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TRANSPORTATION NETWORKS AND THE LOCATION OF HUMAN ACTIVITIES

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Abstract.- The impact of transportation networks on the location of human activities is a surprisingly neglected topic in economic geography. Using the simple plant location problem, this paper investigates such an impact in the case of a few idealized networks. It is seen that a grid network tends to foster a dispersed pattern of activities, while the center of a radial network acts as an attractor. The case of two economies characterized by different network configurations that form a custom union is then analyzed. It is shown that the structural properties of the networks still hold, though some locations are pulled toward the common border. This suggests that no such relocation should be expected within the European Union if the state members endorse similar fiscal and social policies after the formation of the single market.

Key-words.-Transportation network, location, economic integration

1. Introduction

Transportation infrastructure is considered as one of the main instruments of the tool box of spatial planners (Haggett and Chorley, 1972; Taaffe, Gauthier and O'Kelly, 1996). Many decision makers interested in the role of transportation infrastructure take it for granted that more infrastructure is always better than less because it would lead to less congestion and/or to a higher accessibility to existing facilities. In fact, the relationships between the provision of transport infrastructure and the level and distribution of human activities is complex, and can be addressed from different perspectives. First, one may wonder what is the link between the provision of infrastructure and the rate of economic growth? Second, one may also ask what is the influence of a transport infrastructure on the attractiveness of a given area in which the infrastructure is built up? In this paper, we focus on a third question: ***what is the impact*** (if any) ***of the shape of the transport infrastructure on the geographical distribution of activities***? To do so, we take the level of activity as given and study the geographical distribution of facilities within various network-types.

This facet of the problem has not been much studied (see, however, Peeters and Thomas, 1995, as well as Arnold, Peeters and Thomas, 1997, for two exceptions). The overwhelming majority of contributions disregard the impact of (re)shaping the transport system on the locational pattern of human activities. Either space is modeled as being one-dimensional, or the shape of the network is given. Neither approach assesses the impact of the network shape (see Aoyagi and Okabe, 1993, for a related criticism). Yet, in facility location analysis, it has been shown that the choice of a particular metric to model distance leads to quite different locational patterns (Beckmann and Thisse, 1986). Furthermore, the Hakimi theorem establishes that the search for a cost-minimizing location along a network may be limited to the vertices of the network, thus showing that the facility location depends on where the nodes are (Handler and Mirchandani, 1979). These results are clear indications that the shape of the transport network is likely to have a significant impact on the location of facilities. Finally, the empirical evidence collected by Plassard (1976) about France and Italy reveals that new settlements arise only at the highway nodes, thus confirming what the Hakimi theorem suggests.

In order to gain more insights about the impact of transportation policy on the spatial pattern of facilities, we consider different types of toy-networks and study how the ***number*** and the ***locations*** of facilities are affected by the difference in the transport system. More precisely, we focus on the simple plant location problem, the purpose of which is to find the number and locations of (public or private) facilities in order to minimize the sum of the fixed production costs associated with the setting up of facilities and of the transport costs of users to the facilities to be located. This model is one of the prominent location problems studied in facility location analysis and very efficient algorithms have been designed to solve it (see Cornuejols, Nemhauser and Wolsey, 1990, and Labbé, Peeters and Thisse, 1995, for recent surveys).

The simple plant location problem focuses on ***the trade-off between fixed production costs and transportation costs***. This trade-off is at the heart of many location models (Beckmann and Thisse, 1986; Mulligan, 1984) and may be encountered in planning a system of public facilities, such as schools or recreational facilities, as well as in the design of a production-distribution-marketing strategy by a private firm (Erlenkotter, 1977). Observe also that this trade-off is central in economic geography where it appears in the pioneering analyses developed by Christaller (1933) and Lösch (1940). On one hand, the existence of scale economies at the firms' level is a critical factor for explaining the emergence of economic agglomerations. On the other hand, the need to interact among individuals and the corresponding congestion costs (defined broadly in order to include competition for land use), imply that all activities are generally not concentrated in one place. Consequently, it is fair to say that the trade-off between scale economies in production and transportation costs is critical for the geography of human activities, and so regardless of the particular institutional setting in which those activities develop (see Fujita and Thisse, 1996, for a more detailed discussion). This explains why we have chosen to work in this paper with a model focusing on that trade-off.

One may wonder why we have retained the simple plant location problem. There are at least two good reasons for that. First, for any given spatial distribution of demand, the solution to this problem gives us the socially optimal configuration of facilities. Hence, it is likely that our results shed light on what could be the ideal network design policy. Second, to the extent that the market economy yields outcomes that are (more or less) socially optimal, the solution to the simple plant location problem may be expected to be a reasonable approximation of the market solution. In this perspective, the theory of contestable markets suggests that potential competition may well discipline market economies with nonconvex technologies (see Baumol, 1980, for a nice overview of this theory). For our purpose, the work by Demange and Henriet (1991) is worth mentioning since they show the existence of configurations of firms in a spatial economy such that no consumer can be made better off by changing unilaterally the strategy of a firm. In other words, our optimal configuration could well correspond to a certain type of market equilibrium.

For our purpose, we consider various types of transport idealized networks: ***radial*** networks, ***circumradial*** networks, that is, radial networks with a peripheral road, and ***grid*** networks. In this way, we are able to express the impact that different transportation policies may have on facility locations. For example, a radial network is likely to be associated with a centralized policy which aims at the development of a major city or conurbation (e.g., London or Paris), while a rectilinear network corresponds to a decentralized policy aiming to a more balanced spatial development (e.g., Germany, the Netherlands, or the United States). To be sure, most transportation networks are already built up in developed countries but there is still room for possible major modifications, like the construction of peripheral ways. Similarly, when redesigning the European commodity-railway system, one should keep in mind that the choice of a particular configuration is likely to trigger a particular pattern of locations. Finally, most developing

countries are still underprovided in transportation infrastructures and it is important to be able to make recommendations that agree with the long run development objectives of these countries.

It is not clear whether or not transport infrastructure acts as a driving factor in spatial economic development. Consequently, in our experiments, the possible impact that the network configuration might have on the level of activity is disregarded. In addition, since our interest is about macro-spaces, we assume that transport networks are congestion free. The impact of the network on locations is then seized through the following variables. First, we retain the number of facilities. A large number of facilities may indeed be viewed as an indicator of a more dispersed configuration. Second, the location of facilities is also a critical variable. It is shown that *radial networks have a dramatic impact on locations in that they lead to a rather small number of facilities*, a single facility located at the network center being often the only solution when fixed costs are high. By contrast, *a grid network fosters a much more dispersed configuration with a fairly large number of facilities*. These results are not terribly surprising in that they agree with casual evidence. *The addition of a peripheral road reveals how the attractiveness of the center may be weakened when a radial network already exists*. The size of the ring around the center turns out to be a critical policy parameter. This is shown by means of many numerical solutions of the simple plant location problem in the case of a uniform demand and of randomly generated local demands. Hence the addition of specific and particular links to a network may not only improve the accessibility to existing facilities but may also affect the accessibility to the facility system through a change in locations (Blum, Gercek and Viegas, 1992).

Finally, we investigate the locational implications of the opening to trade of two separated economies - a 'radial economy' and a 'grid economy' - by assuming that the network of the common market is now given by *merging* the two national networks. This is an important question from the policy standpoint since the creation of a single market involving economies where different national transportation policies have been followed (for example, France and Germany, or United States and Mexico) is occurring both in North America (NAFTA) and in Europe (EU). There is a growing literature devoted to the impact of globalization on the geographical distribution of activities (see the recent survey by Ottaviano and Puga, 1998). However, this literature fails to deal explicitly with the shape of transportation infrastructure. This is what we aim at investigating here in the hope of providing useful insights. When the long-run locational adjustments have taken place, it is seen that the regional grid economy still involves several facilities whereas the regional radial economy is characterized by a much smaller number of facilities. The *border* between the two regional structures turns out to be critical in that it attracts facilities on the side of the grid economy. These results shed new light on the possible geography that could emerge within a common market. They further suggest that *history matters for locational patterns as far as transport networks are concerned*: the formation of a common market is not likely to have a dramatic impact on the regional structures of locations, even though the absolute level of activities within each region may well be significantly affected. This conclusion is strengthened by our complementary study of the impact of the network density.

Combining two economies endowed respectively with a dense and a sparse grid network (somewhat like in the case of West Germany and East Germany), we observe that the shape of the network seems to have a stronger impact than its density.

2. The Model and Experiments

2.1. *The Simple Plant Location Problem in Operations Research and Economic Geography*

A great deal of attention has been paid in the 1970s and the 1980s by operations researchers and management scientists to the modeling of locational decisions. There now exists a well-developed body of literature which is of great interest to economists, geographers and regional scientists [Francis and Mirchandani (1990) and Drezner (1995) contain several surveys devoted to various aspects of locational decision making].

