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LONG RUN EVOLUTION OF THE FRENCH URBAN SYSTEM

Preliminary version of a paper presented to the meeting of the URBINNO
Working Group n°1: Population and urban structure. Bari, september 1988

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DYNAMIC ASPECTS OF A SYSTEM OF CITIES

In most industrialized countries, where the urbanization rate has very likely reached a kind of upper limit and where demographic growth is henceforth very slow, the urban systems seem now to evolve in a different way than they used to do when urban growth was more rapid. The theory of the urban cycle (Berg & al., 1982) has been developed to give an interpretation of the new spatial aspects of the urbanization process and of the fluctuations in urban population densities. New rules of the spatial division of labour have been put forward to explain the tendencies to deconcentration from core regions to peripheral regions (Vining, Pallone, 1982) which also affected the urban systems. A process of growing importance seems to be the competition between cities or metropolitan areas which are now advertizing for their own development and trying to improve their "image de marque". Empirical studies have shown effective relationships between the attraction of cities during the last forty years and a set of objective indicators associated to their "image de marque" (Pumain, Saint-Julien, 1978 and 1984).

Not too many attempts have been made until now to model the distribution of urban growth in a set of cities. A few results of empirical testing will be given in this paper for very simple models. We will first recall how strong analogies can relate the evolution of urban systems to other types of systems having similar structural properties. As a first approximation, differential urban growth in a set of cities could appear as randomly distributed. As in many other physical and living systems, there is an astonishing stability in the structure of a developing urban system, despite of the increase in the number and size of cities and of the urbanization rate. However, systematic deviations from a stochastic process invite to search for evolutionary models including a competition effect which is more specific to urban systems. The hypothesis is that successive "generations" of cities tend to concentrate a larger part of the development at given periods. For understanding and modelling this interurban competition process, Marchetti's logistic substitution model has been tested as a first exploratory tool. A large data set of the evolution of the french urban system over the last 150 years has been used (it comprises from 617 to 1782 urban units between 1831 and 1982).

I - URBAN SYSTEMS IN THE FRAMEWORK OF GENERAL SYSTEMS THEORY

I-1 - Hierarchical open systems

Urban systems can be conceptualized as hierarchical open systems (Prigogine, Stengers, 1979). They are hierarchical, in the sense that they can be described by using three significant levels : the elements, which are individuals, urban residents (urban households could also be used to define that elementary level) ; the subsystems, which are individual cities, strongly differentiated by the number of elements that they contain (usually from 10^3 to 10^7) ; the whole system, which is the total set of cities. Urban systems are also open systems, since they exchange elements with their environment (migrants from and towards rural areas or another country ⁽¹⁾).

Such defined urban systems share with many other types of hierarchical open systems (as for example galaxies, biological families, or economic firms... cf. Winiwarter, 1984) a few structural and evolutionary properties. All of them are characterized by a Pareto-shaped or log-normal distribution of the sizes of the subsystems, when size is measured by the number of elements that they contain. This Pareto distribution keeps over time a rather constant slope, in a narrow range which is particular to each kind of systems. For urban systems, the value of the slope usually stands between 0.8 and 1.3 (Rosen, Resnick, 1980). The processes which are involved in the construction and persistence of such structures are not yet fully explored. A necessary (but is it sufficient ?) condition seems to be that in such systems, subsystems grow according to a birth-death process of their elements and to a migration process of elements between them. However, models which combine both types of processes are still very few, and most of empirical testing has been done by using models of aggregate growth of subsystems.

(1) Urban systems are supposed here to be delimited by national boundaries, which usually strongly reduce most of interactions between cities. Of course when this is not the case the delimitation of the urban system has to be carefully reconsidered.

I-2 - EVOLUTIONARY PROCESSES

In the case of urban systems, several models of the distribution of growth among cities have been designed in order to demonstrate how they could lead to a Pareto distribution (Steindl, 1965 ; Simon, 1931) or to a lognormal distribution (Gibrat, 1931) of the sizes of cities. Most of them were stochastic models. Their specifications could be different but they were all based on the same kind of main hypothesis :

- cities are growing at each small time interval of a quantity of inhabitants which is proportional to their size (it is equivalent to say that the growth rates of cities are independant of their sizes) ;
- the distribution of growth rates among cities is independant from one time interval to another ;
- there is a constant (or not too variable) ratio between the average growth rate of the population of cities and the relative increase of the number of cities in the urban system (net move of new cities entering the system by exceeding the urban population threshold and of the disappearing ones whose population has declined under this threshold).

I-3 - EMPIRICAL RESULTS

Empirical testings of those models (Madden, 1955 ; Robson, 1972 ; Pumain, 1982) lead to convergent results as to those main hypothesis :

- a proper description of the urban growth process is actually given by the "law of proportional effect", that is, on average, the variations in the number of inhabitants of a city are roughly proportional to its size, or, in other words, in the whole urban system, urban growth rates are randomly distributed respectively to the size of cities. This rule holds for the larger part of the growth process in any urban system, it remains in the actual state of our knowledge the best tool for the general estimation of the evolution of the population of individual cities ;
- Despite non negligible fluctuations of the ratio between the growth rates of urban population and of the number of cities, there is a rather strong parallelism in the evolutions of both rates (figure 5) and then the hypothesis of a not too unstable relationship between those two processes of expansion

in urban systems can also be hold for true (of course, this last observation relies upon the degree of relevance of the geographical definition which is used for the delimitation of urban subsystems) ;

However, systematic deviations prevent from considering the evolution of urban systems as a pure stochastic process :

- There is a slight tendency for city growth rates to be correlated with the size of cities. This correlation has been positive during the urbanization process in old urban systems of industrialized countries (cf. Robson, 1972, Pumain, 1982 and figure 6a). This positive correlation is partly responsible for the increase in the slope of the distribution of city sizes when adjusted by a Pareto model (figure 7). The correlation between city growth and city size was negative in a developing urban system like the American one during the XIXth century (Madden, 1955) ; it has also become negative in the last fifteen years in most of very urbanized countries, leading to a slight decrease in the concentration of city sizes (figure 6a et 7). The interpretation of this tendency as a complete reversal or as the sign of a more fluctuating evolution is still under discussion among specialists ;

- a second type of deviations from a random process seems to be less frequent and to have a less systematic continuity over time but may have stronger effects on the geographical structure of urban systems : city growth rates may be not randomly distributed between time intervals at given periods, or in other words city growth rates may exhibit temporal autocorrelation (figure 6b). For instance in France, this correlation has been high during the end of the XIXth century, and for the last forty years. Instead of a random distribution, there is then a geographical selectivity of urban growth (this process is totally independant from the previous one, since it appears in all categories of city size). This process could have contributed to reinforce the concentration of city sizes in the urban system (as measured by the increase in the slope of the Pareto distribution) but it is also compatible with a de-concentration (as for the 1975-82 period in France, cf fig. 6b and 7).

