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Building bridges and tunnels: the effects on the evolution of traffic

Estratto da
Under and over the water:
the economic and social effects
of building bridges and tunnels

MARCHETTI-047_
Pt.1

Chapter 4

BUILDING BRIDGES AND TUNNELS: THE EFFECTS ON THE EVOLUTION OF TRAFFIC

by Cesare Marchetti*

4.1. *Introduction*

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 Kondatiev 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 potential utility ought to be found in local traffic. It may also stimulate the development of a linear metropolis – along the contiguous coasts of Calabria e 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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4.2. *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 4.1).
- *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 4.2).

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 continual search for opportunities.

TABLE 4.1. *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	
Calgray	1971		1.11	
Montreal	1971		1.18	

SOURCE: Zahavi, 1979.

TABLE 4.2. *Travel expenditures as percentage of disposable income in selected countries and urban areas*

Site	Survey period	% of total household expediture	
Nationwide:			
US	1963-1975	13.18 ± 0.38	
Canada	1961-1974	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

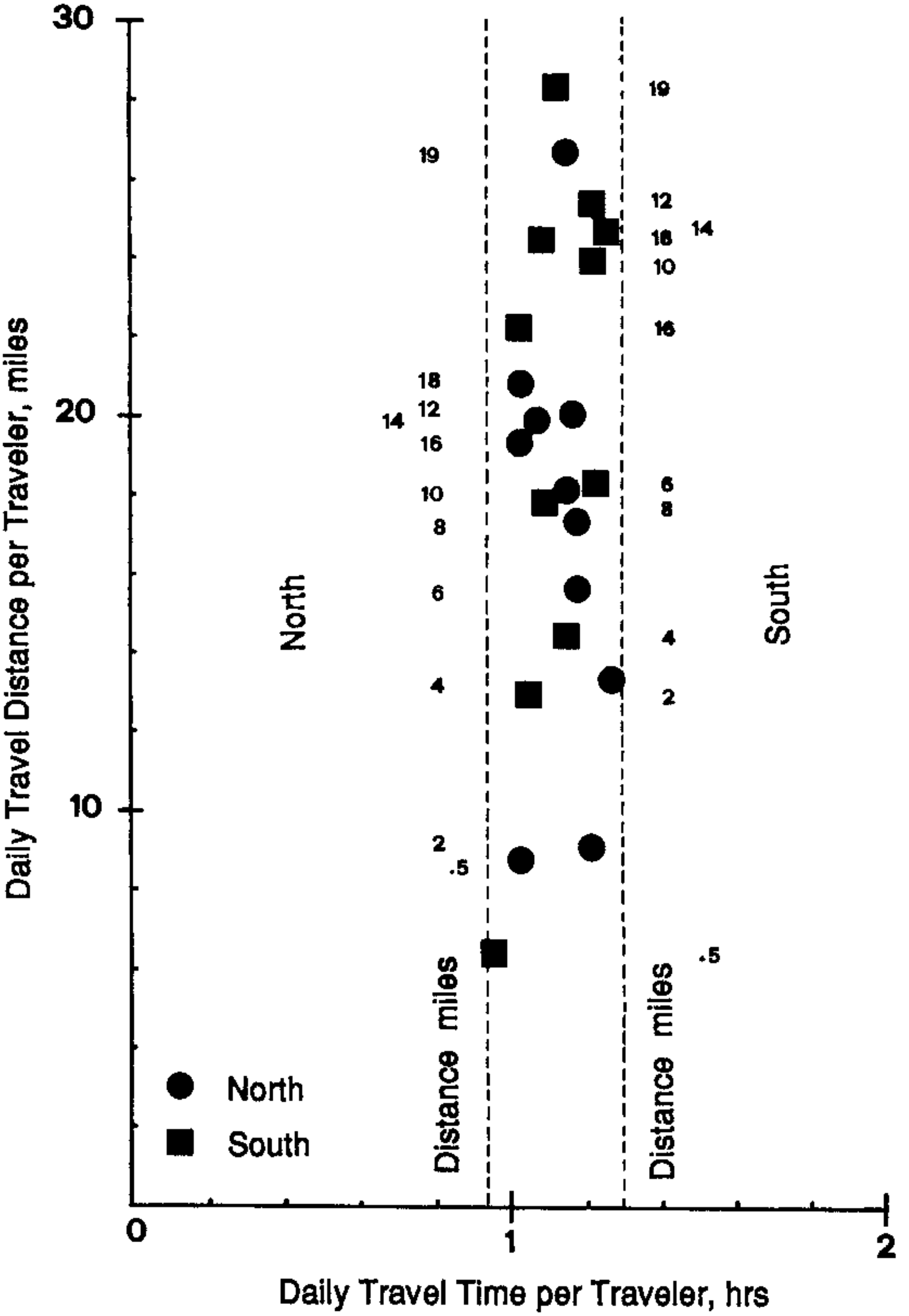
SOURCE: Zahavi, 1979.

The principles of TTB and TMB, with great conceptual parsimony, organize such complex decisions as 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 4.1). 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 4.2.

An important detail is the way people divide their total daily travel distance into *daily trips.* Figure 4.3, 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.

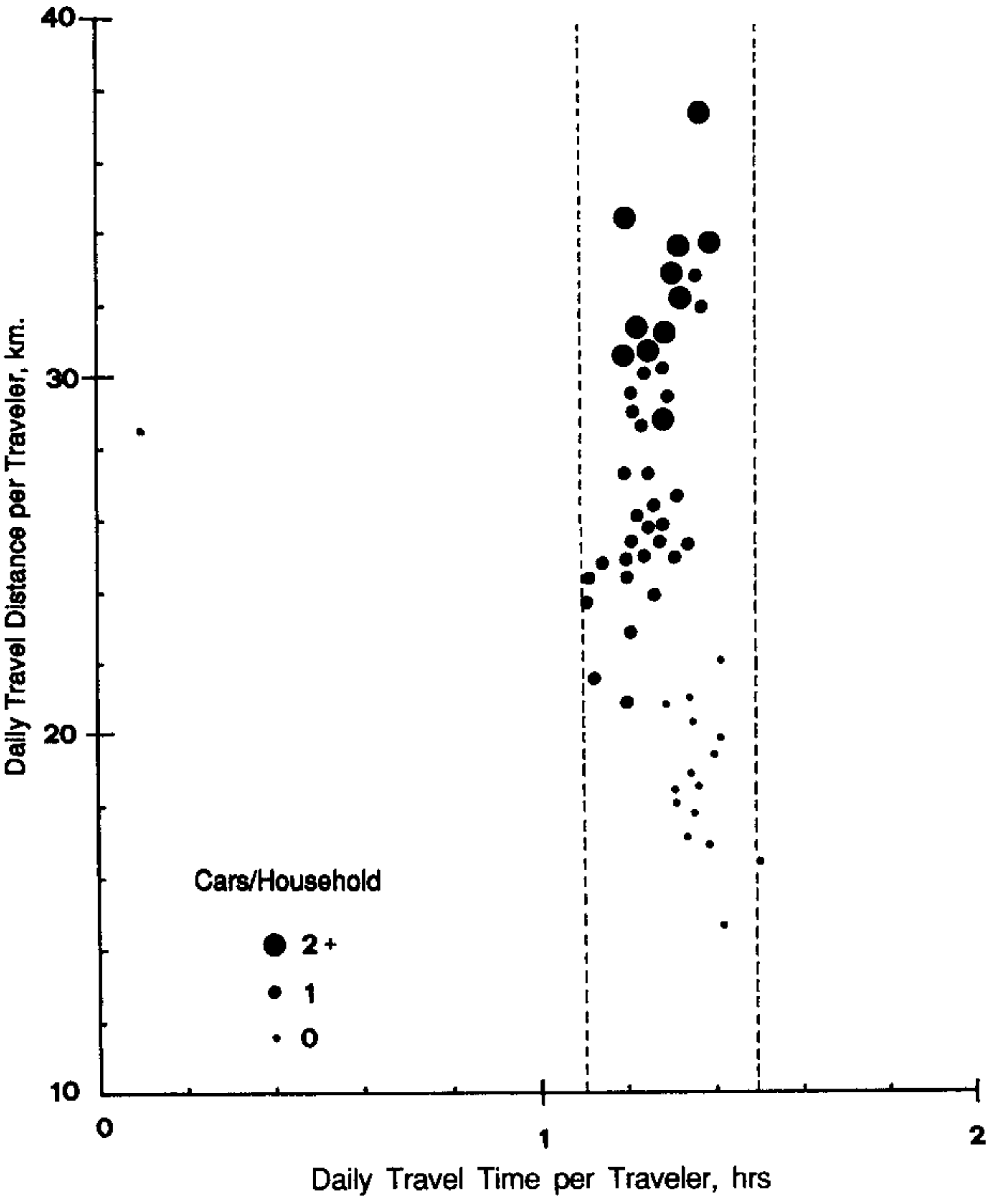
Clearly, when people gain speed they use it to travel farther and not to make more trips. In other words, most individuals treat their territory the same way, regardless of its size. The important parameter in the environment that changes the number of trips is the size of the city. A small city (10^5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

FIGURE 4.1. *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.

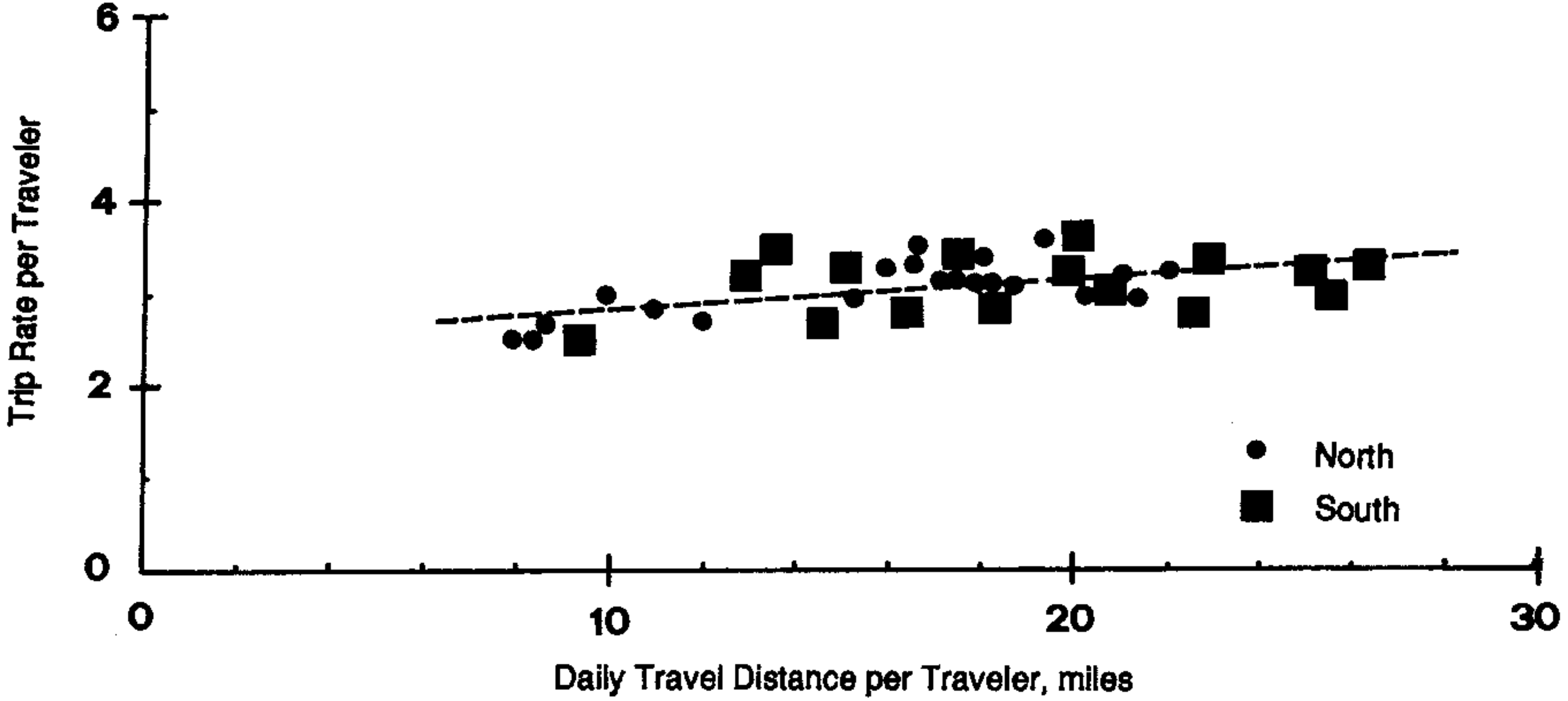
FIGURE 4.2. *Daily travel distance versus daily travel time per traveler, by household car availability, Nuremberg Region, 1975*



SOURCE: Zahavi, 1981.

Table 4.3 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

FIGURE 4.3. *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 4.3. *The use of time in 12 countries* (in hours)

Country/city	Time per Person Spent on Activity								Grand Total
						Travel			
	Work	House-Work	Household Child & Personal Care	Sleep	Total Leisure	Work	Non-work	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	24.01
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., Hoyersweda	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
Perù, 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: Zahavi, 1979.

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.

