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BARCELONA, POLICENTRIC METROPOLIS AND NETWORK OF CITIES

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Abstract: The organization of the production in the space is related to the growth and the economic development. In this research we propose the study of the links between Barcelona and the municipalities of their urban system from three levels of analysis: the metropolitan area, the policentric metropolitan region and the network of cities. The study of the metropolitan area allows checking the change of extension of Barcelona's metropolis, the direction of the expansion and the growing integration with other urban areas of Catalonia. The internal analysis of the metropolitan area allows checking that in spite of the great specific weight of the municipality of Barcelona, the urban system is policentric. The increment in extension of the metropolis is due to the combined expansion of the interaction between Barcelona and a group of cities with an old industrial tradition. The areas of influence of these subcentres are intertwined when they expand, forming a policentric metropolitan region. Finally, the application to the analysis of the theories of networks of cities allows identifying an urban system where the hierarchical relationships coexist with the non hierarchical ones, and relationships of complementarity and synergy are generated. The analysis of the networks of cities in key of knowledge-based economy allows deducing the dependence in the transmission of information and knowledge associated to the vertical and horizontal networks. Later studies should address to quantify the effects of the urban structure on the productivity and the utility.

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0. INTRODUCCTION

The organization of the production in the territory is related to the growth and the economic development. Therefore, it helps to explain why a firm located in a city is more efficient, productive or competitive than the same one placed in another city.

Many researches that have tried to relate the existence of these advantages with the territory have used the regions or the metropolitan areas as the unit of reference. However, the big urban regions, that condense the activities with more economic dynamism, contain very complex and heterogeneous polarities. Therefore, in order to understand how the territorial advantages associated to certain productive processes operate, it seems necessary to separate these big territorial units in other smaller analysis' units with economic meaning. Also, it is necessary to know how these units are related between them.

The dynamics of the urban spatial structure of the Barcelona's metropolis show an example of happened polinucleation of a typical European city. In most of North American cities, the policentric metropolis (metropolis with several centres) is formed because population and activity decentralize from a big city to other small ones of their environment. In the European case, it starts from a group of nearby cities with considerable levels of population and activity, and the policentric metropolis is formed because the direct relations increase between these cities.

This reality is very affected by processes of change in the production methods and in the way of occupying the territory. In the last decades there has been a very important spatial and populational growth. For example, only in a century the metropolis of Barcelona (Barcelona and its metropolitan area) has duplicated the land dedicated to urban uses[1].

From the economic viewpoint, the analysis of the dynamics of the spatial structure requires introducing variables related with the population, work market, specialization and productive diversity, and the interaction between neighbours and non neighbours municipalities. Although, the last objective would be to measure the externalities related with localization and interaction. Here we have a more modest objective. It is to show some evidences for the metropolis of Barcelona about:

[1] Barcelona's metropolitan growth has been interpreted by the urbanistic specialized literature as the result of the simultaneous activation of three different processes (Font et al. 1999, p.102-107): aggregation (continuation of the existent urban infrastructures); dispersion (residential extension with prevalence of isolated housings and productive models based on industries of small dimension); and polarization (installation of new big productive establishments, or big public or private equipment). These processes overlapped in the last decades of the XX century, although aggregation prevails in the 70s, dispersion in the 80s and polarization in the 90s.

a) The change in the scale of the city and the appearance of a model of polinuclear metropolis;
b) The existence of specialized concentrations of economic activity and, at the same time, a high productive diversity;
c) The organization of the urban structure in networks of cities.

1. DELIMITATION OF THE METROPOLIS AND CHANGE OF DIMENSION

After the incorporation to the European Union, Barcelona became an international metropolis. It changed its industrial base, oriented to the production for the Spanish market, towards production of goods and services for external markets. The expansion of the market was accompanied by a change of scale of the metropolis. In this moment, it includes the 10% of Catalonia's surface (3.200 Km^2), and 70% of its population (4,35 millions).

What are the reasons for this change of scale? In the 1960s and 1970s, Barcelona and the cities of its environment grow due to the high number of births and the immigration. In this moment, the growth doesn't respond to demographic reasons. The population's natural growth (births less deaths) is very scarce, due to the low rates of fecundity. The migratory growth, after being stagnated, has increased in the last years, but it is not one of the decisive factors of the scale's change.

In fact, the metropolitan growth responds to two different processes: decentralization and the growth of the spatial interaction.

Decentralization incorporates two principal components: population's decentralization from the central city and other big metropolitan municipalities towards the metropolitan corridors and road axes; and the decentralization of the industrial employment towards the axes of the second metropolitan belt.

The growth of the spatial interaction responds to the improvement in the supply of infrastructures of transport and communications, and to the development of a new production model, increasingly segmented and flexible, that generates additional increases in the demand of mobility. The metropolitan area of Barcelona has grown in extension incorporating municipalities more and more far away from the central nucleus.

How can we measure this change of scale? The application of the EEUU statistical criterions of delimitation of metropolitan areas allows measuring accurately the real growth of the metropolitan area (table 1) [2]. In accordance with the information

[2] Iterative algorithm used in the 90s by the Federal Register (http://www.census.gov/). In December of 2000, the Federal Register changed the methodology for the definition of the statistical areas, although this new one has not been used in this study. The results of the present research disagree

of the census, in 1986 the metropolitan area of Barcelona was formed by 90 municipalities, 3,57 million inhabitants and 1,04 millions of jobs. In 1996 the area is enlarged to more than 200 municipalities, 4,35 million inhabitants and 1,55 million of jobs. The forecasts obtained in diverse simulations, indicate that the metropolitan area will continue extending. Among the year 2000 and the 2001, it could reach 4,9 million inhabitants and more than two million of jobs[3].