Whereas the law of proportional effect could be interpreted as a very general evolutionary process, trivial in a way for any hierarchical open system, since just explaining its Pareto structure, this selectivity in the growth process, as related to the size or to other properties of cities,

appears now as a specific feature in the evolution of urban systems. It can be separated and analysed in relationship with the specific functional nature of those systems.

II - THE INTERURBAN COMPETITION PROCESS

II-1 - TOWARDS A SPECIFIC THEORY OF URBAN SYSTEMS

Even the law of proportional effect is not a purely formal process and is related to the particular behaviour of urban populations. During the development of urban systems, this behaviour has remained rather stable, in accordance with the rules of the "agglomeration principle". This principle leads to a multiplicative growth of the population of cities : natural increase is multiplicative because the biological evolution of populations is either exponential or logistic ; and the second component of growth, net migration, is also proportional to the population of cities since interaction between cities are proportional to their probability of contacts, which is a function of their size (if one or both of those behavioural features of urban populations would change or cease to be rather homogeneous over space, the evolution and the structure of urban systems could be very different).

Large scale interaction is a specific feature of cities, whose function is to exploit resources of situation, that is, resources issued from sites which may be located far away, whereas agricultural or mining settlements exploit local resources of their own site (Reymond, 1981). To be organized in a network is then a specificity of urban settlements. But this organization is more a "self-organized" structure than the result of any planning. This structure has progressively emerged from a continuous process of competition between cities. For instance, B. Lepetit (1984) shows that when the national road-system was constructed in France in the XVIIIth century, the very concept of a road network did not exist. But there was already a very strong and conscious competition between neighbouring cities to attract the infrastructure. Other well-known examples of this interurban competition for development are for instance the choice of the capitals of departments in 1793, or more recently the location of industrial zones, the creation of airports or of "technopoles".

An illustration of the effects of this interurban competition process is given by graphs of changes in the ranks occupied by cities in the urban hierarchy at different points in time (figure 4). This figure shows that except for a dozen of largest cities, for which changes are fewer and of lesser amplitude, the rises and falls in rank are distributed all over the urban hierarchy, over a large period of time as well as for shorter intervals. However, this approach of the interurban competition process is only qualitative. One should be able to give more precise answers to the questions which arose from the study of urban growth rates :

- to which extent do the deviations from a stochastic growth process change the structure of urban hierarchy ?
- is it possible to relate the non-stochastic features of the distribution of urban growth to the properties of specific set of cities ? In particular, can they be related to specific situations, not only evaluated by geographical location but also by functional and social distances ?
- is it possible to use those results to improve the previsions of future developments in the urban system ?

II-2 - MARCHETTI'S LOGISTIC SUBSTITUTION MODEL

After a first attempt by Fisher and Pry (1971), Marchetti and Nakicenovic (1979) suggested to apply the logistic function to describe the substitution process between successive technologies which are competing for the same market. According to them, every given technology undergoes three distinct phases in the evolution of its market share : growth, saturation and decline. A technological subsystem (for instance Coal) tends to increase its share of the market (the total energetic sector) according to a logistic curve. Then it reaches an upper limit when other technological subsystems (for instance oil, then natural gas...) tend to substitute themselves to it and to reduce its share of the market. There is then a phase of saturation after which the technological subsystem reaches a logistic rate of decline. Except during the saturation phase, the evolution with time t of the market share f_i

of a given technology i can be adjusted by the following function :

$$\frac{f_i}{1 - f_i} = \exp(\alpha_i t + \beta_i)$$

assuming that the size s_i of the subsystem i is growing logistically :

$$s_i = \frac{S}{1 + \exp^{-\alpha_i t - \beta_i}}$$

with an upper limit S which is equal to the size of the whole system (and $f_i = \frac{s_i}{S}$) (figure 8).

II-3 - APPLICATION OF MARCHETTI'S MODEL TO GENERATIONS OF CITIES

Marchetti's model is interesting because it focusses on relative rather than absolute growth. As we have seen, absolute growth is not very significant for the analysis of the development of single cities, since there is a very general tendency for the diffusion of growth in every part of the urban system during the urbanization process. It is then in terms of differential growth, of relative evolution, as compared to the one of the whole set of cities, that the substitution of a subset of cities to another can be shown - if it does exist.

The interpretation of the model has to be transposed to a large extent. The hypothesis of cities substituting one to another in the course of history cannot hold. As a matter of fact, it has been observed that about the same set of cities has been successively re-used, in a slight different way, by each of the great phases of urbanization which correspond to major cycles of the diffusion of technical and socio-economic innovations (constitution of a primary urban network on an agricultural economy, formation of the network of the large scale trading cities, industrial and railway revolutions, motor-car diffusion...). It is during each of those large cycles that a substitution may occur between cities having leading positions in the contemporaneous wave of innovations and the ones which remain temporarily aside. Such "generations" of cities may overlap each other, since the same cities can successively belong to the leading or to the declining groups.

One would hypothesize that this substitution at the leading positions for development in the urban system, which corresponds to successive "generations" of cities, is not primarily directed by a size factor. So,

instead of studying the relative development of a-priori defined size categories of cities, we will first consider the trajectories of each individual city and second regroup them after their similarities of shape.

The following hypothesis derive from the use of this model :

- the population of a city tends to grow according to a logistic curve whose limiting factor is given by the total size of the urban system, at a geographical scale which is defined by the hierarchical level which the city belongs to. If the city is very large it enters in competition with all other larger cities and its limiting size may be defined as the population of the whole urban system. If the city belongs to an inferior hierarchical level, the field where it is competing for the attraction of population may be limited for instance at a regional scale and then the limiting factor is equal to the size of the regional subsystem ;
- the evolution of the relative size of a city can be split into phases during which its share of urban population is a linear function of time, according to its participation to the innovation cycles. When the city makes profit from a given cycle of innovation and improves its relative position in the system, this function is increasing, and decreasing in the reverse case.

For each of the two hundreds largest French cities, the share of the population of the city P_i in the total urban population P : $F = P_i/P$ has been computed at each of the 27 censuses between 1831 and 1982. The functions \log are plotted against time on figure 6 for a few of them. Those curves are representative of most of the cases. They show that the evolution of the relative size of cities does not follow more or less random oscillations of short period - as one could expect if the interurban competition process was fully stochastic - but on the contrary that it is made of long phases - about 50 years - of rather constant increase or decrease - inflexion points on the curves are most frequently located just after world-war II, and at the end of XIXth century.