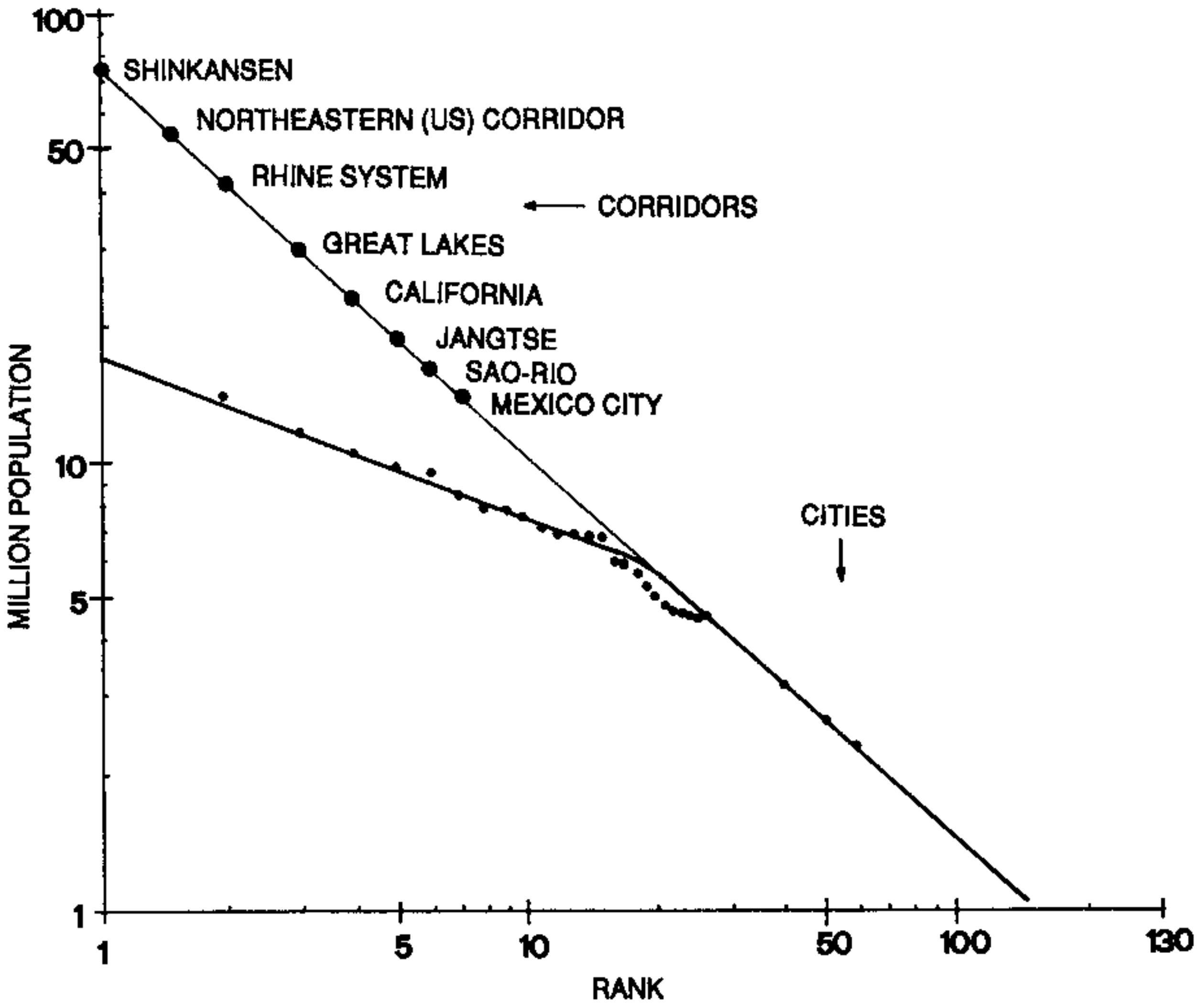
This definition of a city easily accommodates such breakthroughs in transportation technology as that afforded by the airplane. Because available income is increasing, and consequently TMB, and also because cost in real terms of air transport is decreasing, ever-larger strata of users can allocate some 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 into 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 4.4). 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 4.5).

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

FIGURE 4.4. *Rank size distribution of world cities and corridors*

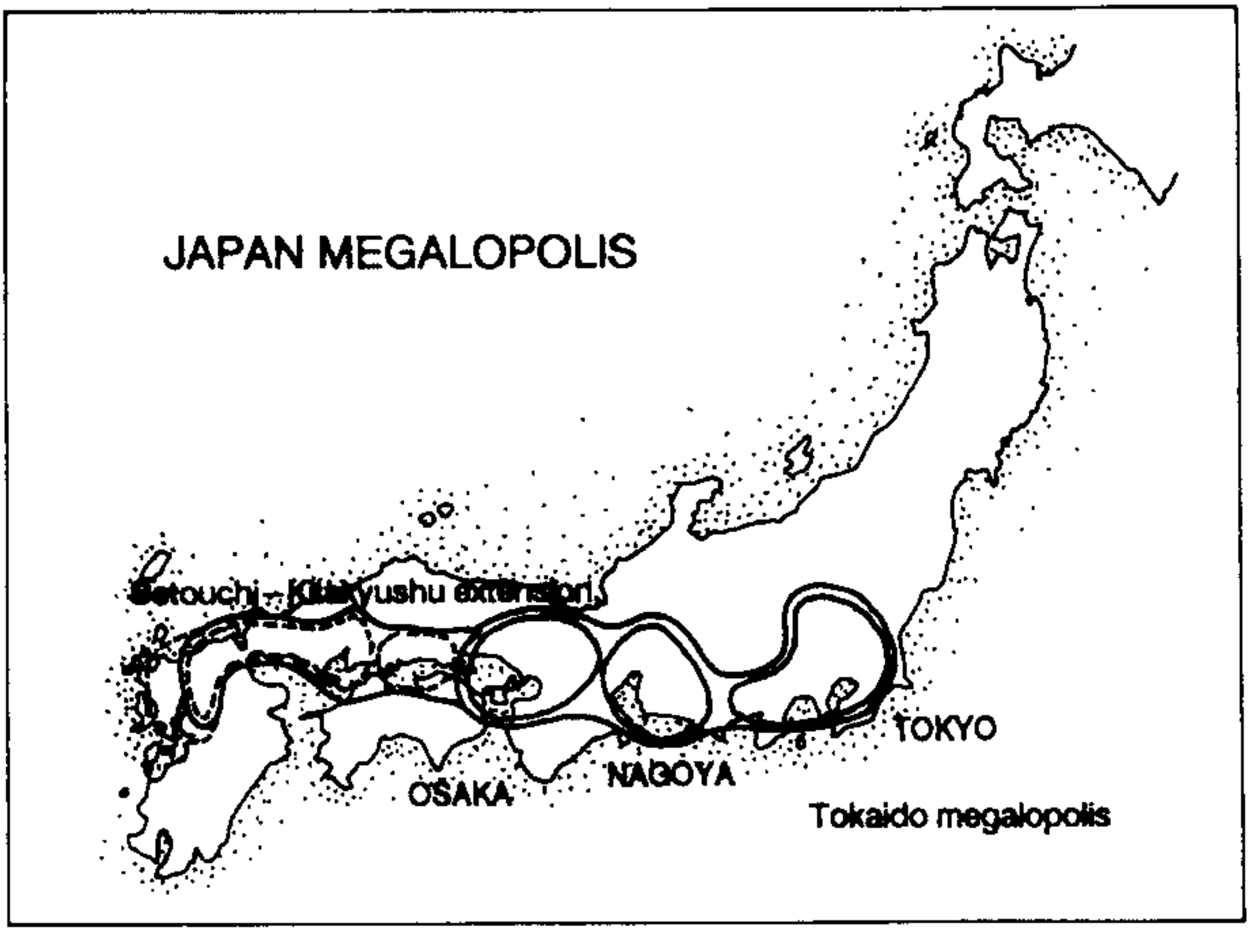


between Milan and Rome cannot compare to the number of passengers transported daily in Milan's Metro. But money is not the sole constraint, as we have seen.

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

FIGURE 4.5. *The coagulation of a corridor into a megalopolis*



SOURCE: Doxiadis and Papaioannou, 1974.

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 for 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.

4.2.1. 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 4.6) and passenger use (figure 4.7). 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 pattern 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 4.8. Unfortunately, data on air pass-km were not available, which in a sense robs the analysis of its look into the future.

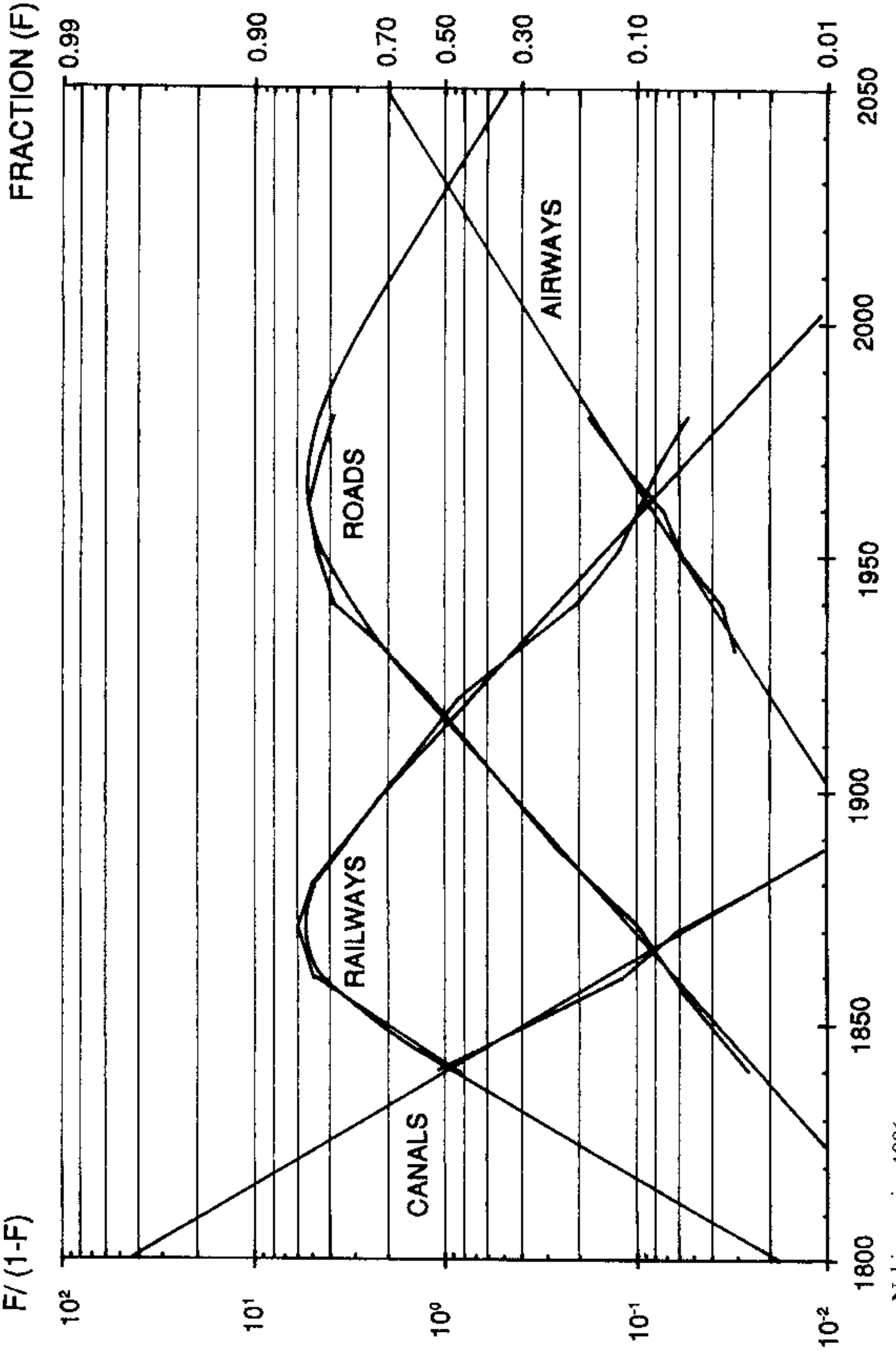
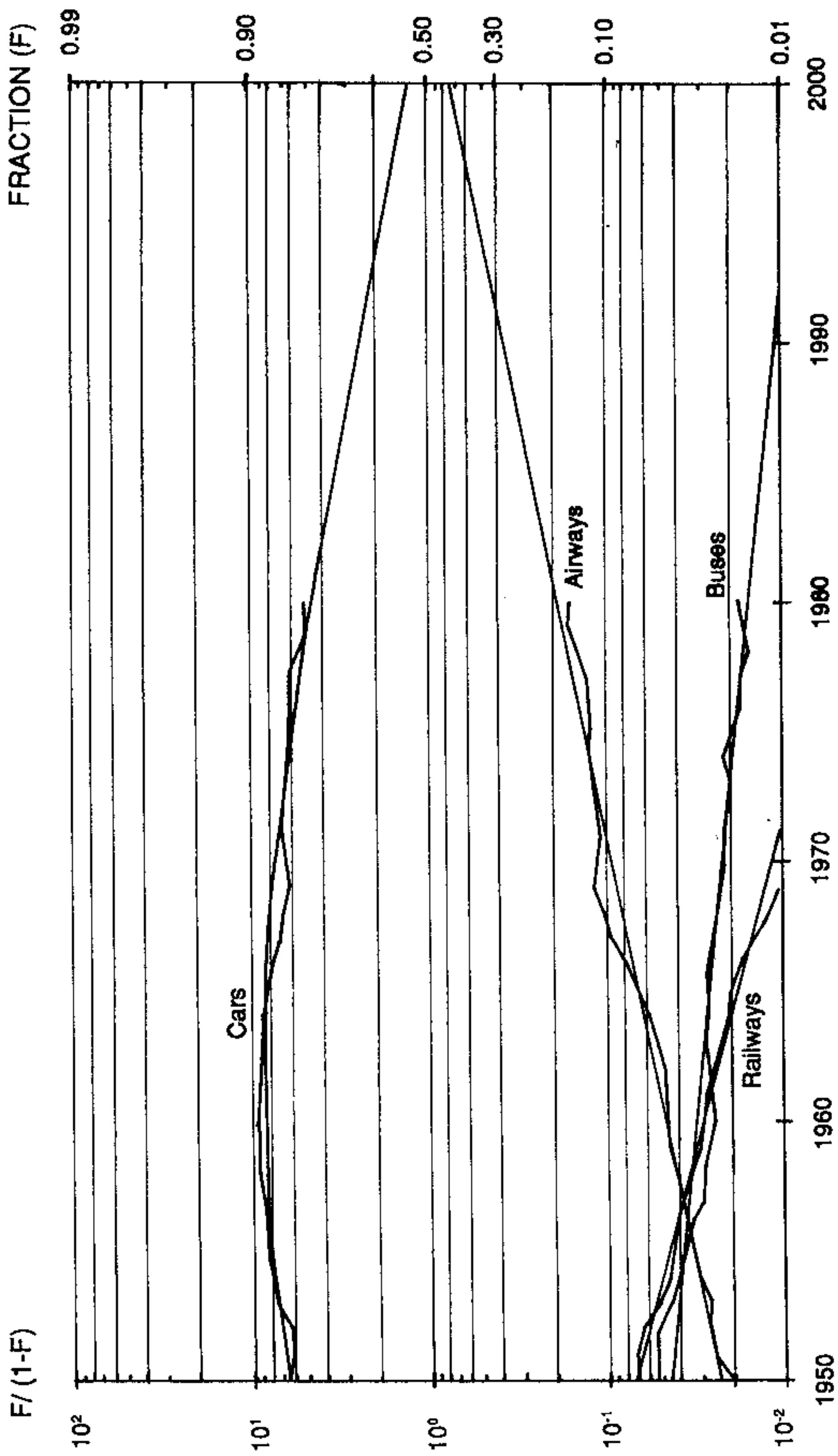


