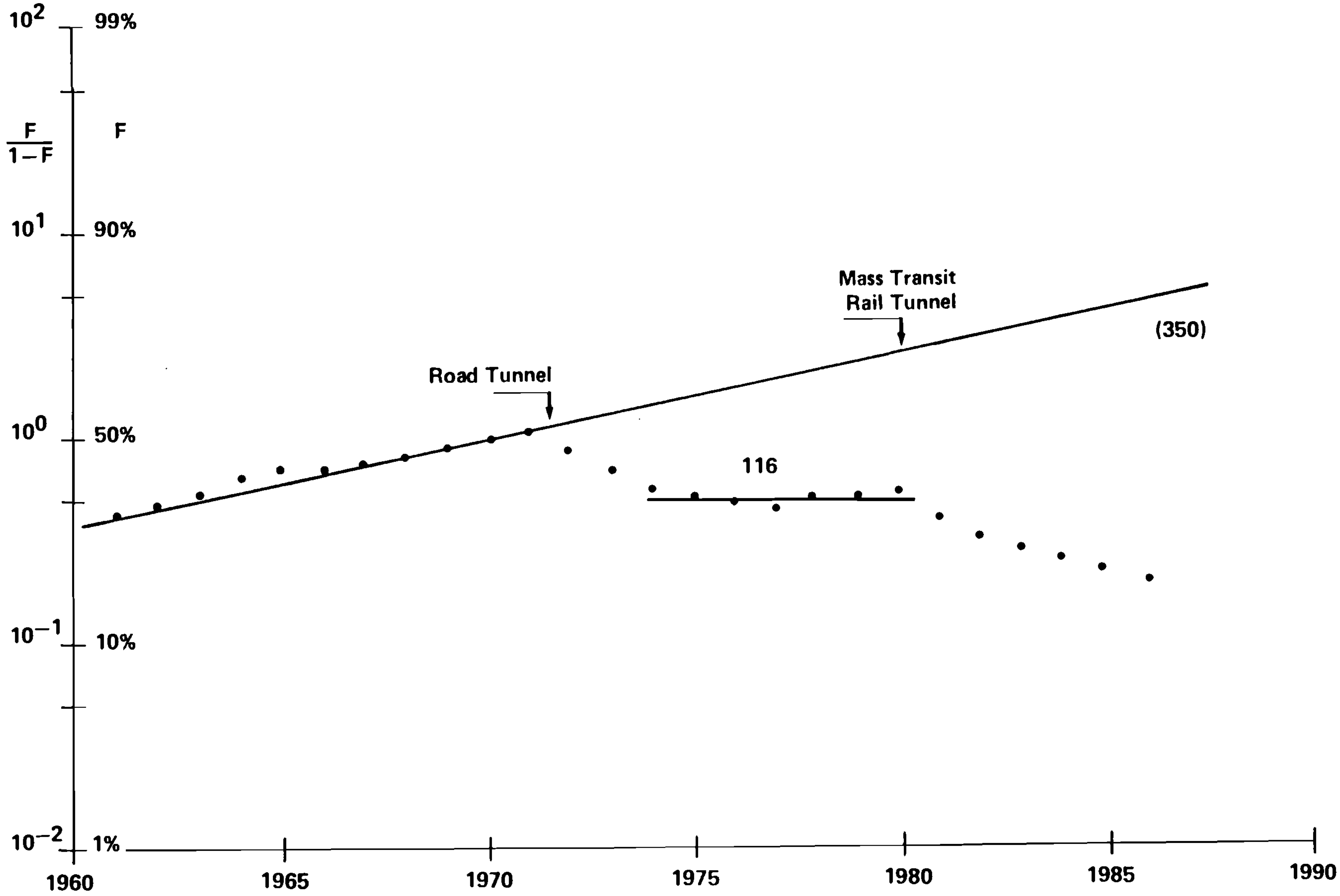


FIGURE 2.22. Trend in total passengers (10^6) crossing Hong Kong Harbor by Hong Kong Yaumati Ferries. (Source: see Figure 2.14.)

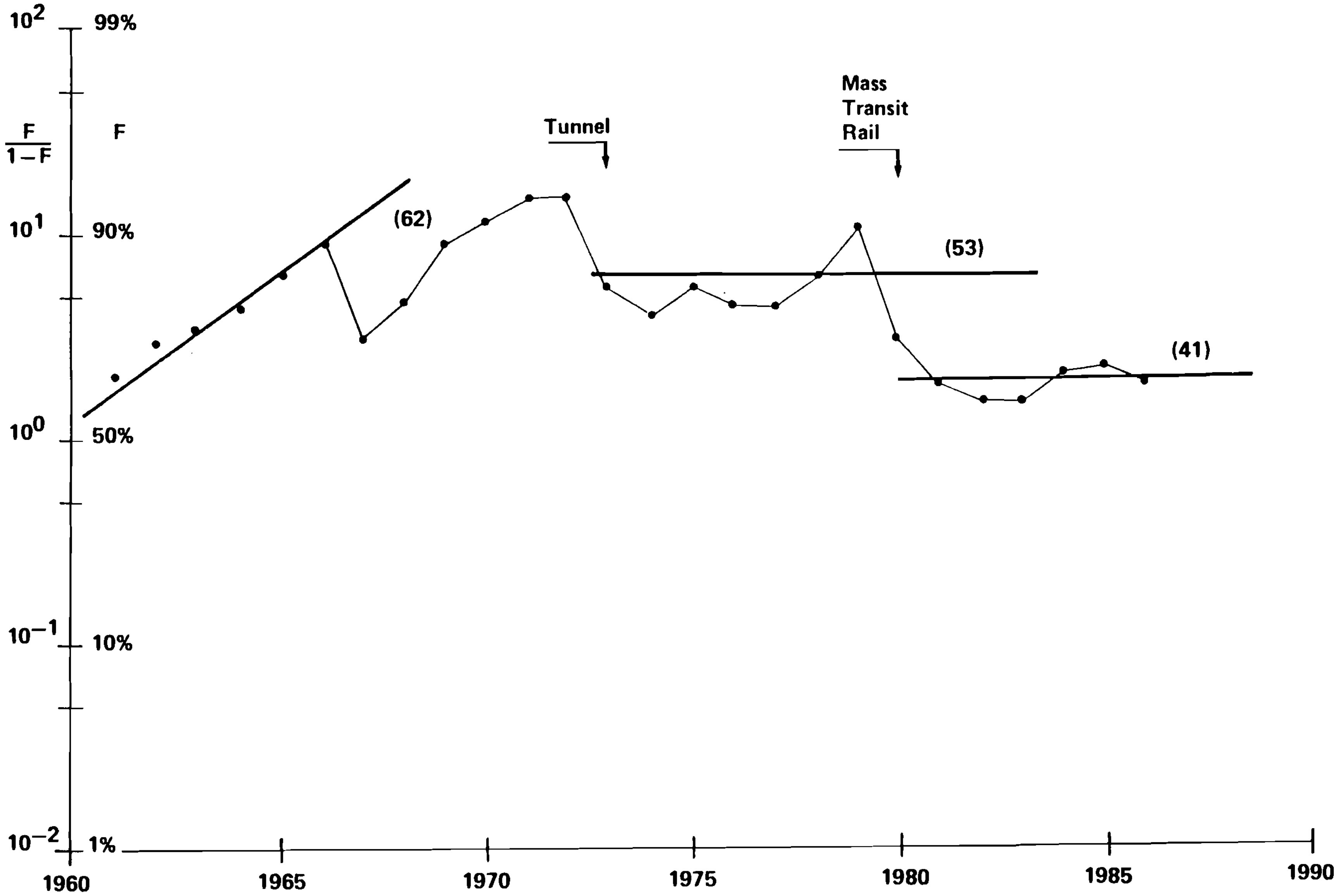


FIGURE 2.23. Trend in total passengers)10^6) crossing Hong Kong Harbor by Star Ferries. (Source: see Figure 2.14).

Lisbon

The center of the city of Lisbon is located on the northern side of the Tago River estuary (Figure 2.24). As happens when any natural barrier is not too impervious, and independent city developed on the southern side. The estuary is relatively wide, a couple of kilometers at the neck, more or less like the harbor channel between Hong Kong Island and Kowloon. Because the ferries have transit times, inclusive access and waiting times, above the critical half an hour, the two cities behaved independently, i.e., *ferry traffic could be considered as intercity traffic.*

As in the case of Istanbul, the decision to build a bridge had no connection with the idea of easing local traffic. The bridge was to be part of a motorway system, intended to shorten the route linking the north and the south of the country. The very visible location near the capital was probably chosen for political reasons: the bridge symbolized the creative capacity of the regime.

While their purpose differed, in part, the Lisbon and Istanbul bridges affected their urban areas in the same way. The cities on the southern bank (primarily, Almade and Seixal) were linked to central Lisbon by ferries carrying people and vehicles. As in Istanbul, waiting, loading, unloading, and transit takes about 40 minutes, which our TTB model defines as an intercity trip. As in the case of Istanbul, the construction of a bridge bringing transit times below the twenty-minute threshold for daily commuting created an explosion of new traffic, as the two urban areas merged functionally into one, with traffic levels characteristic of intracity traffic.

The evolution of the ferry traffic across the Tago is shown in Figure 2.25 for vehicular traffic. Here we have some pre-1940 data, which permits us to pinpoint a previous saturation level of 0.4 million vehicles a year around 1940. During the present Kondratiev cycle, traffic has developed along normal lines, although with a fairly short time constant, 16 years, pointing to some sort of technical saturation of the ferry system. The saturation point can be estimated at 2.0 million vehicles per year plus the carryover of 0.4 million from the previous Kondratiev cycle.

The opening of the bridge in August 1966 instantly reduced this ferry vehicular traffic by 1.0 million vehicles in comparison with expected growth in 1967. The loss still totaled 1.0 million in 1971 owing to a certain recovery of ferry traffic. After that, the traffic appears to smooth out with a time constant of 24 years. It should be 0.24 million in 1988, or 10% of the saturation point (2.0 million + 0.4 million from the previous K-cycle).

If we look at the bridge *per se* (Figure 2.26), vehicular traffic began at about 2.6 million a year and increased logistically with a saturation point of *26 million vehicles* due to be reached in the first half of the 1990s. The time constant of 20 years is the correct one to match saturation with the end of the K-cycle. This saturation is neatly *ten times larger* than in the case of the ferry taken in isolation. As vehicular traffic on the ferry is smoothly disappearing, we can conclude that *the bridge has created 23.6 million annual vehicle transits.*

We can also look at the vehicular traffic, ferry plus bridge, using the same 26 million vehicles per year as the only saturation point (Figure 2.27). This procedure is not strictly correct, but it can be justified because ferry vehicular traffic is already fading and the chart is intended only to give a *vue d'ensemble.*

For passenger traffic, it is not possible to make a general map, because the data for the bridge are not available. They can only be roughly estimated as the traffic is a mixture of cars, buses, and trucks. For that reason, the ferry traffic of passengers must be analyzed *per se*. As shown in Figure 2.28, passenger traffic on ferries saturated at around 10.0 million per year at the end of the K-wave in 1940, and should grow by another 40 million for this current wave. Although some instabilities appeared between 1974 and 1980, they seem unrelated to the opening of the bridge in 1966, because for six years traffic kept growing as usual. The time constant of 26 years is correct for a process starting at the beginning of a K-cycle and ending with it.

Overall, there was an obvious breakthrough in the volume of traffic due to the opening of the bridge – an order-of-magnitude increase, in comparison with the preceding context, if we look at the bare saturation levels. Following the principles of traffic generation, this should be local traffic, stimulated by the shortening of transit times *below the critical level.*

This hypothesis was confirmed by a 1979 inquiry on origin–destination of vehicles crossing the river. Most of the traffic is of urban–suburban character, linked to the urban development of the southern bank. Because urban developments and city growth have time constants much longer than the 20 years predicted for the development of traffic on the bridge, one should expect another pulse of expansion after 1995, i.e., for the next Kondratiev cycle.

Saturation of the technical capacity of the bridge (2 x 2 lanes) occurred in 1977, and saturation of the reinforced capacity (2 x 3 lanes) is expected to occur in 1989 (Ferreira, 1987). This is not far from the logistic saturation of 26 x 10^6, and corresponds on the logistic to 25.3 x 10^6 vehicles per year.

Obviously, the bridge cannot accommodate the next growth pulse, and this is a very important point to be considered for the Messina bridge. As these structures are meant to last for 100 years and more, they should be conceived from the beginning in such a way that expansion of the capacity is possible without rethinking their whole structure (as in Hong Kong) or without building more bridges (as in Istanbul). A second bridge is, in fact, being considered also in Lisbon.

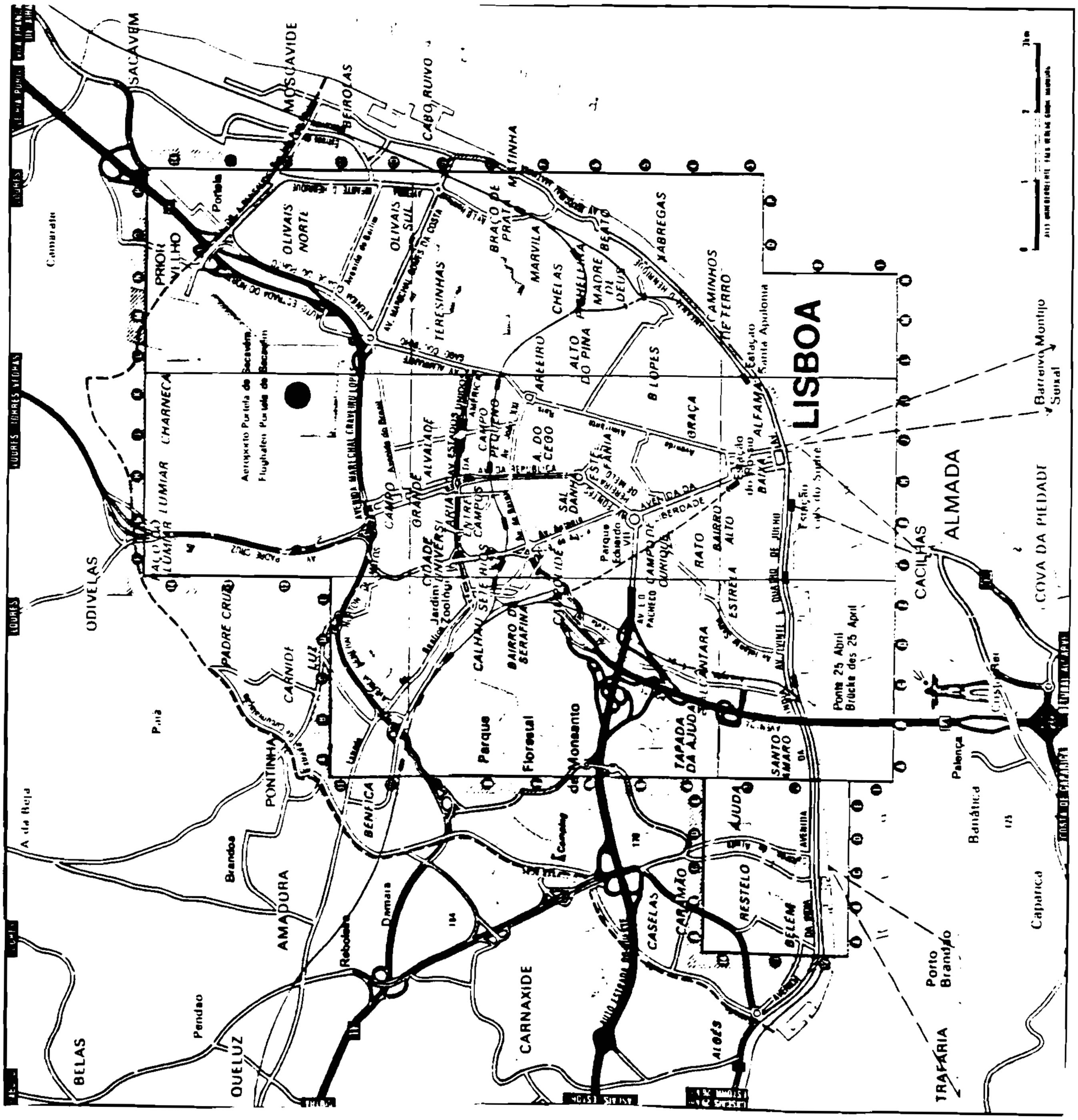


FIGURE 2.24. Center of the city of Lisbon.