Those tendencies to an increase or to a decrease of the relative importance of cities in the urban system may then be related to the main waves of innovations during the last 150 years. This can also be seen when the individual curves of cities are regrouped according to their similarities in

shape (by the means of an ascending hierarchical cluster analysis). Figure 10 shows five types of relative evolution :

- the most frequent is a continuous decrease of the relative share of urban population (which corresponds however to an almost constant increase in absolute size). Most of those cities are among the smallest and disseminated all over the territory. As those relatively declining cities are numerous, they mean that the urban hierarchy undergoes a simplification from below, which is very likely related to the increasing territorial ranges of larger cities ;
- The second type groups cities which had a similar evolution until world-war II, but which were in average slightly larger in size. They undergo an increase of their relative size during the last forty years ;
- a third type of cities started from rather small sizes to arrive among the largest : they increased almost continuously and very fast their relative share of urban population, due to the industrial revolution of the XIXth century (but at the same time cities like Cannes, Nice... were also developing for other reasons), then to the second industrial revolution (like Toulouse between the wars) and to recent modernization (for Parisian satellites and cities of the western past) ;
- the fourth group seems to deny the usefulness of Marchetti's model to describe urban evolutions. Those cities exhibit a remarkable stability of their relative importance in the urban system. They took their part in each of the successive innovation cycles. Most of them are very large cities like Lyon, Marseille, Nantes, Strasbourg... which resist to the Parisian centralization ;
- the fifth group as a matter of fact mainly concerns the Paris agglomeration which increased its relative importance in the urban system until about 1936 and then started to decline.

This classification shows that the relative evolution of cities populations proceeds in a rather continuous way over long time periods. The tendencies to relative growth or decline are continuing for a longer time than if the process was purely stochastic.

Empirical studies about the more recent evolution (1954-82) and its more detailed socio-economic contents (Pumain, Saint-Julien, 1978 and 1984) have demonstrated that the various changes which orientate the tendency towards relative growth or decline are not of a different nature but on the contrary are of the same kind in every cities. Those changes are only more or less intense or rapid according to the cities. Most of those fluctuations around the general tendency of evolution are random. It is only when they do persist with the same sign in the same cities over a long period of time that the phenomena of a "generation of cities" which are favoured or defavoured by a given class of innovations can occur.

We think that this large uniformity in the diffusion of changes is mainly due to the interurban competition and that it is a permanent process in urban systems.

The large uniformity of changes explains the large stability of urban hierarchy and the persistence of the socio-economic dimension of the urban system. Differential changes produce modifications of this structure. Such re-organization of urban systems are not only depending upon very concentrated innovations like the ones due to mineral deposits during the first industrial revolution. In France they have also been depending upon the size of cities (largest metropolis convergence towards an almost unique model of city, decline of the smallest), upon their administrative function (general development of regional capitals), upon their social composition and geographical environment (recent growth of southern cities).

Considering the large analogy between the structure and evolution of urban systems and other hierarchical systems, one may imagine a formalization of such processes which could be derived from the ones being used to describe the appearance and qualitative modification of morphological structures in physical-chemical or living systems.

III - DISCUSSION

From our first partial application of Marchetti's model to the interurban competition process, what can be retained ?

- the model is very useful, because it gives a framework for the study of the relative evolution of cities in urban systems. It helps describing how innovations waves tend to reorganize the structure of an urban system ; it may then be used to improve projections of the population of cities, by taking into account the tendency of their relative evolution. However :

- a first difficulty is that the model cannot be applied in its full extent to cities because the competition in urban system does not occur by substitution of cities to each other but by re-utilization of the same sites. It is then more hasardous than for technological substitution to predict when a type of cities may undergo a saturation of its relative share ;

- one also should add that in the contemporary interurban competition process, an increasing size, as measured by the relative population size, may no longer be a criteria of success for cities. The qualitative internal structure (age of technology, skill of the labour force, level of amenities...) seems to become more and more significant ;

- on methodological grounds, it may also be objected that the theoretical proof has not yet been given of a logistic evolution stemming from a multiple competition process : it is demonstrated only for one subsystem growing with an upper limit (Malthus case) or for two competitors (Voltera-Lotka's case).

- one should then try to elaborate models which would better precise how interurban competition occur, by making more explicit the migration process. Models of the distribution of growth in urban systems cannot avoid to specify the spatial behaviour of people.

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Figure 1. EVOLUTION OF THE SIZE OF THE URBAN SYSTEM