A particular model, known as the **simple plant location problem** (in short, SPLP), has emerged as the main prototype. The SPLP captures the trade-off emphasized in the work of Christaller and Lösch: given some requirements for a composite good distributed over space, the purpose is to determine the number and locations of facilities so as to minimize the sum of production and transportation costs.

On the demand side, social needs are expressed by some fixed **requirement** for a **composite good**. Requirements are distributed over a finite number of points $j = 1,...,m$ and the requirement for the composite good in site j is denoted by $_j$. On the supply side, facilities can be placed at a finite number of potential locations $i = 1,...,n$ while production involves **scale economies**. The set-up cost F_i and marginal cost c_i are constant; hence the production costs of a facility at i with output q_i are given by $F_i + c_i q_i$. Different fixed costs (F_i) may account for differences in fixed factors endowments, while the marginal costs (c_i) may reflect particularities in local competition for variable production factors. Finally, the cost of shipping one unit of the composite good from site i to site j is a constant t_{ij}. Clearly, the matrix (t_{ij}) of transportation costs is general enough to allow for different shapes of the transportation network and various access conditions to local markets. Note that a rise in fixed production costs is formally equivalent to a fall in transportation costs; hence studying the impact of the F_i on the locational pattern amounts to studying the impact of the t_{ij}.

Formally, the SPLP is defined as follows:

$$\text{Min} \quad _i \quad _j \left(c_i + t_{ij} \right) \,_j \, x_{ij} + \,_i F_i \, y_i$$

subject to

$$0 \quad x_{ij} \quad y_i, \quad i,j$$

$$_i x_{ij} = 1, \quad j$$

$$y_i \quad \{0,1\}, \quad i$$

where x_{ij} stands for the (nonnegative) fraction of the demand at j supplied by a facility at i, and y_i a 0-1 variable which equals 1 when a facility is set up at i and 0 otherwise. The first set of constraints implies that no demand can be supplied from a site where no facility has been built. The second set of constraints means that the total requirement in each j must be met.

2.2. *Lattice, Networks and Demand Structures*

Computational experiments are conducted on **idealized networks**. Choosing a theoretical lattice rather than a real-world layout enables us to better isolate the tested problems from many other sources of variation and to control as much as possible for spatial layout. A hypothetical settlement allows us to conduct tests without the additional complexity introduced by empirical modeling; it is completely free from any contamination related to data collection, coding or other errors and, therefore, should lead to a greater generality of the conclusions.

As discussed above, we consider simulations on a discrete transportation space. The set of points chosen among the possible spatial configurations is a 17×17 **squared lattice** with 289 points where each point j has the same spatial environment as every other, at the exception of the border points. Each point j of the lattice is simultaneously a demand point and a potential location for a facility. Each j is characterized by its coordinates (x_j, y_j) and is linked by an edge to its closest neighbors. Each link has a length of 100 for horizontal or vertical edges and 141 for diagonal edges.

A quantity $_j$ is associated to each point j of the lattice. It stands for the quantity demanded of the composite good in that point. In a first set of simulations (see § 3.1), this quantity is supposed to be invariant with j, that is, the distribution of demand is uniform with $_j =$ 3 for all j (where the value 3 has been chosen in order to make the comparison with the stochastic demand case easier). In a second set of simulations (see § 3.2), demand varies randomly across locations. Specifically, the support of $_j$ is given by the integers between 1 and 8, the total demand ($_j$ $_j$) being the same in both sets of simulations. We allow for substantial variations in the spatial pattern of local demands in order to gain more robustness in our results.

The number of edges and their spatial organization define the transportation network. Three families of transportation networks are designed on the squared lattice of points. Our choice is motivated by the fact that the selected networks approximate fairly well real-world networks. More precisely, we consider grid (denoted *Rect*) and (circum)radial networks (*Circ_r* , r 0). In network *Rect*, only the horizontal and vertical edges are considered as transportation links, thus corresponding to a grid network (see the RHS of Figure 1). Radial networks have fewer links than regular networks. *Circ_0* represents a radial network without any peripheral link (see the LHS of Figure 1). It is well known that this type of network tends to favor the center for accommodating a facility location (Perreur and Thisse, 1974). When adding a belt to a radial network, one obtains a circumradial network (*Circ_r* , $r > 0$). In this type of network, accessibility is improved because there are more edges. Perreur and Thisse (1974) then show that optimal

facility locations may also occur on the peripheral road, that is, at the intersections with the radial axes. In a companion paper, Peeters and Thomas (1995) show that the position of the peripheral road is of prime importance for the choice of facility locations in the p-median problem. The same result is expected to hold for the simple plant location problem. In the present paper, r is an index that stands for the position of the ring road. When r is equal to 1 the ring road is close to the network center; when r is equal to 8, the ring road is located at the outer limit of the lattice.

Last, we merge two squared networks in order to see how far the optimal locations in a common market depend upon the underlying regional networks. Our ***mixed network***, represented in Figure 1, is made of two squared lattices. Simulations have been performed on several sizes of rectangles and show that the size of the network does not affect our results. So we here refer to a rectangle of 289 points, made of two 12 ×12 squared lattices. On the left squared lattice, a radial network is designed and a central point is added (145 points); on the right one, a grid-type network is designed on the 144 remaining points. Finally, the two squared lattices are bound together by 12 horizontal links. In this set of experiments, demand is supposed to be the same across locations.
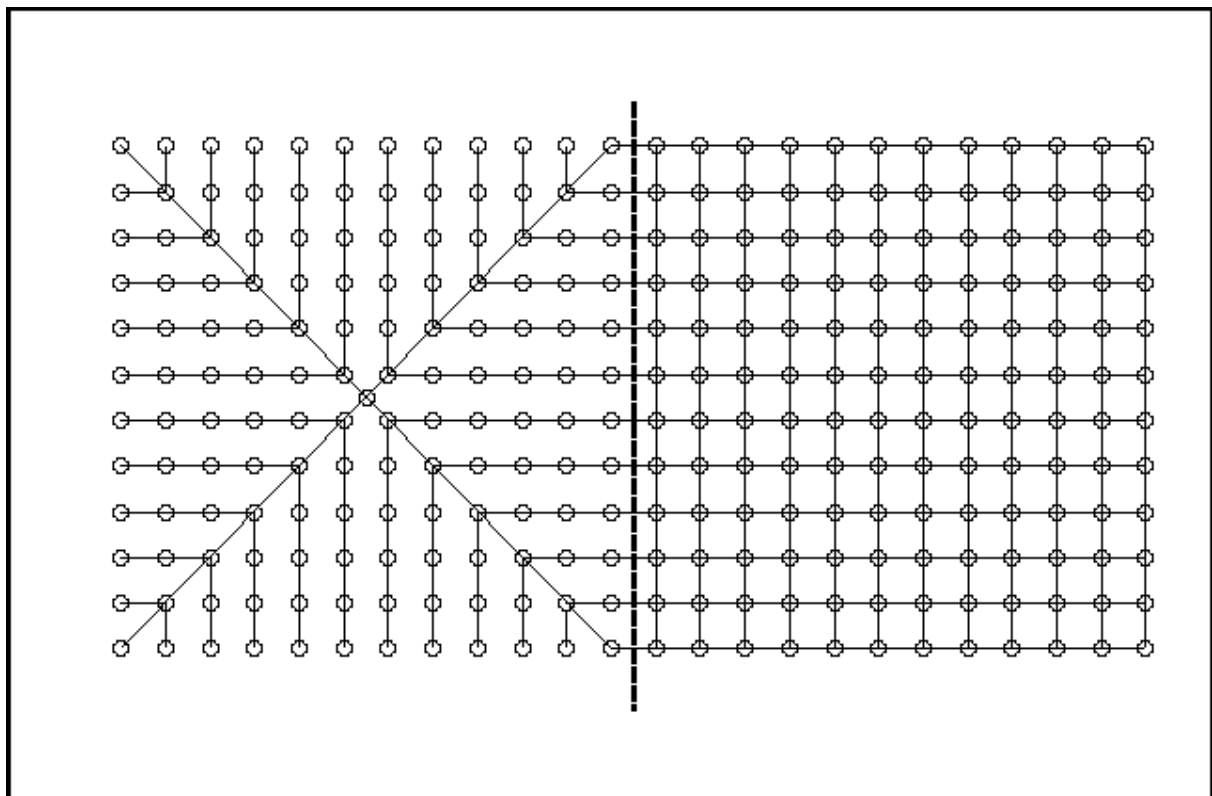

Figure 1 : Map of the mixed network.