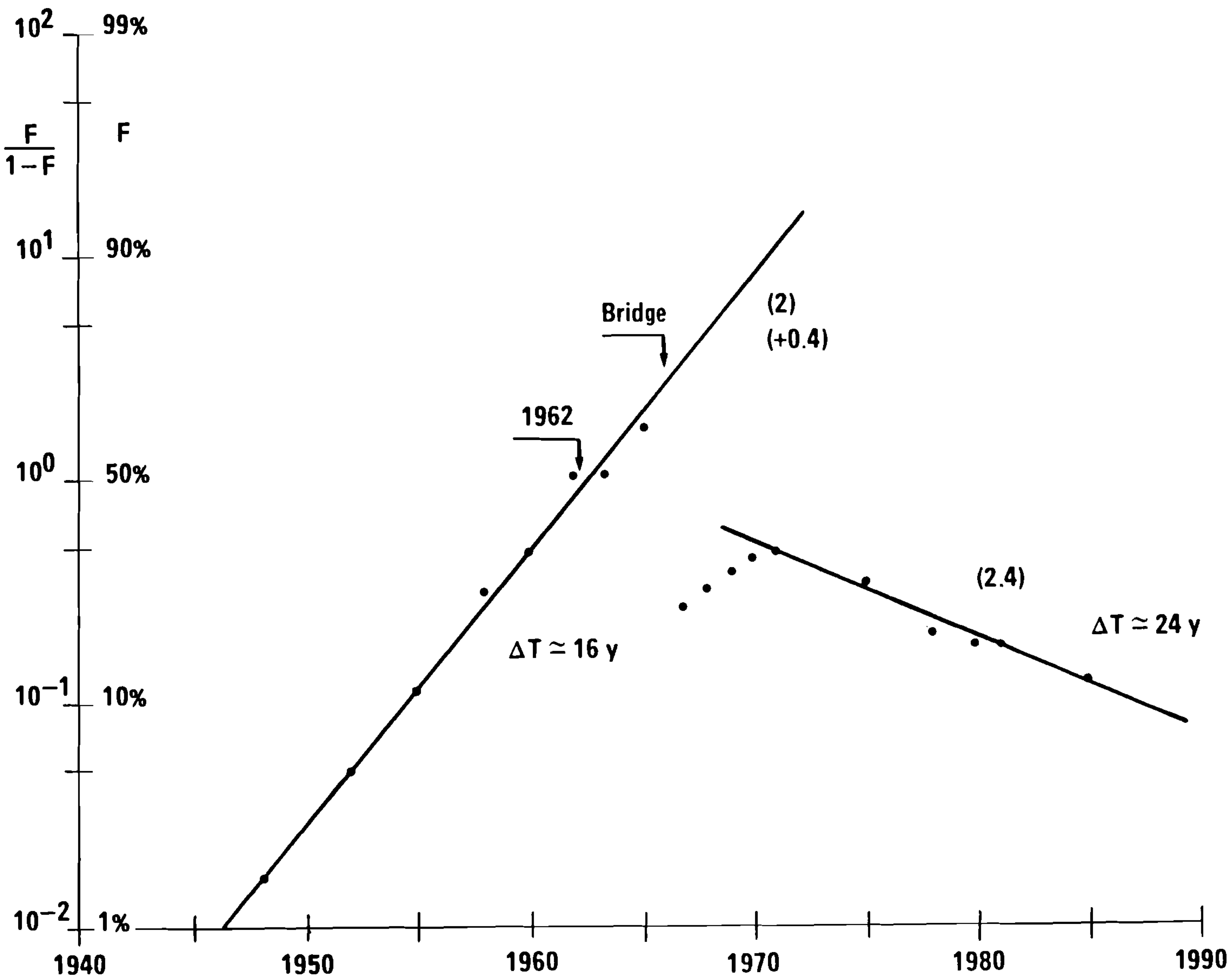


FIGURE 2.25. Trend in total vehicles (10^6) using Lisbon ferry service. (Based on data provided by Ferreira, 1987.)

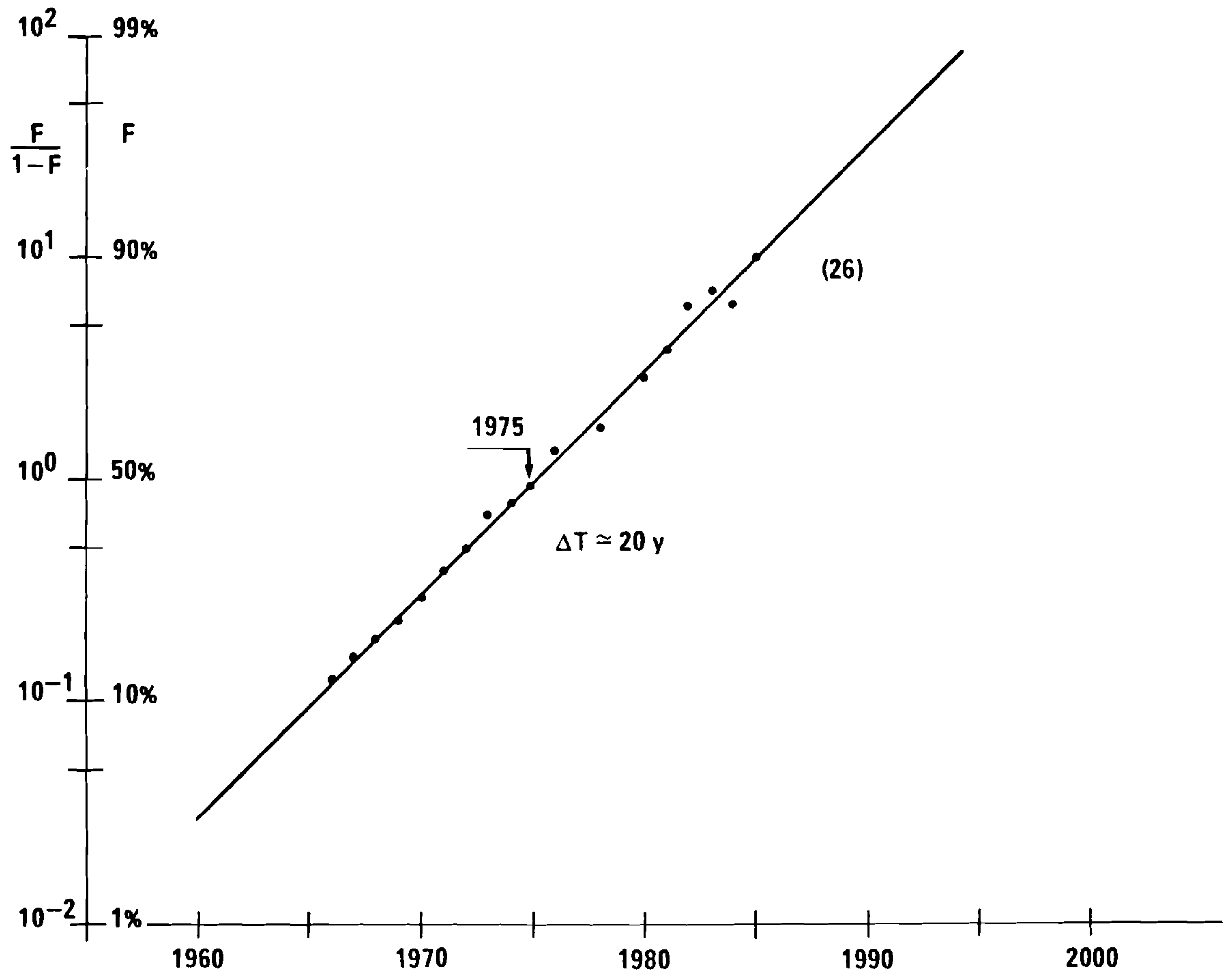


FIGURE 2.26. Trend in total vehicles (10^6) using the Tago Bridge. (Source: see Figure 2.25.)

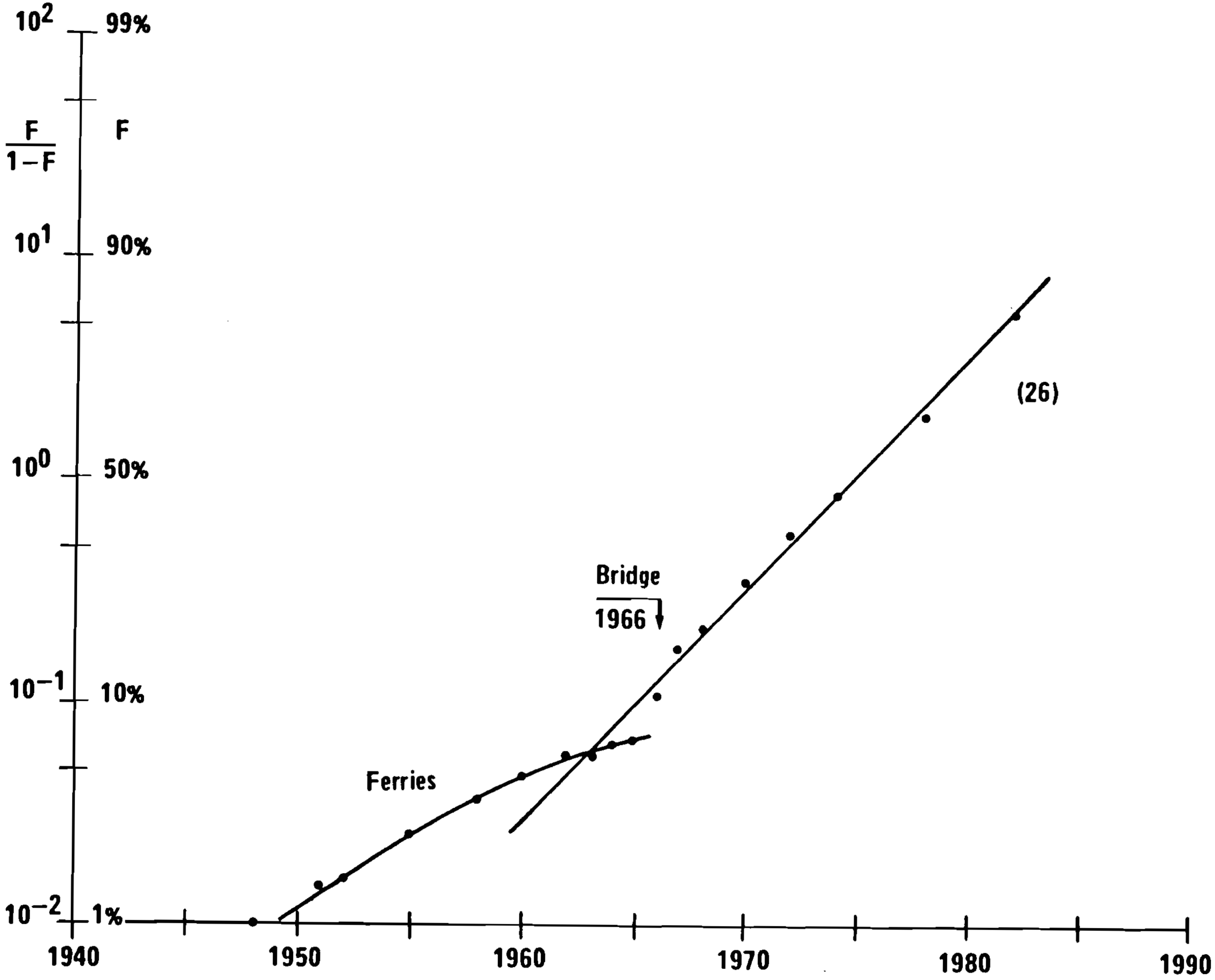


FIGURE 2.27. Trend in total vehicles (10^6) using Lisbon ferries and the Tago Bridge. (Source: see Figure 2.25.)

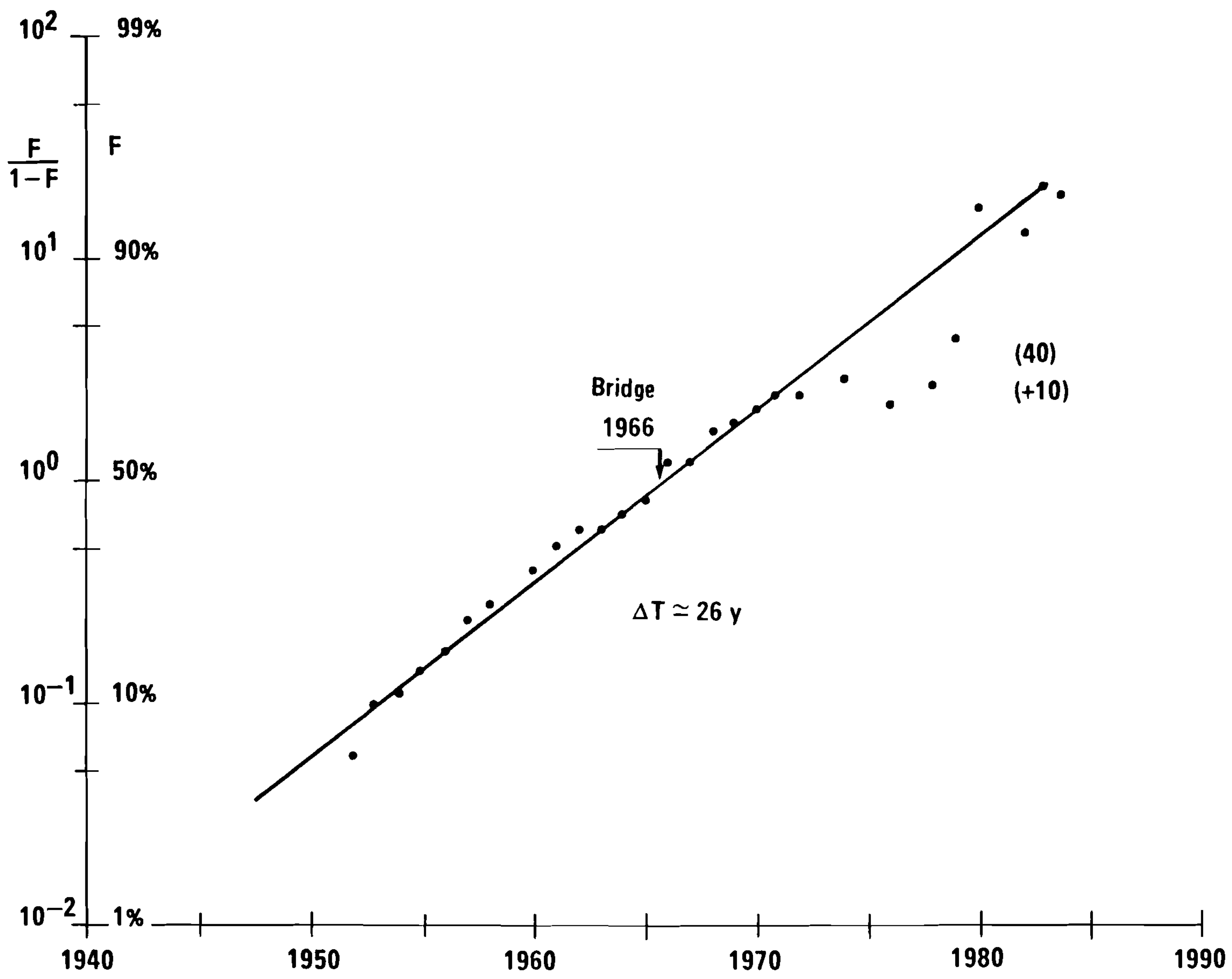


FIGURE 2.28. Trend in total passengers (10^6) using the Lisbon ferries. (Source: see Figure 2.25.)

The Mersey Tunnels

This Britain case is methodologically interesting because it shows very clearly what happens when capacity is added without substantially modifying transit times. Traffic data have been gathered only for the tunnels, and apparently no study documents the traffic between the regions before the tunnels were constructed, so we have to limit our analysis to the point quoted above.

The first tunnel, *Queensway*, opened in 1935, appears to have attracted a rush of experimenting travelers during its early years (Figure 2.29). The flow stabilized after World War II on a logistic path with a central point in 1958 and a ΔT of 31 years, meaning that traffic grew at an annual rate of 7.3% over that 31-year period. The center point date and the ΔT are appropriate for a saturation at the end of a K-cycle, if slightly early.

The traffic saturation point is 21 million vehicles per year, but technically the Queensway began to be clogged by traffic in the mid-1960s, and a second tunnel, *Kingsway*, was opened in 1973. Traffic split between the two, but not 50/50 between the two equivalent tunnels, as one might expect. It took commuters about four years to adjust to the new access route. At present, the Queensway share is not half of the current traffic, but *exactly half of the saturation traffic* for the logistic of growth. As I found no physical reason for this peculiar split, the reason might be metaphysical. The conclusion here is that a logistic of traffic growth is not perturbed when extra capacity is introduced. A factor of ten increase in traffic during a K-cycle of 55 years is equivalent to a mean growth of 4.2% per year, which can be considered in line with GNP growth in real terms, and general traffic growth (ton-km or pass-km) which typically increases a little faster.