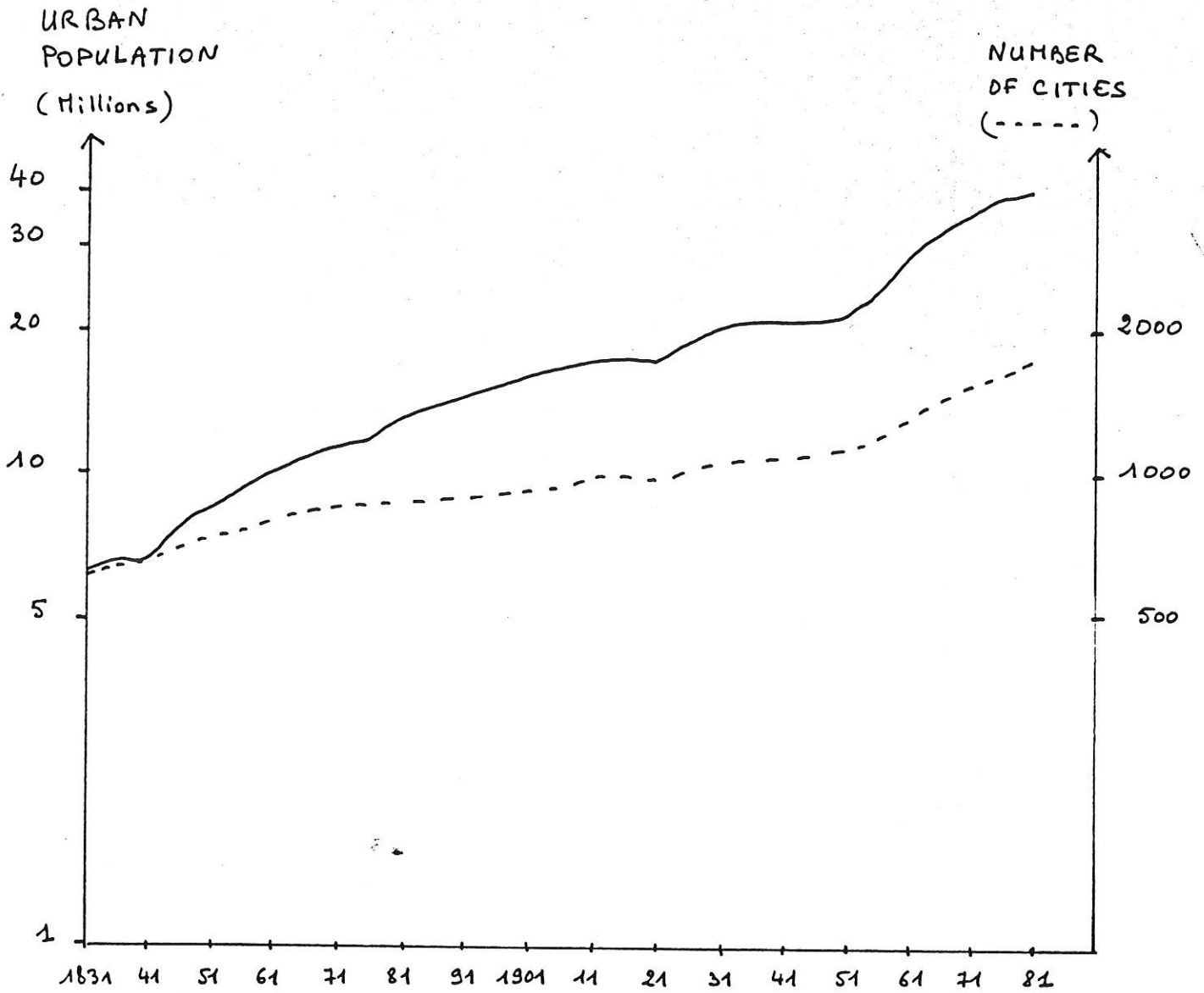
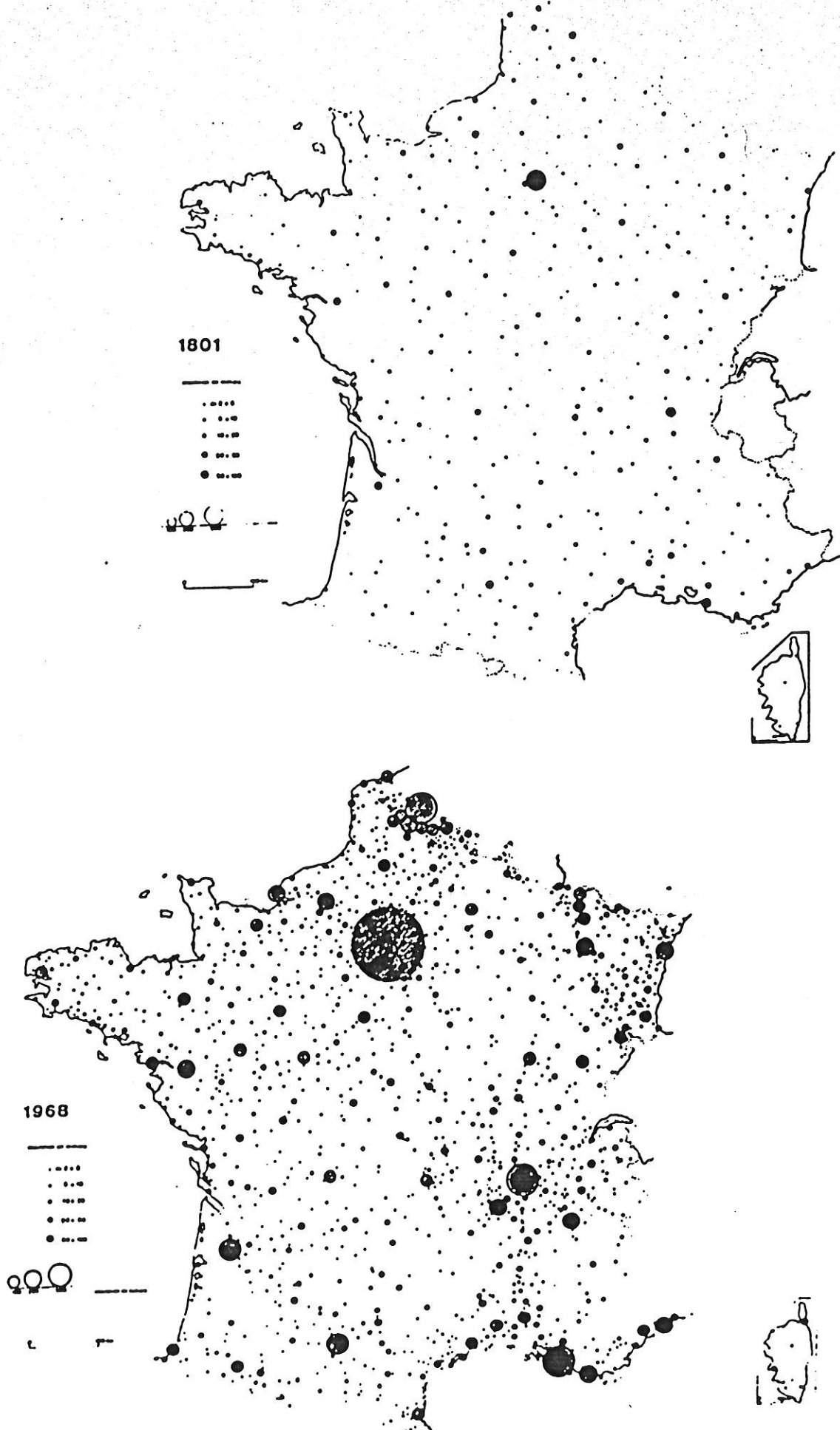


FIGURE 2 PERSISTENCY OF THE SPATIAL STRUCTURE OF THE URBAN SYSTEM



After : Fontanel C. et Pescoux C. : Potentiel de population et réseau urbain en France. L'Espace Géographique, 1976, n° 4.

Table 1 GENERAL STABILITY OF URBAN HIERARCHY

Correlation coefficients between rank of cities in urban hierarchy at different dates:

	1831	1982
		0.71
	1911	0.83

Transition matrix by hierarchical levels 1831-1982

1982 \ 1831	0	1	2	3	4	5	6	7	8
0	.05	.60	.23	.09	.02	.01			
1	.13	.50	.27	.07	.02	.01			
2		.14	.45	.31	.08	.01			
3			.06	.27	.50	.13	.04		
4					.22	.44	.33		
5						.28	.43	.28	
6							.25	.50	.25
7									1.0

Hierarchical levels (size classes)

0	< 2500 inhabitants	5	40 000 - 80 000
1	2500 - 5000	6	80 000 - 160 000
2	5000 - 10000	7	160 000 - 320 000
3	10000 - 20000	8	> 320 000
4	20 000 - 40 000		

Figure 3 - RANK-SIZE DISTRIBUTION OF FRENCH URBAN AGGLOMERATIONS

POPULATION
(thousands)