Following the suggestion made by a referee, we have also investigated the question of dense vs. sparse networks by merging two grid networks, one of which is described by a 15 × 15

squared lattice and the other by a $k \times k$ squared lattice where k stands for the number of horizontal or vertical links and takes, respectively, values from 2 to 8 while the length of the corresponding edges is adjusted for the covered area to be the same. In so doing, we want to control for the country size effect. First, we assume that the global level of activity is the same in both economies in order to isolate the sole impact of the density of the network. This implies that local demand in the sparse network is higher than in the dense network (for example, when k = 5, $_j$ = 9 in the sparse network whereas $_j$ = 1 in the dense network). Second, since a sparse network is often associated with a lower level of activity, we perform the same set of experiments when the local demand is the same everywhere in the two countries ($_j$ = 1 for all j).

In each experiment, the simple plant location problem is studied (see § 2.1). For each network, the model is applied several times, one for each selected value of the fixed costs. In our experiments, this parameter, denoted F, varies from a floor-value of 1,000 to a ceiling-value of 200,000. Since we focus on the impact of the transportation network, we assume that fixed costs are equal across locations in order to control for the role of differential factor endowments. Specifically, transportation costs are linear in distance while marginal production costs are zero. This implicitly means that tariffs are set to zero between the two countries.

3. The Impact of Transportation Network on Location

3.1. *Comparing Networks under Uniform Demand*

In this section, we consider a squared lattice of 289 vertices over which demand is supposed to be uniformly distributed. In this way, we concentrate on the sole geographical implications of the network configuration. The four networks described above are studied.

(i) Figure 2 gives the optimal number n^* of facilities for F varying from 5,000 to 200,000 for all four networks. As expected, the optimal configuration of facilities contains fewer and fewer facilities as F rises. In the radial network case, we see that the decrease in n^* is very sharp; a single facility solution is obtained from a fairly low value of the fixed cost, thus suggesting that *the center of a radial network is the source of a strong agglomeration force*. On the contrary, in the case of the grid network, the optimal configuration involving a unique facility is obtained with a value of F which is three times as large as in the radial case, confirming the intuition that such a network yields more dispersion in human activities. For circumradial networks, we obtain intermediate solutions. This means that the construction of a peripheral road is indeed an instrument that can be used by spatial planners in the aim of fostering a more scattered distribution of human activities. Observe that the analysis of the values taken by both the transportation costs and installation costs confirms the results presented in Figure 2 in that transportation costs rise with the level of fixed costs through a fall in the number of facilities. Though all these observations depend on the fact that F is the same across locations, no major change is expected to arise when variations in fixed costs are not too large.
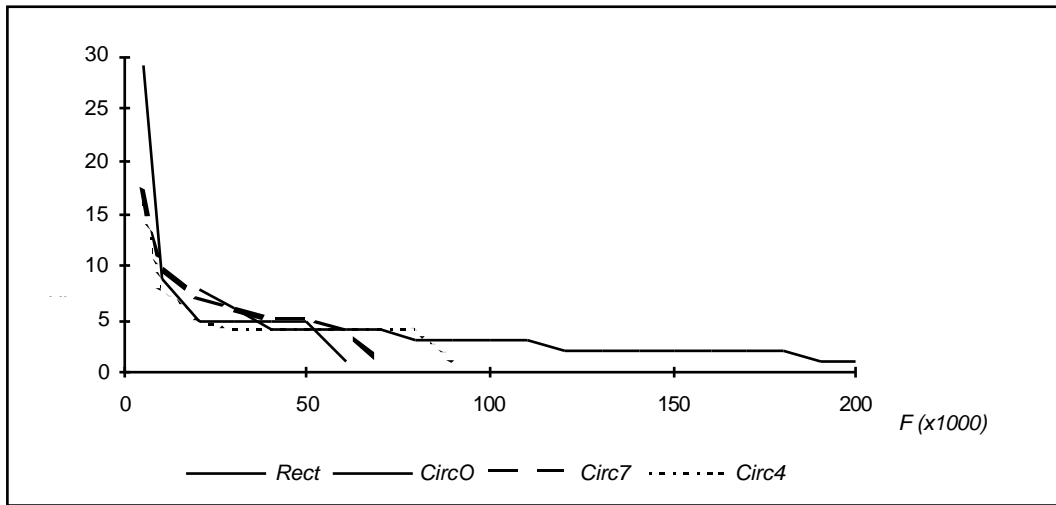
Figure 2 : Variation of the number of facilities with F.

(ii) We now turn to the characterization of the optimal locations. We retain the value F = 80,000 which leads to typical results in our many experiments. Starting with a radial network, we observe immediately that a single facility is set up at the center (see Figure 3a). This is reinforced by the fact that there is always a facility at the center for all admissible values of F. On the other hand, a grid network leads to the construction of three facilities which are (more or less) evenly spaced (see Figure 3b).

Interestingly, if a peripheral road is installed at some intermediate distance from the center ($r = 4$), the optimal configuration then involves four facilities, all located at the crossing of the radial roads and of the ring road (see Figure 3c). This shows that the attractiveness of the center may completely ***vanish*** when a peripheral road is built at a well-chosen distance from the center. Again, such an observation is confirmed for other admissible values of F. It is worth noting that the choice of the radius r is crucial for this result. Indeed, varying r from 1 to 8, we can show that the center does no longer accommodate a facility when 2 r 4, but is included the optimal configuration for the other values of r. For low values of r, the ring road has almost no impact on the optimal pattern of locations because the nodes it generates are too close to the center. On the other hand, large values of r are such that these nodes are now situated at the outskirts of the area so that they have only small hinterlands to supply, a fact that strongly reduces their attractiveness.
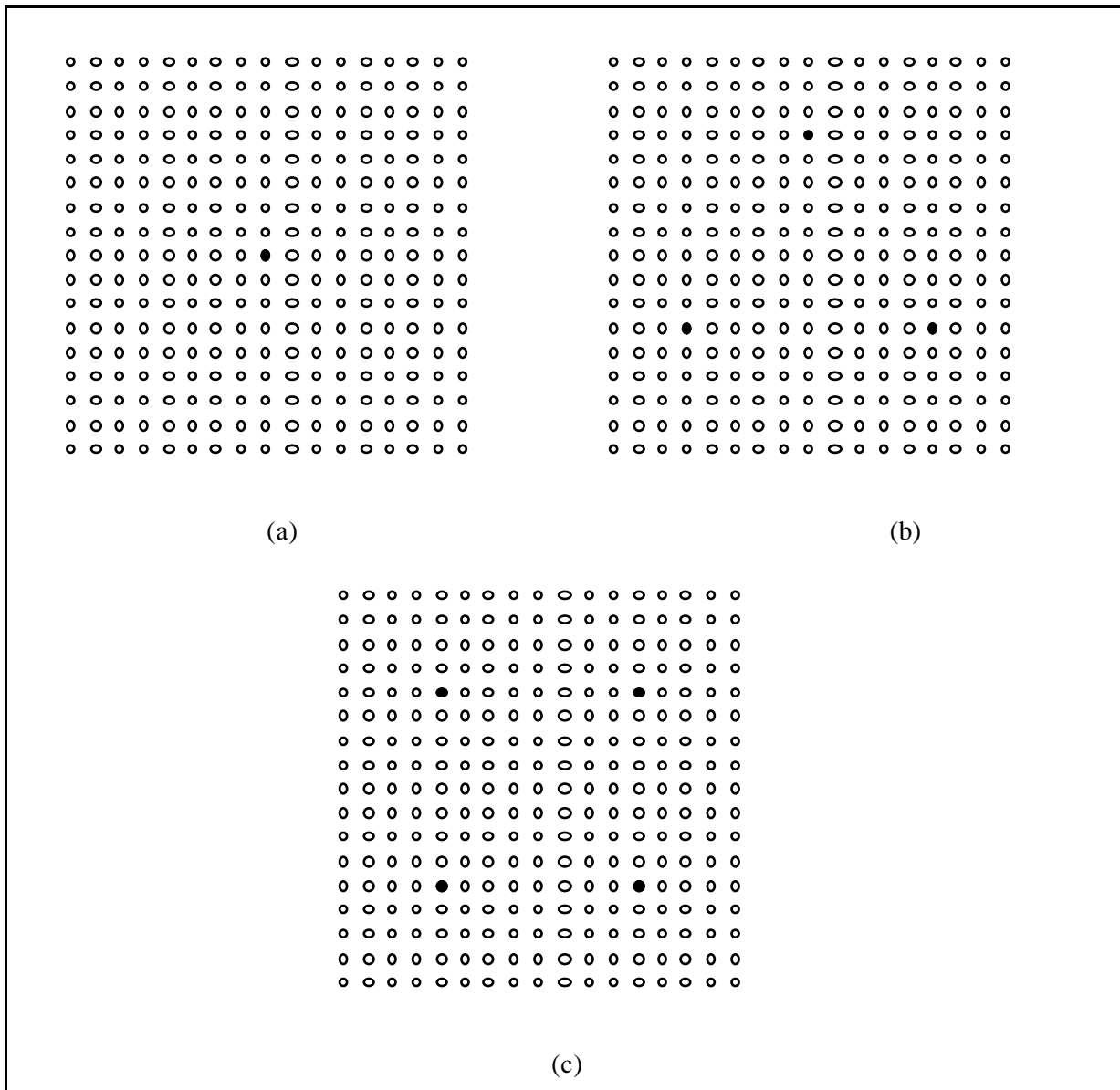
Figure 3 : Optimal locations with F=80,000.
(a) : Radial network (*Circ_0*); (b) : Grid network (*Rect*); (c) : Circumradial network (*Circ_4*).