This change of scale consolidates Barcelona like one of the six more populated metropolises of the European Union. The metropolises of Madrid and Barcelona are in the first rank of the Spanish system of cities, with practically identical contingent of population and activity.

In the same direction of change of scale, the metropolitan areas of Tarragona-Reus-Valls (Camp de Tarragona), Lleida, and to a lesser degree, Girona and Manresa, have significantly increased their area of influence:

- In 1996, the metropolitan area of the "Camp de Tarragona" contains around 70 municipalities, 312.000 inhabitants and 115.000 jobs.
- Metropolitan area of Lleida contains more than 50 municipalities, 176.000 inhabitants and 63.000 jobs.
- Metropolitan area of Girona includes around 62 municipalities, 191.000 inhabitants and 77.000 jobs.
- Metropolitan area of Manresa includes around 31 municipalities, 149.000 inhabitants and 50.000 jobs.

In Barcelona's metropolitan area, the direction of this growth is more intense towards the Southwest (Tarragona) and the West (Lleida). We detect a fast interaction process with the area of "Camp de Tarragona", as well as with the central nucleus of the metropolitan area of Lleida. In physical terms, in spite of existence of network links among the Catalan municipalities, the process of integration of work markets is built on the base of an intense process of land occupation, or around the big road axes of Catalonia. It is the well-known phenomenon called "urban sprawl"[4].

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with Clusa and Roca Cladera (1997). Main differences come because they try to adjust the metropolitan region to seven counties. In our researches, contiguity criterion is applied in a more relaxed way, since our objective is not to form a homogeneous closed area, but defining a space of interaction.

[3] Forecasting has been carried out extrapolating the variation in the commuting between 1991 and 1996, and multiplying it for a score factor.

[4] The "sprawl" refers to the excessive growth of the urban nuclei's extension, usually in a model of low densities.

Table 1. *Metropolitan areas in Catalonia 1986, 1991 y 1996*

Variable	Area	Non contiguity			Contiguity (order 1 or 2)		
		1986	**1991**	**1996**	**1986**	**1991**	**1996**
Number of municipalities	**Barcelona**	90	157	252	88	144	218
	Girona	41	58	62	39	58	62
	Lleida	16	45	59	16	40	54
	Manresa	17	26	31	16	25	31
	Tarragona	17	56	71	15	53	68
Population	**Barcelona**	3.577.469	4.182.769	4.359.596	3.577.175	4.180.013	4.351.700
	Girona	123.714	170.957	191.688	123.455	170.957	191.688
	Lleida	128.774	157.123	177.934	128.774	156.405	176.251
	Manresa	101.746	141.183	149.144	101.707	141.150	149.144
	Tarragona	220.781	282.355	312.933	220.480	282.147	312.751
Employement	**Barcelona**	1.039.151	1.555.414	1.557.517	1.039.080	1.554.804	1.555.337
	Girona	45.145	71.719	77.068	45.092	71.719	77.068
	Lleida	40.742	57.686	63.450	40.742	57.512	63.152
	Manresa	31.004	48.920	50.296	30.984	48.883	50.296
	Tarragona	65.972	99.430	115.473	65.897	99.372	115.446

Source: Elaborated from Censuses (IDESCAT: http://www.idescat.es), PTMB and Federal Register (http://www.census.gov/).

Elaboration: We use and adaptation of the Federal Register methodology. First, we identify the metropolitan cores, formed by the nuclei above 50.000 inhabitants. Then, we include new municipalities in the area using a commuting criterion in three iterated stages (15% of commuting in each stage on the anterior consolidated aggregation). In the fourth stage, we add a density criterion. A municipality only pertains to an area. The final objective is not the definition of closed homogeneous areas, but to approximate their hinterland.

Between 1996 and 2001, the growth of the economic activity and jobs of these areas can leads to a growth in the spatial interaction and to a reinforcement of their metropolitan nature.

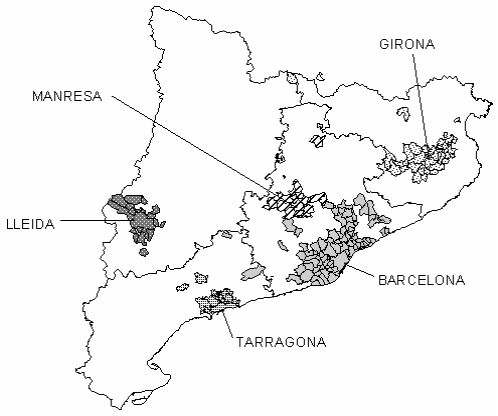
Adopting a conservative hypothesis of growth of the mobility between 1996 and 2001 similar to the same one experienced between 1991 and 1996, Barcelona and the "Camp de Tarragona" will share in a very few years the same metropolitan space. Also Girona will be very near of the integration with Barcelona. In 1996, the cities of Manresa and Vic, and their hinterlands, were in the limit of the integration with the metropolitan space of Barcelona. The conversion of second residence in permanent residence allows explaining an important part of the growth of the metropolitan spatial interaction, incorporating municipalities very far away of the integrated work market.