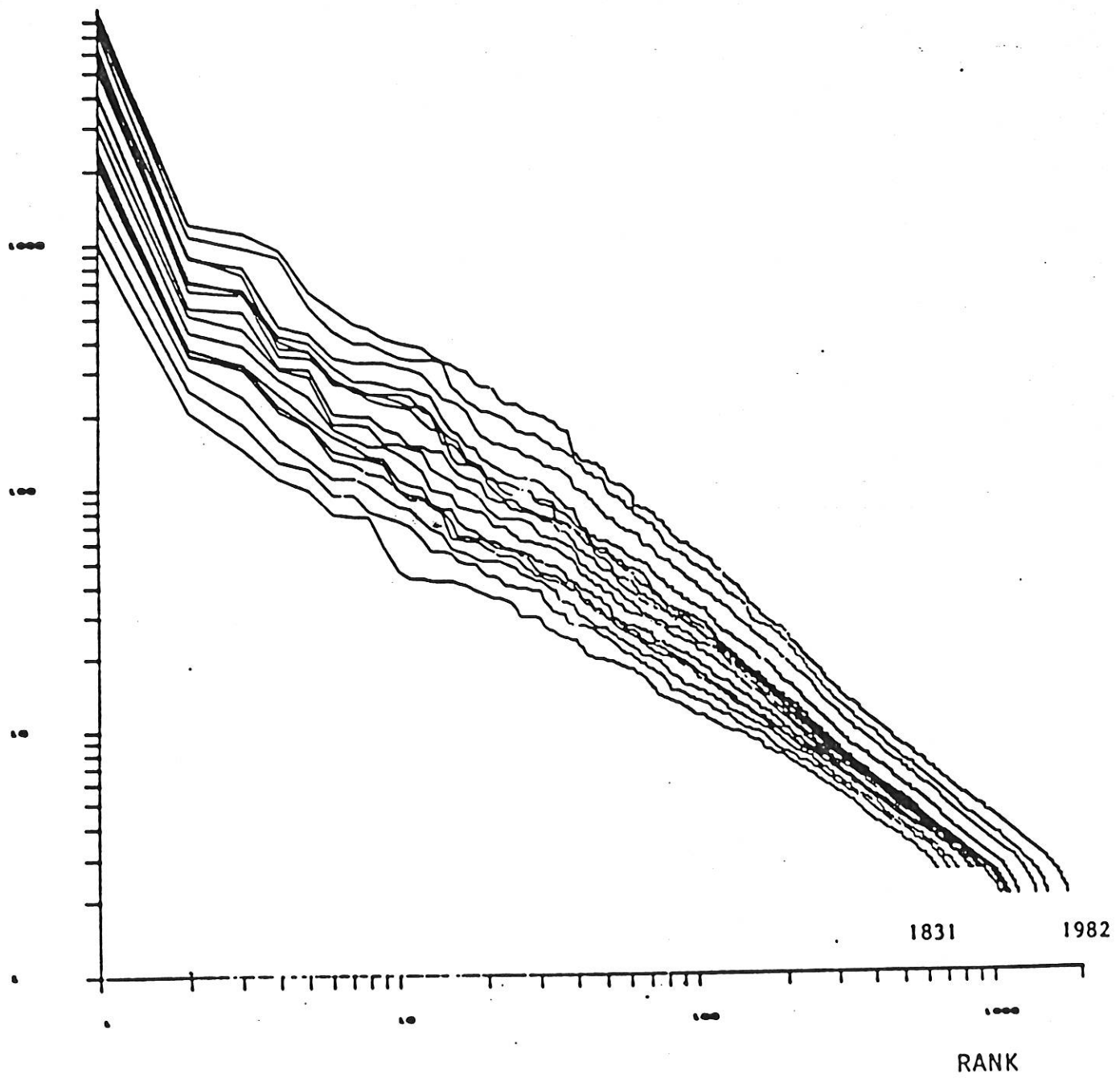
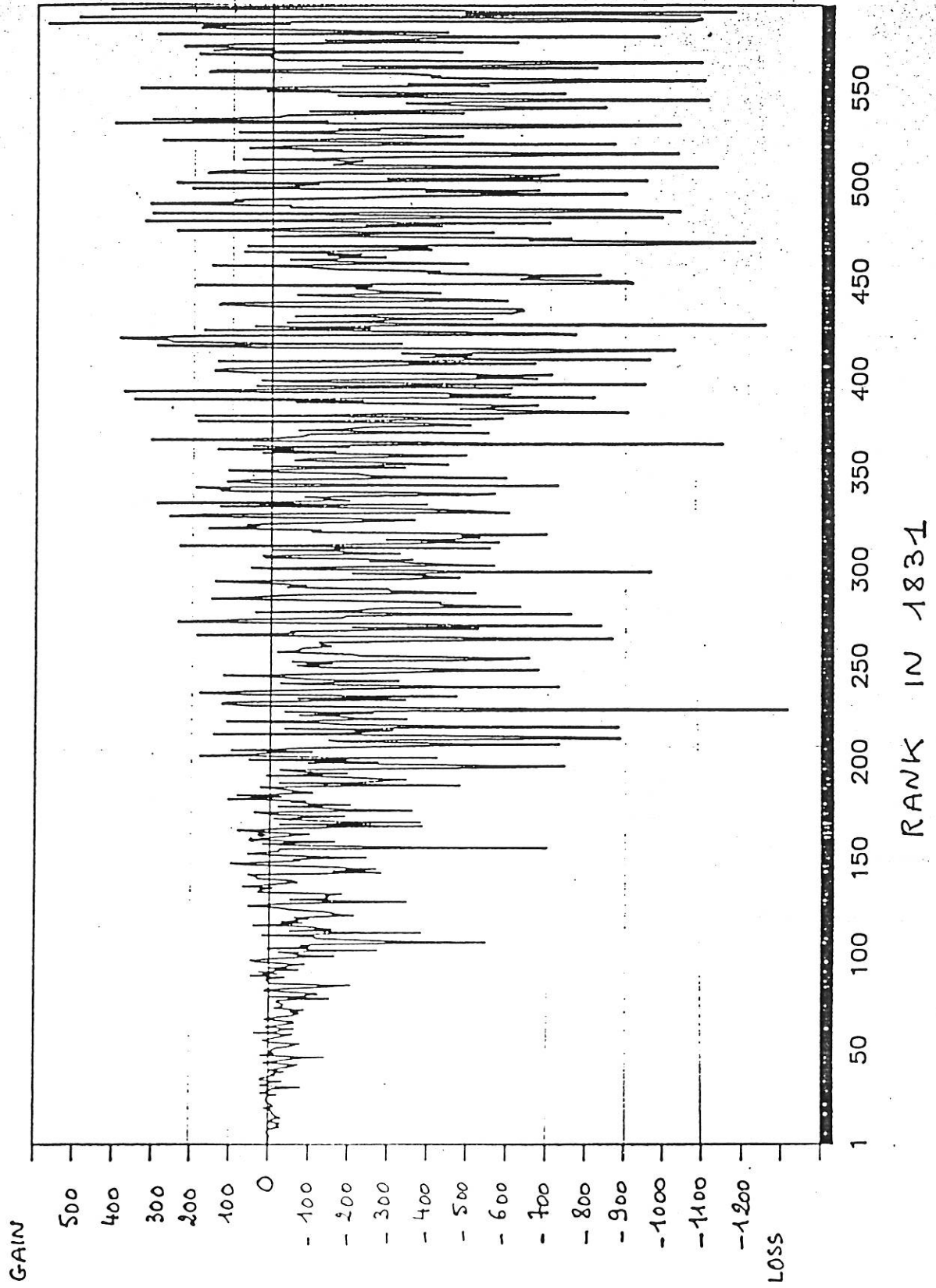


Figure 4

COMPETITION IN URBAN HIERARCHY



(Realisation: F. GUERIN)

Figure 5 - FLUCTUATIONS OF GROWTH OVER TIME
IN THE URBAN SYSTEM

MEAN ANNUAL
GROWTH RATE
(%)