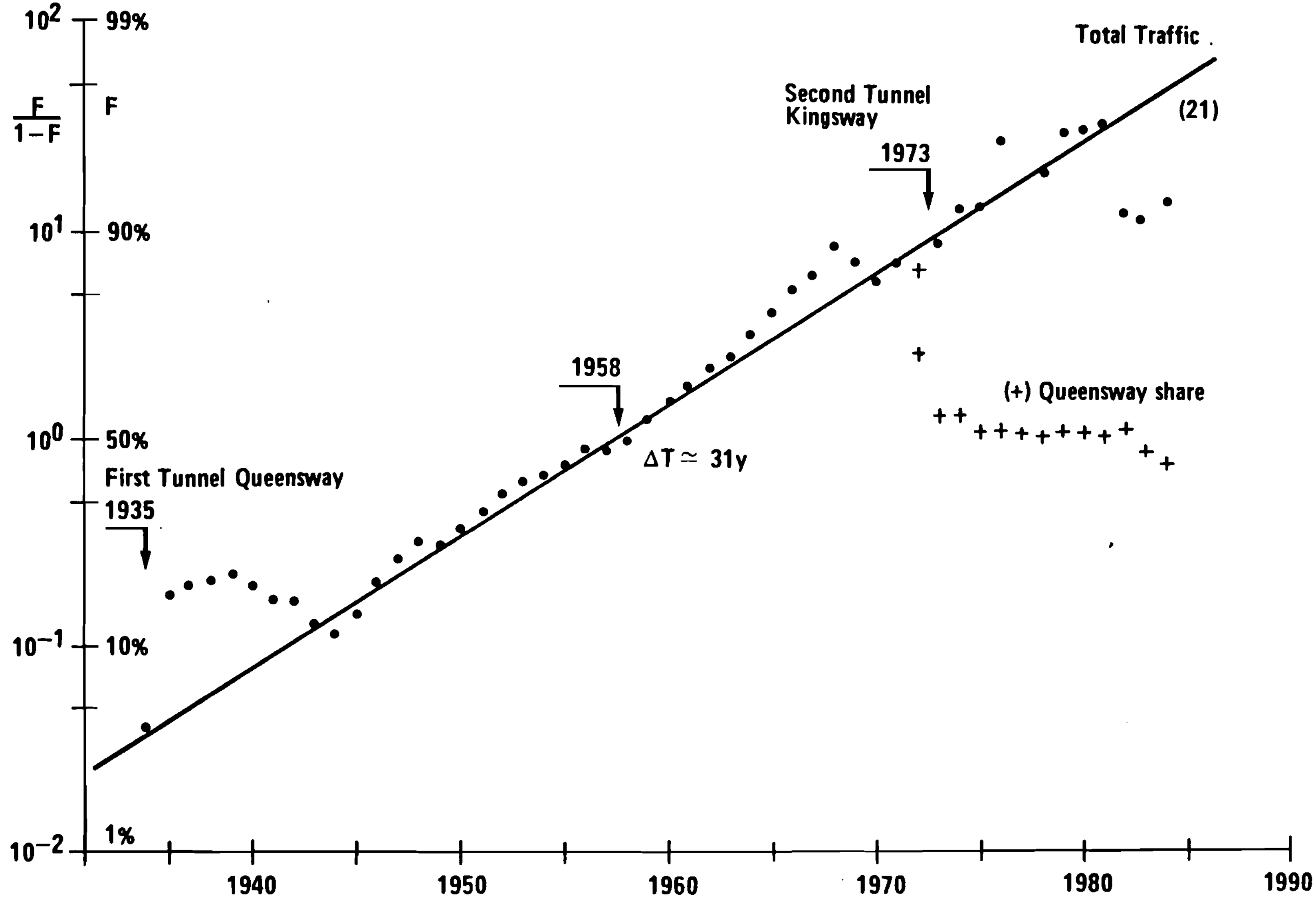


FIGURE 2.29. Trend in total vehicles (10^4) using the Mersey tunnels. (Source: Mogridge, 1996).

The English Channel

Although the famous Channel Tunnel has not yet been built and one can only speculate about its effects, it may be interesting to examine the evolution of the traffic there in connection with our models.

Traffic between Great Britain and the Continent has intensified over the centuries, stimulated by the increased number, activity levels, and mobility of the populations on the two sides of the Channel. The number of *air* passengers between London and Paris and London and Amsterdam ranks at the top for traffic between cities in Europe.

Looking at population densities, one sees a single megalopolis developing in the Brussels–Amsterdam–Ruhrgebiet area with tails toward Paris and Frankfurt. On the British side, a London–Manchester "corridor" is in the making. These two conurbations, holding perhaps 50 million people, will inevitably develop their own fast transportation networks, with the Channel becoming the barrier to be made porous.

Airplanes will not be adequate to handle the massive traffic that will want to cross that barrier in the next 50 years; the only viable solution appears to be a Maglev train, running at 1000 km/h or so, presumably in a tunnel of appropriate topography (Marchetti, 1987).

However, Channel entrepreneurs (it will be privately financed!), like old generals, try to win the next war using the weapons and the strategies of the last one. The problem is that current and advanced train technology with rails and wheels will not be capable of providing sufficient speed and/or perhaps even capacity to satisfy the demand of the year 2050. This is an obvious time horizon for an infrastructure of the size and complexity of the tunnel under the British Channel.

The evolution of passenger, car, and truck traffic across the Channel in the last 50 years is mapped in Figures 2.30 and 2.31. Car traffic will reach its saturation point in the 1990s, with 4.0 million cars/year carried on the ferries – a very modest figure if we compare it with, say, the 26 million crossovers of the Lisbon bridge or the 29 million of the Bosphorus bridge (which represent more the limits on their technical capacity than a measure of future demand).

Thus, Channel traffic is intercity, interregional traffic and not very sensitive to relatively small changes in transit times. Nor is it *sensitive to large changes in capacity*, as the Mersey tunnels case has shown.

The number of trucks is also relatively modest: 1.25 million per year with a saturation point that will come, as usual, around 1995. The time constant is correct, and the mean growth over the central half of the Kondratiev cycle is comparable to the mean growth of European economy during that period. The only hint of a breakthrough is that the *opening of the economic frontiers in 1992 will make the political boundaries more permeable.*

However, nobody seems to have explored to date the *time constant* for a system *to react to the suppression of a political barrier*. Our analysis of intracity processes indicate time constants in the range of 10–20 years, at the national level. The time constants for international adjustments may well take one or two Kondratiev cycles.

The conclusion that can be safely drawn is that the tunnel, which will only marginally reduce long-range trip-time, *will not* "create" new traffic. New traffic will be generated only when the tunnel hosts a very fast transportation system, joining the megaclusters of populations on the two sides of the Channel, with transit times comparable to those in the single city context. Then the traffic will switch from an intercity to an intracity mode, increasing between one and two orders of magnitude, following the pattern of the Istanbul and Lisbon cases.

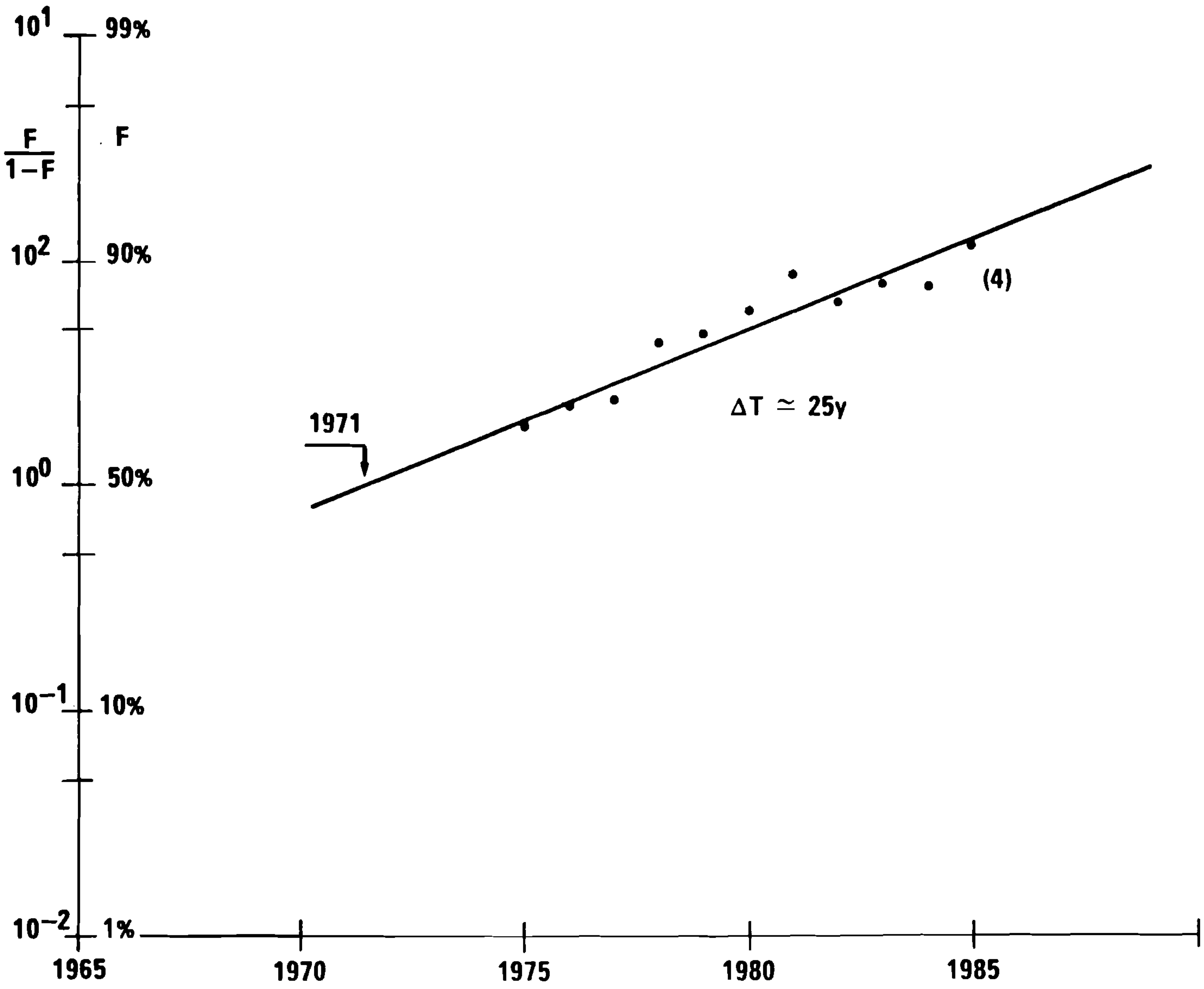


FIGURE 2.30. Trend in passenger cars (10^6) crossing the English Channel by ferry, 1970–1990. (Based on data provided by the U.K. Department of Transport, 1982).

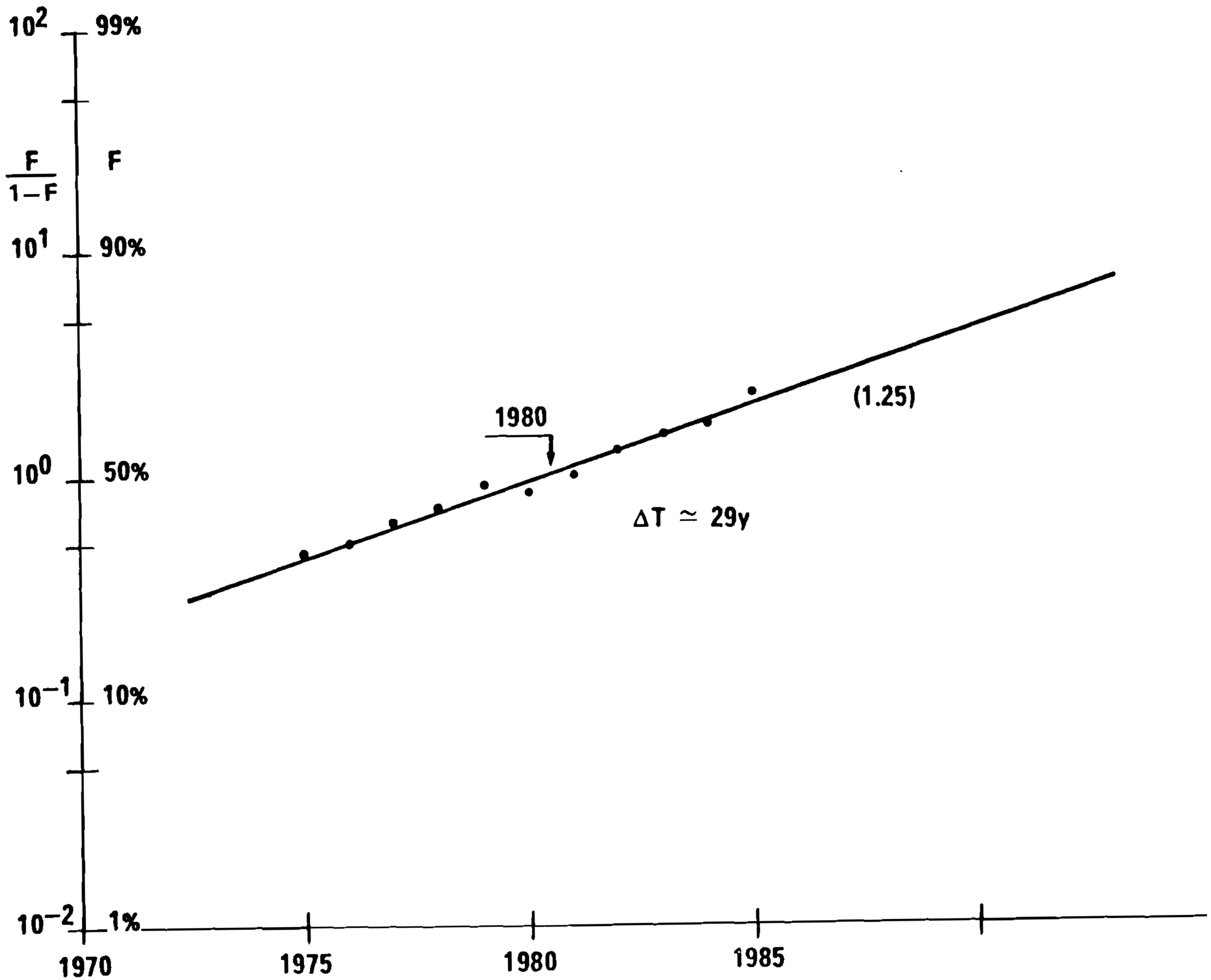


FIGURE 2.31. Trend in trucks (10^6) crossing the English Channel by ferry. (Source: see Figure 2.29.)

Part III: The Messina Case

The Strait of Messina not only separates the continent from a large island (Sicily) with about five million inhabitants, but also constitutes the gap in a conurbation basin estimated to contain a couple of million people, counting cities and communes from Catania to Patti on the Sicilian side and from Reggio to Vibo Valentia on the Calabrian side. According to Doxiadis and Papaioannou (1974), the coastal strips will host part of a megalopolis that can be expected to develop progressively during the next 100 years (Figure 3.1).

During its technical lifetime of at least 100 years, the Messina bridge must therefore serve two different classes of demand – the one coming from the interaction of Sicily with the continent, and the second coming from internal movements in the megalopolis. Because the two classes of demand have different characteristics and dynamics, they will be analyzed separately.

The Sicily–Calabria Connection

Sicily and Calabria are marginal regions in comparison with the activity cores in central–northern Italy and in central–northern Europe. This is well shown in a study sponsored by the Commission of the European Communities (Keeble et al., 1982), in which a gravitational model was applied to productive activity and transport in Europe to construct a connection intensity or *accessibility map* (Figure 3.2). Interpreting from the map, the marginality index of Sicily and Calabria is about five times that of Bavaria. In this situation air traffic can indicate the demand from the subsystem for a higher connectivity with the larger system. Incidentally, as our studies on global traffic in Europe show, air transport of goods is growing rapidly as goods of ever-low specific value are accepted.

Passenger traffic trends for the airports of Catania, Palermo, and Reggio are analyzed using the logistic growth model and reported in Figures 3.3 and 3.4. Palermo airport has a saturation point of 1.1 million passengers (in and out), to be reached around 1995 with a time constant of 38 years. This implies a mean growth rate for the 38 years (around the central point in 1970) of about 5% per year. Catania has a saturation point of 1.6 million passengers, a time constant of 50 years, and a mean growth rate for the 50 years around the central point of 4.5% per year. The central point (50% of saturation) for Palermo is in 1967, and for Catania in 1976, showing a later development for Catania which was predestined to become, due to the higher saturation point, the busiest airport in Sicily. Catania airport passenger traffic overtook Palermo's actually in 1985. Reggio airport plays a much less important role in the area, with traffic about 20% that of Catania.