3.2. *Comparing Networks when Demand is Random*

In order to gain more insights about the robustness of the results displayed in the foregoing section, we now assume that the requirements are generated randomly. Roughly speaking, the results are quite similar to those obtained with a uniform demand. We compare in Figures 4a, 4b and 4c the optimal number of facilities for the uniform demand and a typical realization of the random demand. It is seen that, regardless of the network configuration, the number of facilities is almost the same under the two demand structures. The same holds for most optimal locations. Consequently, *the shape of the transportation network seems to have a stronger impact on the optimal facility locations than the spatial distribution of demand*. This is rather unexpected in

view of the amount of work devoted to the impact of demand in one-dimensional location models and given the large variety in local demands we have allowed for in our experiments.
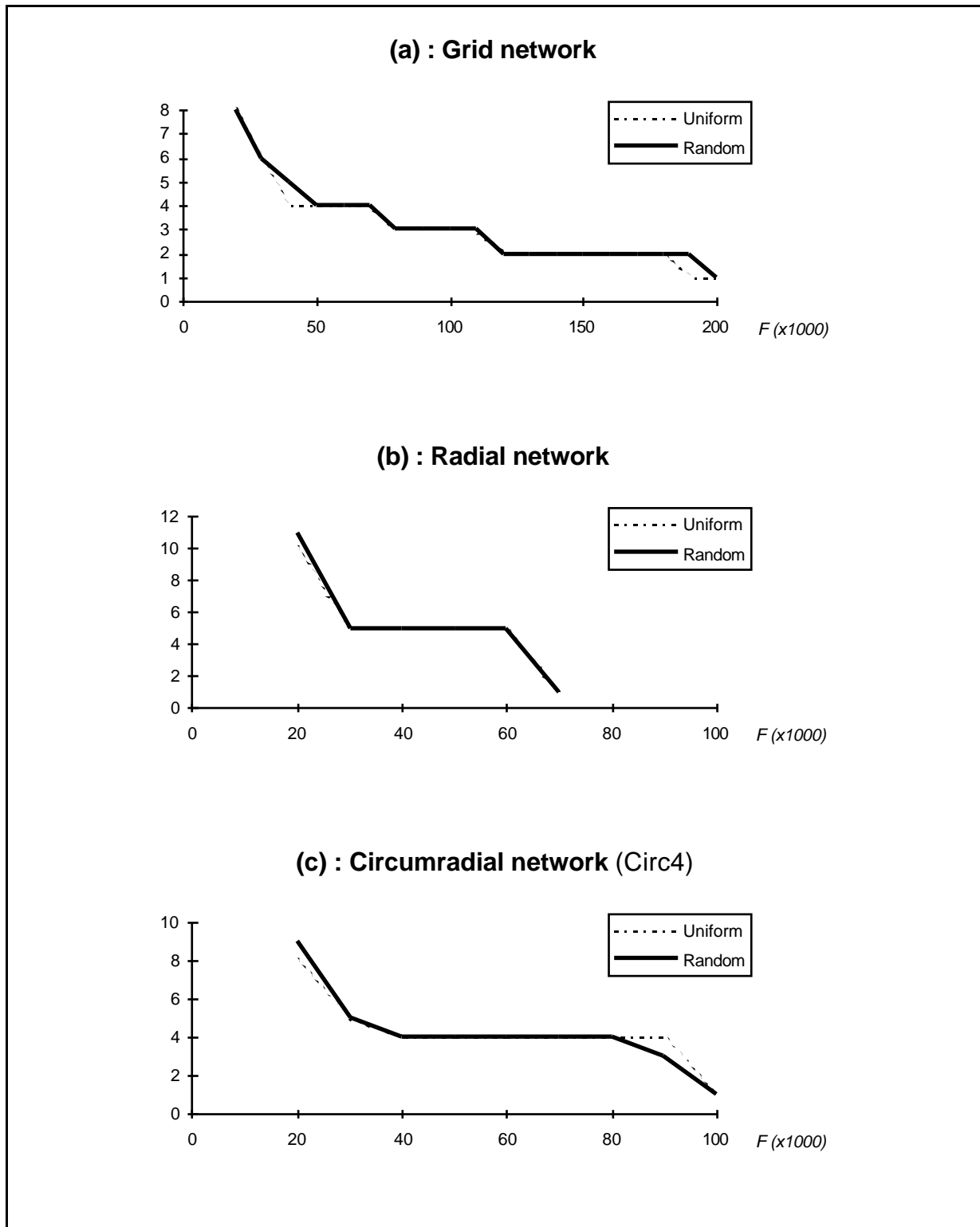

Figure 4 : Variation of the number of facilities with F, for 3 networks.

3.3. *Merging Different Networks in a Common Market*

In this section, we want to evaluate the impact of network configuration when two economies characterized by different networks are integrated. For the reasons discussed in the introduction, we focus on radial and grid networks that are adjacent. The total size of the integrated economy is the same as the one of a single economy (289 points and uniform demand). We assume that both economies have the same size in order to control for the size effect and that the number of 'gates' between the two economies is equal to the common number of horizontal links in both networks.

(i) In Figure 5, we give the optimal number n^* of facilities in the integrated economy as well as in each separate economy. For small or large values of the fixed cost F, the total number of facilities is about the same. In other words, with low- and high-scale economies, the opening of the economies is not likely to have a strong impact on the locational pattern (assuming of course that the spatial distribution of demand remains the same). On the other hand, for intermediate values of F, the integrated economy typically involves a number of facilities smaller than the total number of facilities operating in the separate economies. In this case, market integration seems to yield more geographic agglomeration.
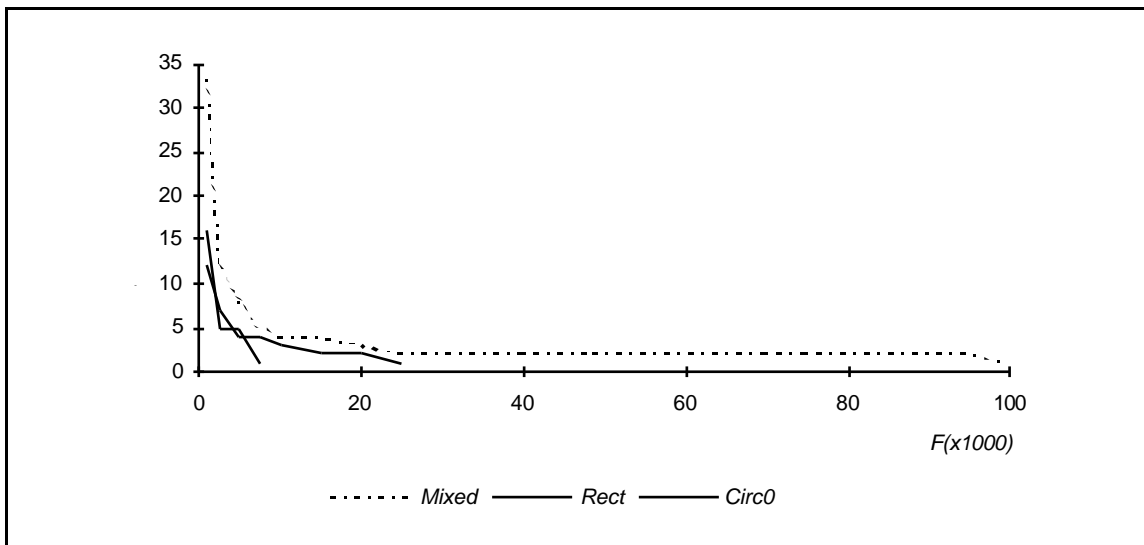

Figure 5 : Variation of the optimal number of facilities with F.
(*Rect* : 144 grid network; *Circ₀* :145 points radial network; *Mixed* : 289 points mixed network).