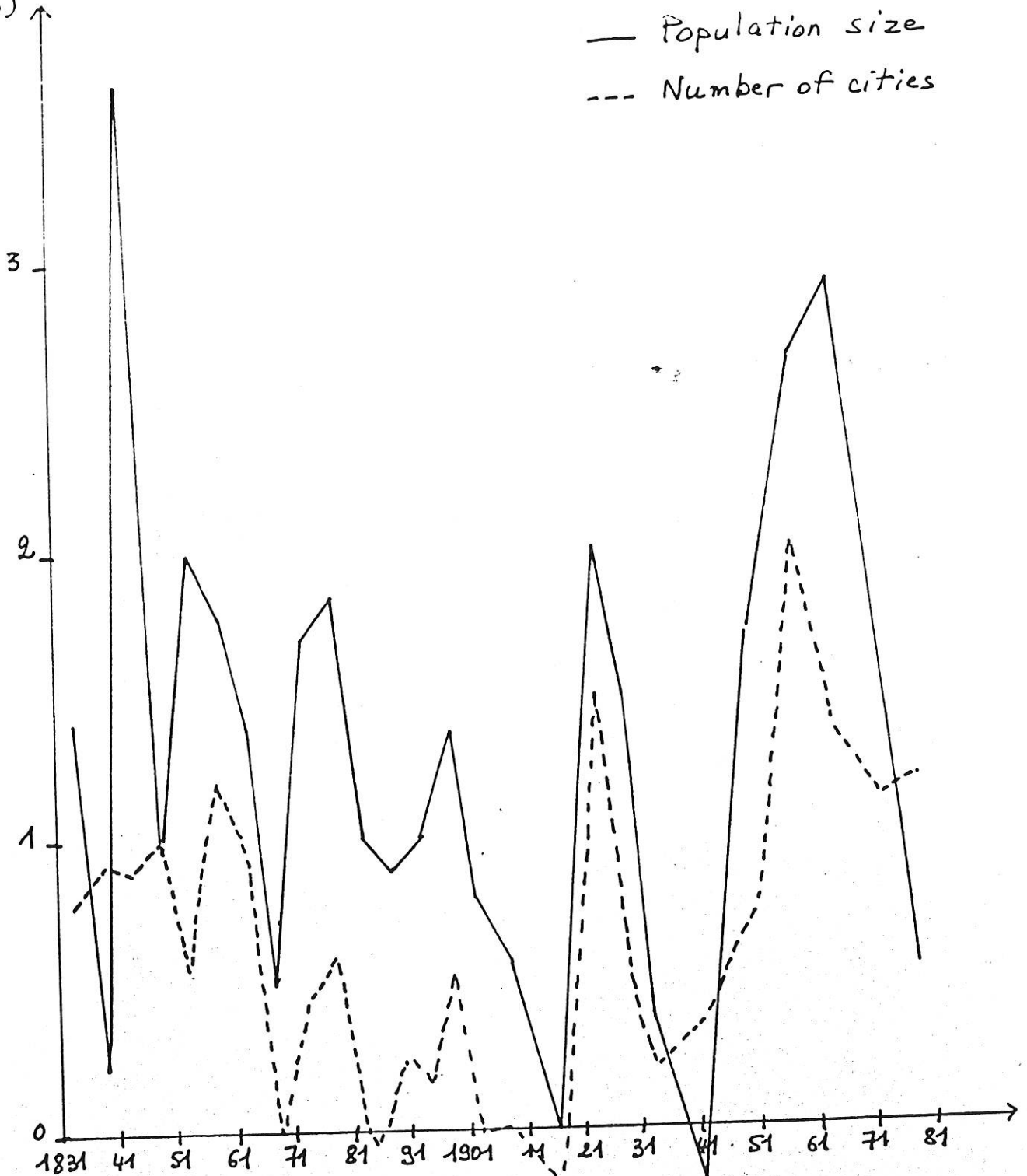
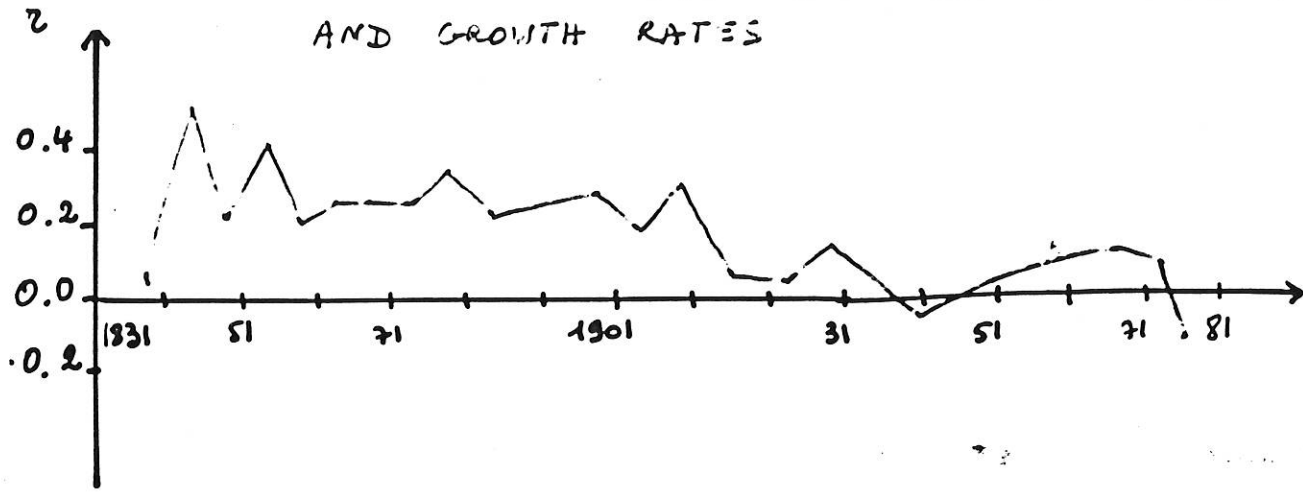