Looking at the situation in mainland Italy, as a point of comparison (Figure 3.5), we find a central point for Italy in 1970, more or less in tune with Palermo, but with a time constant of only 20 years, i.e., a growth rate for the 20 years around 1970 of 12% pear year. Looking at the saturation points, however, 34 million passengers for Italy and 2.6 million for Sicily, we find a ratio of 8%, which corresponds to the ratio of the population.

In other words, the isolation of Sicily stimulated some early air traffic, which grew at a slower pace than in Italy as a whole, but which will reach the all-Italy level around the end of the century in terms of passengers per population. Lower income levels in Sicily seem exactly to compensate the greater advantage to take a flight to central or northern Italy.

As a European transport study shows (Marchetti, 1987), air traffic should increase by a factor of 20, at least during the next Kondratiev cycle, i.e., up to 2050 worldwide. It is not reasonable to expect in this period that any surface connection to the continent, up to Rome and Milan, could compete with the one- to two-hour transit time of the airplane. Consequently, one should not expect new long-range passenger traffic to be channeled through a bridge.

The next step is to look at freight movement through the Strait of Messina. Much freight goes by truck nowadays, and the dynamic of the situation is reported in Figure 3.6, in which one can see a neat pulse of growth, saturating at 1.0 million annual transits (both ways) in the 1990s. The central point in 1975 and the time constant of 10 years shows this to be a recent and very rapid phenomenon (mean growth rate between 1970 and 1980 of 25% per year).

The switch from transporting goods by railway to road, a process that started all over Europe in the 1960s, will reduce railways to carrying only the cheapest goods - and not large amounts of it. This is a typical process when a new transport technology supersedes an old one. The phenomenon can be studied from the beginning to completion, e.g., in the case of steamships versus sailing ships, and runs identically down to details.

At the national level ton-kms carried by railways have been basically level during the last 50 years, with strong oscillations around the mean. Traffic grew (in two 50-year Kondratiev pulses) during the last century and a half, up to the 1930s. In the ecology of large systems, two cycles up, one steady and the next down, is the normal pattern; thus, we may expect railways to lose ground in *absolute terms* from the beginning of the next cycle in the 1990s.

How the railway lost traffic to the road is reported for Italy in terms of market *shares* in Figure 3.7. In 1985, 90% of the total ton-kms were transported on trucks. Although the data often miss the logistic at the end of a cycle, one can forecast a market share of 1% for the Italian railways as a whole in 2010. The situation differs somewhat from country to country, but the figures for Europe and the USA are in the same ballpark. Even a railway revival there could not be expected to affect the Italian situation.

As for freight car movement across the Strait of Messina (loaded and empty, one-way), as Figure 3.8 shows, the trend is downward, and with a relatively short time constant of 36 years. A cross-check with loaded cars (Figure 3.9) yields similar results. The 33-year time constant means that traffic, totaling about 150,000 cars in 1978, will drop to 30,000 in 1995 and 3000 in 2010, when the bridge will presumably be in full operation. It is not improbable that railways will have given up by these dates. In any case, *such a diminished level of traffic might be well accommodated by the existing ferries.* A loss of transit time that can be estimated in tens of minutes certainly makes no significant difference for freight cars that take days and weeks to complete their journey.

It is apparent then that *freight trains will not be a customer of the bridge.* This statement alone merits deeper research, because the absence of *freight trains* may well *simplify the design of the bridge.* On the other hand, constructing a stronger bridge that might some day accommodate trains, just in case, could be a way to provide the recommended expandable capacity, which will inevitably be needed if the system is intended to facilitate the formation of a *proximal megalopolis.*

According to the rules of Volterra substitution, road transport, being the most recent to develop, will dominate the freight transport market during the next Kondratiev, completely absorbing railway traffic and possibly even diverting traffic from ships. Clearly, the *bridge must take care of truck traffic*, and an effort should be made to prognosticate its volume how it will look like during the next century.

The last-plus-one technology of freight transport is airplanes, which will become more important in terms of value of goods transported. The highest-value-freight entering by that mode may well be fruits and vegetables. Off-season fruits from South Africa are already on North European markets, at prices comparable to Italian fruits *in season*. This may not influence substantially the tons of traffic through the bridge, but it will substantially reduce the *rush traffic* of brief shelflife products, such as fruits and especially of vegetables.

The situation is more variegated if we look at passenger traffic across the Strait. Total traffic can be perfectly matched by a logistic from 1950 to 1983, and a central point in 1969, with a time constant of 54 years – just one Kondratiev cycle. The mean growth rate for the central 54 years is about 4.2% per year, moving at a pace similar to that of the global economy (Figure 3.10). A saturation point of *20 million* passenger transits per year, estimated to be reached at the end of the cycle (1995), may constitute a good basis for considering a bridge. The number looks puny, of course, in comparison with the *800 million* passenger crossings of the harbor channel in Hong Kong. But transit times across the Hong Kong harbor make the two sides a single city!

Let us look at this traffic in some detail. Figure 3.10 shows that Aliscafi's share of total traffic went up and down, reaching its maximum around 1969. This may be simply due to the fact that the system served a special submarket that became saturated at that time. Looking at Aliscafi traffic in isolation (Figure 3.11), we see in fact a regular development, fitted with a logistic with center point in 1965, time constant of 16 years, and saturation point at 0.9 million passenger transits. Traffic levels became very scattered thereafter, and focusing on that particular subsystem may help us to understand local mechanisms.

When we look at ferry passenger traffic from a different angle – that of private versus public services, such as railway ferries – we find private firms making inroads into the public, but saturating for the moment being at around 60% of the total (Figure 3.12).

To examine car transport by the ferries, we have statistics from three different sources that do not match well. Nevertheless, they are to give an approximate idea of the situation. The results are reported in Figure 3.13 for the total traffic, saturating at about 1.3 million transits per year (both ways). The sharp increase of 0.62 million cars (transported by private ferries) between 1981 and 1980 – almost doubling their number in one year – seems improbable. Therefore, we omitted the figures for 1981, 1982, and 1983. In any event, the difference between *one or two million* does not change the conclusion that the traffic is small and comparable with that of Lisbon *before* the Tago River bridge was built. The builders of the Messina bridge should be encouraged by the facts that the Tago River bridge is already saturated at *26 million* transits per year and the Bosphorus bridge more or less at the same level.

Car transits over F.S. Ferries were reasonably smooth until the private ferries began operating in 1965 (Figure 3.14). Although F.S. traffic continued to increase until 1973, it then started oscillating and now seems stabilized at the level it had in 1965, i.e., about 0.4 million transits per year both ways.

Conclusions

A posteriori application of the models to various case studies shows them to be a sharp lens for *inspecting* the details of what happens when a new infrastructure changes the boundary constraints of a given traffic milieu. The models also provide a tool for *forecasting* inside a Kondratiev cycle. (Forecasting over longer periods of time is possible, but reliable statistics over a couple of cycles, i.e., in the range of 100 years, are necessary. The exercise has been done at IIASA for France and the United States.)

A bridge across the Strait of Messina will probably not modify long-range freight traffic. This freight will be carried primarily by *trucks* that will take the bridge for simplicity's sake, even if the gain in time is not significant.

F.S. trains are bound to have a decreasing importance, and consequently it may not pay to have them on the bridge. The capacity of the F.S. ferries, which is now sufficient, will be redundant in the near future. A revival of F.S. function, providing *"gliding auto routes"* east–west in northern Italy, and north–south for the rest of the country, although very interesting conceptually, will not penetrate the institutional barriers, in my opinion.

Passenger traffic is the real plum because the number of transits can easily switch from the present estimated saturation point *of 20 million* to *200 million*, if the appropriate *time formula* is found. *If* the link to another conurbation requires a transit time, say, of 40 minutes, like the ferries in Istanbul, plus some waiting time, then the two conurbations are time-separated and operate as independent units with traffic typical of *intercity traffic*. *If* the link to the other conurbation becomes a fast one, requiring a few minutes for the connection, then the conurbations become *time-connected* and the traffic becomes typical of *intracity traffic*. The definition of the latter notion means each person has a chance more or less daily to "cross the straits" – which psychologically becomes equivalent to crossing the street – and do all business, jobs, shopping on both sides.

An idea of the intensity of intracity traffic is given by Hong Kong, where the 1.5 million people living in Victoria interact freely with the 2.0 million living in Kowloon, generating roughly 800 million trips per year across the harbor. This roughly accounts for one crossing (one way) per person per day.

A useful rule of thumb is to imagine every citizen making three trips per day outside the home – one of them longer. This longer trip will "cross the river" if the transit time is not larger than 20 minutes or so. In the Messina situation, the number of transits per day would be roughly equal to the current population of the smaller city, Reggio Calabria, beyond the strait: 200 million transits per year. The rule works for Hong Kong and Lisbon.

The *Messina bridge* should be made the *link that functionally fuses Reggio Calabria and Messina first, and later a chain of smaller cities down to Catania.* This could be done by a *fast transport, organized as a Metro*, with short, very frequent (minutes) trains. The new technologies *of magnetic levitation*, already commercially available, offer superb comfort, speed and complete automatization. To fuse Reggio and beyond to Messina and Catania into a single functional unit, these Metro trains should be capable of at least 200 km/h and have very good acceleration, both characteristics easy to obtain with Maglevs.

This infrastructure would also create the preconditions for a linear city along which the inevitable emigration from inland will condense in urban conditions more desirable than the blobs of central cities. Such necklaces of urban "beads" are appearing around the world, often referred to as "corridors", unified by air shuttles. The most gigantic of them, the Tokyo-Osaka "Shinkansen" corridor will be unified (one-our transit time!) most probably by a Maglev line. As the evolution of this megalopolis-corridor is nearly complete, a short description may be useful in considering the shape of the Messina system.

Messina–Reggio as the Nucleus of a Megalopolis?

The emerging Japanese megalopolis may provide useful analogies for the planned Messina project. In 1966, the year of consolidation into one continuous unit from Tokyo to Yahato, its population was 69.2 million, its area 76,000 km^2, and its population density was 900 inh./km^2 (Doxiadis and Papaioannu, 1974). It had four main centers (see again Figure 1.5).

The backbone of the transportation system along this strip has been the train, in particular the famous "bullet train". The bullet train covers the distance between Tokyo and Osaka, the more densely populated stretch of the megalopolis, in about three and a half hours. This time is at the limit for an eperopolis, where one goes, occasionally, from A to B to do business and comes back to A the same day. The time strain is well manifested by the increasing number of passengers *flying* along the corridor, as is done with the famous "shuttle" flights in the US east and west corridors.

The high density of the demand can be satisfied only by misusing large plans, often Jumbo 747s designed for long-range service, in the absence of short-range planes (2000-3000 km) of appropriate size. This caused a major accident. There is growing need for a high-density mode having the same *speed* characteristics of a plane. Japan, in fact, has been developing its own brand of Maglev for the past 20 years.

This train is planned to cover the distance Tokyo–Osaka (about 600 km) in one hour. (Incidentally, the mean speed of an airplane, taking into account takeoff, landing and ceiling times, is about 600 km/h.) Because Japan is a hilly and mountainous country and the track of this fast train must run almost straight, about 50% of the track will be in tunnels.

Complete enclosure of the track in a "pipeline" would eliminate aerodynamic noise and the bangs when the train enters or leaves a tunnel. A buried pipeline would also solve the problem of expensive rights of way in Japan. With complete enclosure, moreover, air pressure inside the tube can be reduced, permitting much higher speeds at reduced drag, as for airplanes flying at high altitude.

Although these developments may take another 20 years to be incorporated into an operating project, they promise bulkhead to bulkhead transit times in the range of 20 minutes, welding the megalopolis into a single unit, where people may travel in an *"intracity spirit"*, with a couple of trips per day per person to any destination inside the city range. Of course, this will be possible only if the travel cost is aligned with the disposable income of the local population. These trains could then carry on the order of *100 million passengers per day* – the potential demand in the Japanese corridor if the TTB and TMB are appropriately met. The technologies to manage such fluxes of passengers at the stations have yet to be invented however.

Coming to the much more modest, but conceptually identical, case of the *Catania-Messina-Reggio* megalopolis, we observe that the "attraction of the sea" and the "repulsion from the mainland" led to a rapid increase in the population of a necklace of cities located along the eastern coast of Sicily.

The three provinces in the strip have almost equal area and about a couple of million of inhabitants. It is not too difficult to calculate the order of magnitude of the potential traffic across an arbitrary line, e.g., the bridge. One has to know, however, speed and cost of the main transport system, plus disposable income of the population. The first two parameters can, to a point, be controlled by the planners: the third can be estimated from the secular trends.

Trip rate is one of the measurements more thoroughly analyzed as generator of urban traffic, and shows good regularities. To simplify to the bone, the average active adult makes about three trips per day. Extended field measurements show that when the system provides more speed, e.g., through highways, the distance traveled increases accordingly, but the number of trips remains basically constant. This means a large territory is treated like a small one, size providing only a better choice of facilities, i.e., travel objectives. Available speed being different in different directions, these movement fields (territories) tend to be elliptic, with the long axis pointing toward the center of the nearest city, as transportation infrastructures usually radiate from it.

Assuming that any city developing out of the link between Catania and Reggio with a superfast public transport will be linear, and further postulating a Maglev subway *taking 20 minutes for the whole stretch*, we can estimate the *conceptually maximum* flow of passengers across the bridge.

The 60 minutes of TTB can be allocated to one long trip taking 10 + 10 minutes Maglev and 10 + 10 minutes walking, and two short trips taking 5 + 5 minutes by car each. In this scenario every traveler living in the area of Reggio will cross the bridge (two ways) every day. Roughly half the population travels; this means the crossings (one way) originated from Reggio will roughly correspond to its population.

Assuming the targets of the trips would be distributed in proportion to the population in a certain area, then the *incoming* traffic will be roughly the same. In other words, the *population on the smaller side of the linear city linked by the bridge is the direct indicator for the number of crossings.*

If this simple, but intuitive and visual, way of reasoning seems completely unrealistic, we can check it against some real case, e.g., Hong Kong, where *Victoria*, the city on the island, has about *one million inhabitants.* Kowloon and the mainland are linked by a number of ferry lines and two fast tunnels – one for road traffic and the other for a subway. Most passengers (80%) are carried through the tunnels. As shown in the logistic analysis of the development of this cross-harbor traffic, the saturation point will be about 8 x 10^8 single crossings per year, estimated to be reached toward the end of the century. This corresponds to about *one million double crossings per day.* In 1986 the traffic had already reached 70% of the saturation point, i.e., 0.7 million.

In the case of the Tago estuary crossing in Lisbon, ferries will saturate with 50 x 10^6 passengers per year and the bridge with 26 x 10^6 vehicles per year. As these vehicles include buses, one can roughly add 5O x 10^6 passengers per year. These 10^8 pass/yr point to a city of about 140,000 people on the south bank of the estuary, which is approximately its actual size.

Considerations on the Transport of Goods

Because the Messina bridge should be useful and appropriate for its technical life, the technologies for transport of goods, as well as passengers, should be seen in a similar time perspective – say, 100 years. As always, it is instructive to look at their evolution in historical context, in order to assess the rules of the game.

First, the most expensive goods tend to move by the fastest and more reliable means of transport. When they first appeared, steamers were much more expensive than sailing ships, in terms of capital investment and their profligate use of fuel. Their coal, in fact, was carried to their bunker points around the world by the much cheaper sailboats! But steamships had two important advantages: they were not merely *faster*, they could *keep schedules*. So the most important items carried then were mail and human flesh. Achievements in machinery performance and general design made steamships progressively more competitive, in ton/km cost terms, and in a mere 100 years sail-powered ships no longer carried freight (Figure 3.15).

A similar story can be told for railways, which at the beginning also transported essentially mail and people, and successively higher-value goods. At their zenith in many parts of the world, trains carried almost everything. Now they haul almost only low-value goods. Taking away coal and grain, very little business would be left on American railway systems, in its heyday the most powerful network of the world. Similarly, when the Italian railways want to deliver goods on the mainland, e.g., from Milan to Rome, with appropriate speed and reliability, they use lorries. This indicates the point in their trajectories they have reached now, and leaves little hope for the next 100 years, unless they are drastically reconfigured.

The most advanced technology now is the airplane. Airplanes started their commercial career carrying mail, especially in the USA, during the heroic 1920s.

In the 1930s they began carrying a significant number of passengers. During the last 20 years, progress in machine performance, size and general design has made them increasingly competitive for the transport of goods.

Dedicated Jumbo 747s now carry ripe pineapple from Honolulu to New York and the East Coast, or auto bodies from Turin to Detroit. The cutoff line for the value of the goods that can profit from the characteristics of the air system – speed and efficient handling – becomes progressively lower. Fresh summer fruits from South Africa sell in winter in Vienna at prices not significantly different from the same fruits in summer, coming from Italy or Spain.