(ii) Turning to the optimal locations, two cases are considered: Figure 6 describes the optimal locations when both economies are integrated, while Figure 7 corresponds to the case where the two economies are separated. We may summarize our main results as follows. First, the center of the radial subnetwork attracts a facility in both the integrated economy and the separate radial economy. Second, the grid regional economy often admits a larger number of facilities than the radial regional economy. Hence, even when a grid economy is integrated with a radial one, it retains most of its properties regarding the dispersion of human activities. Third, for values of F

not too large, Figures 6a and 6b show that *some facilities set inside the grid regional economy are established near the border between the two economies* (think of Strasbourg or of some segments of the American-Mexican border). Hence, though the formation of a single market has an impact on locations, these ones are primarily to be found in the region endowed with a network inducing the dispersion of activities. Hence *the history of national transportation policies should matter for the geography of the integrated economy*. We will return to this point in the next section. Last, recall that tariffs are supposed to be zero in the custom union since transportation costs are unaffected by the crossing of the border. The existence of positive tariffs would lead to configurations closer to those obtained in each separated economy (see Figure 7).
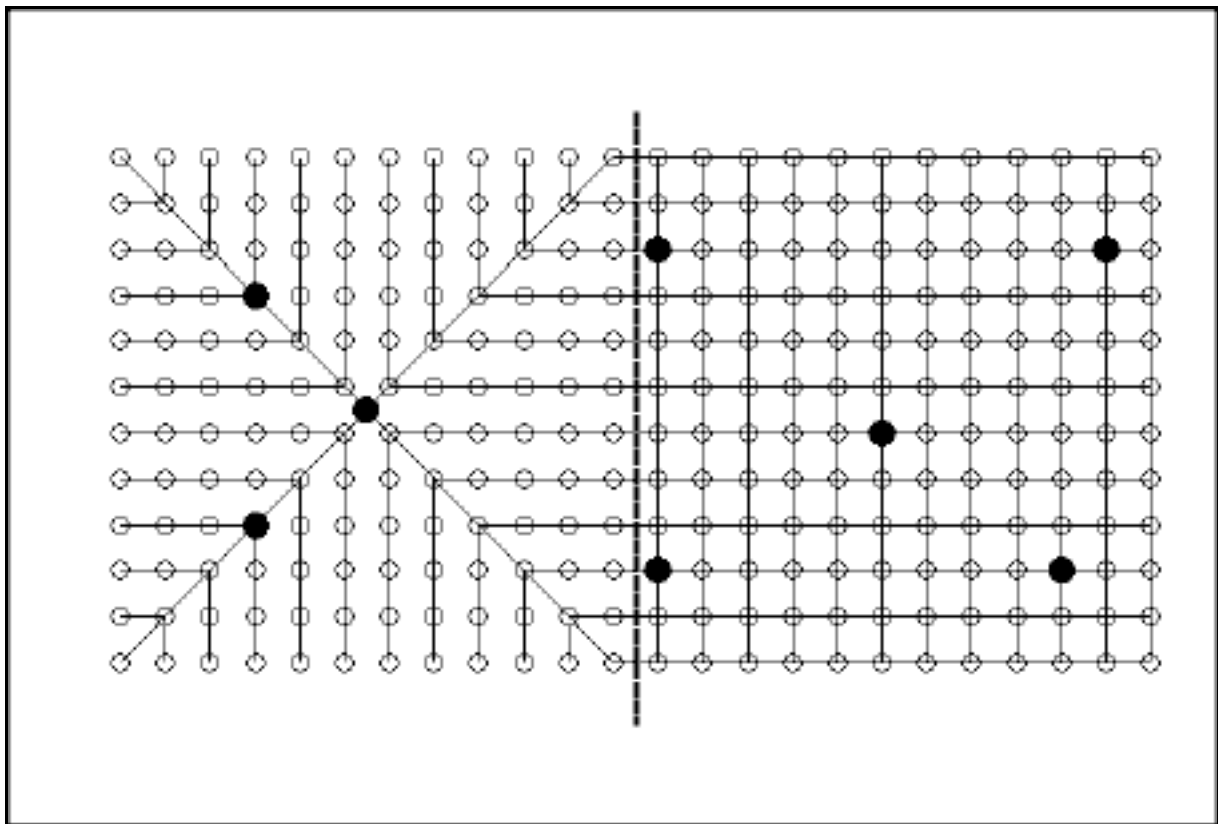

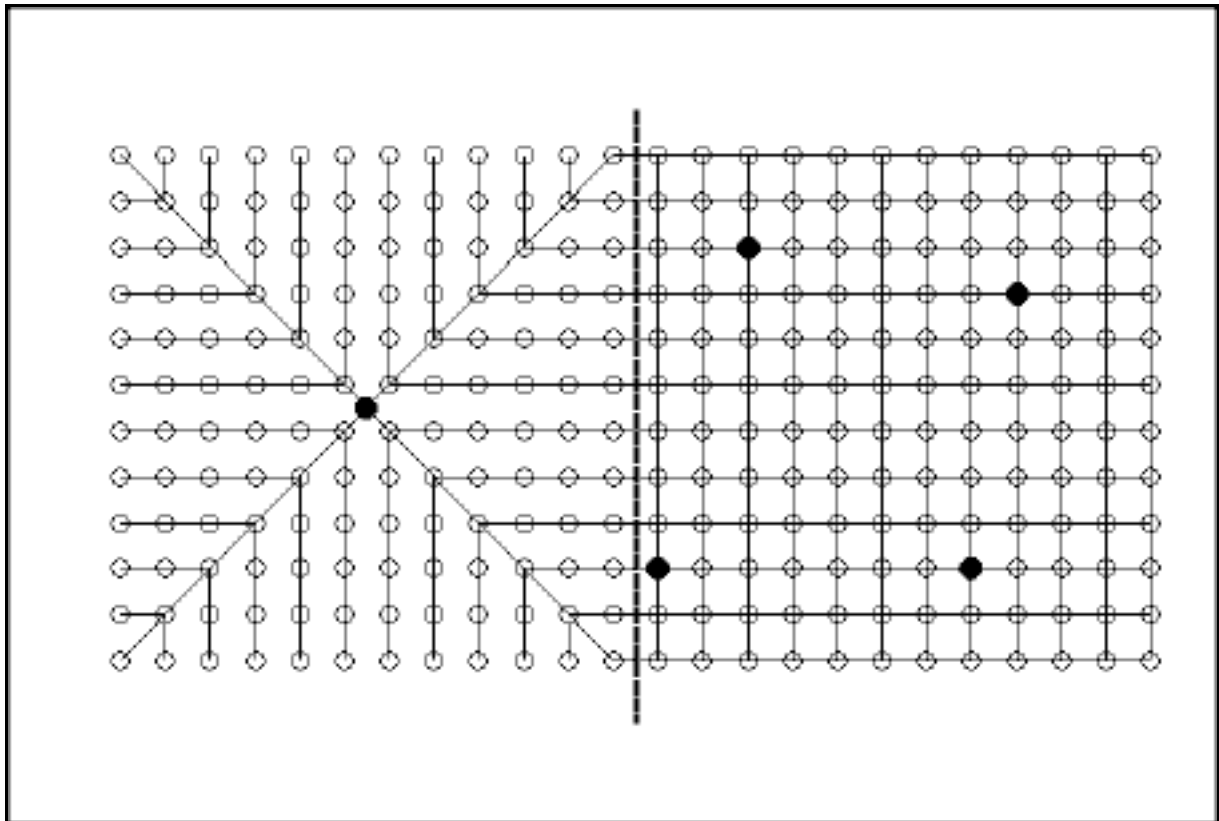**Figure 6a**: Optimal locations for a mixed economy and for F = 5,000.