Figure 6
 TWO DEVIATIONS FROM GIBRAT'S PROCESS
 OF URBAN GROWTH

CORRELATION BETWEEN LOG OF POPULATION SIZE
 AND GROWTH RATES



CORRELATION BETWEEN SUCCESSIVE GROWTH RATES

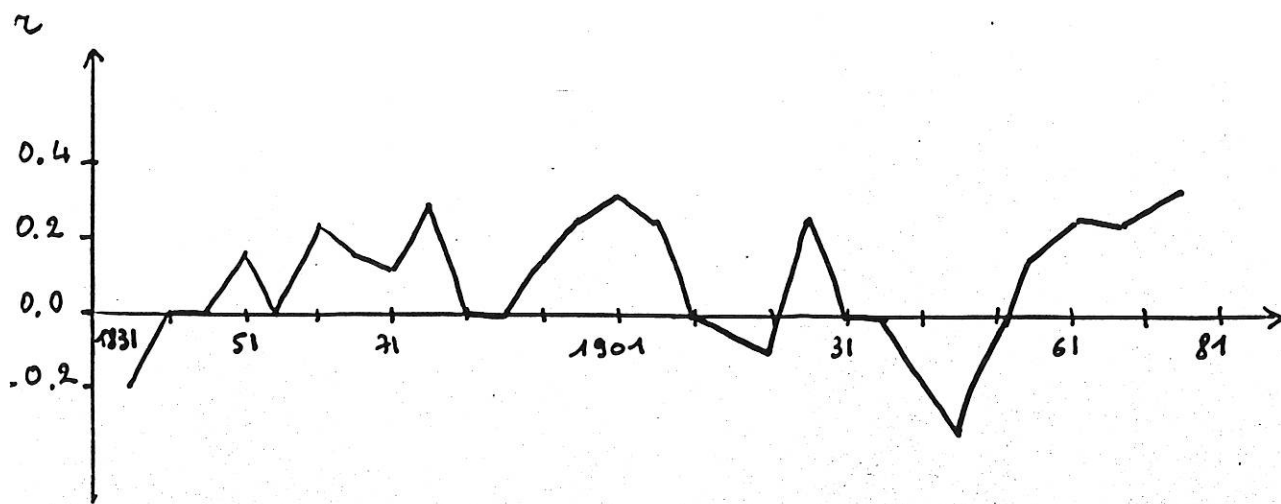


Figure 7

EVOLUTION OF THE SLOPE
OF RANK-SIZE DISTRIBUTION
1831 - 1982

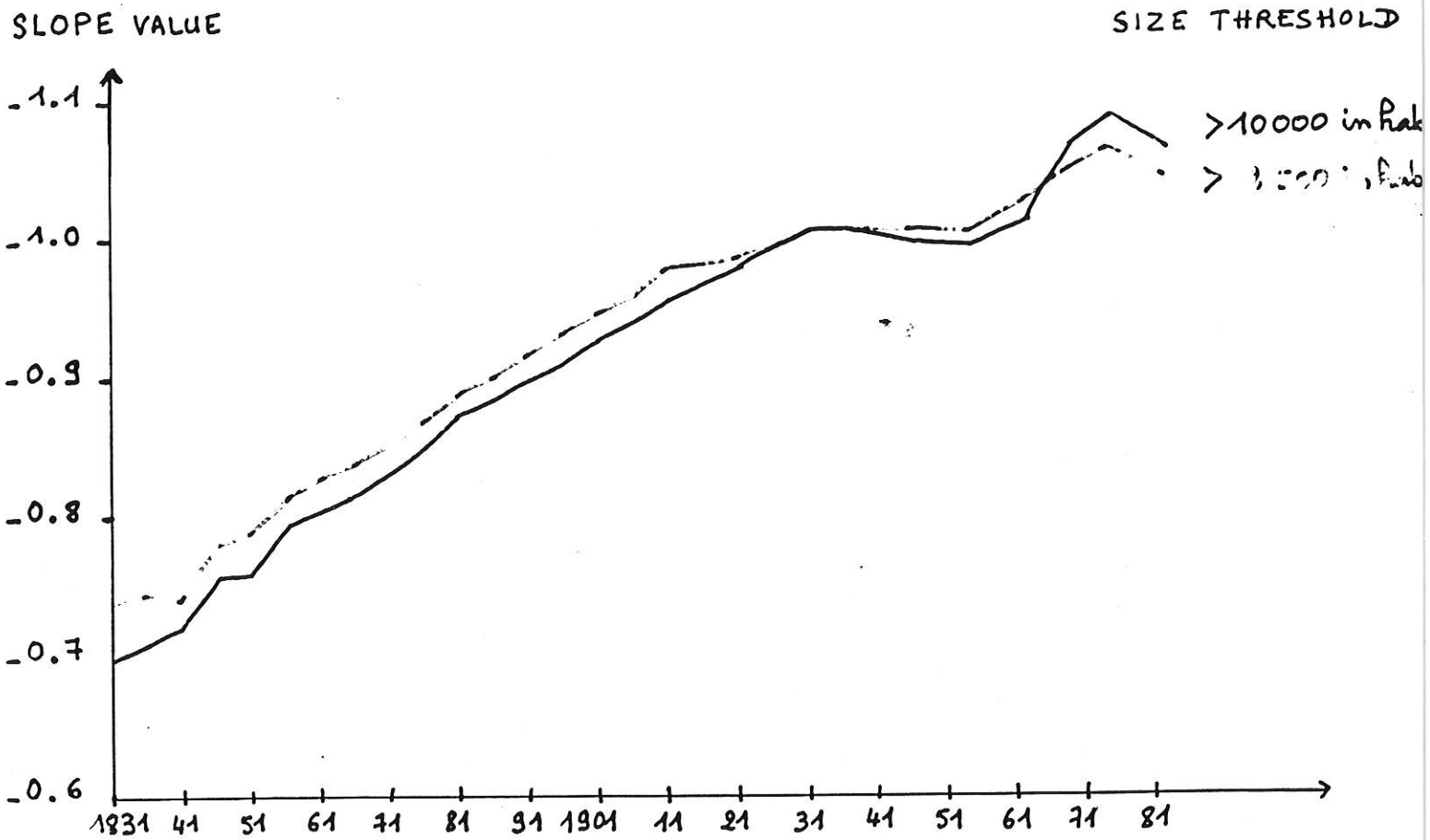
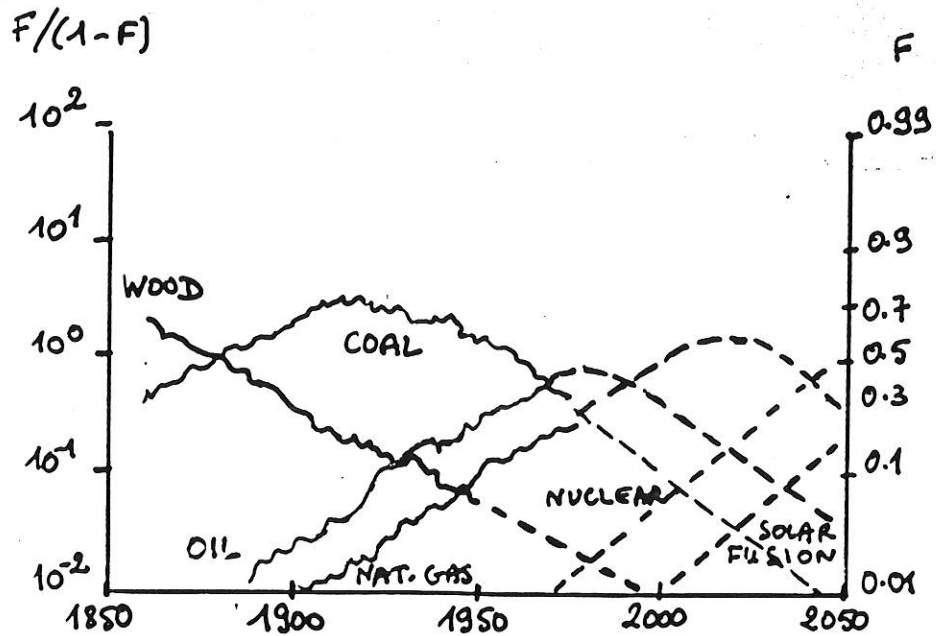


FIGURE 8 -

WORLD. PRIMARY ENERGY SUBSTITUTION



After: PARCHETTI, NAKICENOVIC
The dynamics of energy systems and the
Logistic Substitution Model.
I.E.A.S.A. 1979.