This means that *vegetables and fruits* from Sicily which now are in search of speed in order to reach the markets of northern Italy and Northern Europe in perfect condition, may take to the air, shunning progressively all other means of transport. Contrary to many critics, then, the construction of the Messina bridge will probably have *no consequences* in this field.

Freight now accounts for only 15% of the air transport traffic (ton-km), worldwide. Most goods are actually transported using the extra capacity of passenger flights and, in few cases, using airplanes originally designed for passenger traffic and adapted for freight. The largest, the 747, carries about 100 tons. With the growth in traffic, a variety of planes specifically designed for freight will emerge, and technically 1000 ton freighters may be possible. As in the case of all-freight steamers, such air freight carriers may revolutionize the transport of goods, reducing the role of the road to retailing operations. The time horizon for such a process is about 50 years, within the next Kondratiev cycle.

From a functional point of view a solution for the possible revival of the Italian railways would be to provide "gliding auto routes" for the competing road vehicles – thus, sharing their success if only in a subordinate way. This would be consistent with the general trends of traffic in Europe described in Marchetti (1987).

One of several proposals would reduce operated track to one line east–west in northern Italy, and two lines north–south along the shores. Railways would operate train platforms at a ***mean*** speed attractive for road traffic (150 km/h) with embarking–disembarking points every 200 km or so. These points should be chosen to facilitate the final retailing by major auto route, and have no strict connections with the cities and their centers, where railway stations are usually located and which do not usually constitute divergence points for freight traffic. All railway crossings would overfly road traffic, so that trains and road do not interact. The frequency of these platform trains should be in the 10-minute range, if a sizable fraction of the long-range road traffic is to be absorbed by such mode of transport.

A similar situation occurred when steamships began to replace unpredictable, and consequently unscheduled, sailships, for carrying passengers, mail, and valuable cargo. These steamers, which required large amounts of coal, had to refuel at convenient places along their routes. All the coal to service these bunker points was transported by sailships, providing brisk business *for a good 50 years*.

This is the only configuration I can imagine to resurrect the railway system and ***produce consistent long-range train traffic for the bridge during the next 50 years***. But institutional resistance makes its implementation very improbable.

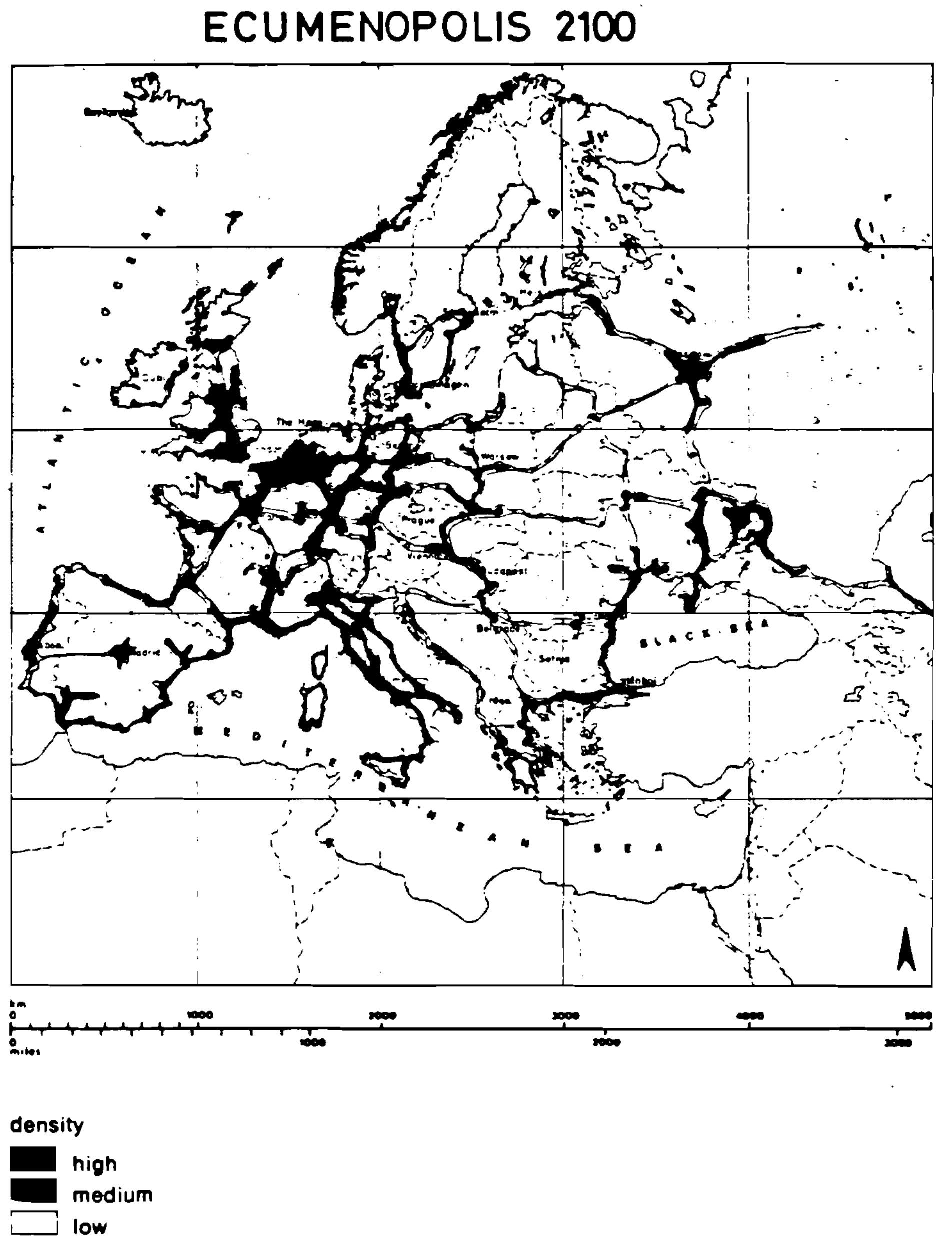


FIGURE 3.1. Contiguous urban development in Europe, in 2100. (Source: Doxiadis and Papaioannou, 1974.)

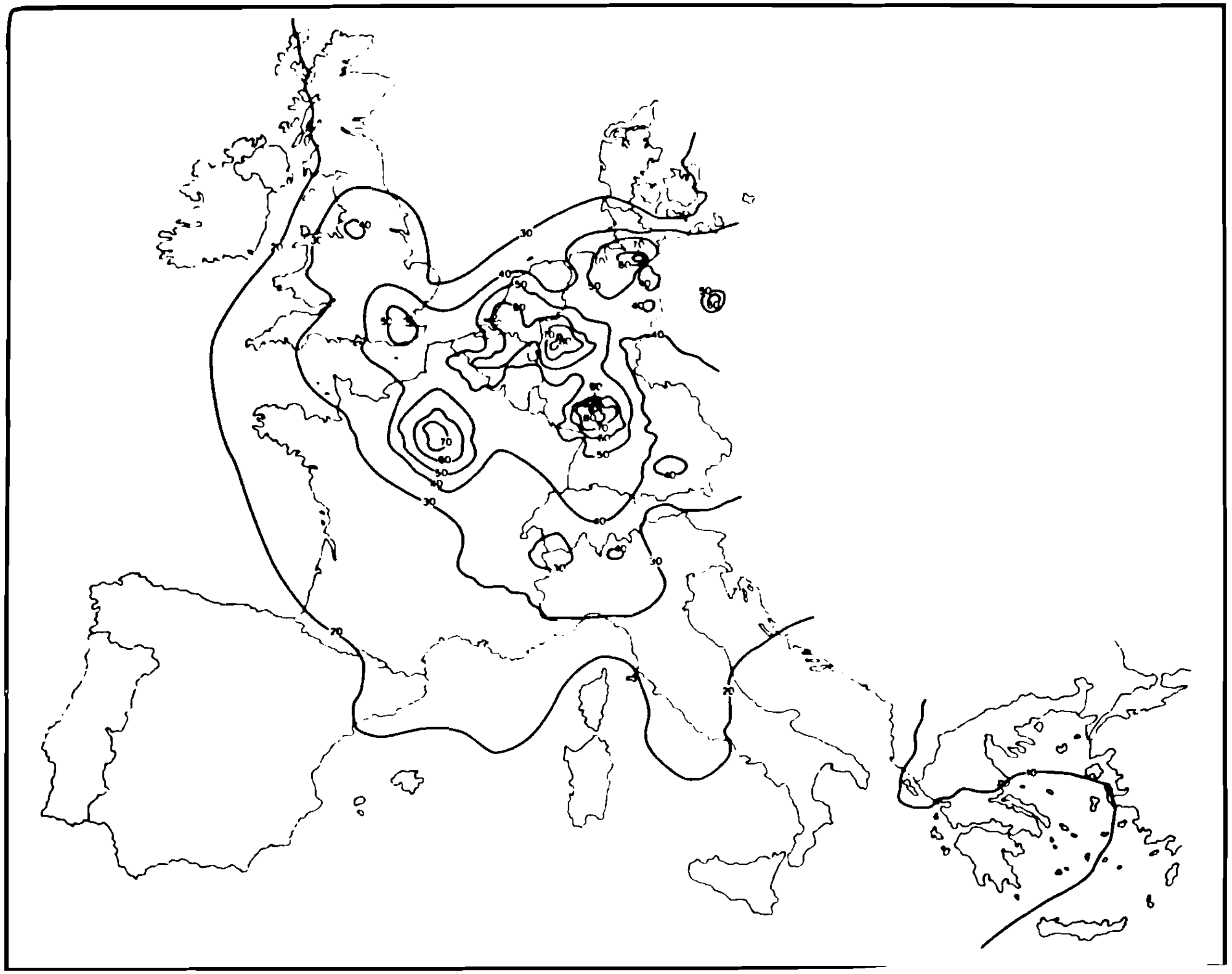


FIGURE 3.2. Regional accessibility and economic potential in the European Community. (Source: Keeble, 1982.)

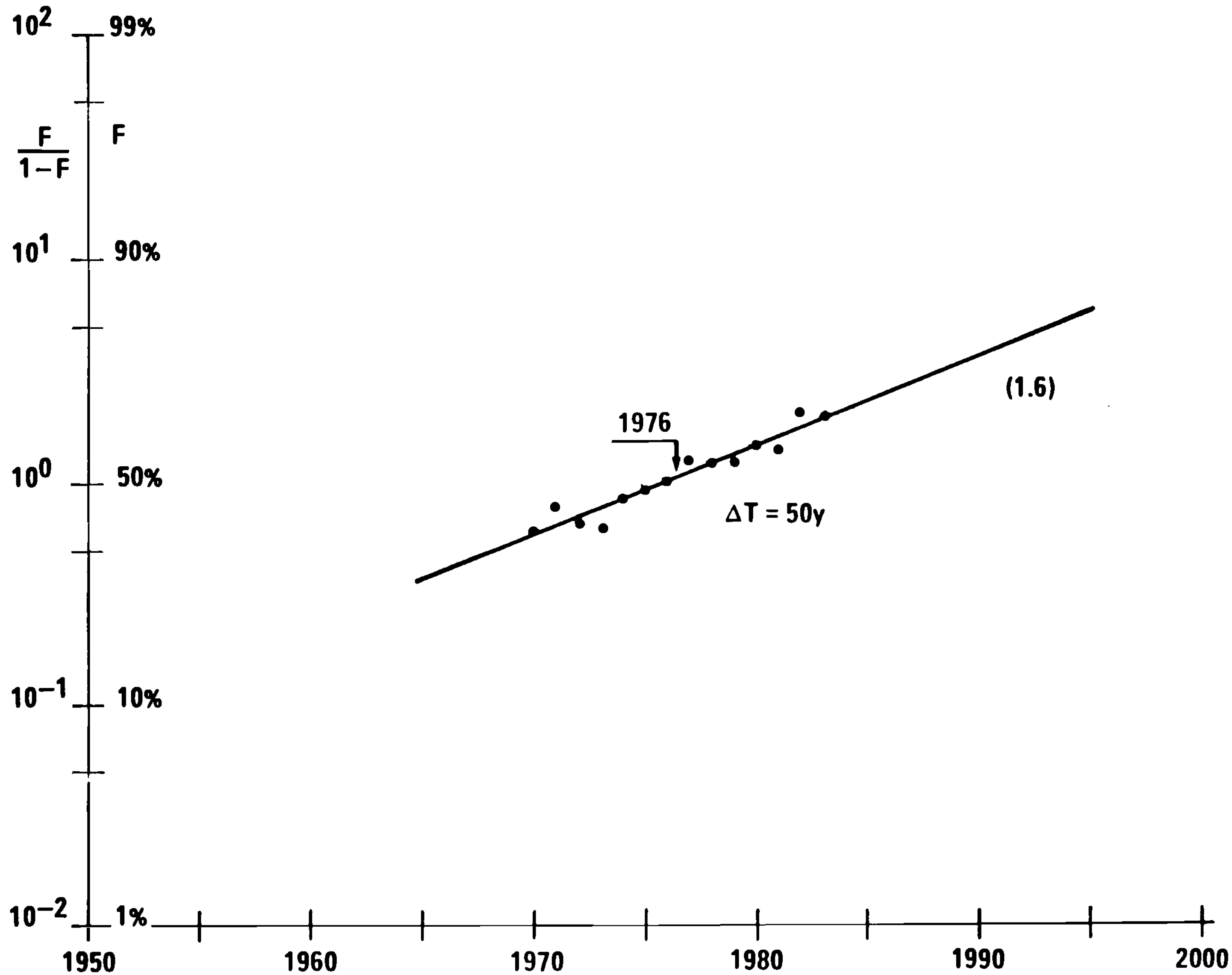


FIGURE 3.3. Trend in passengers (10^6) in and out of Catania airport. (Based on data provided by SOMEA, 1985.)

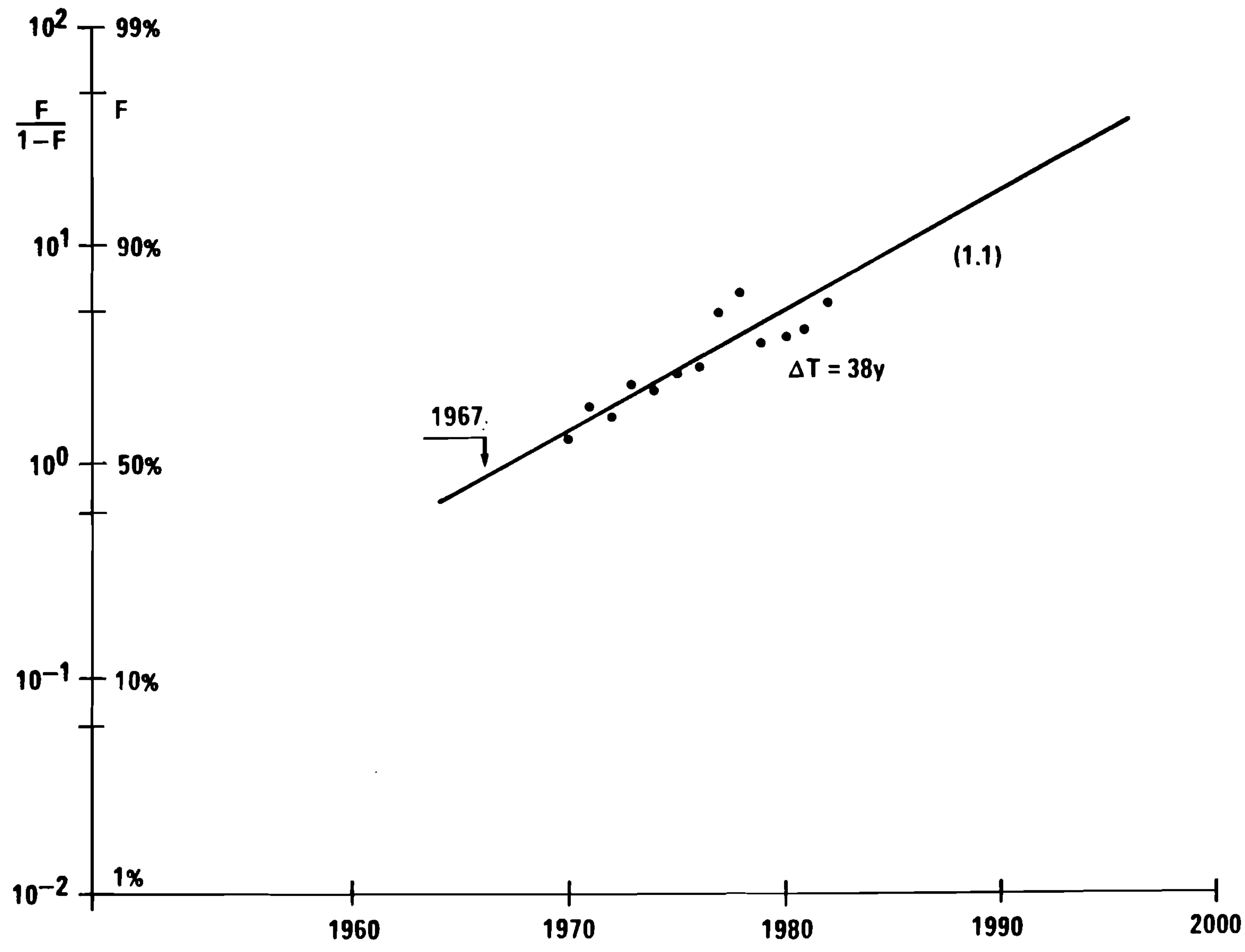


FIGURE 3.4. Trend in passengers (10^6) in and out of Palermo airport. (Source: see Figure 3.3.)