FIGURE 4.6. *USA – transport infrastructure substitution, 1800–2050*

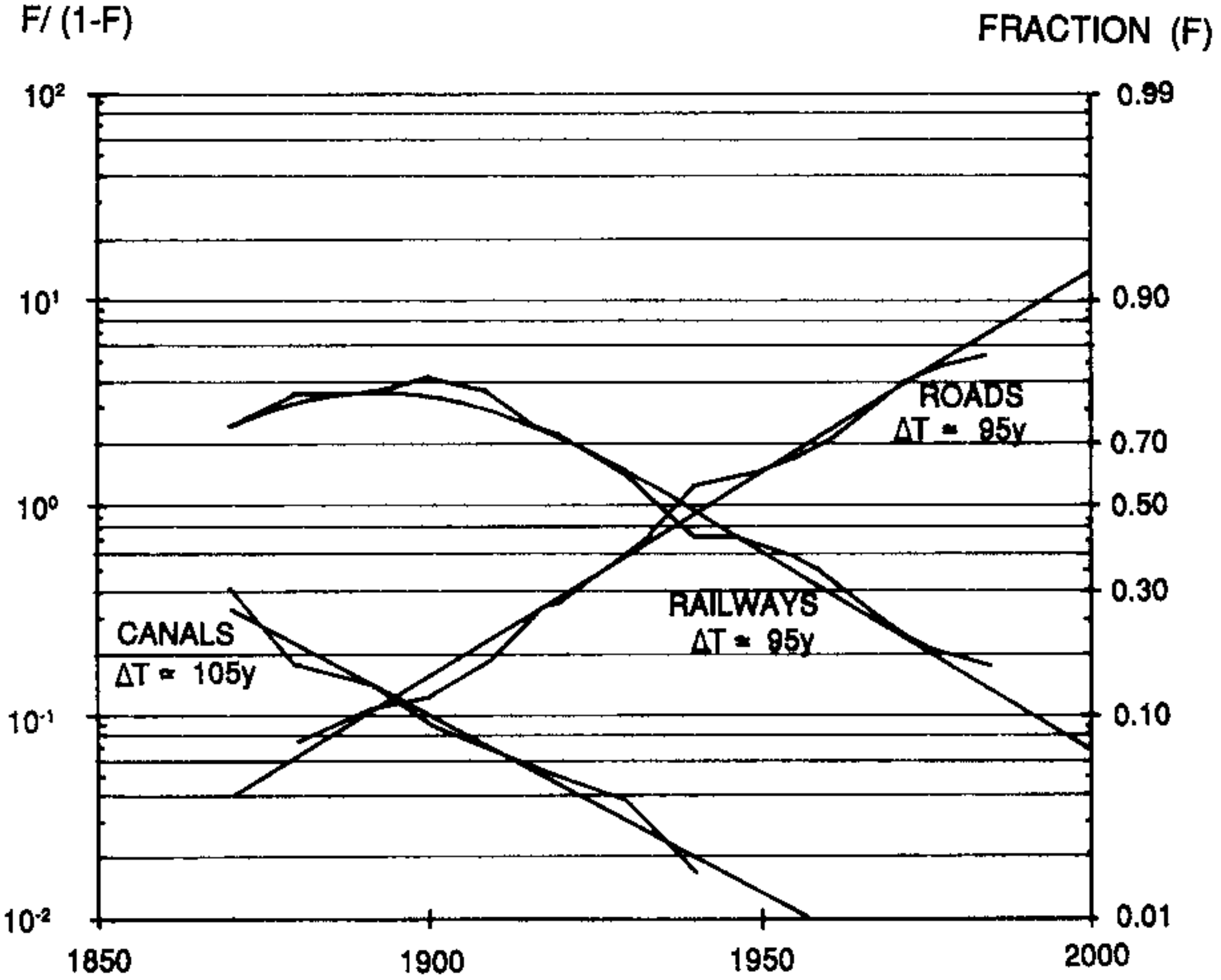
SOURCE: Nakicenovic, 1986.

FIGURE 4.7. *USA – intercity passenger traffic substitution (in passenger-km)*



SOURCE: Nakicenovic, 1987.

FIGURE 4.8. *USSR – transport infrastructure substitution*



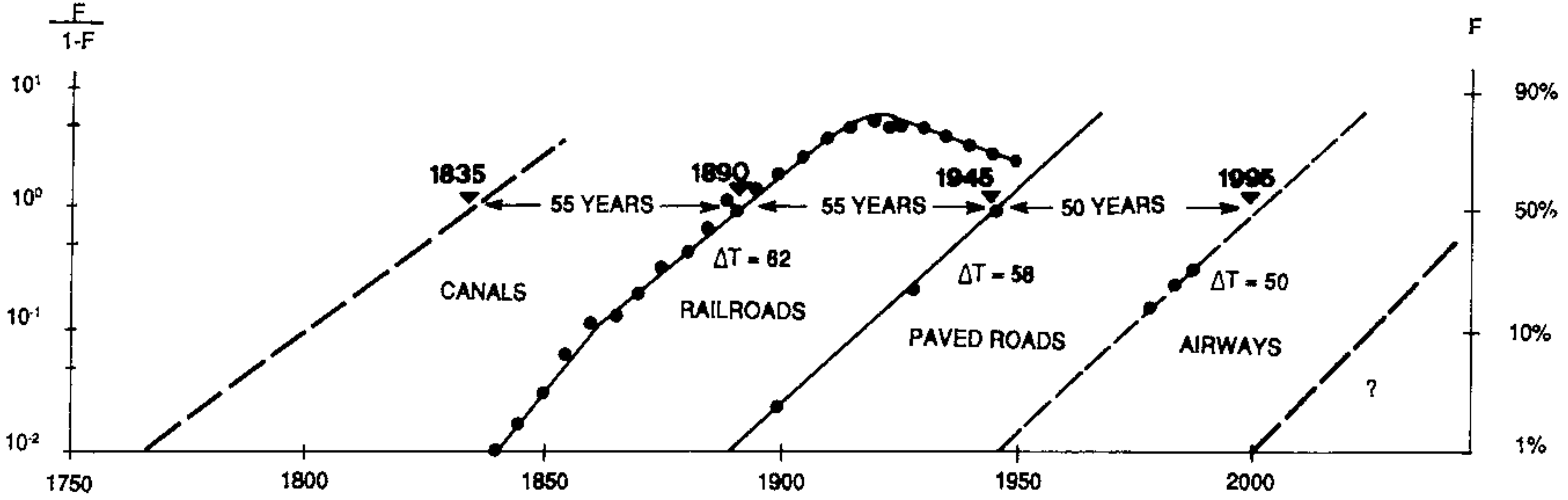
SOURCE: Grübler, 1987.

The analysis of figures 4.6 and 4.8 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 systems' infrastructures. 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 4.9 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

FIGURE 4.9. *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.

introduction of primary energy sources. From the records, one could have predicted the peak of oil consumption 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., to operate on 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.

Part II: Case Histories

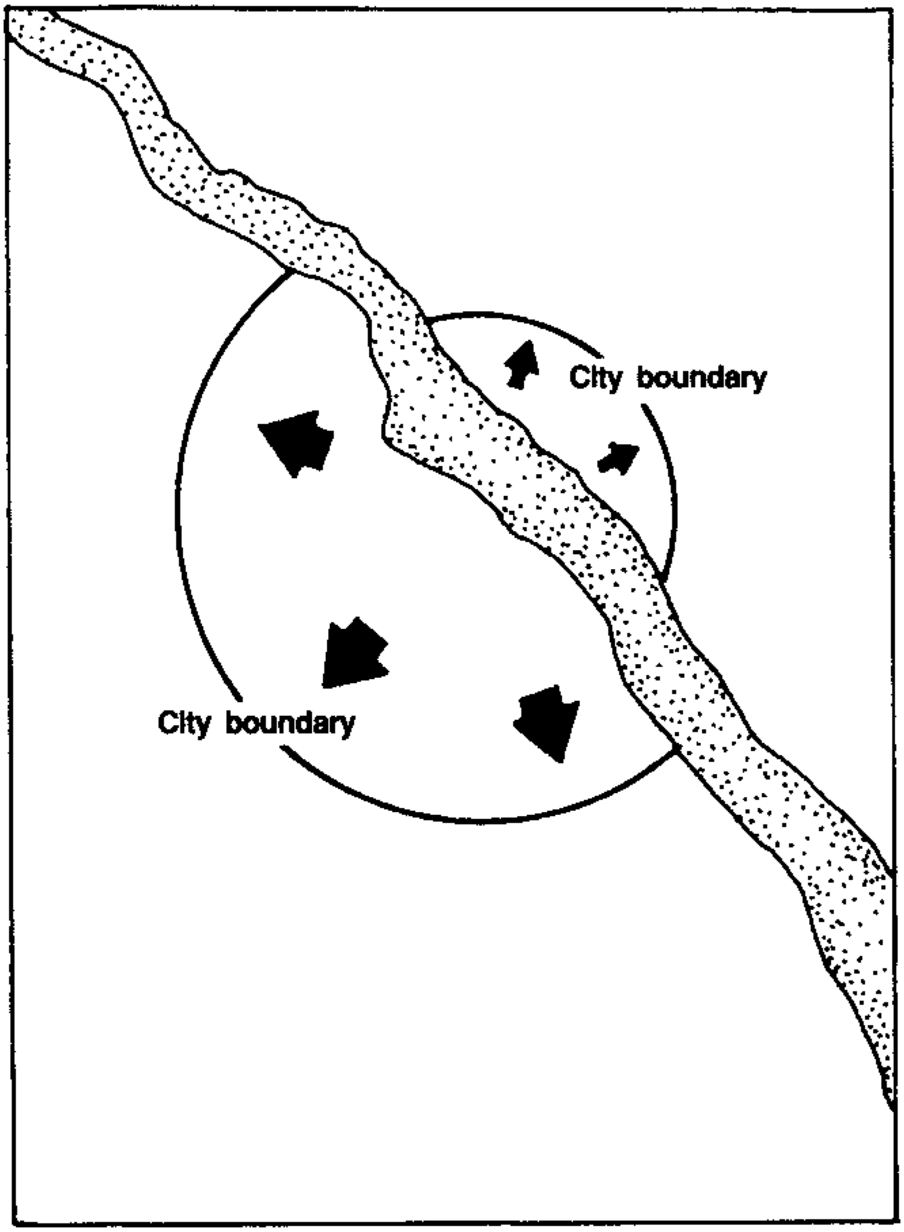
4.3. *Overcoming Natural Barriers*

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 in 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 4.10. The city on the left side of the river, where the original settlement was located, sy-

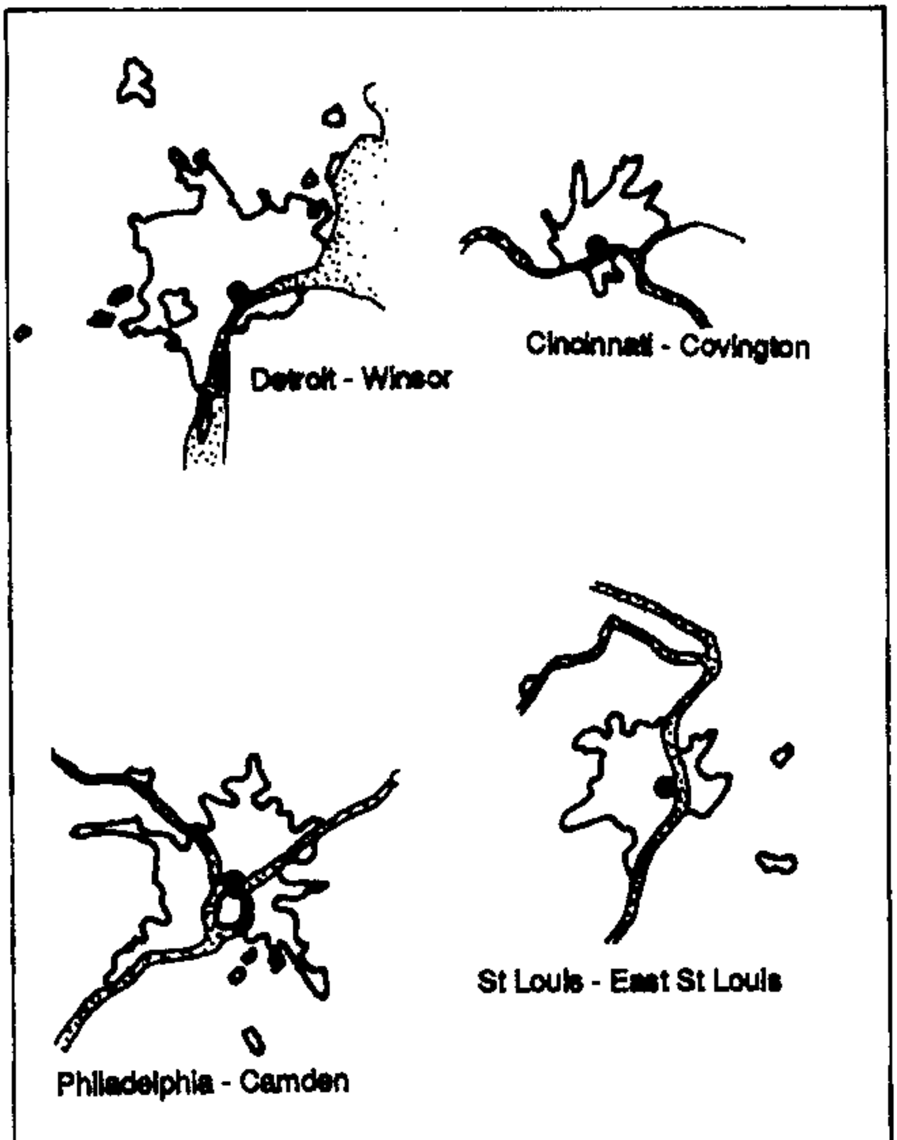
FIGURE 4.10. *Effect of a permeable river barrier on the diffusion of a city*



SOURCE: Abler et al., 1972.

stematically 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 4.11). 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 4.12 at four different dates, between 1884 and 1948, with arrows indicating the actual thrust of growth.