The construction of the high-speed train (that will link the four metropolitan areas) will allow increasing the mobility in the network of cities of Catalonia, reinforcing its nuclei and next areas. Therefore, we are very near to the effective construction of a new territorial model for Catalonia, which will integrate the 90% of the

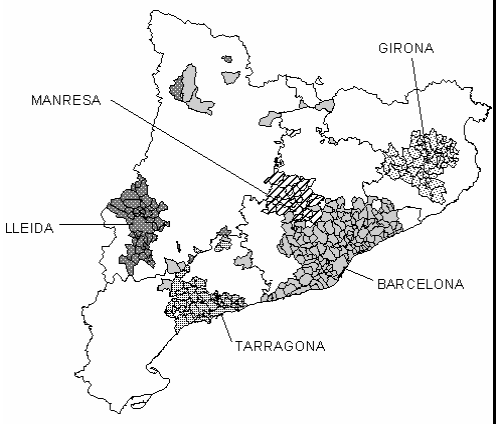
Catalonia's population in the same space of daily commuting relations. This phenomenon set out new changes to the territorial organization of Catalonia. As we will see later, the notion of "networks of cities" seems more appropriate that the notion of homogeneous region as an instrument for the territorial analysis and intervention.

Figure 1. *Metropolitan areas in Catalonia 1986, 1991 y 1996*

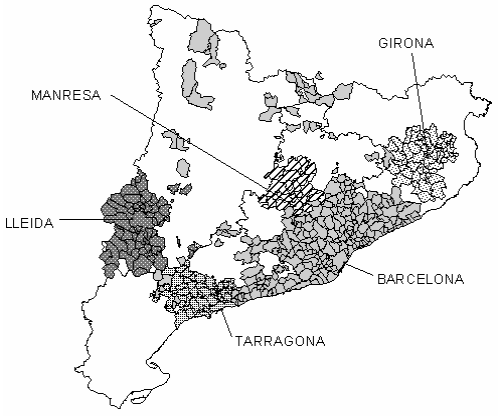
a) 1986



b) 1991



c) 1996



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2. POLICENTRISM, SPECIALIZATION AND DIVERSITY

Recently, the literature about the spatial structure of the urban areas has underlined the importance of the decentralization and subcentres' creation in the advanced metropolises. Mills (2000) has pointed out that the future of the research in urban economics resides in the elaboration of a synthesis about the subcentres' formation and the growth in metropolitan spaces[5]. Theoretical literature mainly focuses the urbanization processes of the American metropolis, but it doesn't think in a systematic way the most common European case, in which the dynamic of decentralization of the metropolis incorporates metropolitan cities already existent.

The policentric European metropolis is an appropriate object of study for the applied urban economy, because it proposes an interpretation of the metropolitan dynamics that starts from the base that it doesn't operate on empty peripheries. It operates on an external urban system in which pre-existent cities, with a previous urban trajectory, are reached by the metropolitan growth.

For example, the formation of the economic-territorial system of Barcelona shows a long historical trajectory. García Espuche (1998) detects important changes in the Catalan territory that result in the formation of a specialized system of cities, and point out the complementarity of the urban system, among Barcelona and cities like Sabadell, Terrassa, Vilafranca del Penedès or Mataró. Some of these specialized cities will become the current subcentres of the Barcelona's metropolis.

It is early to present a general theory of the policentric city. Therefore, we study outstanding cases that start from suppositions very close to the existent reality[6].

Policentrism is defined as the tendency of the population and the economic activity to agglomerate in some nuclei of the urban system with capacity to exercise influence on the urban structure.

Different criterions exist to identify the urban subcentres, the most common ones are the visual inspection of density maps, the definition from size and specialization of the jobs, and the specification of minimum thresholds of density (Cervero and Wu, 1997).

In this research, we have considered two criterions for to identify the subcentres[7]:

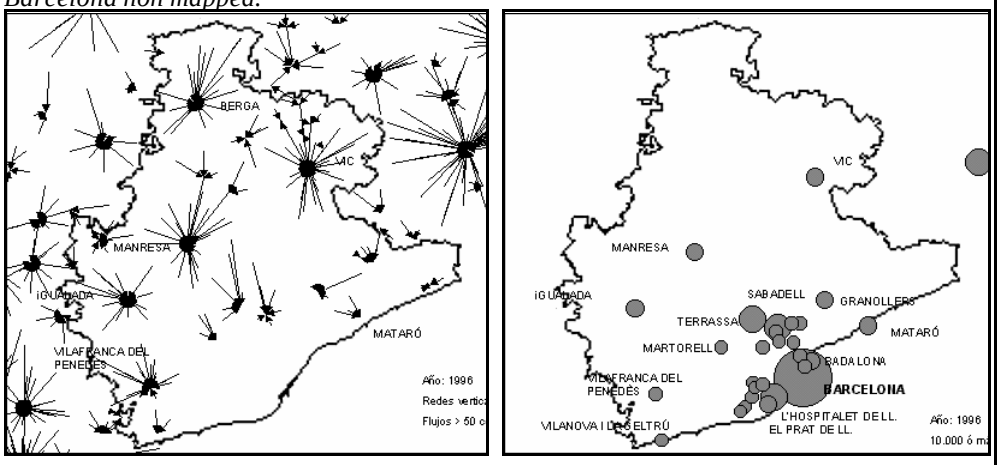
a) the municipality is the first external destination for the commuters of other municipalities (minimum two municipalities);
b) the municipality concentrates a minimum of 10.000 jobs[8].