Figure 6b: Optimal locations for a mixed economy and for F=7,500.
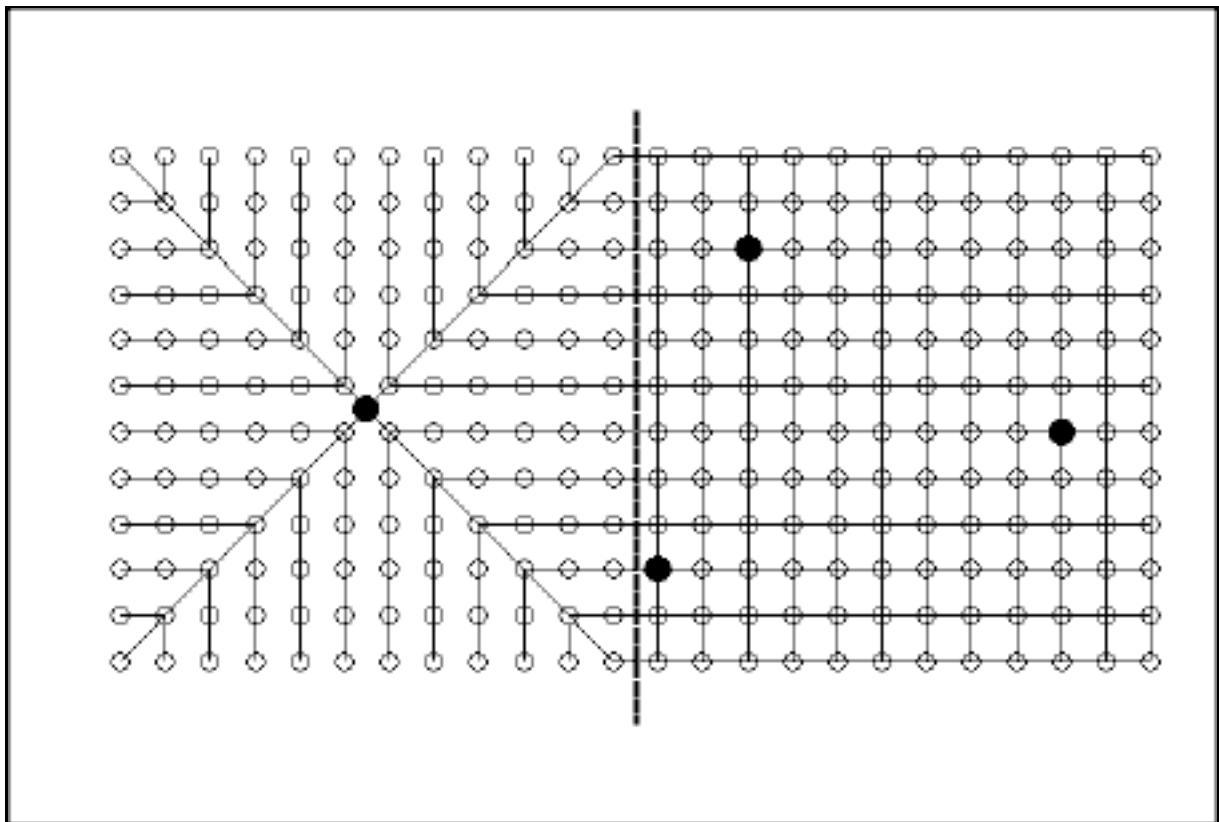

Figure 6c: Optimal locations for a mixed economy and for F=10,000.
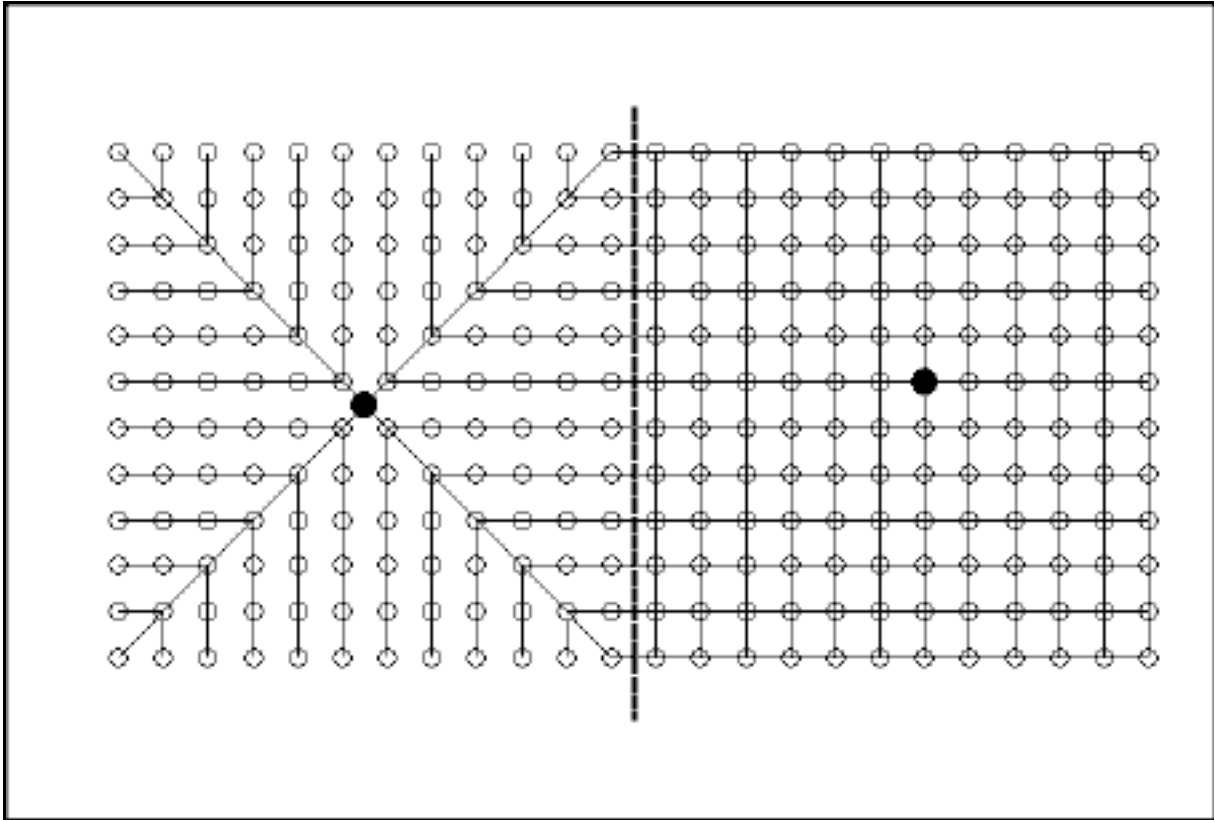
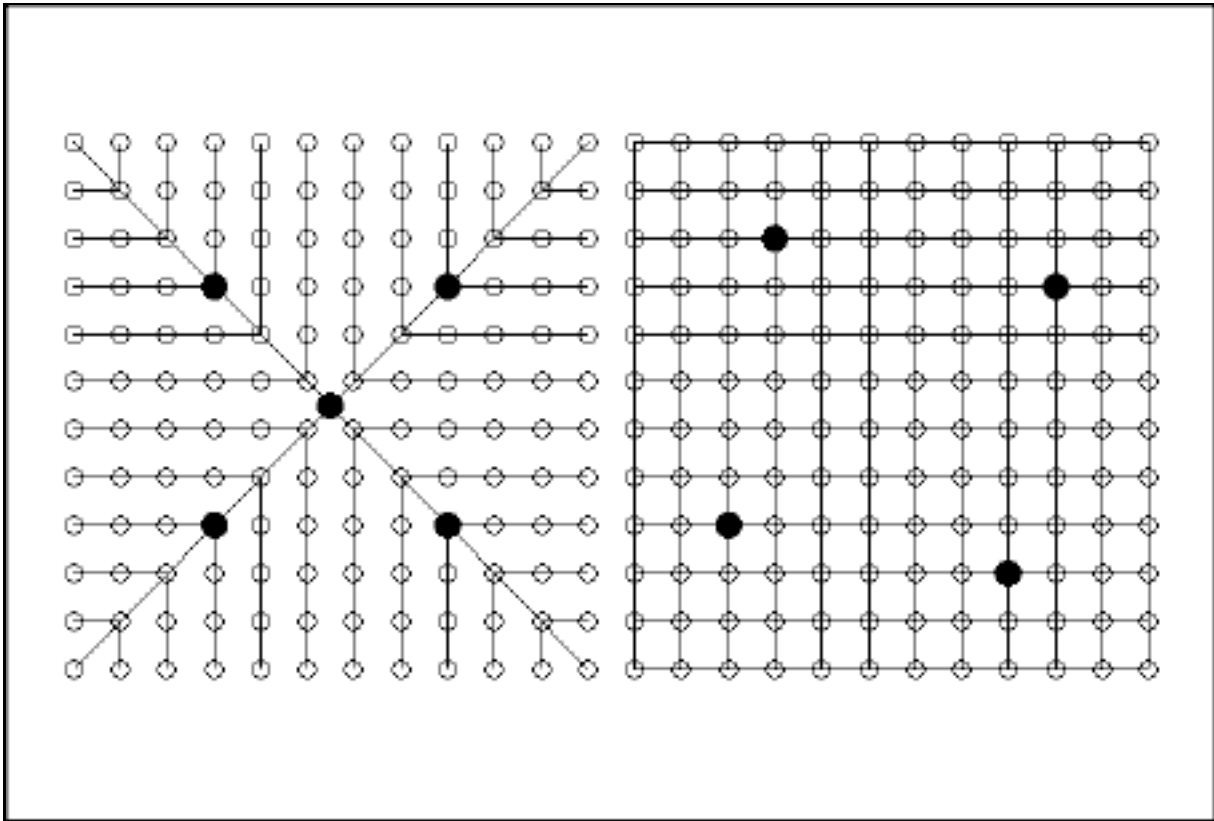**Figure 6d**: Optimal locations for a mixed economy and for F =30,000.