FIGURE 4.11. *Barrier effects of rivers on four pairs of North American cities*

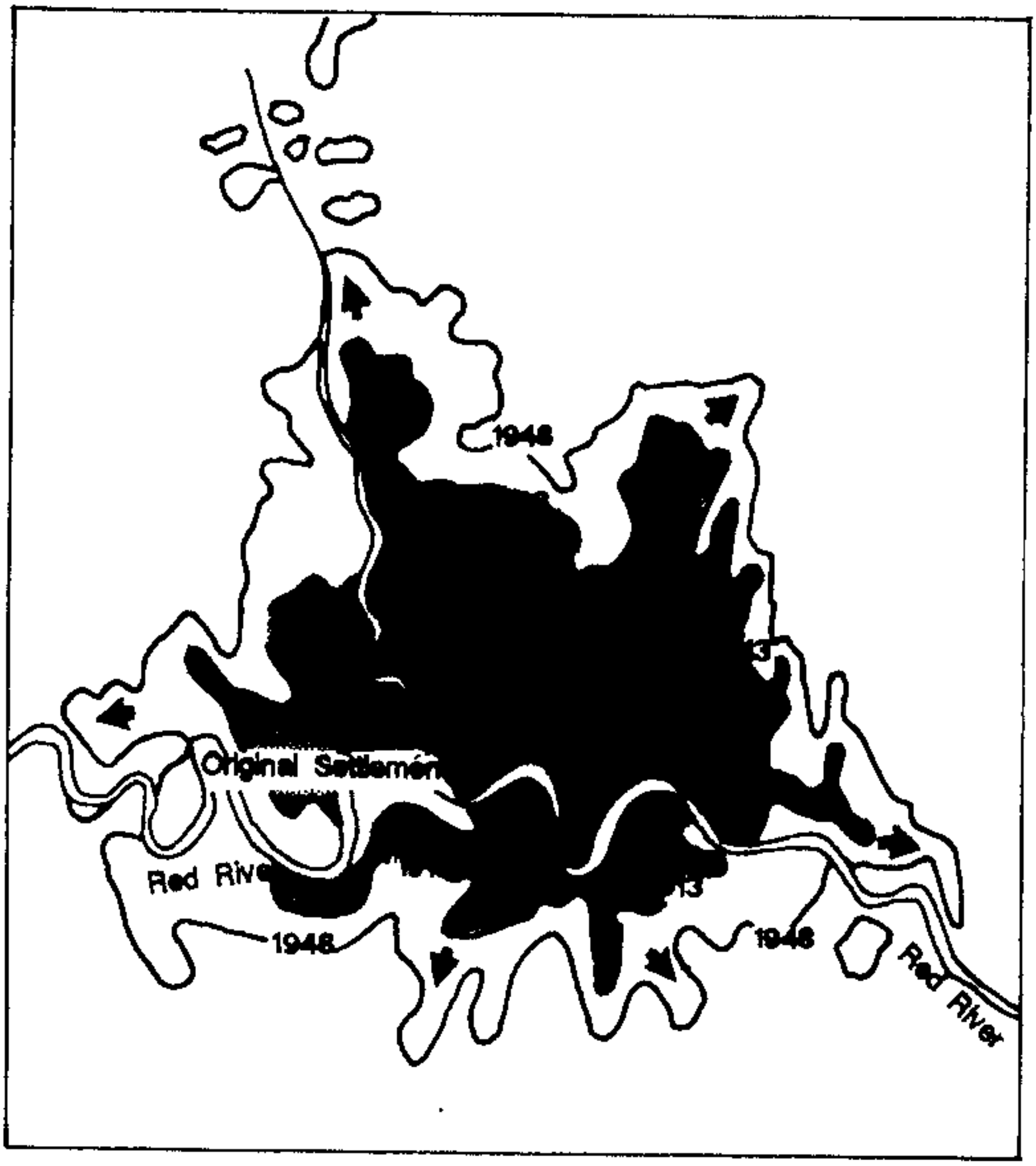


SOURCE: Abler et al., 1972.

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 4.13, where the width of the bars represents density of telephone conversations from Gossipville to its environs and other cities, based on a gravitational model in a homogeneous system and divided by an appropriate factor linked to the permeability of the barrier.

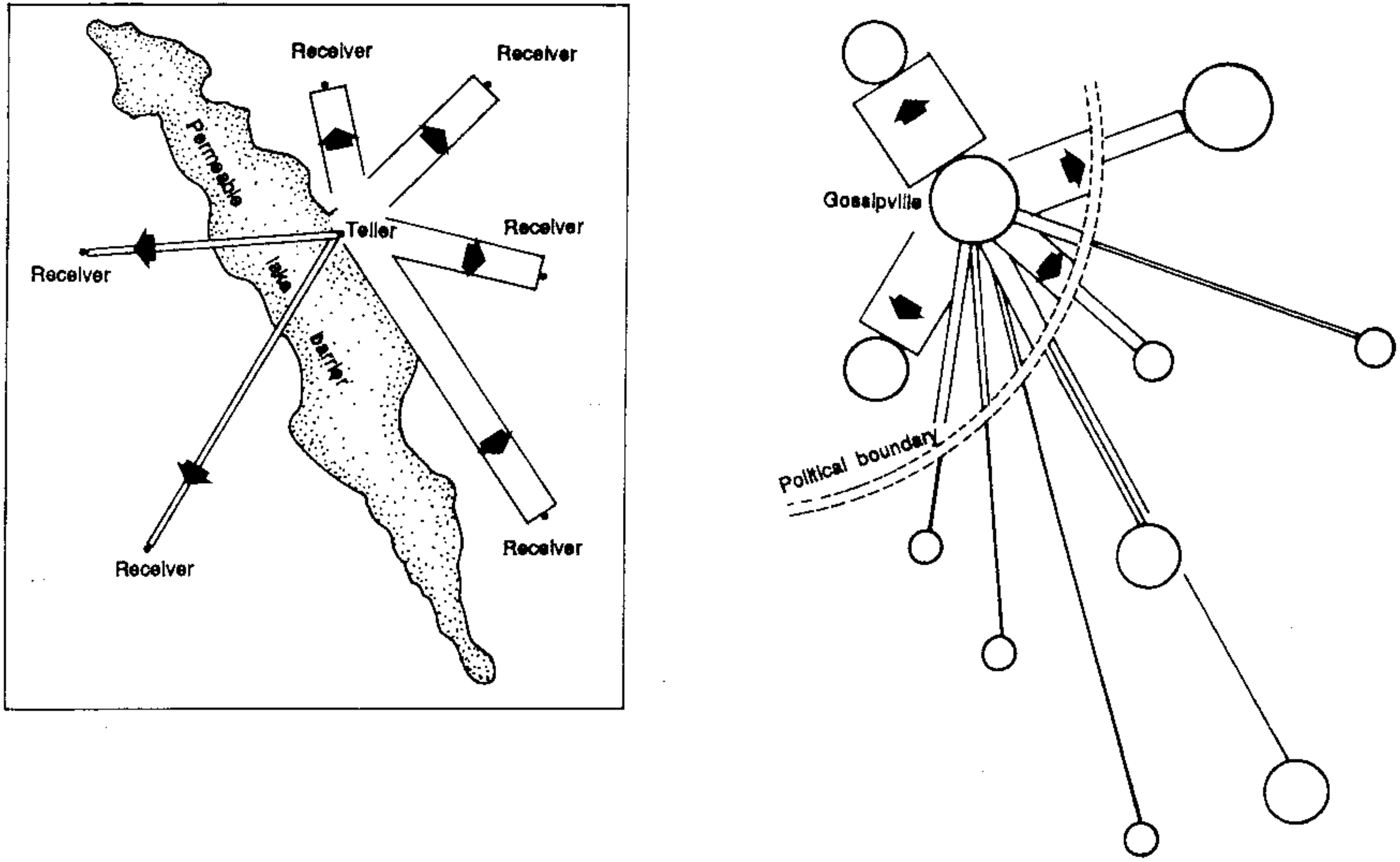
FIGURE 4.12. *Diffusion on Winnipeg from site of original settlement on the Red River, 1884-1948*



SOURCE: Abler at al., 1972.

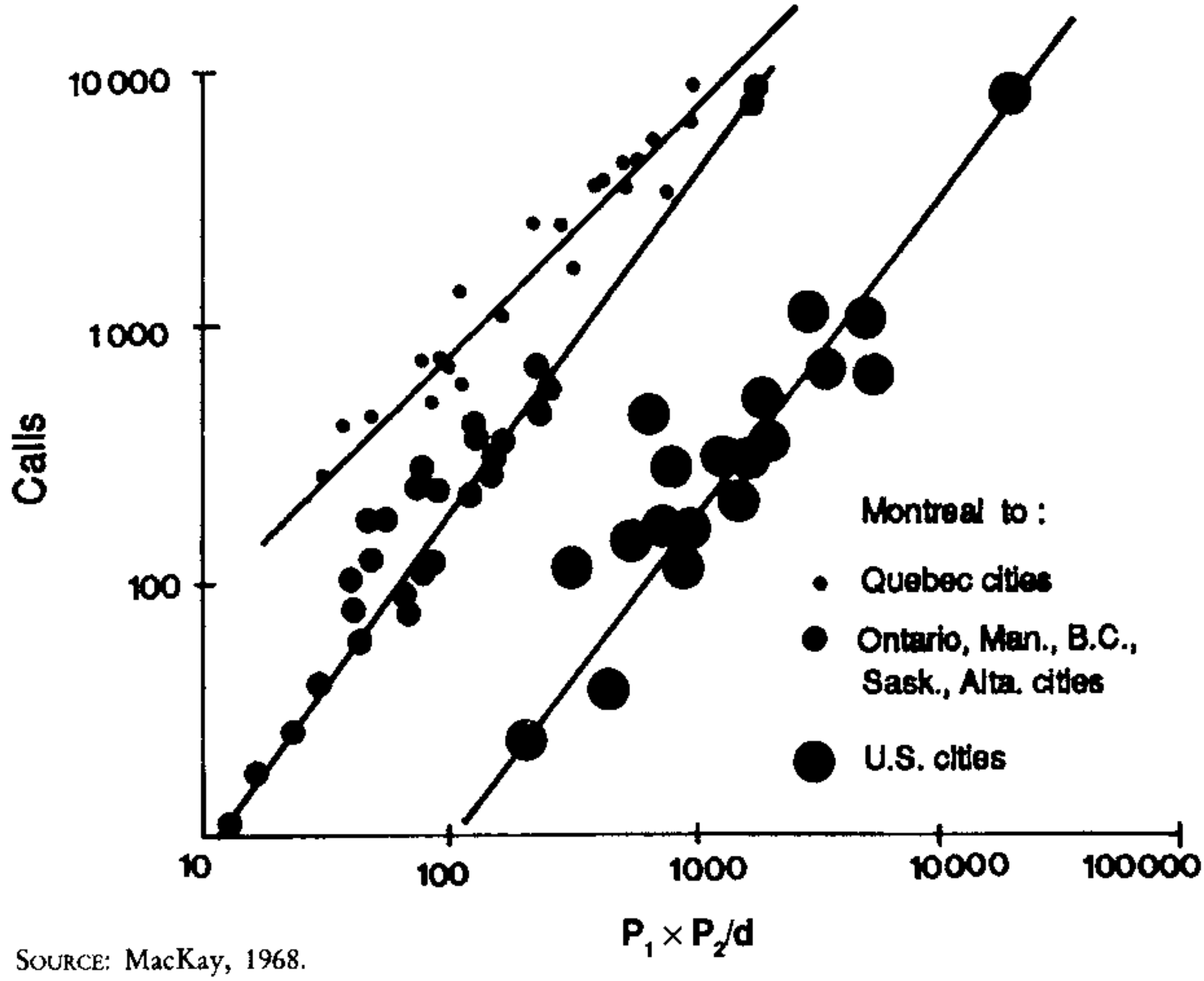
When a lake is the barrier, the communication effect is sketched in figure 4.14 to visualize the process. The barrier can also be linguistic and cultural, as for the French-English boundary in Canada, or political as for Canada-USA. The last cases were studied by Ross Mackay (1968), using the gravity model for calibration and are illustrated in figure 4.15 These figures show amazing results. Telephone 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

FIGURE 4.13. *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 to people's movement is introduced*



SOURCE: Abler et al., 1972.