[5] Mills (2000, p.37) notices that if the governments make appropriate decisions, this process can leads considerable reductions in the commuting times.
[6] Anas, Arnott and Small (1998, p.1440) point out the importance of the applied research for the advances in the economic analysis of the policentric city.
[7] These two approaches are used in the database "Indicadors Economics i Territorials 2002" (http://selene.uab.es/jtrullen/urban.htm).

In the figure 2, the policentric configuration of the territory is observed from both approaches. The "commuting approach" emphasizes the policentric character of the external nuclei of Barcelona's metropolitan region, because in the central part, Barcelona absorbs many of the first flows. The "jobs approach" reveals the existence of more than 30 municipalities that overcome the 10.000 jobs in the year 1996. Some of these municipalities are contiguous to Barcelona (l'Hospitalet de Llobregat and Badalona), while other are far distributed, as Igualada, Manresa, Vic, Sabadell, Terrassa, Mataró, Granollers, Vilanova i la Geltrú, and Vilafranca del Penedès. All these municipalities concentrate the same jobs than Barcelona (622.139 the subcentres and 657.383 the city of Barcelona)[9], and many of them, including Barcelona, contain concrete specializations in some productive sectors. If both approaches are jointly considered, they would be identified as metropolitan subcentres: Barcelona, Mataró, Granollers, Sabadell, Terrassa, Martorell, Vilafranca del Penedès, and Vilanova i la Geltrú. Other subcentres out of the metropolitan region are Igualada, Manresa and Vic. As we have seen, many of these municipalities were already specialized manufacturer centres in the XVI century.

Figure 2. *Policentrism. 1996*

a) First destinations of the commuting flows. Barcelona non mapped. *b) Nuclei above 10.000 jobs.*



Source: Elaborated from Censuses (IDESCAT: http://www.idescat.es).

When the production is concentrated in the territory, they operate a kind of advantages called "agglomeration economies" (Hoover 1937). Agglomeration economies can be internal or external to the firm. The former are called "internal economies", and the second one "external economies". The "external

[8] Giuliano and Small (1991) use a threshold above 10.000 jobs, joining a job density criterion. This approach is very common in the works mentioned by Cervero (1997), and Anas, Arnot and Small (1998).

[9] Jobs in the year 1996. Source: Censuses (IDESCAT: http://www.idescat.es).

agglomeration economies" can be of two types: "localization economies" and "urbanization economies"[10].

Among other factors, the existence of "localization economies" is usually associated with the presence of strong local sectoral specializations. Sectoral specializations in a municipality can be detected using a double filter: a coefficient of localization above 1,1, and an index of sectoral concentration above 5% [11]. Joining the two criteria, we identify specialized concentrations in Martorell (automobile), Cerdanyola (education) and El Prat de Llobregat (transports). In these municipalities we can find big manufacturing firms (SEAT-Volkswagen) or services (UAB, airport). Furthermore, we can find high coefficients of localization in municipalities like Mataró (textile), Terrassa (textile) or Sabadell (textile, finances and metallurgy)[12]. The city of Barcelona also presents high coefficients in tertiary activities like Finances or Real estate agencies.

Although we can found important specializations in some subcentres, they aren't monospecialized. The subcentres present high coefficients of diversity. This denotes that their productive structure is **strongly diversified**[13]. Diversification of the productive structure is associated (jointly with the dimension of the municipality) to the generation of "urbanization economies" (Jacobs 1969). Then, the existence of important local specializations is not opposed to the diversification of the global structure of the municipality. Therefore, they are subcentres with a diversified productive structure that contain one or more sectoral specializations.

[10] "Localization economies", also called "external to the firm and internal to the industry", are advantages derived from the concentrated localization of firms of the same industry or productive sector. The concept of "urbanization economies" is more difficult to define. There is the consensus that this urbanization economies are external to the industry (sector) and internal to the city. Both concepts are detailed in Hoover (1937, p.89-93). For a more recent revision of the same ones we can consult Camagni (1992, p.56-67).

[11] The "coefficient of localization" is $CLz_{ij} = \left(E_{ij}/E_j\right)/\left(E_i/E\right)$; E = jobs; i = municipality; j = sector. A coefficient above 1 indicates a specialized concentration of the sector in the municipality. The "coefficient of concentration" is $HHI = \sum_j \left(E_{ij}/E_j\right)$. We use this second coefficient for eliminate the effect of irrelevant specializations, generally in very small municipalities.

[12] These municipalities show a small size of their firms and productive establishments.

[13] Diversity has been measured with an index of Hirschmann-Herfindahl $HHI = \sum_j \left(E_{ij}/E_j\right)$, where i is the municipality, and j is the sector.

3. NETWORKS OF CITIES

We have seen how the municipalities of Catalonia form metropolitan areas. However, they are not compact and homogeneous urban concentrations. Inside these metropolitan areas we can find some important municipalities that act like subcentres. They contain outstanding sectoral specializations at the same time that a diversified productive structure. The traditional urban economy relates some characteristics like specialization, urban dimension and diversity, with the generation of external economies of localization and urbanization. Another kind of advantages derives from the organization of the system of cities. The theory of the networks of cities studies how the links with these municipalities generate "network externalities".