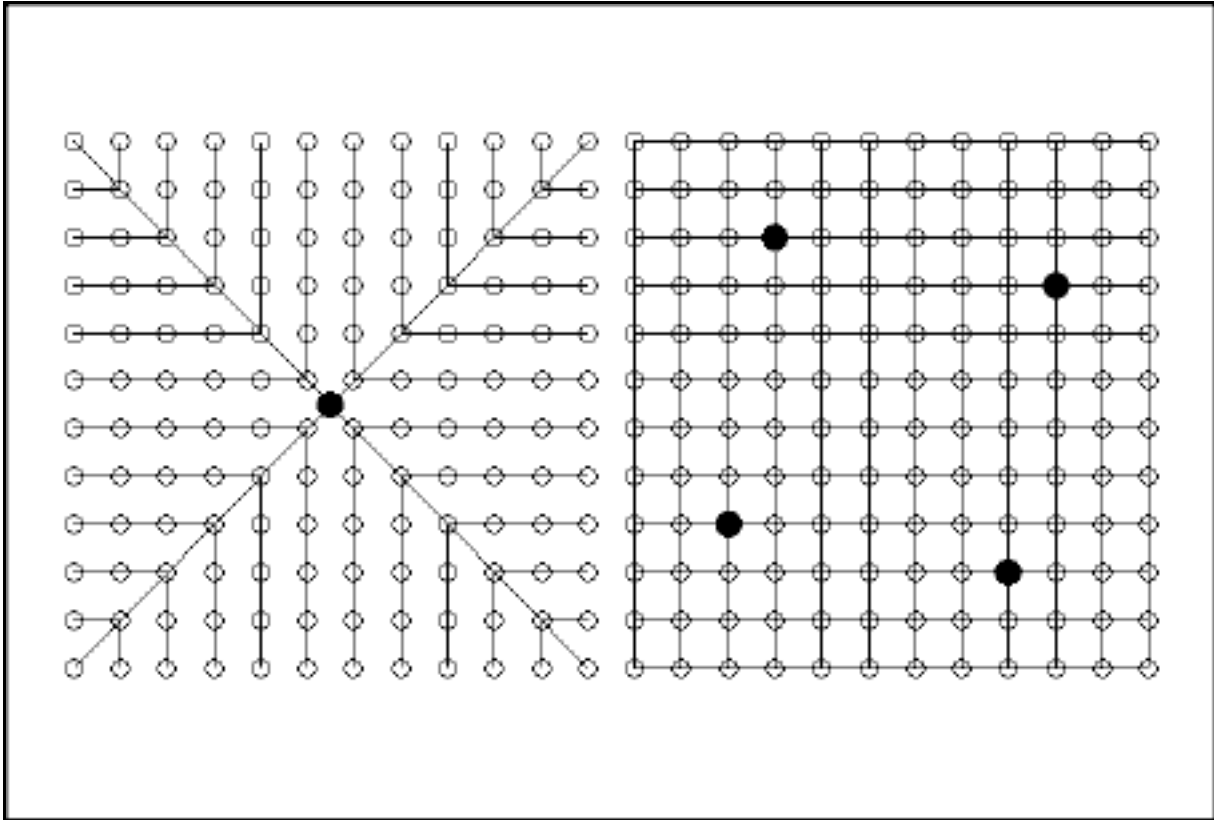**Figure 7a**: Optimal locations two separated economies and for F=5,000.

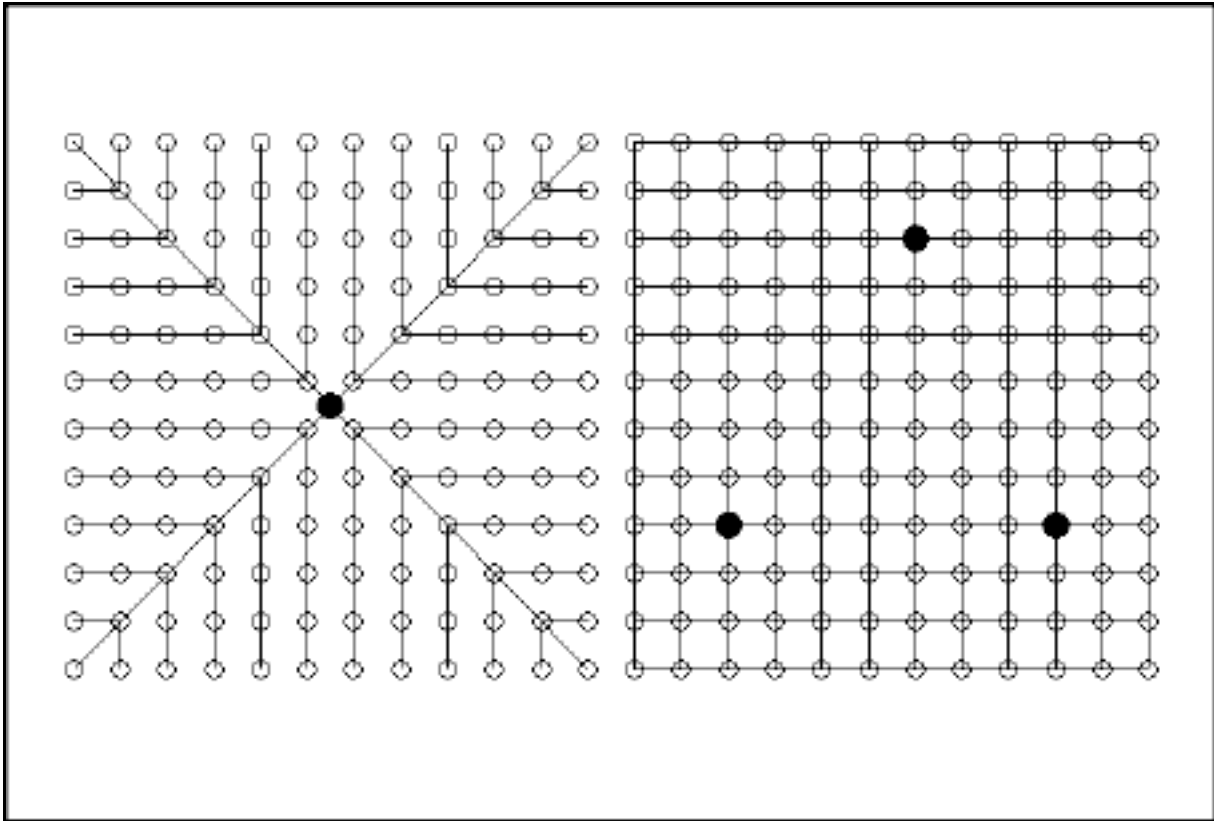**Figure 7b**: Optimal locations two separated economies and for F=7,500.

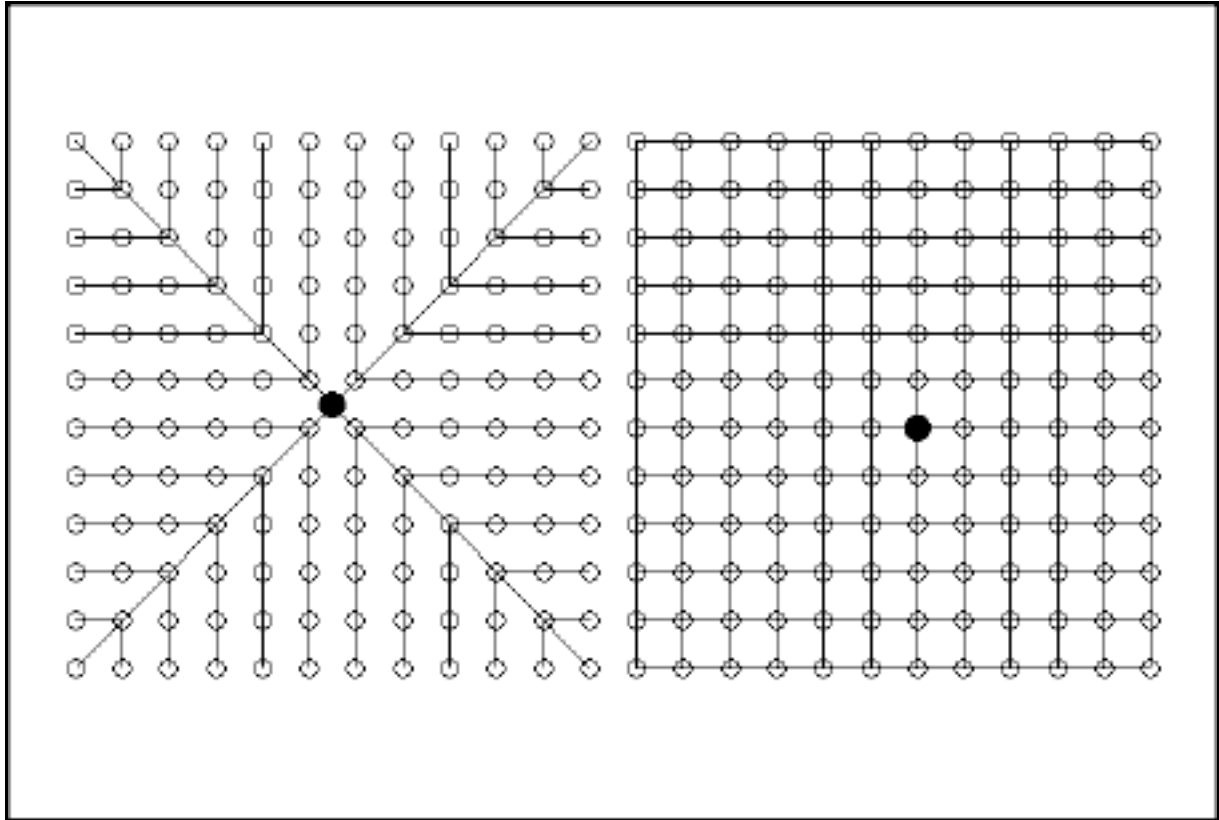**Figure 7c**: Optimal locations two separated economies and for F=10,000.