FIGURE 4.14. *Gravitational plot of telephone calls between cities in French speaking Canada, English speaking Canada and the US [calls÷pop(1)x pop(2)/distance]*



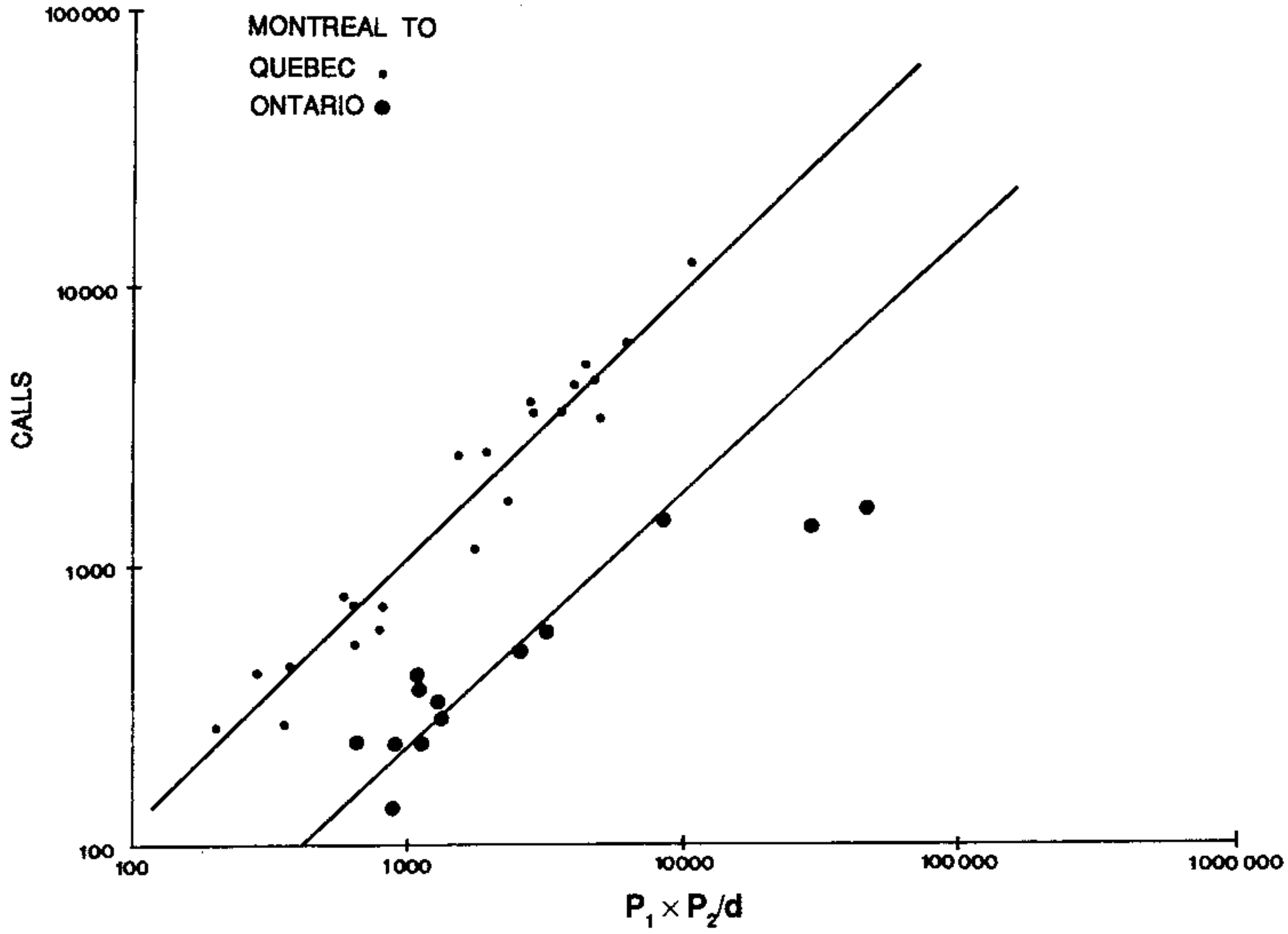
SOURCE: MacKay, 1968.

between Montreal and French-speaking cities were more frequent than for Montreal and 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 4.16 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.

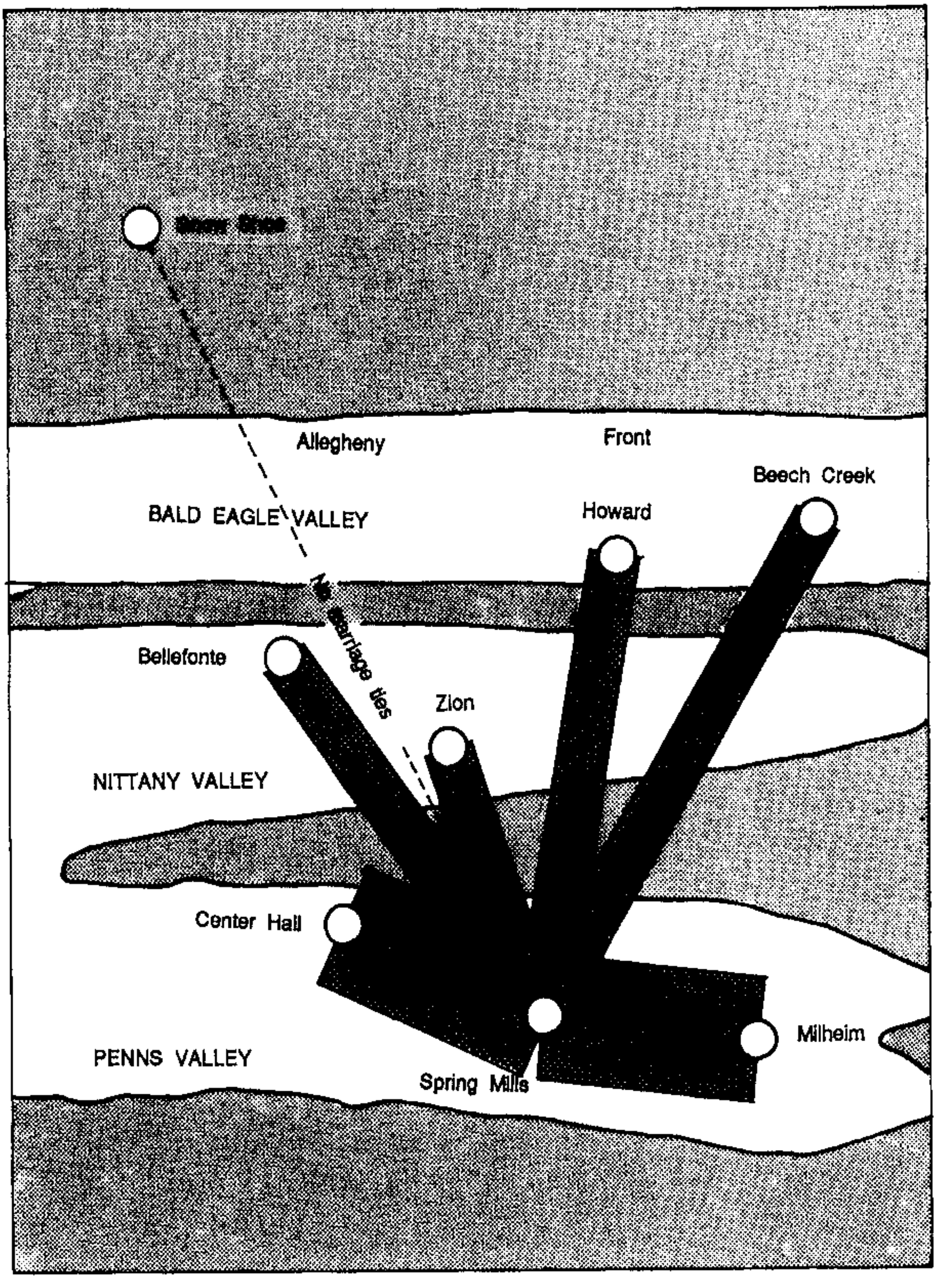
The same pattern occurs in the microenvironment of a city, noted by Zipf (1972) (figure 4.17), who counted residential blocks between the prior home addresses of newlyweds. The relation is perfectly gravitational. (In two dimensions gravity forces appear as 1/distance and not as the inverse squares as in three dimensions).

FIGURE 4.15. *Quasi gravitational plot of telephone calls from Montreal to Quebec cities (upper line) and Ontario cities (lower line)*



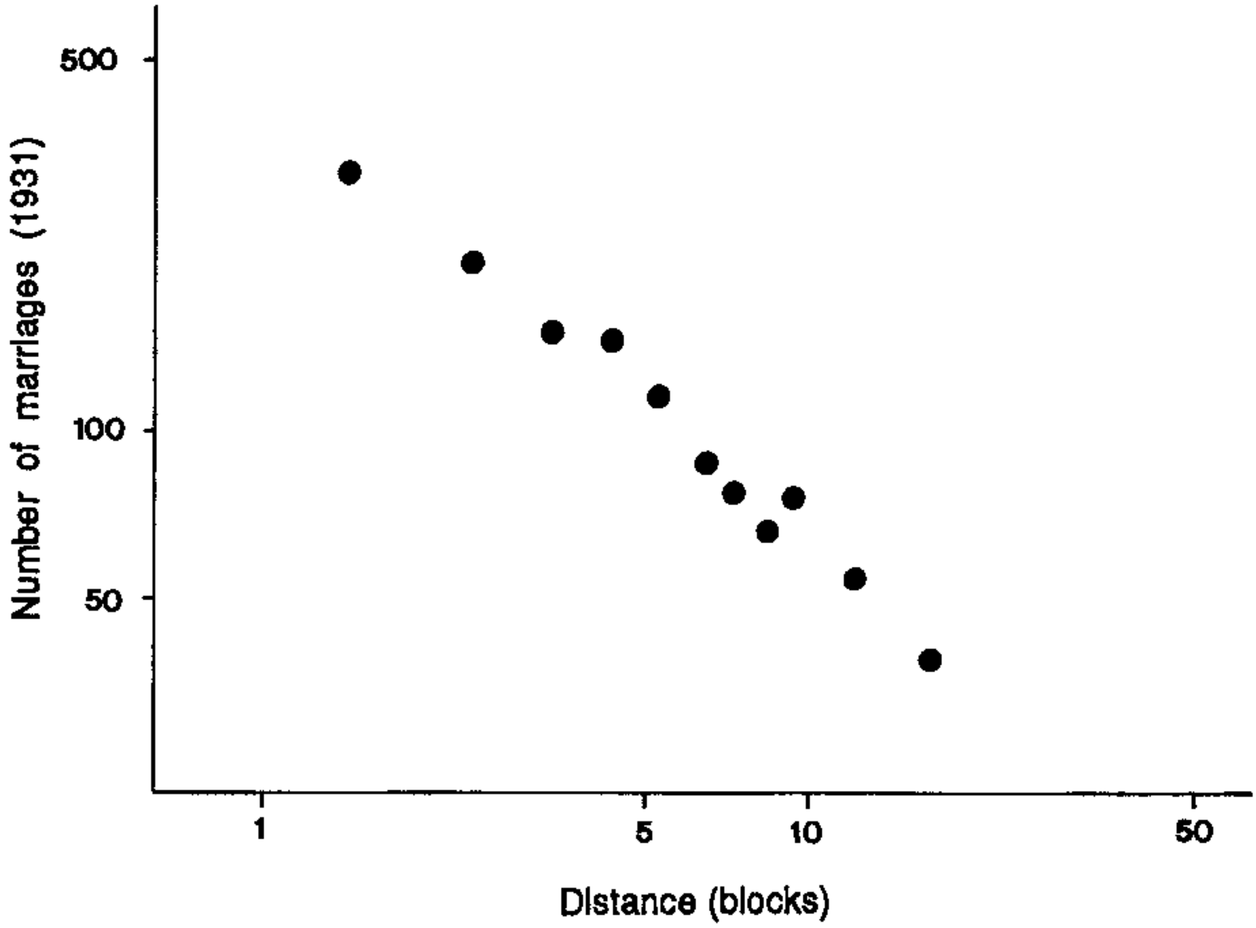
SOURCE: MacKay, 1968.

FIGURE 4.16. *Marriage ties between Spring Mills, Pennsylvania, and neighboring communities: valleys are white; mountain areas are shaded*



SOURCE: Abler et al., 1972.

FIGURE 4.17. *Number of marriages in a city as a function of distance between the partners' prior residences*



SOURCE: Zipf, 1972.

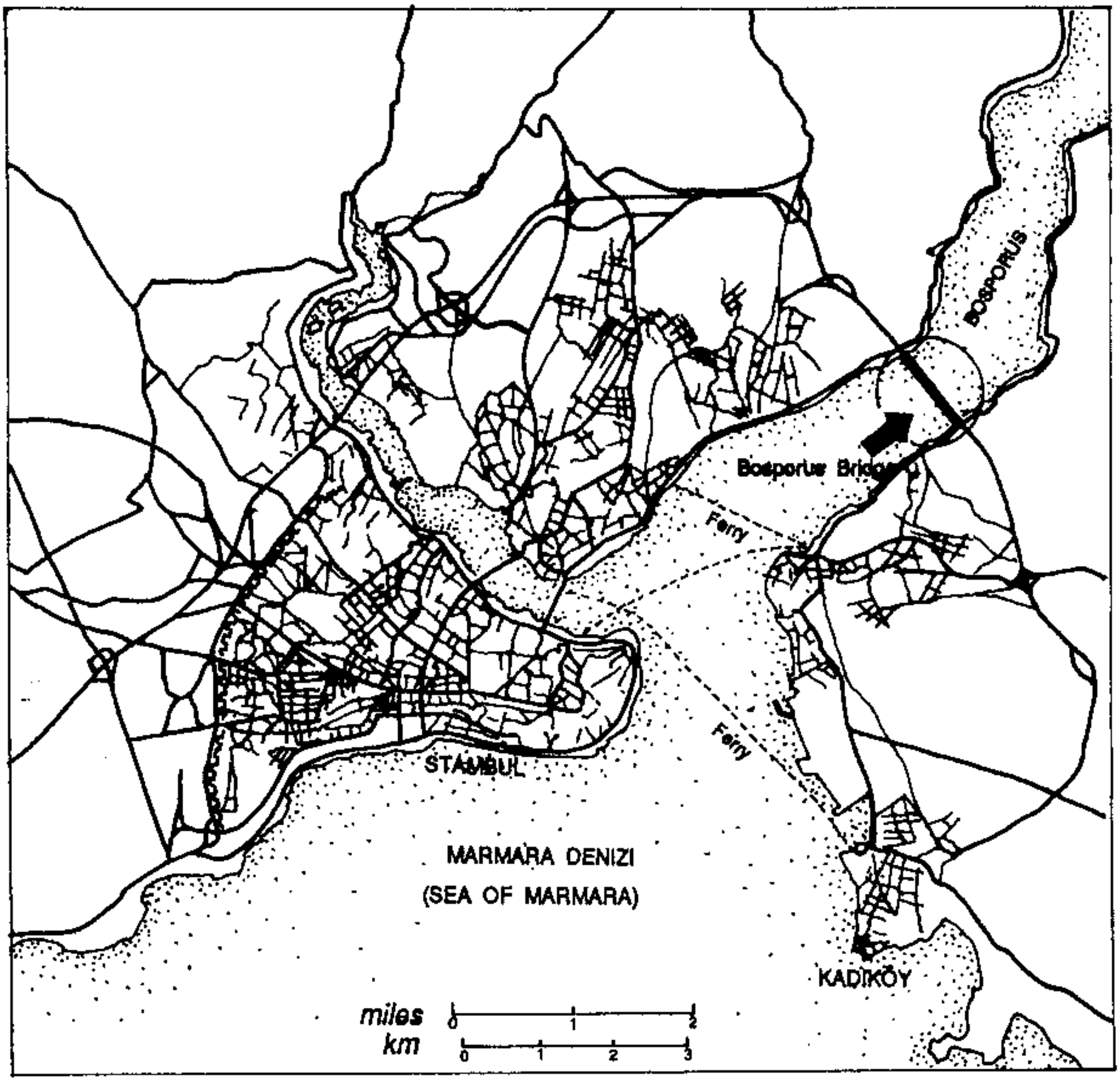
These examples emphasize the importance of objective forces (such as physical geography) in shaping human behavior – an important reason for choosing objective models to help map and forecast traffic flows.