3.1. What are the networks of cities?

Urban economics and economic geography use the term "networks of cities" to refer to an interpretation of the economy in the space where the cities (municipalities) are connected by links of socio-economic nature, and flows of different types are exchanged, sustained on infrastructures of communications and telecommunications.

The theory of the networks of cities replaces the "central place models". These ones derive from Christaller (1933), and they were very used between the 1960s and the 80s.

Christaller proposes that the relationships between cities are based on the existence of a hierarchy of centres, where the big cities contain all the functions (including the superior ones), and the small cities depend of this higher rank centres[14]. However, they don't explain why there are important economic relationships between municipalities of the same size (rank), or why some high level functions are located in small and medium cities[15].

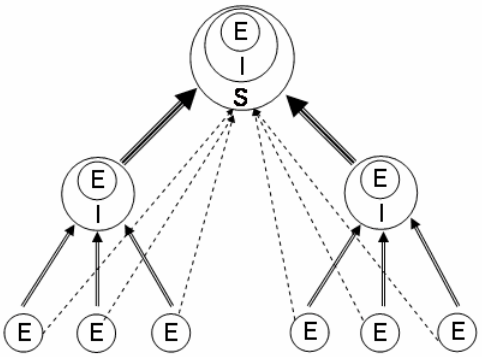
The theory of the networks of cities explains both phenomena. The links between cities (municipalities) don't occur only among cities of different size, and they are also observed among cities of the same size. These relations can be among cities with a similar function o with a different function.

[14] The central place theories originate in Germany between the first and second half of the XX century with Christaller (1933) and Lösch (1940). They are continuators of von Thünen, Grandmann and Alfred Weber. These models will be developed later by authors like Woldenburg, Timbergen, Beckmann and McPherson, Parr, White, Berry, Mulligan, Beguin, and Allen and Sanglier. Recently, Fujita and Krugman have used this principle for the construction of territorial economic models of general equilibrium. We can find an application of this principle to Catalonia in *L'Organització Territorial de Catalunya* (Casasses and Clusa, 1981), where the identification of hierarchical relationships leads the main objective of dividing Catalonia in nodal regions.

[15] Camagni and Salone (1993).

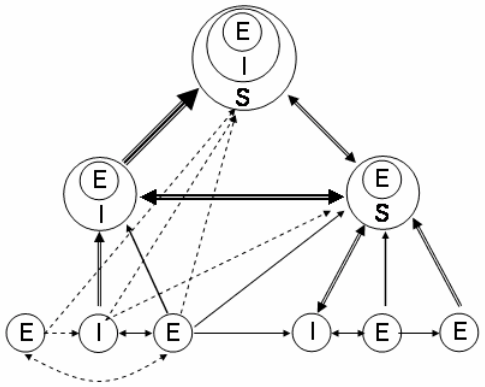
Figure 3. *Stylized representation of the central place and network models*

a) Central place models



If we have three city sizes (Big, Medium, Small) and three goods (Elementary, I Intermediate and Superior), the Big city will provide the three goods, the Medium city will provide the Elementary and Intermediate ones, and the Small city only the Elementary one. Then, the Medium city will buy the Superior good in the Big city, and the Small city will buy the Intermediate good in the Medium and Big cities (in the nearby one) and the Superior good in the Big city.

b) Network models



One of the Medium cities provides the Superior good, and several Small cities provide the Intermediate good. The relationships are not structured only in a hierarchical way. The exchange occurs when the goods are similar or different. The system is more complex, and it resembles a net. It is difficult to divide it in separate homogeneous parts, and the contiguity is not needed.

3.2. Network externalities

When we have spoken about policentrism, we have seen that there was a kind of advantages called "agglomeration economies". They derived from the concentration of population and activity in the territory. There is another type of advantages, called “mobile economies” (Robinson 1958) that doesn’t depend exclusively of the proximity (spatial concentration). The networks of cities are an additional element for the generation of competitive advantages. These advantages are not linked to the concentration of the activity, but to the organization of the urban system.

The external network economies are generated when the economic interaction between two or more cities (municipalities) generates non-market advantages. The interaction can be generated between neighbour cities, but also with spacely distant cities.

3.3. Types of networks of cities

We can identity different types of networks of cities. The more common typologies are the division between horizontal, vertical and policentric networks (Dematteis

1990 and 1991), and the distinction between synergy and complementarity networks (Camagni and Salone, 1993). Trullén and Boix (2001) incorporate an additional classification of the networks of cities, related to the generation and transmission of knowledge.

3.3.1. Vertical and horizontal networks

The "vertical or hierarchical networks" are those that link some nodes (municipalities) of different rank, when some nodes dominate the other ones in the exchange. The "horizontal or non-hierarchical networks" use to link municipalities of the same rank, and there is not dominance. Horizontal networks can also link municipalities of different rank, when doesn't exist any relation of dominance[16].

To identity vertical and horizontal networks, we use data of censuses: population and commuting[17]. We implement a simple procedure in three steps:

First we decide when a network relation exists between two municipalities. We use the commuting data, and consider that a flow A→B is significant when it is above 50 commuters[18].

Second, we use the population to define seven ranks of municipalities, and we assign each municipality to a rank.