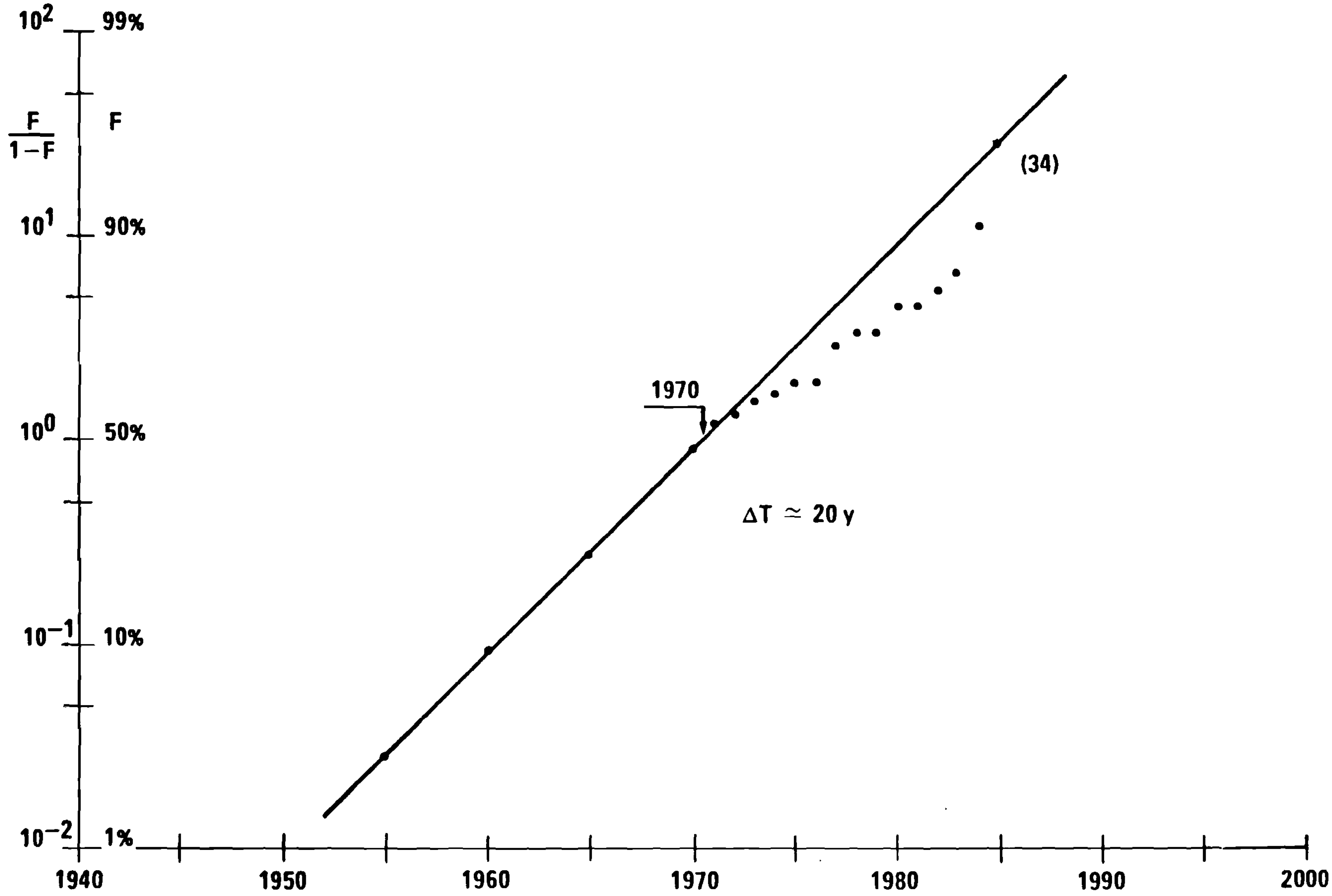


FIGURE 3.5. Trend in passengers (10^6) in and out of mainland Italian airports. (Based on data provided by Annuario Statistico Italiano, various years.)

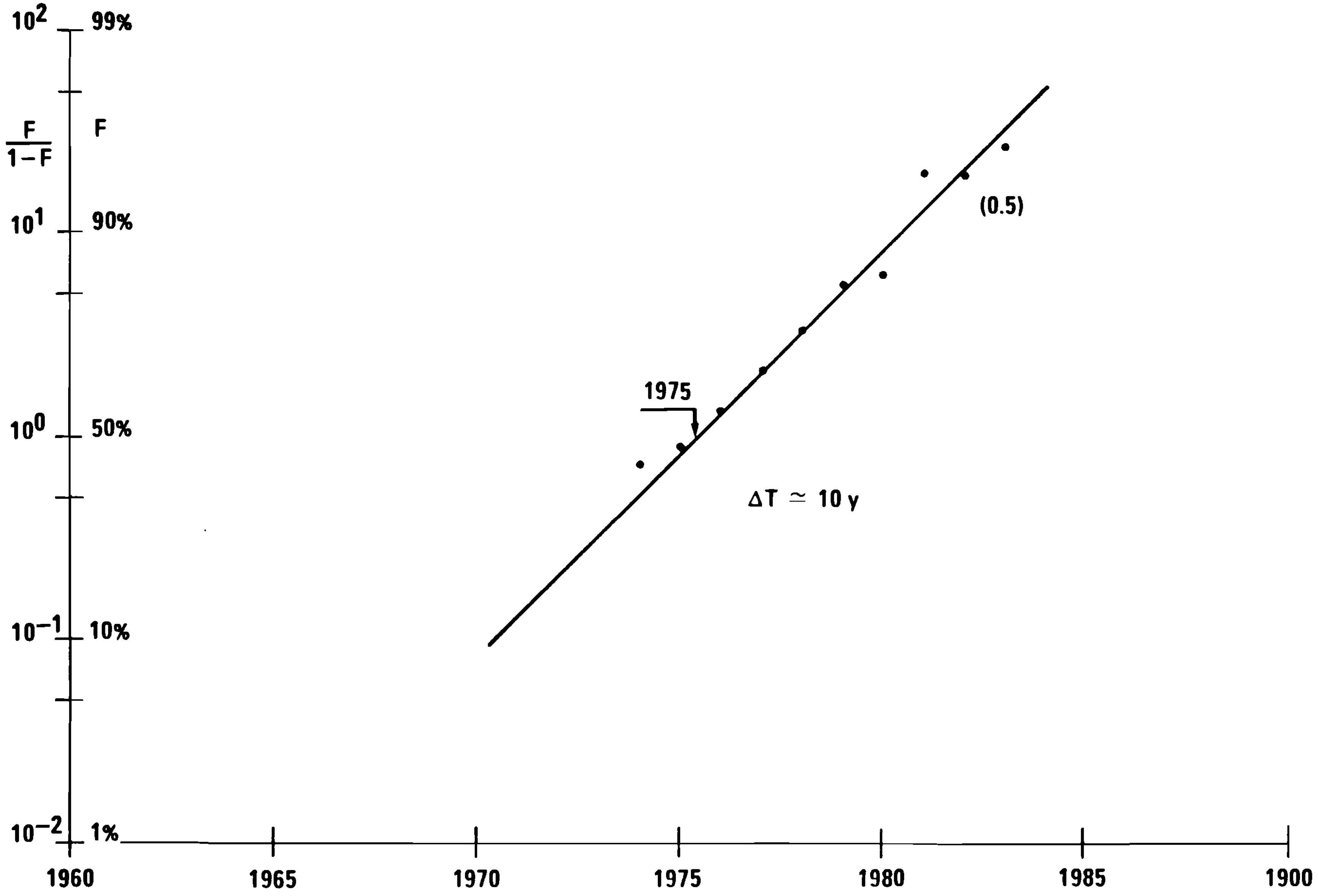


FIGURE 3.6. Trend in trucks (10^6) crossing the Messina Strait from Calabria to Sicily. (Source: see Figure 3.3.)

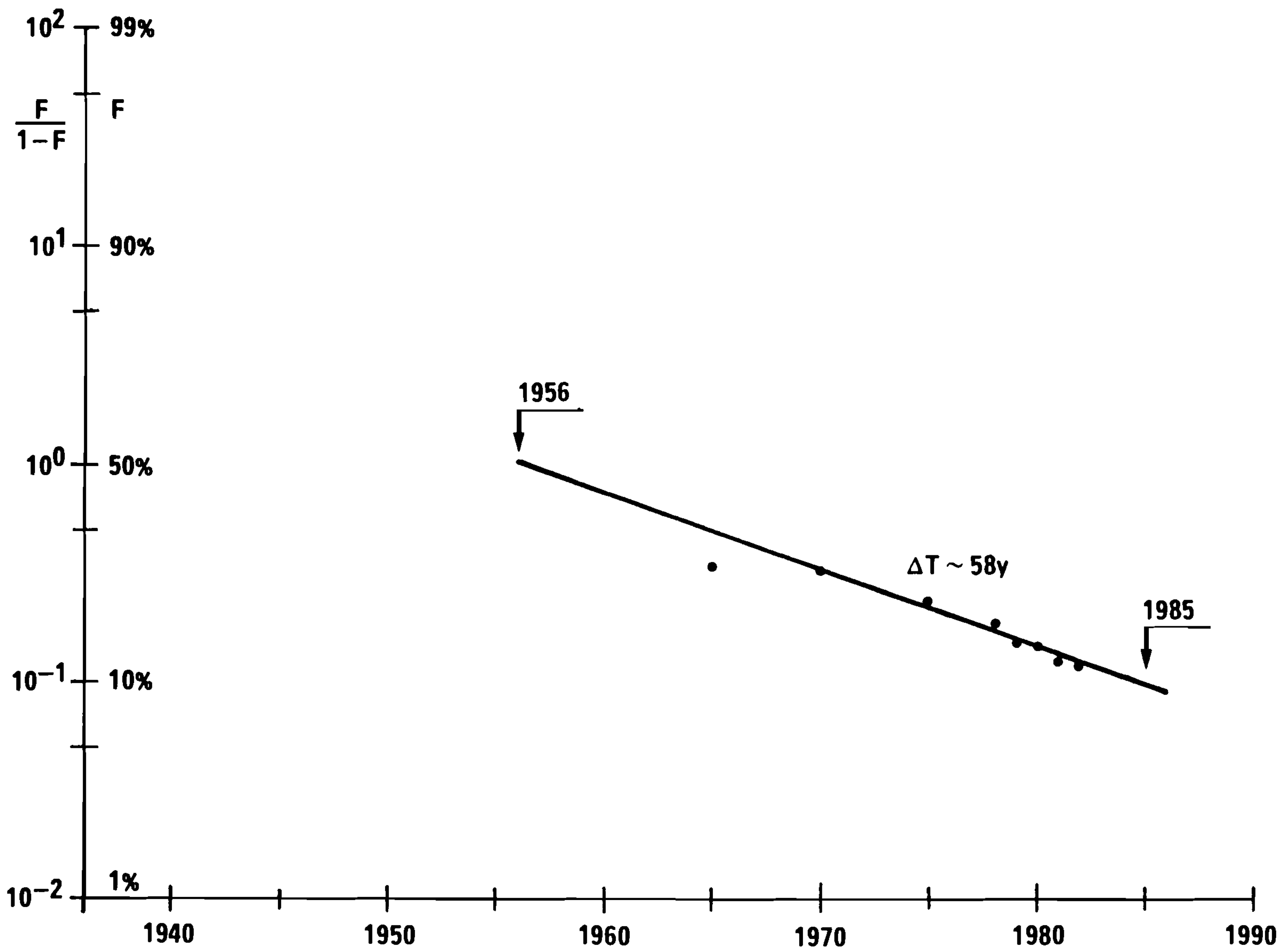


FIGURE 3.7. Trend in freight (ton-kms) carried across the Messina Strait by rail versus road transport. (Source: see Figure 3.3.)

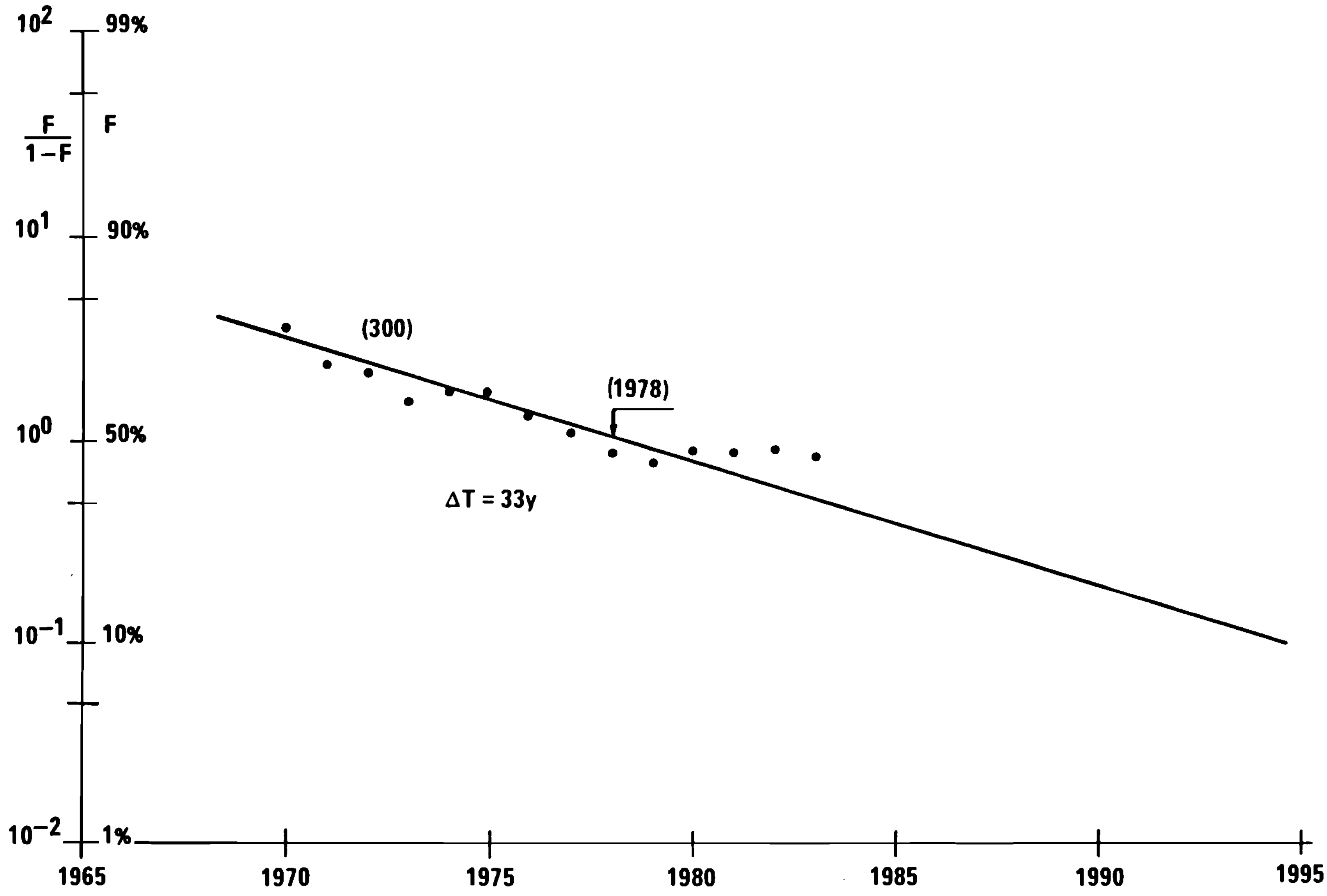


FIGURE 3.8. Trend in freight cars (10^3) crossing the Messina Strait. (Source: see Figure 3.3.)