4.3.1. 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 4.18). 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

FIGURE 4.18. *Location of the Bosphorus bridge (1974) and ferry routes between European and Asian shores of Istanbul*

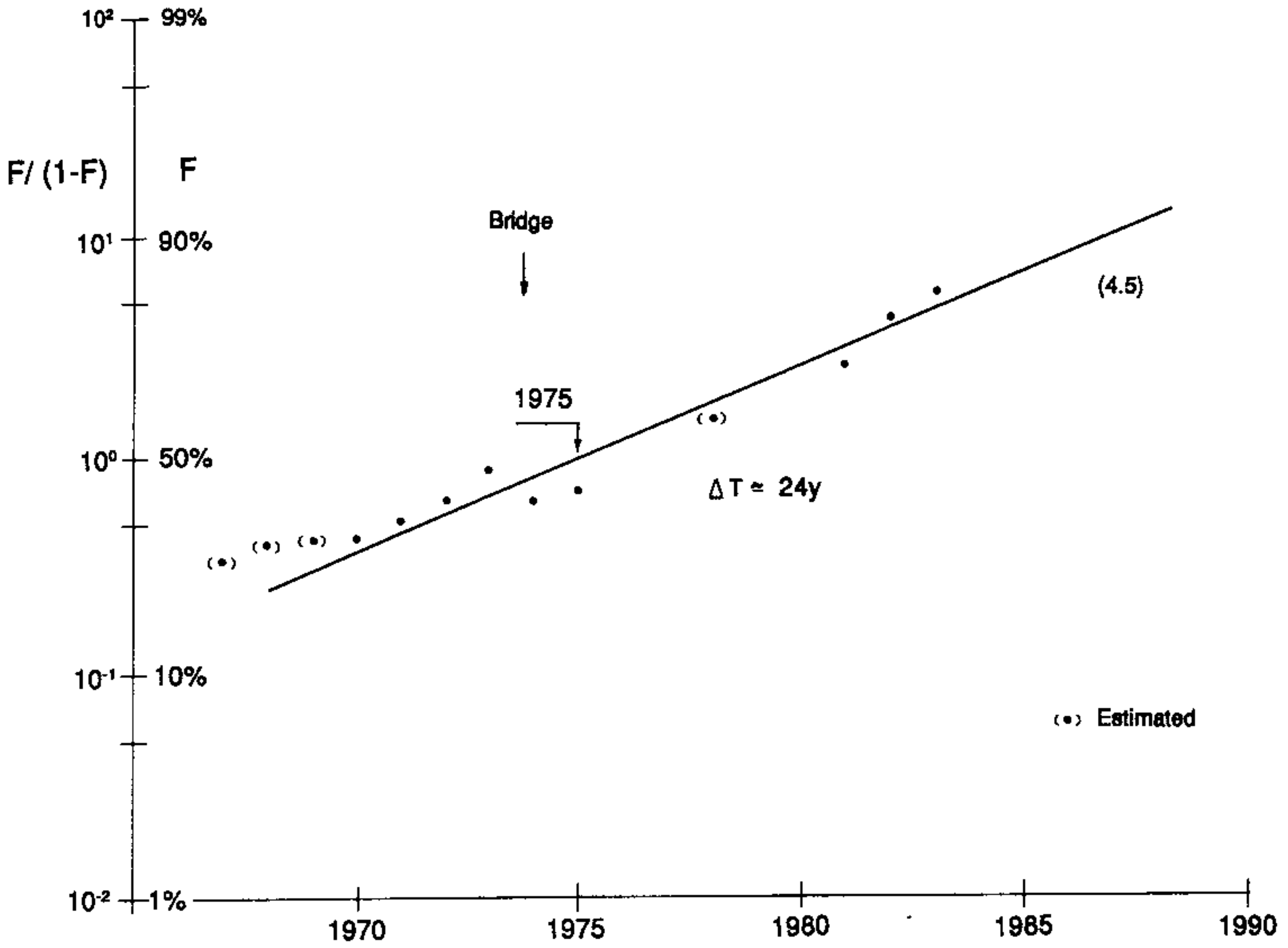


escaped the bridge planners and Freeman Fox-Botek Construction Engineers, who gathered traffic data before and after completion of the project:

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 (collective taxi), to

FIGURE 4.19. *Trend in total trucks (10^6) crossing the Bosphorus, by ferry and bridge, 1966-1990*



Based on data from Freeman Fox-Botek, 1985.

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 4.19, where truck crossings over the Bosphorus by bridge *and ferry* are set out 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.

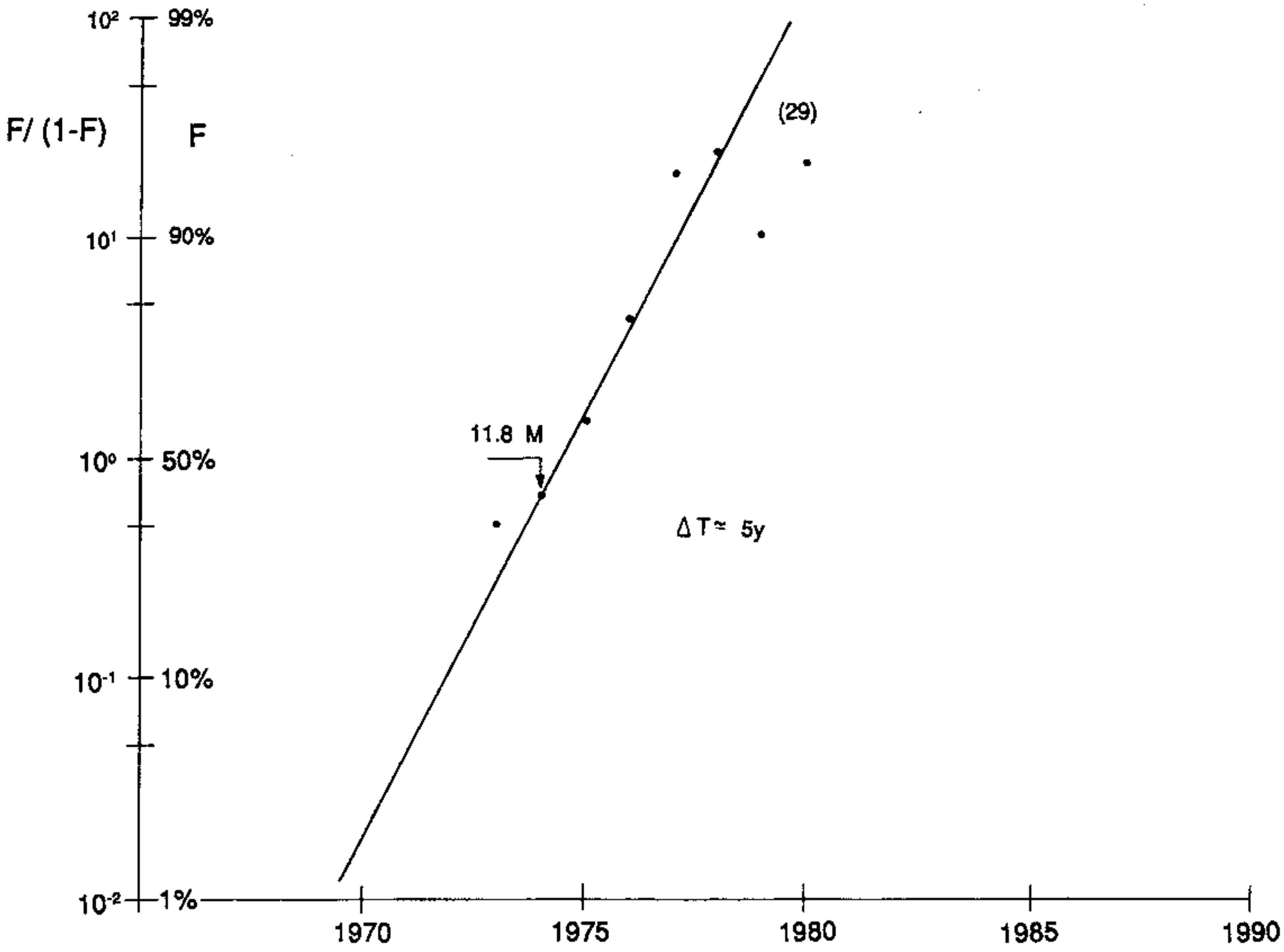
What comes out clearly from this analysis, imperfect in many ways, is that the opening of the bridge has not influenced truck traffic much during the last ten years. The increase can be completely attributed to normal economic development and evolution of the motorway interchange.

We can cross-check this finding by observing that a time constant of 24 years means 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 4.20). 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 4.21). The *rest was «created»*.

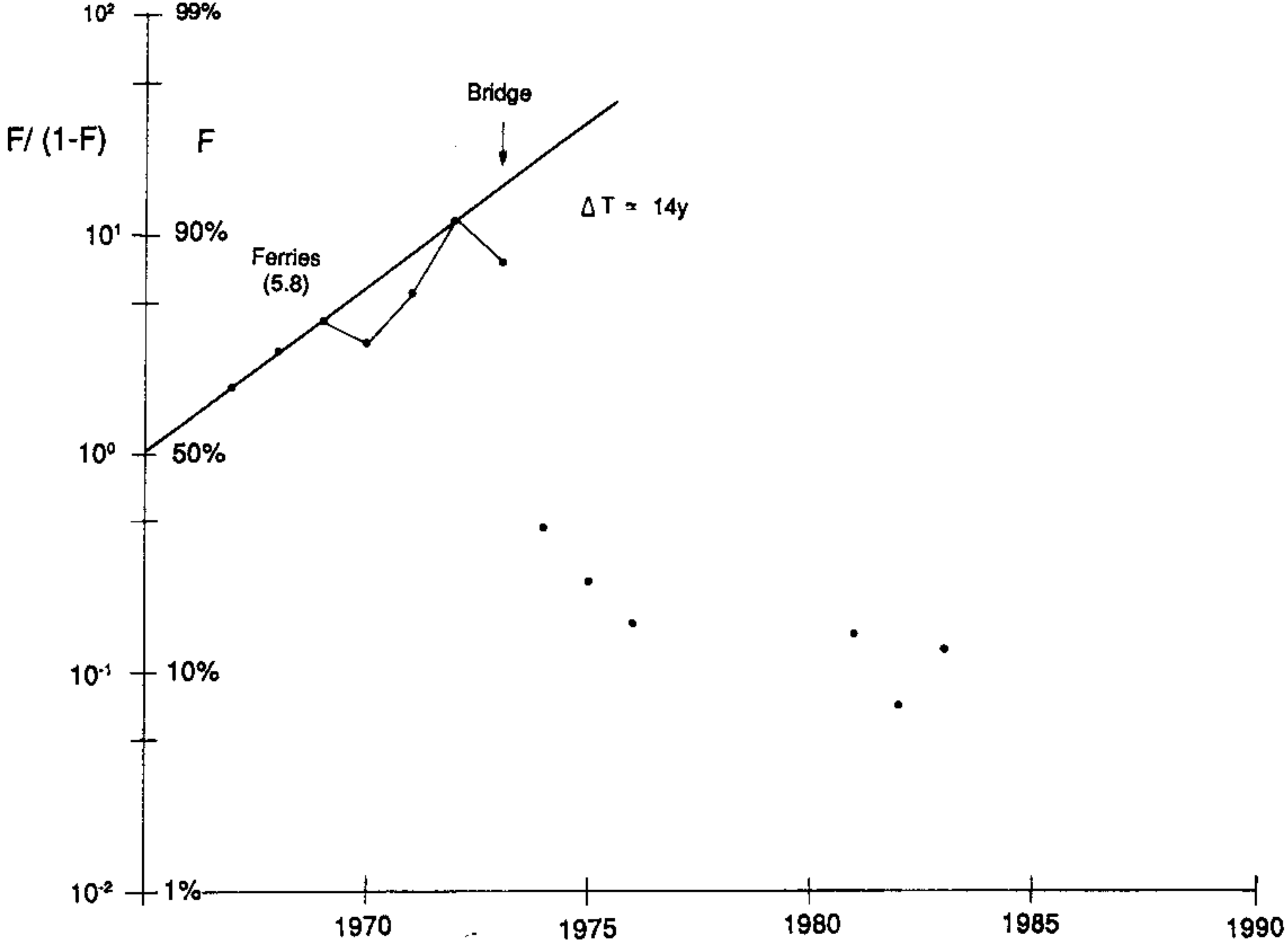
In 1974 the bridge carried 11.8 million vehicles of which only 3.75 million were taken from the ferries (projected minus actual traffic). The

FIGURE 4.20. *Trend in total vehicles (10^6) crossing the Bosphorus, 1969-1980*



Based on data from Freeman Fox-Botek, 1985.

FIGURE 4.21. *Trend in total vehicles (10^6) crossing the Bosphorus by ferry, 1965-1984*



Based on data from Freeman Fox-Botek, 1985.

traffic created was then 8.0 *million vehicular transits* 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 fallen 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.