Third, we compare the origin and destination ranks of every dyad (pairs of municipalities). We can find two cases:

> a) Only a significant flow A→B exists between each dyad. Then, for and unique flow A→B, when the rank of destination is superior to the rank of origin (the origin municipality is bigger than the destination one), it is considered that the relationship is hierarchical (vertical network). When the rank of both municipalities is the same, or the rank of A it is superior to the rank of B, it is considered that the relationship is not hierarchical (horizontal network).
>
> b) Two significant flows exist (A→B; B→A). Then if the rank of both municipalities is the same, we suppose that the hierarchical relationship dominates the horizontal one, therefore it is assigned as hierarchical.

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[16] The existence of horizontal networks supposes one of the main points of the paradigm of the networks of cities. It moves away from the Christallerian models (central place models), where the relationships were fundamentally between municipalities of different rank (hierarchical links).

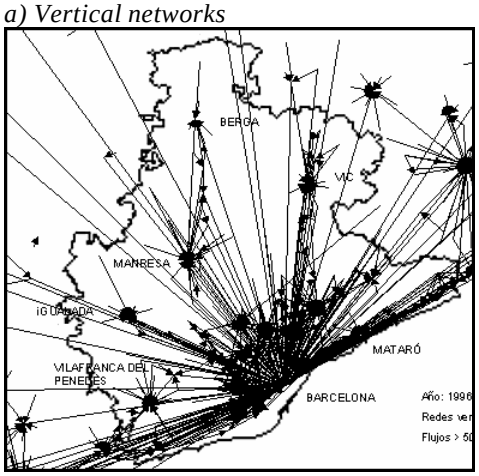
[17] For an accurate identification of the networks of cities we need different kinds of flows: commuting, communications, retail, trade, managerial links and so on. We use commuting like a proxy, because other sources of data are not available. However, it has the advantage that it is easier to compare with the identification of policentrism and metropolitan areas, because we use the same data.

[18] It has been proven with other thresholds above 100 or 200 commuters. The trends revealed by the data don't vary significantly with these thresholds.

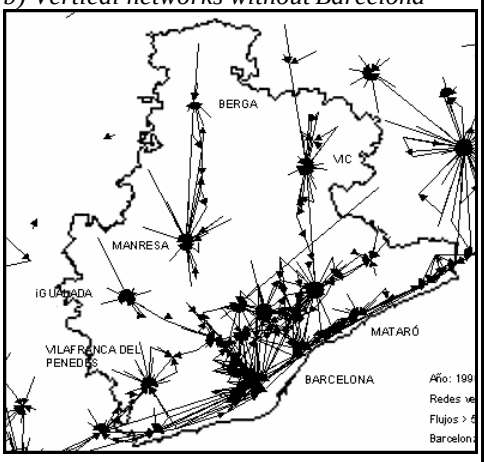
The procedure is applied to all municipalities of Catalonia. Most number of networks links are of the vertical type (around 66%). Denser sub-network is concentrated in the central part of the Barcelona's metropolitan region. In this sub-network, that contains many medium cities, we can find the majority of horizontal networks of the system. These municipalities are multidirectional transmitter and receivers. In the rest of the system, horizontal networks grant a bigger cohesion that if the relationships were strictly hierarchical, since they constitute the 34% of the total relationships of the system.

Figure 4. *Commuting flows: destination and hierarchy. Filter above 50 commuters. 1996*

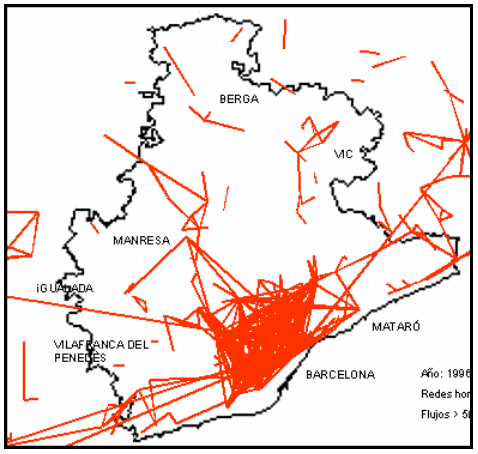
a) Vertical networks



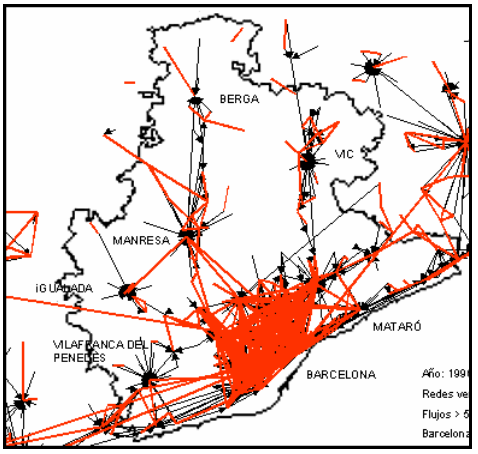
b) Vertical networks without Barcelona



c) Horizontal networks



d) Vertical and horizontal networks without Barcelona



Source: Elaborated from Censuses (IDESCAT: http://www.idescat.es).

Elaboration:

1. To identify the significant links.

2. To establish the rank of the nodes.
3. To compare each dyad (link between each pair of nodes) in function of the ranks of the municipalities, to establish if the link is vertical or horizontal.

3.3.2. Synergy and complementarity networks

The networks of synergy and complementarity (Camagni and Salone, 1993) are related to the productive and functional characteristics of each municipality inside the network. Synergy networks link municipalities with very similar functions or productive orientations. Complementarity networks link municipalities with different functions or productive orientations.