Figure 7d: Optimal locations two separated economies and for F=30,000.

3.4. *Merging Similar Networks with Different Densities*

We now consider the case of a 15×15 grid network together with a $k \times k$ grid network in the hope of evaluating the impact of network density by varying k from 2 to 8 (see § 2.2).

(i) When we control for the demand level, we observe that the patterns of location in each country are, in most cases, unaffected in the integrated economy while changes in locations are minor in the other cases. This confirms our previous finding that the history of a national transportation policy is important in determining the impact of a common market on the locational pattern of activities.

(ii) Similar experiments have been carried out assuming equal demand across locations within the integrated economy with $_j = 1$ for all j. Unless fixed costs are very low, we observe some predatory effects at the expense of the sparse network: the dense network economy dominates the sparse network economy whatever its size. The latter experiences a substantial decrease in the number of facilities; in the limit, the corresponding country empties out. Clearly, this dramatic effect is due to the fall in the number of demand points, and not much to the discrepancy in network densities. Such a situation might fairly well correspond the merge of West and East Germany in that the latter tends to benefit from the same social advantages than the former.

4. Concluding Remarks and Policy Implications

Recall that the existence of scale economies in human activities is a critical factor for explaining the formation of the socioeconomic landscape. The mere existence of indivisibilities in production makes it desirable to concentrate production in a relatively small number of facilities producing for dispersed consumers. However, the geographical extension of interaction areas implies the existence of positive transportation costs (defined broadly in order to include all the impediments to trade), imply that the entire production is generally not concentrated in one place. Therefore, there is a fundamental trade-off between scale economies and transportation costs in a spatial economy, whence our interest in the simple plant location problem. Since the beginning of the Industrial Revolution, the increasing spatial concentration of activities has been caused by the fall in transportation costs and the rise in fixed production costs (Bairoch, 1985), two facts captured by the SPLP.

It is our belief that obtaining general results regarding the impact of the shape of the network on the location of facilities is highly problematic because of the combinatorial nature of the problem, even in the case of toy-networks. However, we also believe that the many experiments we have made provide us with particular, but meaningful, results. Several comments are now in order. First, *the outcome of the spatial trade-off is strongly affected by the shape of the transportation network*, thus confirming the robustness of the localization theorems obtained in facility location analysis (Beckmann and Thisse, 1986; Labbé, Peeters and Thisse, 1995). More precisely, we have seen that radial networks lead to more concentrated patterns of production, the center playing the role of a powerful attractor. In contrast, a grid network leads to a more dispersed pattern with several locales accommodating facilities. Though such results probably belong to the folk wisdom of human geography, it seems to us that our many experiments give them more robustness.

However, radial economies are not necessarily stuck with concentrated geographical patterns. *The construction of a peripheral road around the center of a radial network can boost a major deconcentration of human activities towards the nodes situated at the crossings between the radial roads and the ring road*. If such a policy is to be implemented, the choice of the ring radius turns out to be a critical variable. A too small radius leads to a circumradial network that does not depart enough from the original configuration to generate dispersion, while a large radius yield nodes with too small hinterlands to become attractive. Clearly, even when the radius of the peripheral road is well chosen, it would be illusive to expect the outward pull discussed above to generate its effects in the short or medium run. *The possible impact of such a policy on locations will become visible only in the (very) long run*.

This conclusion must be qualified in view of some recent contributions in spatial economics. As discussed by Arthur (1990) and Krugman (1991), human activities may be locked in at some particular places for reasons that have nothing to do with the transportation network

(examples are provided by the 'industrial belt' in the US or the 'golden triangle' in Europe). Indeed, it seems that modern economies are more and more characterized by a ***putty-clay geography*** in which there is *a priori* a great deal of flexibility in the choice of locations but a strong rigidity in spatial structures once the process of agglomeration has started. The forces generating lock-in effects are based on the spatial interdependence between consumers and producers. They are not present in the SPLP where the spatial distribution of demand is fixed. Such forces should normally reduce the impact that the construction of a peripheral road might actually have on locations, even in the very long run. Yet, it remains true that ***the main nodes of the transportation network are likely to be the focal points of an economic geography in which human activities become more and more footloose*** (a spectacular example of such a phenomenon is provided by Chicago; see Cronon, 1991). Stated differently, major nodal points chosen in the past as locations of facilities will probably be the most advantageous places in the future because most of them have experienced the accumulation of a wide array of comparative advantages that will permit them to remain attractive. Note also that the spatial structure of demand is supposed to be fixed in our experiments. It seems reasonable to believe that some individuals will choose to relocate in order to be closer to the facility locations. This opens the door to the mobility of households, which may vary across countries or regions.

Second, the role of transportation infrastructure in an integrated economy has been a very much neglected topic. To the extent that the construction of transportation infrastructures can be regarded as irrevocable, networks are hostages to the past and keep influencing the decisions made in the new economic and political environment. This legacy is heavy: ***within the limits of the regional economy, a network has about the same impact on the spatial organization of activities as in the case of autarky***. Even though the level of activity is likely to be affected by the integration of various economies, it is less clear that the geography of human activities within each one of them is to be drastically modified (Krugman, 1991). On the contrary, the developments above suggest that the geographical organization of economic and political activities might well remain approximately the same within each original territory. Accordingly, one must be careful before drawing clear-cut implications about the impact of economic integration on the spatial distribution of human activities. Indeed, ***transportation networks, especially radial networks, are to be viewed as a strong force of inertia*** in the location of human activities, that could supplement those discussed above.

Last, network configurations have long-run implications for the spatial organization of human activities. This is a strong message for developing countries that invite us to reconsider standard policies. Radial networks have often been adopted in such countries (Alonso, 1969). And there are good reasons for such a choice. First, radial networks are organized around the main metropolitan area of the corresponding country, that is, around a place with much need. Second, they require less resources to be built than grid networks but we did not consider the total cost of construction of a network. However, what seems to be a sensible decision from the short/medium run point of view may no longer be reasonable in the long run because the resulting balance of

activities in space is very uneven. This suggests a gradual policy in which irrevocable decisions regarding the shape of the transportation network are delayed in the hope that more resources will become available for the construction of a grid-like network covering the whole territory under consideration.

A second warning regarding policy is in order. Krugman and Elizondo (1996) have studied the impact of trade policy on urban concentration in developing countries. They show that there is a surprising linkage between trade policy and urban development: free trade would foster urban decentralization while restrictive trade practices would induce more spatial agglomeration. To the extent that local production is more and more directed to the world market, access to the main domestic market becomes less crucial than in autarky, thus reducing the lure of the primatial city. To obtain their result, Krugman and Elizondo assume that the developing country is formed by two regions with no spatial extension and no transportation networks. Here also, our results suggest that strong policy recommendations based on such simple models are to be reconsidered within a more general framework accounting for transportation infrastructure.

Our analysis is incomplete in several respects. Among the possible extensions that are worth studying, we would like to mention the following ones. First, using general networks, one may study the possible impact of the construction of additional links as well as the increase of the capacity and quality of existing links. This is especially relevant in the case of the merging of several economies since national transport policies typically neglect the global impact of international connections. Second, we could improve upon our framework by assuming that national networks are connected through specific gates. Clearly, an uneven distribution of gates should have a significant impact on locations. Third, we restrict ourselves to a small number of toy-networks but our approach could be extended to other typical configurations. Fourth, when the focus is more on micro-spaces such as urban areas, one should account for the presence of congestion along some edges when assessing the impact of new links.

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