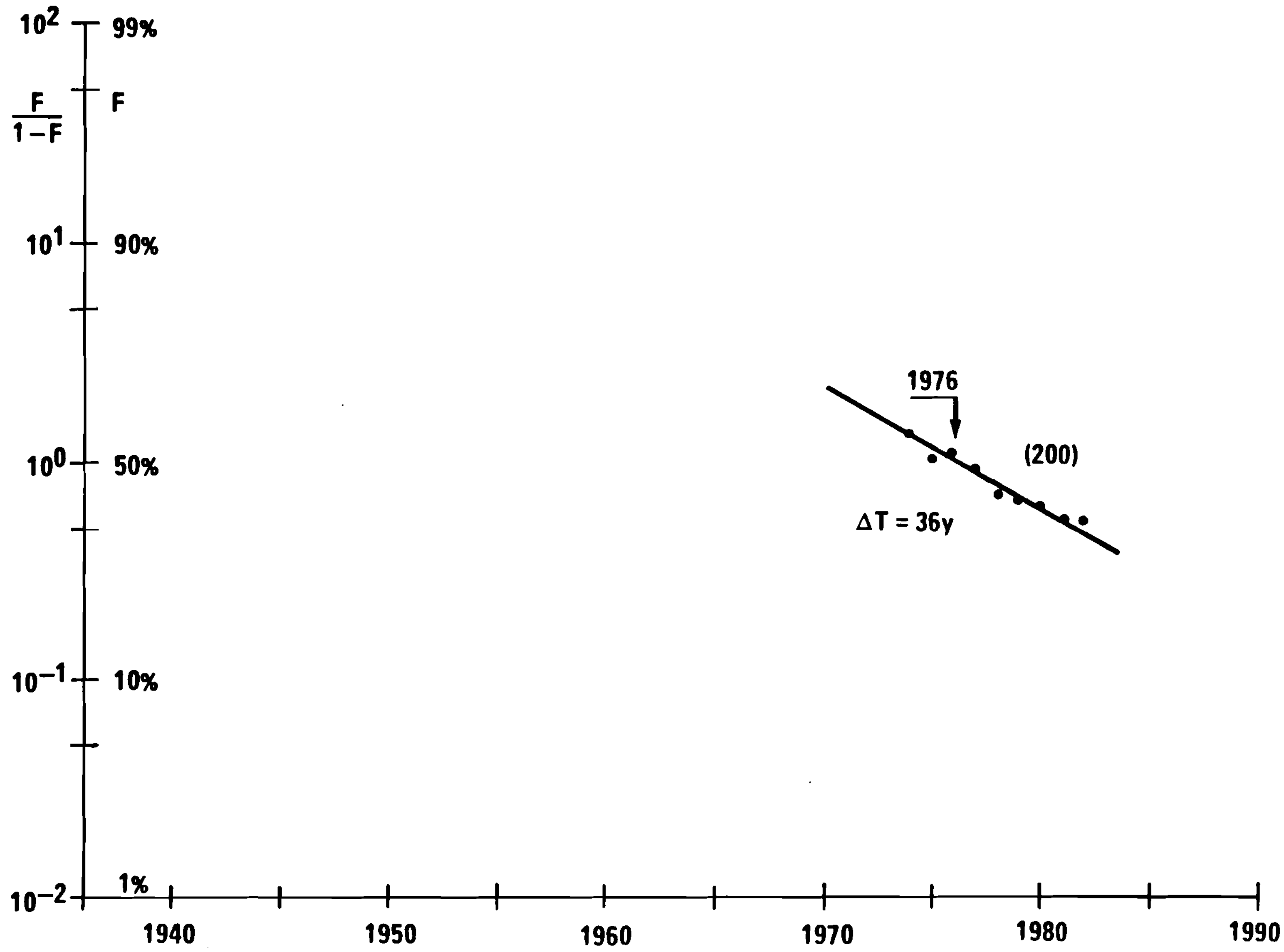


FIGURE 3.9. Trend in loaded railway cars (10^3) crossing the Messina Strait from Sicily to Calabria. (Source: see Figure 3.3.)

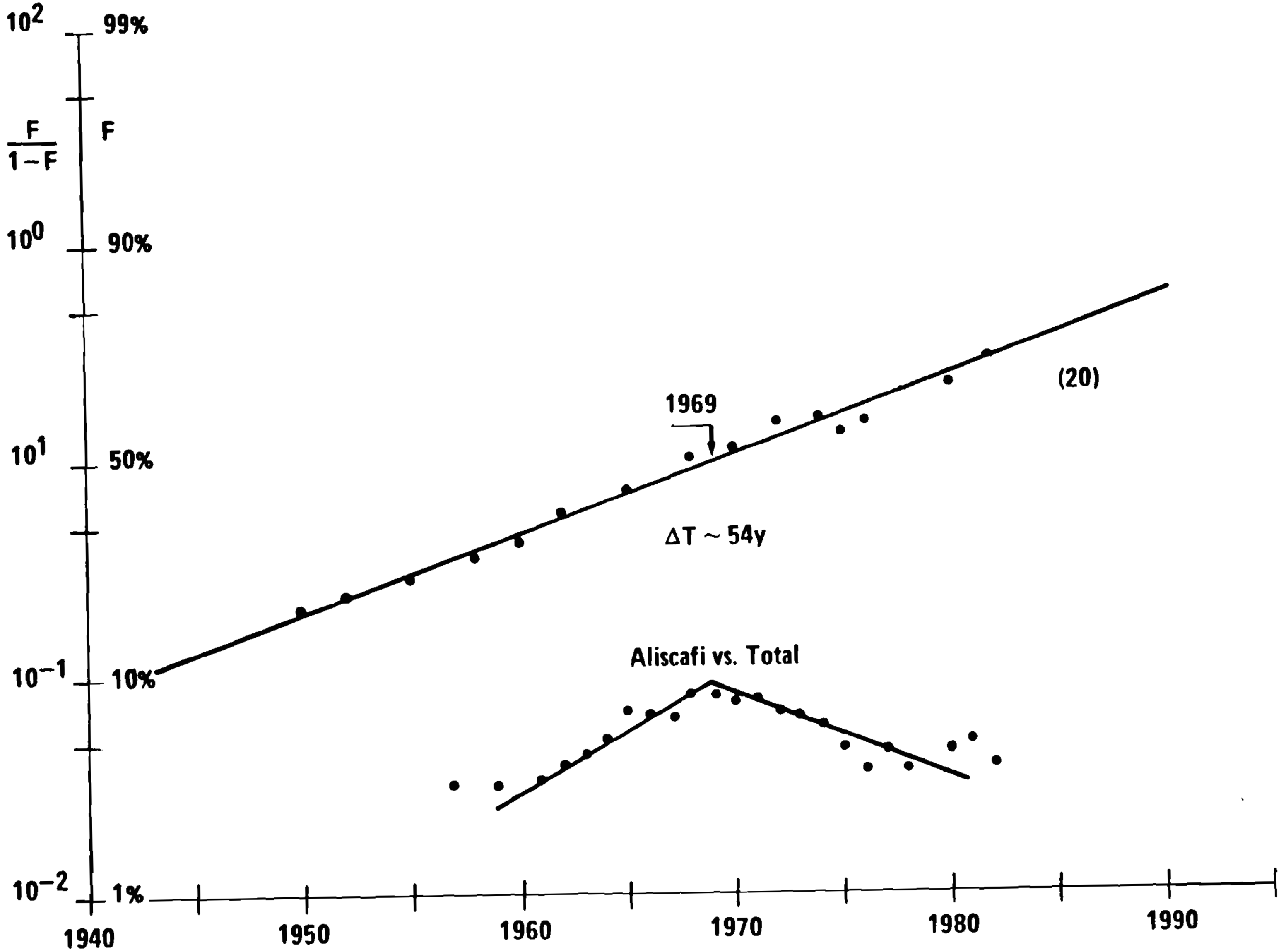


FIGURE 3.10. Trend in total passenger vehicles (10^6) crossing the Messina Strait. (Based on data provided by Valleri, 1986.)

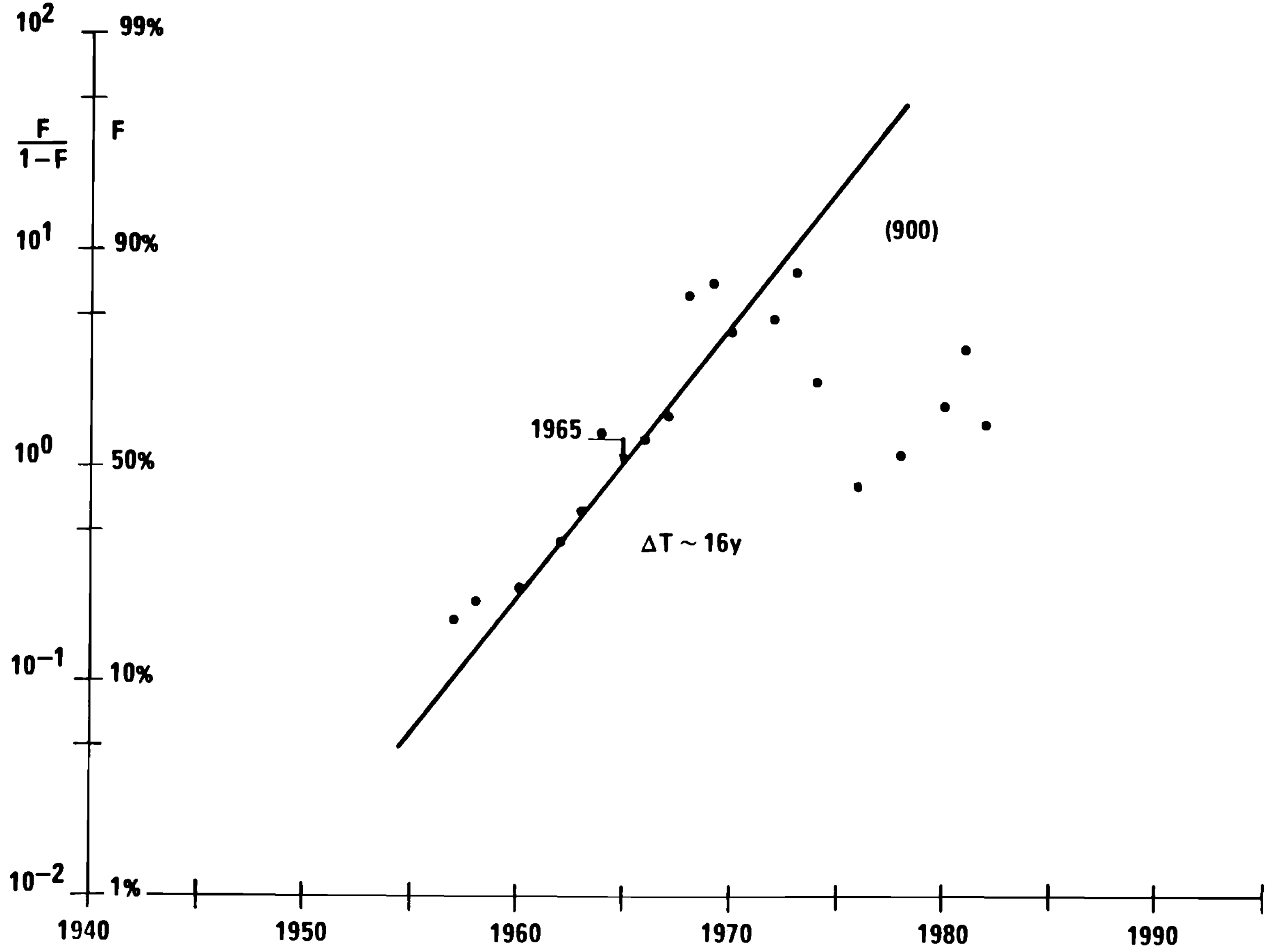


FIGURE 3.11. Trend in passenger vehicles to and from Aliscafi as a percentage of total Messina Strait passenger crossings. (Source: see Figure 3.10.)

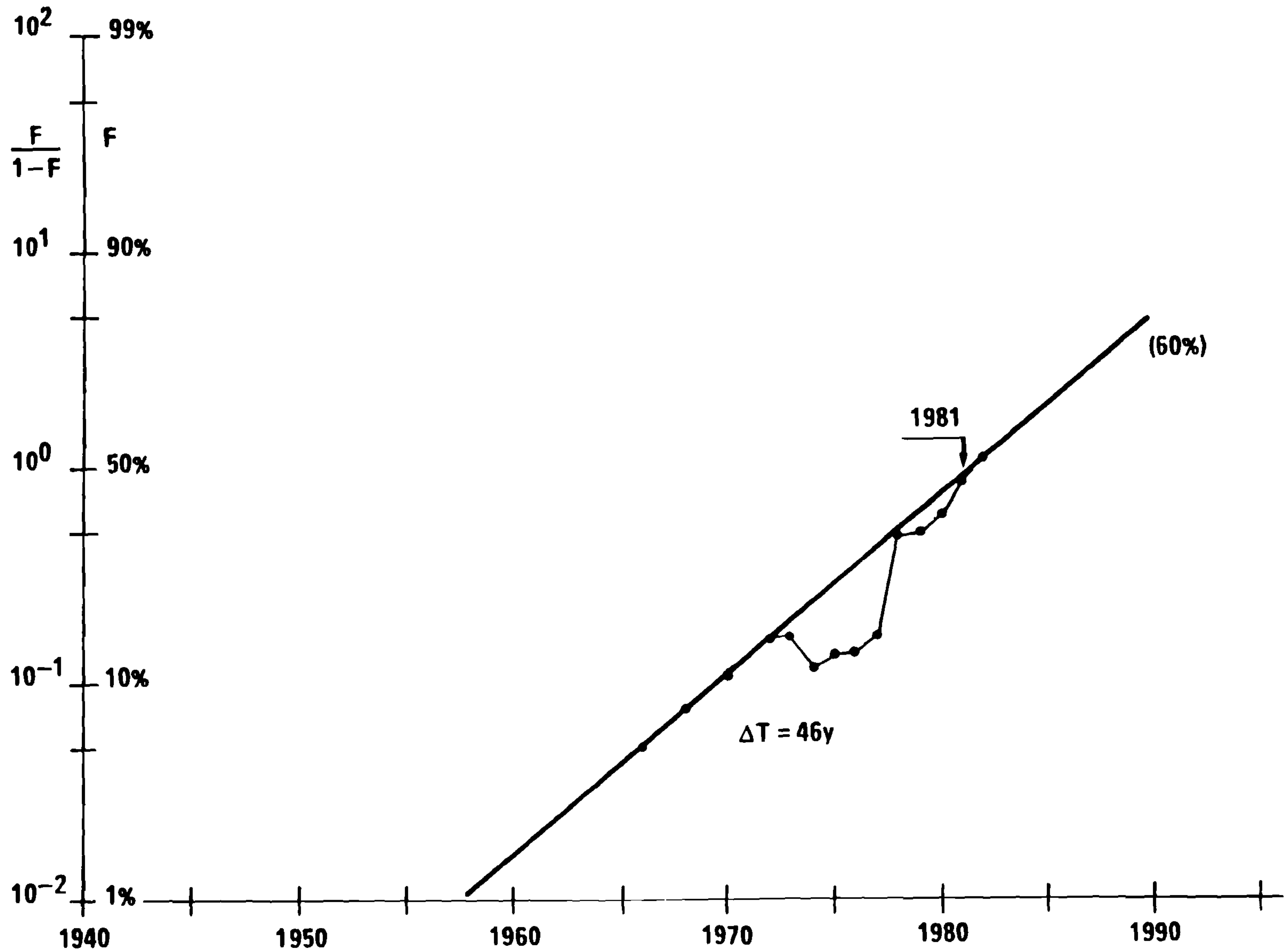


FIGURE 3.12. Trend in private ferry passenger vehicles as a percentage of total ferry passenger vehicles crossing the Messina Strait. (Source: see Figure 3.10.)