To identify these networks we use data of censuses: sectoral employment (222 sectors Nace Rev.) and commuting. We implement a three steps procedure:

First, we use commuting flows to decide if there is a network relationship between two municipalities. A flow A→B or B→A is significant above 50 commuters. Here, the flow's direction is indifferent (A→B, B→A or both).

Second, we use the "cluster k-means" methodology (annex 1) to identify groups of municipalities with a similar productive structure (similar profile)[19]. We use the municipalities like individuals, and the productive structure of these municipalities (percentage of each sector on the total jobs of the municipality)[20] like variables.

Third, we compare the profile of each couple of network-linked municipalities. If both network-linked municipalities have the same profile (they have the same productive structure, then they are in the same cluster), we consider that we have a synergy network. Otherwise, if they are in different clusters (different profiles), we consider that we have a complementarity network.

We use this methodology, and the results show that the complementarity networks mark the policentric structure of the urban system, drawing figures in star's form around most of the subcentres: Igualada, Manresa, Vic, Vilafranca del Penedès, Sabadell, Terrassa, Mataró and Granollers.

In some sub-networks, the structure shows a mesh form, i.e. in the Llobregat's corridor (from El Prat to Martorell). It points out the position of Barcelona as the main complementary centre in the network of cities. Barcelona shows complementary links with other nearby cities, and with the municipalities of other

[19] The "k-mean" is a cluster methodology that searches to carry out a single partition of the individuals (municipalities) in k groups, using an algorithm that uses the individual's characteristics to form relatively homogeneous conglomerates. We use this methodology because our objective is to identify groups of similar cases starting from numeric data, and we have a high number of municipalities.

[20] Once assigned each municipality to a group, we can characterize each cluster using a variance analysis (ANOVA).

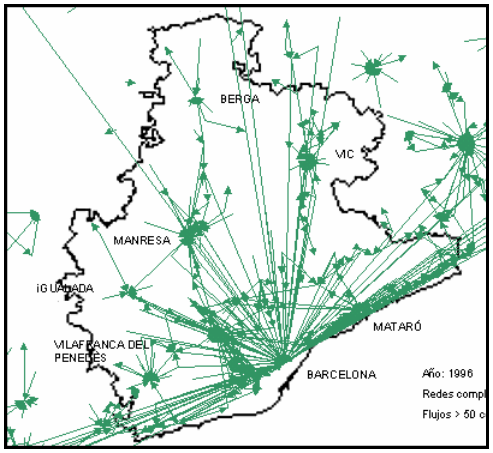
sub-networks. Complementarity links are the 47% of the network relationships. The groups that have more complementary relationships with the other ones are those specialized in services, construction, hotels and restaurants, textile, primary activities and tourism.

We found that the 53% of the network relationships are synergic. Synergy networks are concentrated in the centre of the Barcelona's metropolitan region, where the municipalities have very similar productive structures, and it forms a dense meshed network. Its sectoral structure is rich in services, and forms the most synergic cluster. We also find synergy relationships focused on Igualada, Manresa and Vic, and between some municipalities of the Tarragona's network with the Barcelona's one. The city of Barcelona maintains strong synergy relationships with some municipalities of its metropolitan region, and with other distant municipalities. The central metropolitan network also remains strongly synergic without Barcelona.

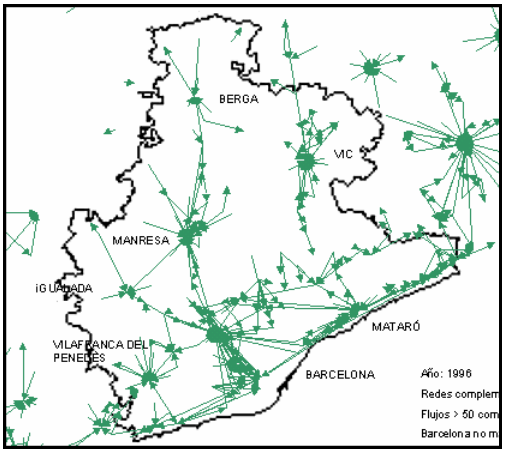
Additionally, we can divide these networks with regard to their hierarchical orientation (vertical and horizontal): complementary-vertical networks (35%), synergy-vertical networks (32%), complementary-horizontal networks (13%) and synergy-horizontal networks (21%). Complementary relationships trend to be more hierarchical than the horizontal ones.

Figure 5. *Synergy and complementarity networks. Filter above 50 commuters. 1996*