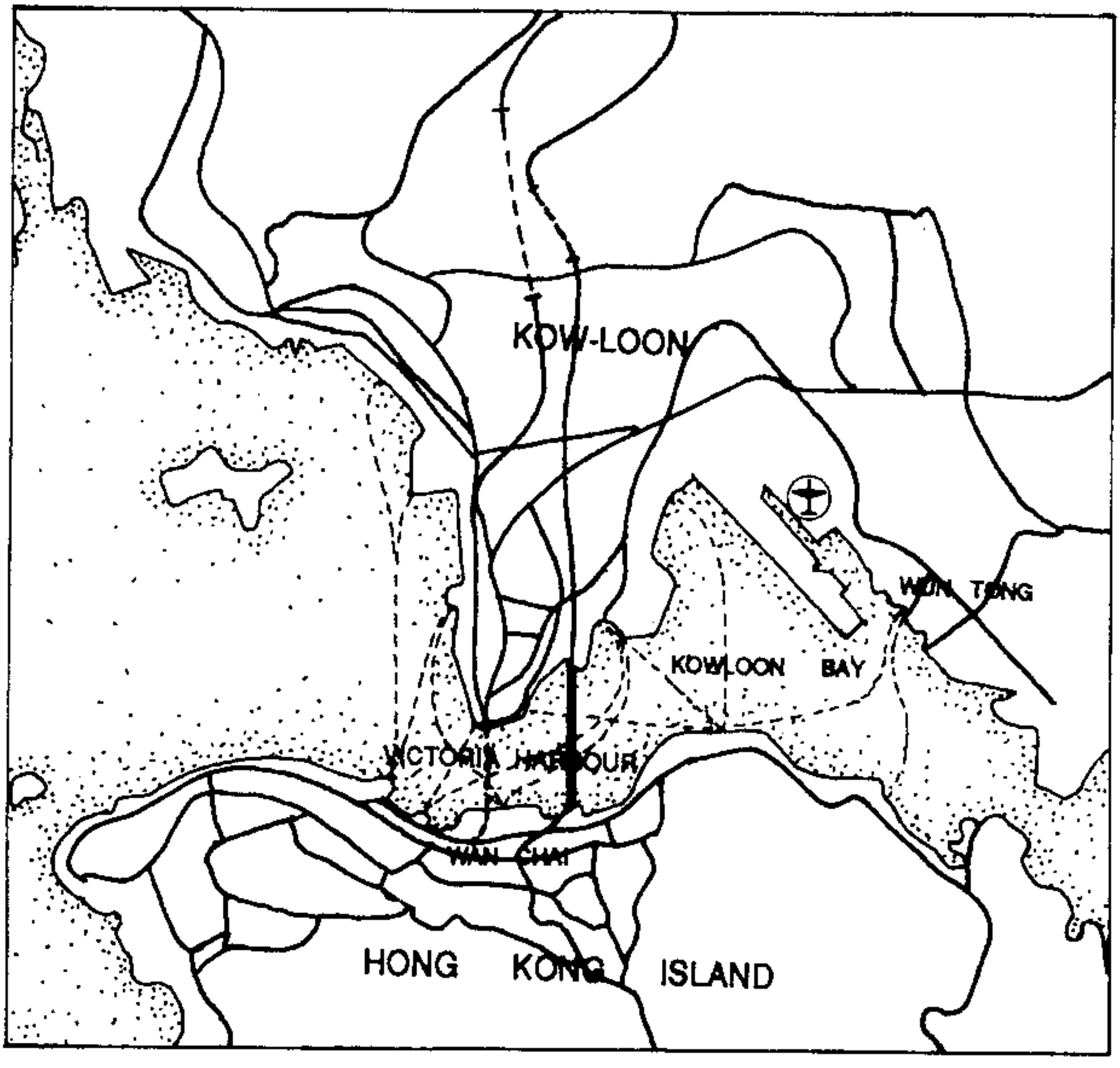
It would have been very interesting to analyze also passenger traffic, on vehicles and on foot, but data were not available. As in Hong Kong, where such analysis could be done, the next successful infrastructure would be a Metro line, providing fast transit between Istanbul city center and the area of 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.*

4.3.2. 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 4.22).

Until 1972, all traffic between Hong Kong Island and the mainland was by sea, through a network of very efficient ferries. A road tunnel

FIGURE 4.22. *The Hong Kong harbor channel which separates the Kowloon Peninsula (Kowloon) from Hong Kong Island (Victoria)*



Based on data provided by the Hong Kong Government Transport Department, 1987.

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 4.23 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 the pattern of 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 4.24 and 4.25), 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.

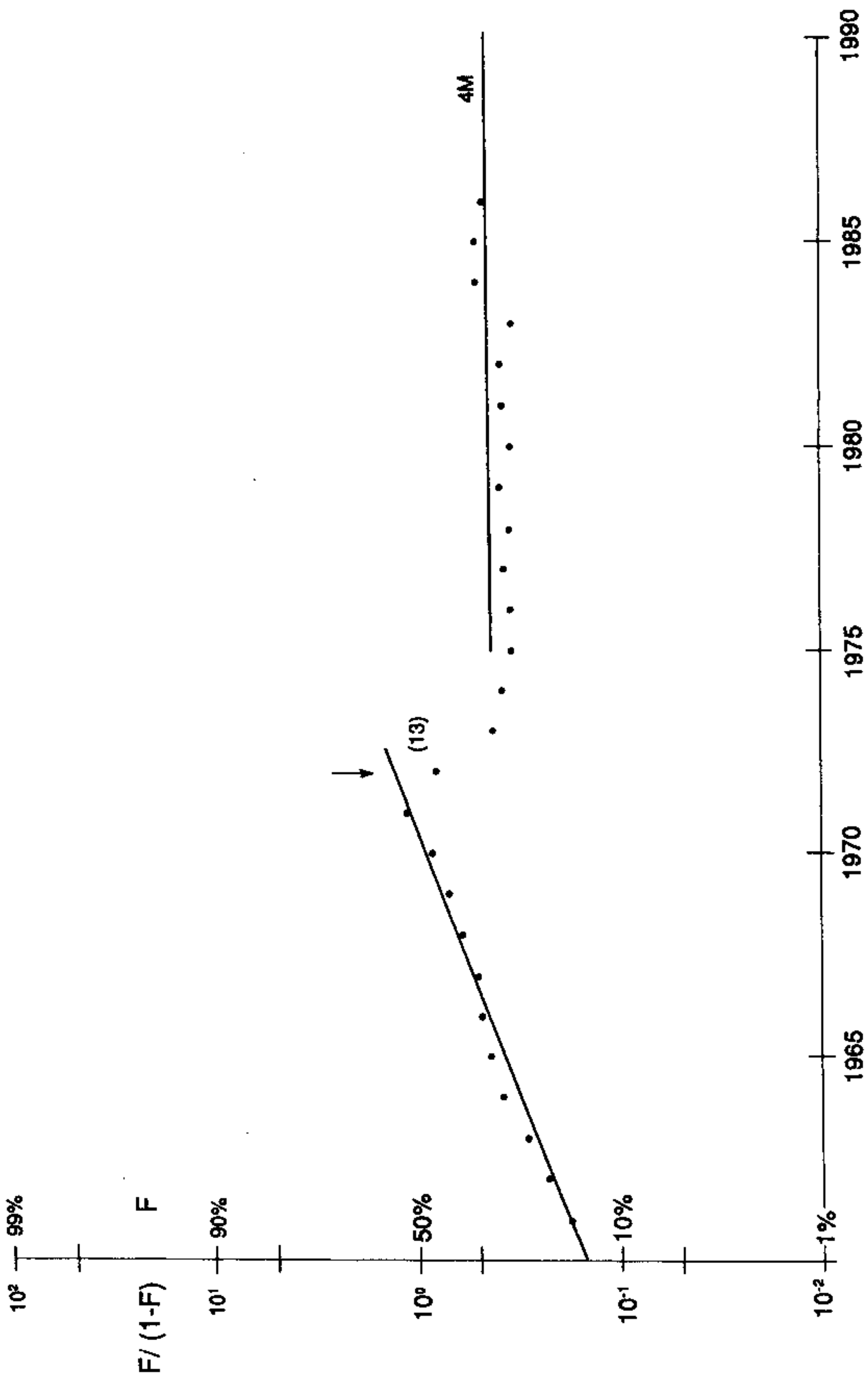
If we compare the saturation point of the evolution of vehicular traffic in ferries (13 million vehicles per year) and that of the tunnel (45 million vehicles per year), we can conclude that the *tunnel-created traffic totals 32 million vehicles per year*, and that peak tunnel traffic will be about 41 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 4.26), 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 4.26 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 (≈ 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.

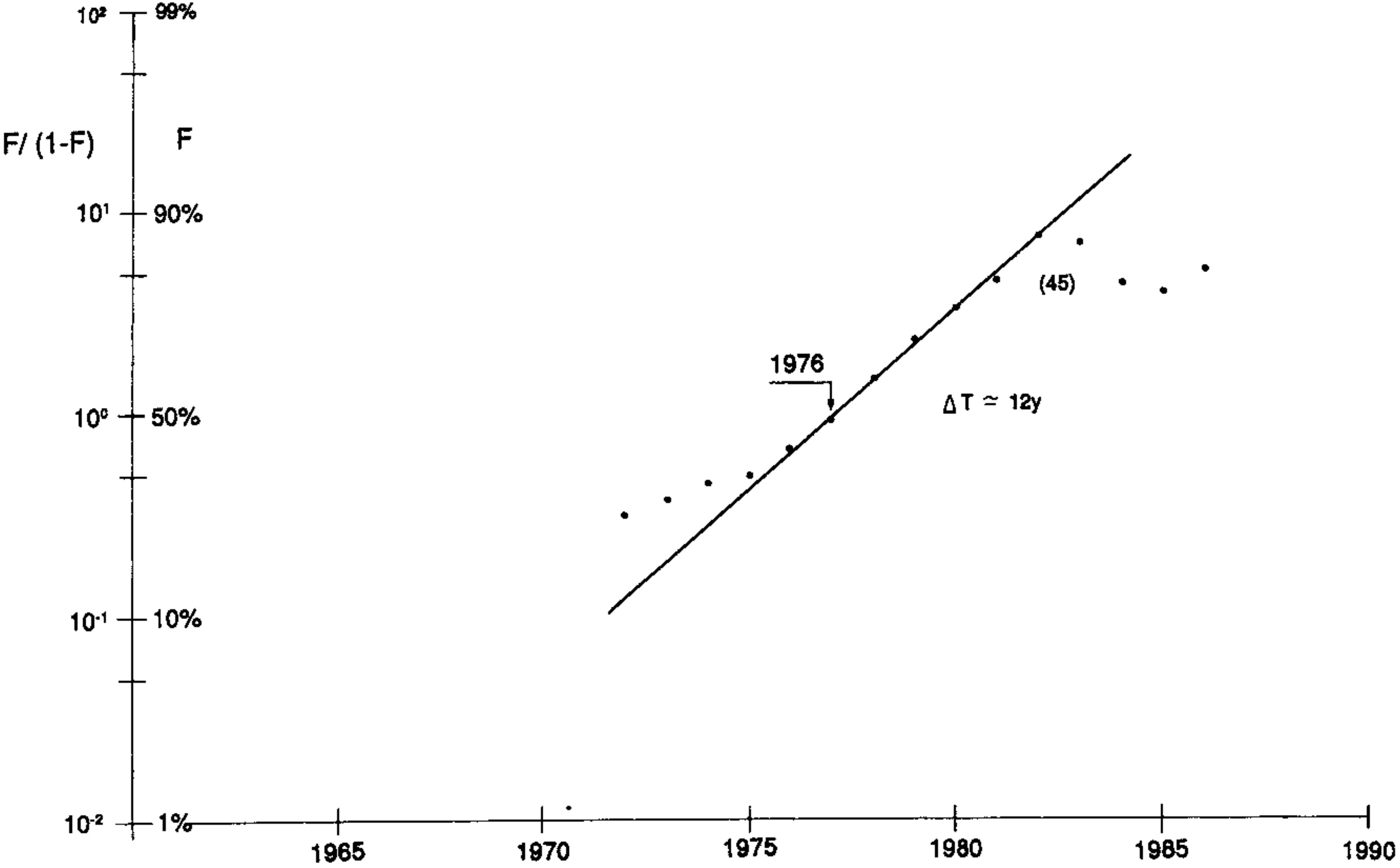
It is useful to examine the details of the whole operation to better understand the mechanisms at play. First, we can look at the *substitution* process whereby sea links are replaced by land links (figure 4.27). This evolution unfolds according to the prescriptives of Darwinian substitution. Already 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.

FIGURE 4.23. *Trend in total vehicles (10^6) crossing Hong Kong Harbor by ferry, 1960-1990*



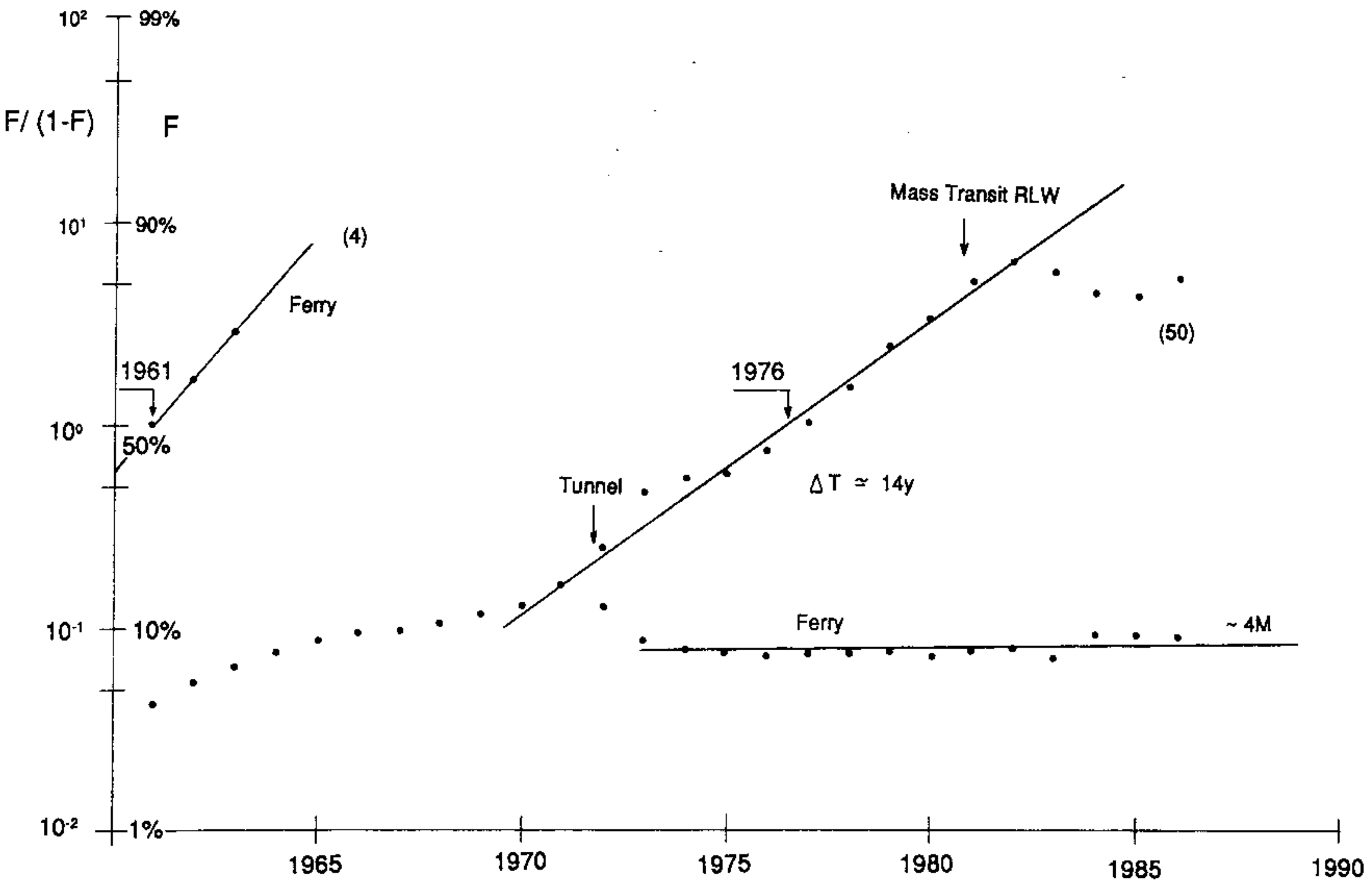
Based on data provided by the Hong Kong Government Transport Department, 1987.