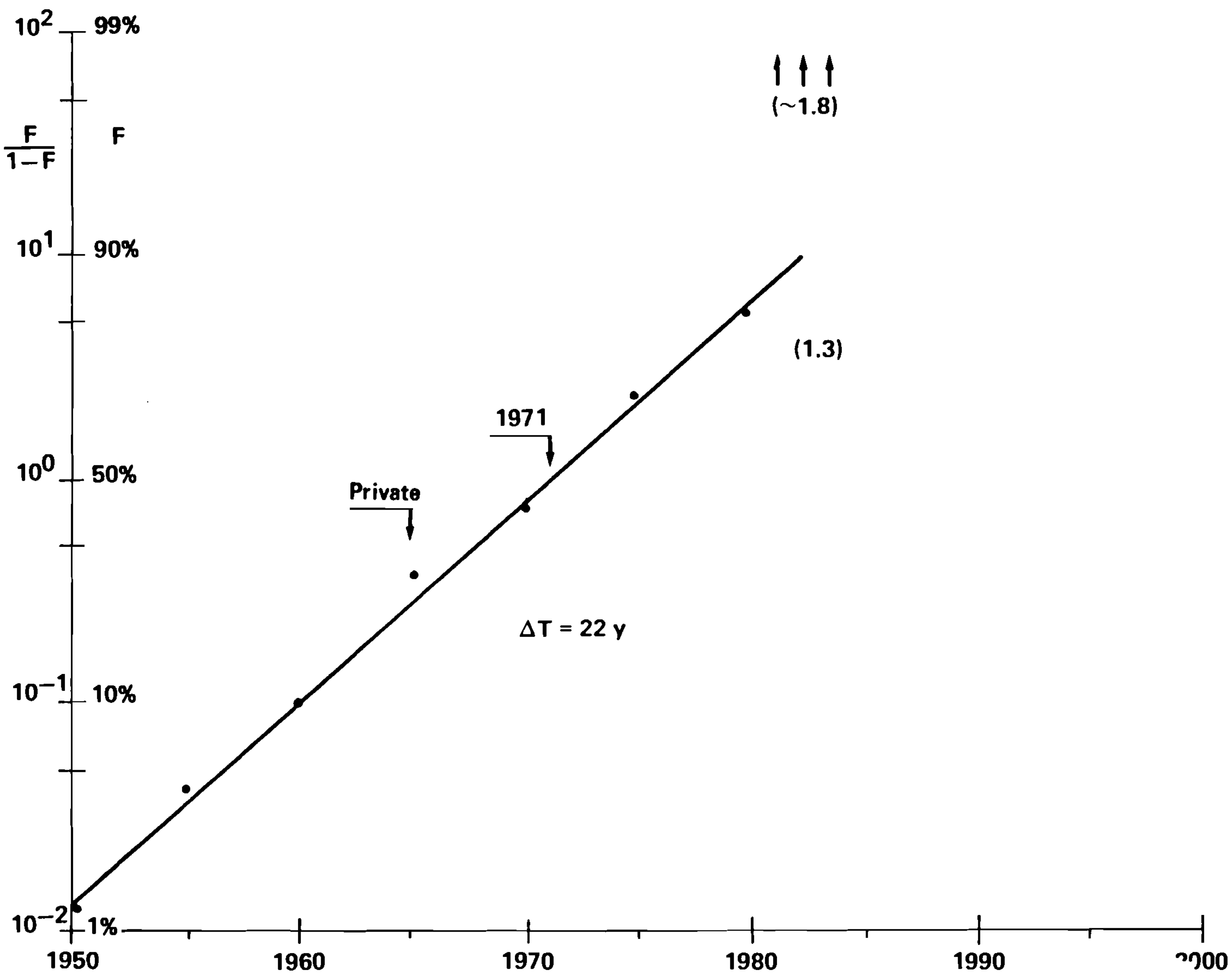


FIGURE 3.13. Trend in total cars (10^6) crossing the Messina Strait. (Source: see Figure 3.10.)

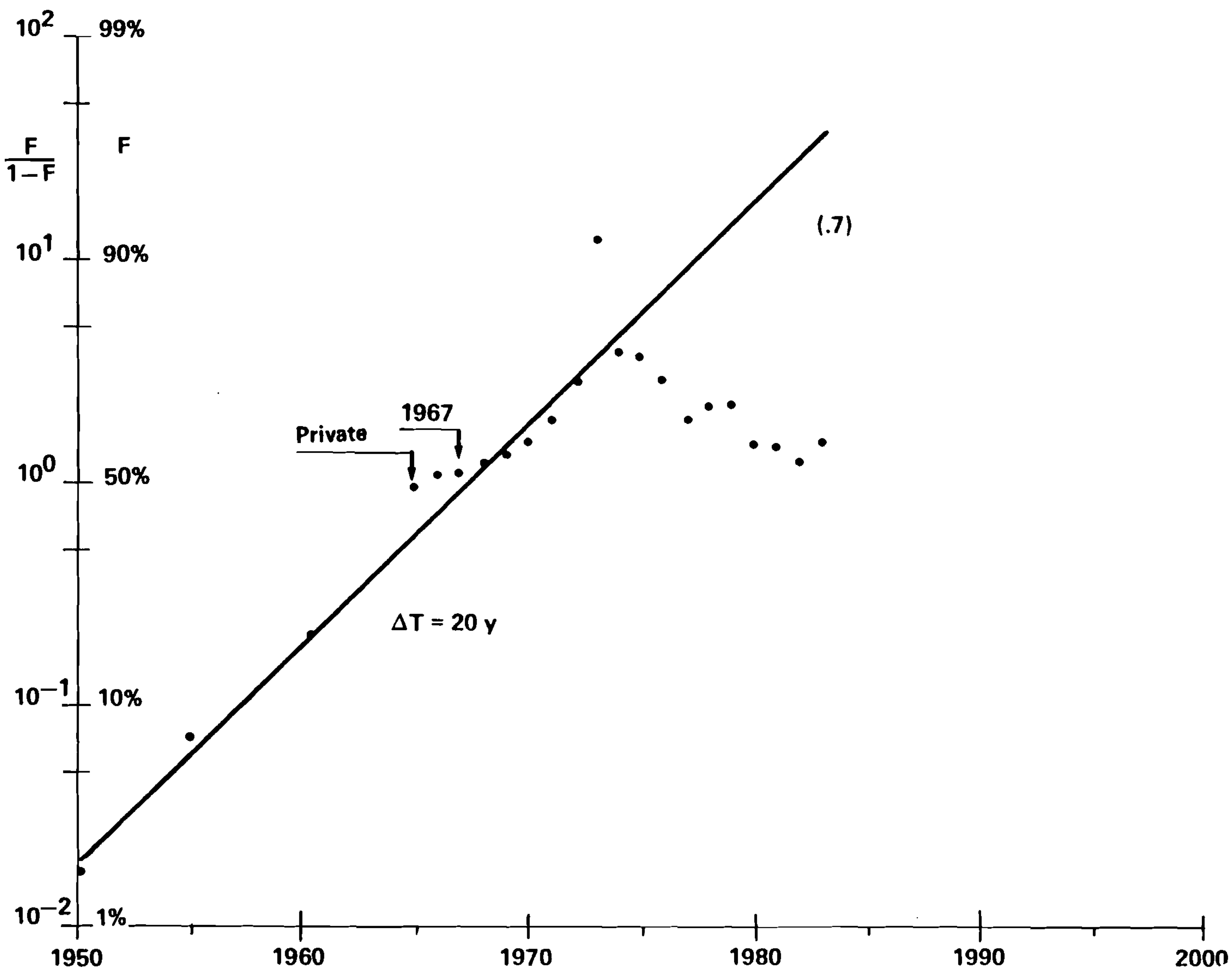


FIGURE 3.14. Trend in cars (10^6) crossing the Messina Strait by F.S. Ferries. (Source: see Figure 3.10.)

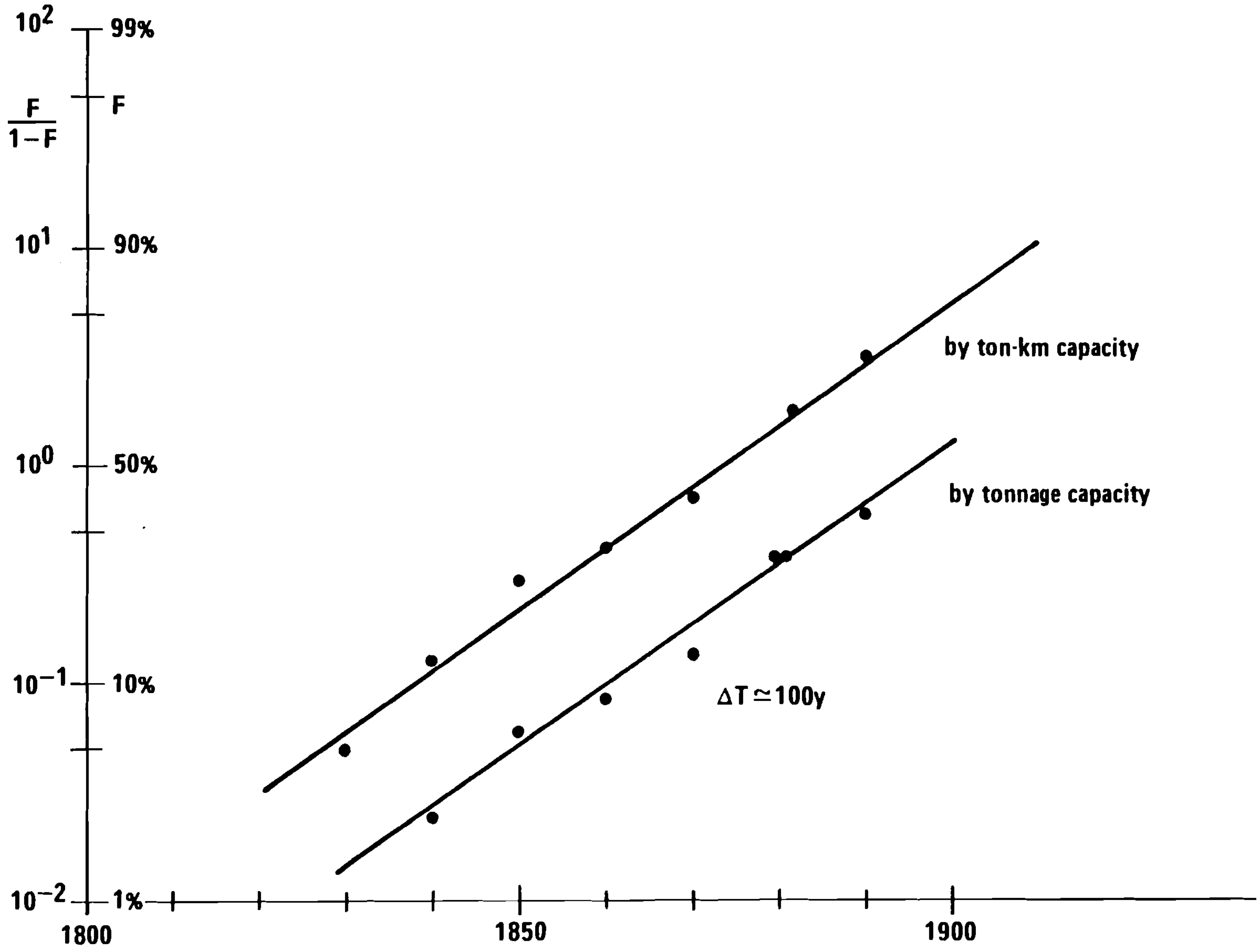


FIGURE 3.15 Steamship versus Sailship performance in tonnage and productivity, world-wide.

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MATHEMATICAL APPENDIX

The equations for dealing with different cases are reducible to the general Volterra–Lotka equations

$$\frac{dN_i}{dt} = K_i N_i + \beta_i^{-1} \sum_{n}^{i=1} a_{ij} N_i N_j \quad , \tag{1}$$

where N_i is the number of individuals in species i, and a, β, and K are constants. The equation says a species grows (or decays) exponentially, but for the interactions with other species. A general treatment of these equations can be found in Montroll and Goel (1971) and Peschel and Mende (1986). Since closed solutions exist only for the case of one or two competitors, these treatments mainly deal with the general properties of the solutions.

In order to keep the analysis at a physically intuitive level, I use the original treatment of Verhulst (1845) for the population in a *niche* (Malthusian) and that of Haldane (1924) for the competition between two genes of different fit. For the multiple competition, we have developed a computer package which works perfectly for actual cases (Marchetti and Nakicenovic, 1979), but whose identity with the Volterra equations is not fully proven (Nakicenovic, 1979).

Most of the results are presented using the coordinates for the linear transform of a logistic equation originally introduced by Fisher and Pry (1970).

The Malthusian Case

This modeling of the dynamics of population systems started with Verhulst in 1845, who quantified the Malthusian case. A physically very intuitive example is given by a population of bacteria growing in a bottle of broth. Bacteria can be seen as machinery to transform a set of chemicals in the broth into bacteria. The rate of this transformation, *coeteris paribus* (e.g., temperature), can be seen as proportional to the number of bacteria (the transforming machinery) and the concentration of the transformable chemicals.

Since all transformable chemicals will be transformed finally into bacterial bodies, to use homogeneous units one can measure broth chemicals in terms of bacterial bodies. So $N(t)$ is the number of bacteria at time t, and $\bar{N}$ is the amount of transformable chemicals at time 0, before multiplication starts. The Verhulst equation can then be written

$$\frac{dN}{dt} = aN(\bar{N} - N) \quad , \tag{2}$$

whose solution is

$$N(t) = \frac{\bar{N}}{1-e^{-(at+b)}} \quad , \tag{3}$$

with b an integration constant, sometimes written as t_0, i.e., time at time 0; a is a rate constant which we assume to be independent of the size of the population. This means that there is no "proximity feedback". If we normalize to the final size of the system, $\bar{N}$, and explicate the linear expression, we can write equation (2) in the form suggested by Fisher and Pry (1970).

$$\log\frac{F}{1-F} = at + b \quad , \quad \text{where } F = \frac{N}{\bar{N}} \quad . \tag{4}$$

Most of the charts are presented in this form. $\bar{N}$ is often called the *niche*, and the growth of a population is given as the fraction of the niche it fills. It is obvious that this analysis has been made with the assumption that *there are no competitors*. A single species grows to match the resources ($\bar{N}$) in a Malthusian fashion.

The fitting of empirical data requires calculation of the three parameters $\bar{N}$, a, and b, for which there are various recipes (Oliver, 1964; Blackman, 1972; Bossert, 1977). The problem is to choose the physically more significant representation and procedure.

I personally prefer to work with the Fisher and Pry transform, because it operates on *ratios* (e.g., of the size of two populations), and ratios seem to me more important than absolute values, both in biology and in social systems.

The calculation of $\bar{N}$ is usually of great interest, especially in economics. However, the value of $\bar{N}$ is very sensitive to the value of the data, i.e., to their errors, especially at the beginning of the growth. The problem of assessing the error on $\bar{N}$ has been studied by Debecker and Modis (1986), using numerical simulation.

The Malthusian logistic must be used with great precaution because it contains implicitly some important hypothesis:

- That there are no competitors in sight.
- That the size of a niche remains constant.
- That the species and its boundary conditions (e.g., temperature for the bacteria) stay the same.

The fact that in multiple competition the starts are always logistic may lead to the presumption that the system is Malthusian. When the transition period starts there is no way of patching up the logistic fit.

The fact that the niches keep changing, due to the introduction of new technologies, makes this treatment, generally speaking, unfit for dealing with the growth of human populations, a subject where Pearl (1924) first applied logistics. Since the treatment sometimes works and sometimes not, one can find much faith and disillusionment among demographers.

One-to-One Competition

The case was studied by Haldane for the penetration of a mutant or of a variety having some advantage in respect to the preexisting ones. These cases can be described quantitatively by saying that variety (1) has a reproductive advantage of k, over variety (2). Thus, for every generation the ratio of the number of individuals in the two varieties will be changed by $\frac{1}{(1-k)}$. If n is the number of generations, starting from $n = 0$, then we can write

$$\frac{N_1}{N_2} = \frac{R_0}{(1-k)^n} \quad , \quad \text{where } R_0 = \frac{N_1}{N_2} \text{ at } t = 0 \quad . \tag{5}$$

If k is small, as it usually is in biology (typically 10^{-3}), we can write

$$\frac{N_1}{N_2} = \frac{R_0}{e^{kn}} \quad . \tag{6}$$

We are then formally back to square one, i.e., to the Malthusian case, except for the very favorable fact that we have an initial condition (R_0) instead of a final condition ($\bar{N}$). This means that in *relative terms* the evolution of the system is not sensitive to the size of the niche, a property that is extremely useful for forecasting in multiple competition cases. Since the generations can be assumed equally spaced, n is actually equivalent to time.

As for the biological case, it is difficult to prove that the "reproductive advantage" remains constant in time, especially when competition lasts for tens of years and the technology of the competitors keeps changing, not to speak of the social and organizational context. But the analysis of hundreds of cases shows that systems behave exactly *as if*.

Multiple Competition

Multiple competition is dealt using a computer package originally developed by Nakicenovic (1979). A simplified description says that all the competitors start in a logistic mode and phase out in a logistic mode. They undergo a transition from a logistic-in to a logistic-out during which they are calculated as "residuals", i.e., as the difference between the size of the niche and the sum of all the *ins* and *outs*. The details of the rules are found in Nakicenovic (1979). This package has been used to treat about one hundred empirical cases, all of which always showed an excellent match with reality.

An attempt to link this kind of treatment to current views in economics has been made by Peterka (1977).