FIGURE 3 - EVOLUTIONS OF RELATIVE SIZES

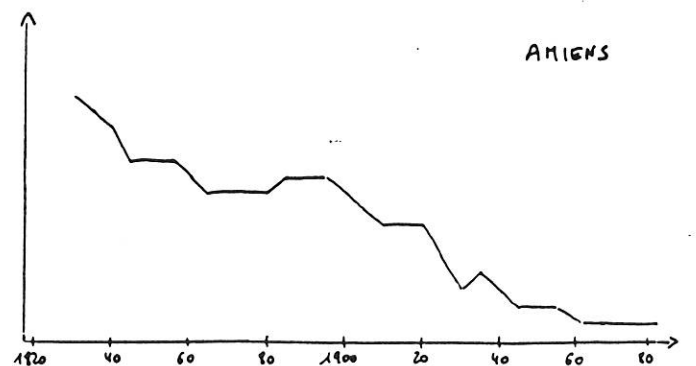
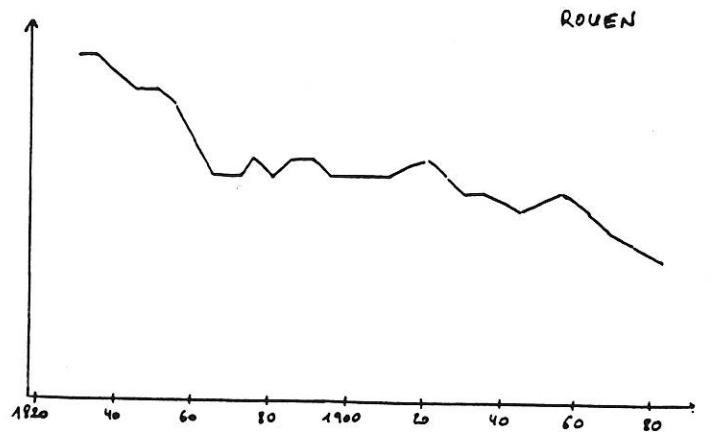
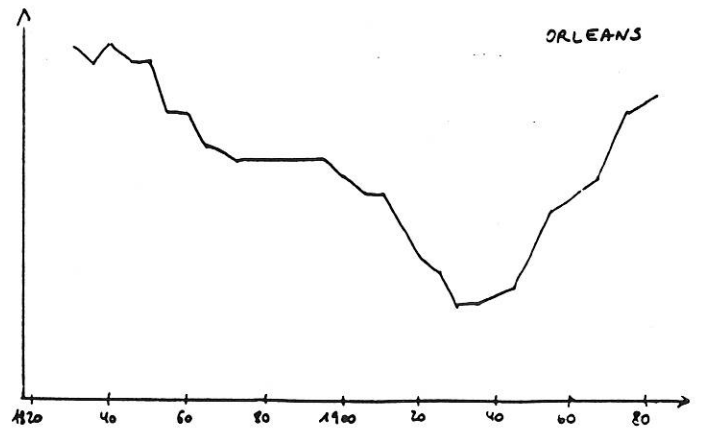
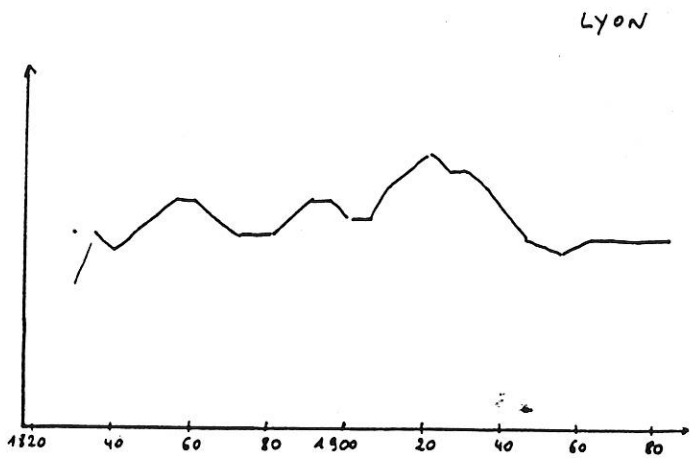
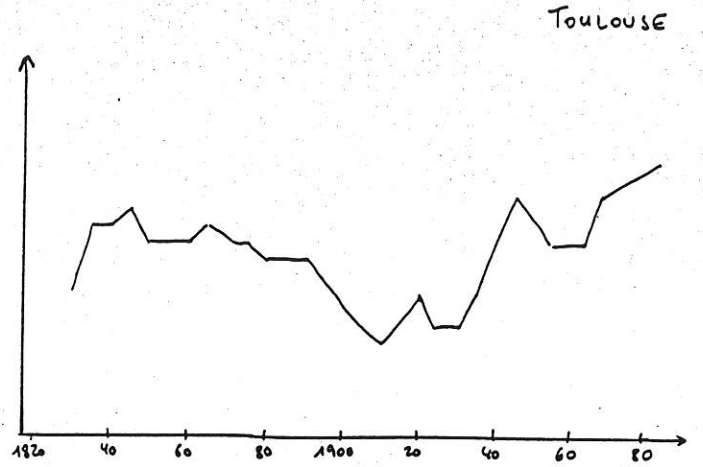
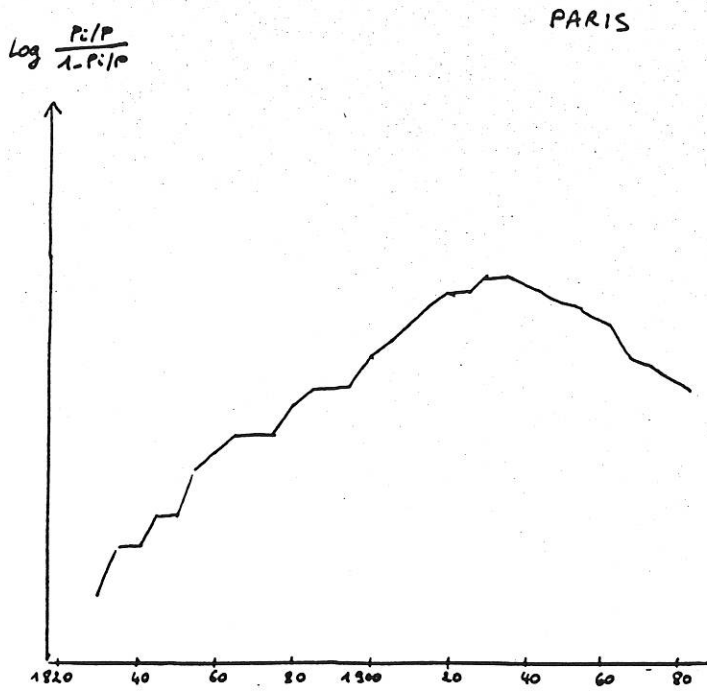


Figure 10 - TYPES OF URBAN GROWTH 1831 - 1982