FIGURE 4.24. *Trend in total vehicles (10^6) crossing Hong Kong Harbor by ferry and the first tunnel, 1971-1985*



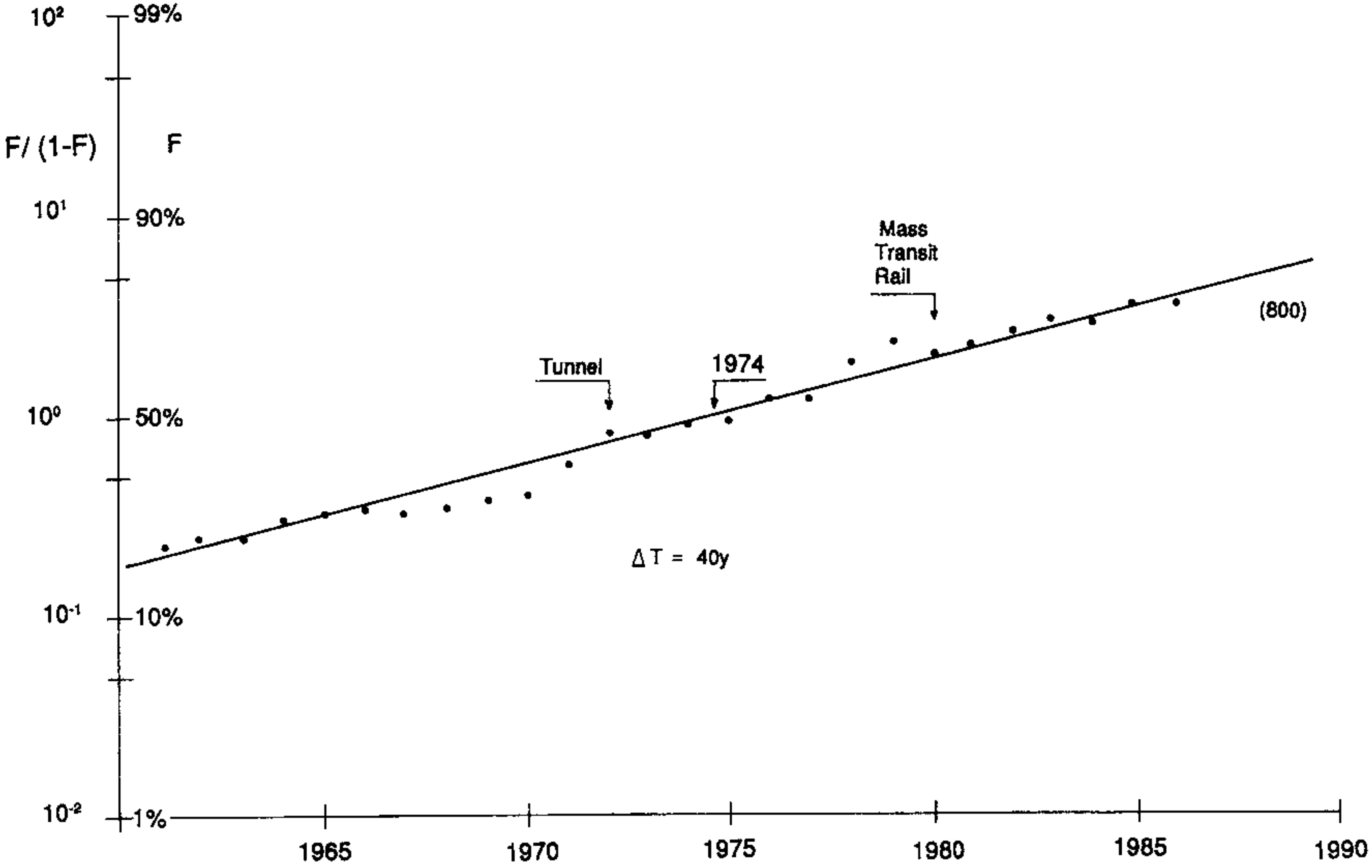
Based on data provided by the Hong Kong Government Transport Department, 1987.

FIGURE 4.25. *Trend in total vehicles (10^6) crossing Hong Kong Harbor by ferry and two tunnels, 1961-1990*



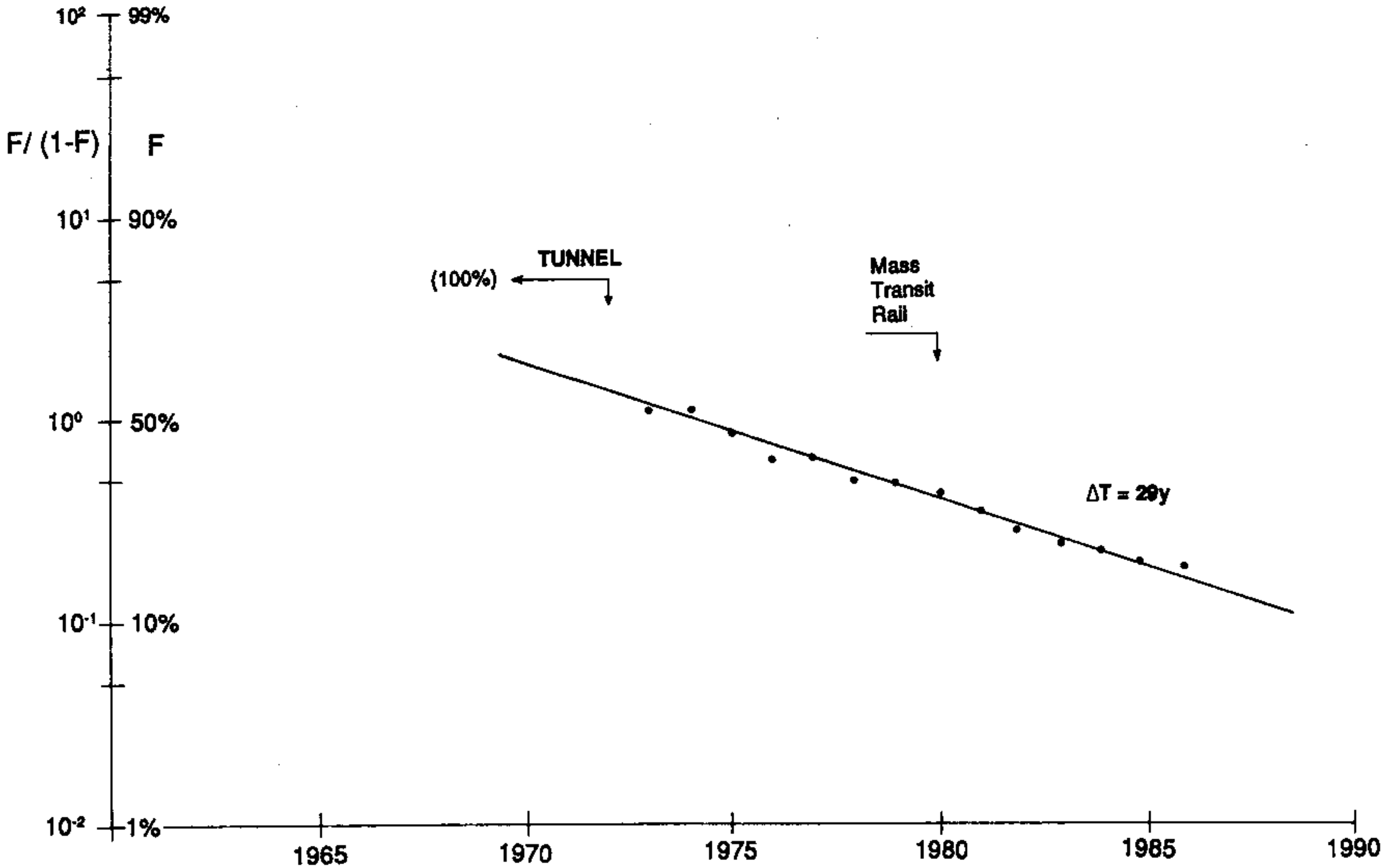
Based on data provided by the Hong Kong Government Transport Department, 1987.

FIGURE 4.26. *Trend in total number of passengers (× 10^6) crossing Hong Kong Harbor by all transit means*



Based on data provided by the Hong Kong Government Transport Department, 1987.

FIGURE 4.27. *Trend in ferries' share of total passengers (10^6)*



Based on data provided by the Hong Kong Government Transport Department, 1987.

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 after the opening of the Mass Transit Railway, which in my opinion indicates a natural and timely response to the qualitative and quantitative increase in 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 4.28). The opening of the Mass Transit Railway in 1980 (figure 4.29), when the calculated traffic should have been 410 million passengers, wooed 78 million road tunnel passengers, most of them from franchised buses.

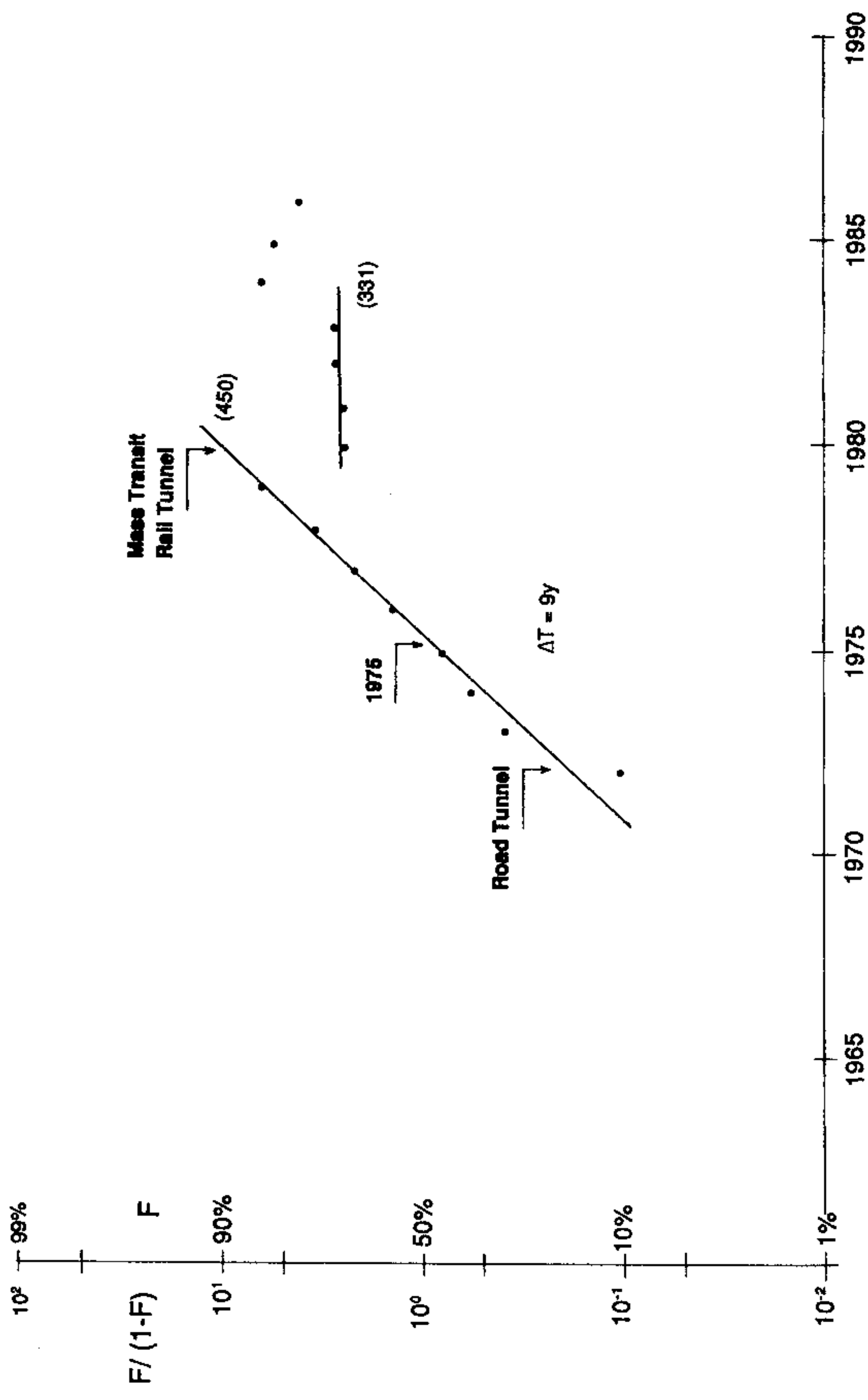
This is shown in figure 4.30, where ground traffic on public services, i.e., franchised buses plus Mass Transit Railway, follows a good logistic growth path with no perturbation when the Mass Transit Railway was introduced. Incidentally, a time constant of 18 years, with 1981 as middle point, will bring 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 4.31). 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 4.32). The company seemed near saturation (62 million passengers per year) in the second half of the 1960s, oscillating around 90%

FIGURE 4.28. *Trend in total passengers (10^6) crossing Hong Kong Harbor by road tunnel*



Based on data provided by the Hong Kong Government Transport Department, 1987.