a) Complementarity networks

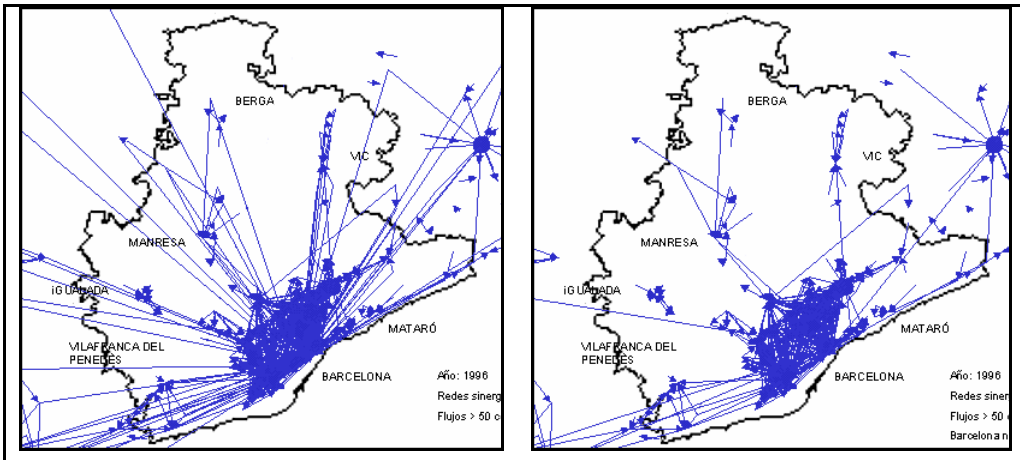


b) Complementarity networks without Barcelona



c) Synergy networks

d) Synergy networks without Barcelona



Source: Elaborated from Censuses (IDESCAT: http://www.idescat.es).

Elaboration:

1. To identify the significant links.
2. To apply the "cluster k-means" methodology. The individuals are the municipalities, and the variables are the sectoral structure of the municipality.
3. To compare each dyad (link between each pair of nodes) in function of the profile (cluster) of the municipalities. If two municipalities are of the same cluster, it is a synergy network. Otherwise, it is a complementarity network.
4. OPTIONAL: To use a variance analysis (ANOVA) to know which sectors determine the profile of each cluster.
5. OPTIONAL: To divide the synergy and the complementarity networks in vertical and horizontal.

3.3.3. Knowledge-based networks

The links among cities can be specified like flows of knowledge and information, flows of communications, investment or commuting. From this approach, we can analyze the process of generation and diffusion of knowledge through the urban structure.

"Central place models" link the production of innovations with the rank of the city in the urban system (Webber, 1972). Therefore, the amount of knowledge accumulated in a city is ordered in a hierarchical way according to the population of each city. Innovations and knowledge spread in a hierarchical way from the bigger cities (municipalities) to the smaller ones.

In the "network models", knowledge spreads in hierarchical and horizontal ways: from cities of superior levels to cities of inferior levels, among cities of the same rank, and also from cities of inferior rank to cities of superior rank (Trullén and Boix, 2001).

To identify the "knowledge-based networks", we use an adaptation of the OECD's classification of the sectors by intensity of knowledge (OECD 2001), and sectoral commuting data. The approach is the same used in Trullén and Boix (2001).

First, we divide the sectoral commuting flows in "high knowledge" (intensive in knowledge) and "low knowledge" (non intensive in knowledge)[21].

Second, we identify the network relationships between two municipalities in function of the knowledge. It is considered that there is a knowledge-based network link between two municipalities when there is a flow (A→B or B→A) above 50 commuters in high knowledge sectors. The same criterion is applied for the flows of low knowledge[22]. It is noticed that between two municipalities, high and low knowledge-based relationships can simultaneously exist.

The results show that Barcelona is the principal receiver of high and low knowledge-based flows. The main density of **high knowledge** network links is located in a metropolitan arc with centre in Barcelona and vertexes in Mataró, Granollers, Sabadell-Terrassa, Martorell and Gavà. Some figures like stars appear around Manresa, Vic and Vilafranca del Penedès. The **low knowledge** network is denser, and is less dependent of Barcelona[23]. Between 1991 and 1996 the links between the different sub-networks trend to growth.

We can also divide these networks in vertical and horizontal. In both networks, the rate of vertical links is higher than the horizontal one: high knowledge-vertical = 67%; high knowledge- horizontal = 33%; low knowledge-vertical = 62%; and low knowledge-horizontal = 38%. This suggests that a share of the knowledge is transmitted in horizontal structures. If we increase the threshold (i.e. above 100 commuters), the proportion of vertical relationships increases an 8% (high knowledge), and 6% (low knowledge). It suggests that the vertical network is more robust than the horizontal one. However, without more information, it is very difficult to know what kind of flows (vertical or horizontal) is more important for the knowledge. It is because the generation of new knowledge doesn't depend only of the flow's intensity, but of the receiver's ability to transform these flows in a differential advantage. The results also suggest a high dependence of the city of Barcelona for the transmission of the high knowledge flows. Low knowledge flows would have a better meshed network, with more options for the spread of the information if Barcelona is excluded.

The number of horizontal network relationships is denser in the metropolitan region of Barcelona, especially in the high knowledge network. In the low

[21] The adaptation of the classification of the OECD (2001) is explained in Trullén, Lladós and Boix (2002). The NACE Rev. sectors of low knowledge are: 01, 02, 05, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 25, 26, 27, 28, 36, 37, 40, 41, 45, 50, 51, 52, 55, 60, 61, 62, 63, 70, 75, 90, 91, 92, 93, 95 and 99. High knowledge sectors are: 24, 29, 30, 31, 32, 33, 34, 35, 64, 65, 66, 67, 71, 72, 73, 74, 80 and 85. However, we must use a 31 sectors re-aggregation, because we have some problems of homogeneity in the data. There are two main changes in the services: "Mail and Communications" are included with the services of low knowledge, and the "Real Estate" sector is included with the services of high knowledge. Another strong hypothesis is that in a regional level, commuting flows are good indicators of the urban structure and they are important for the transmission of information and knowledge.

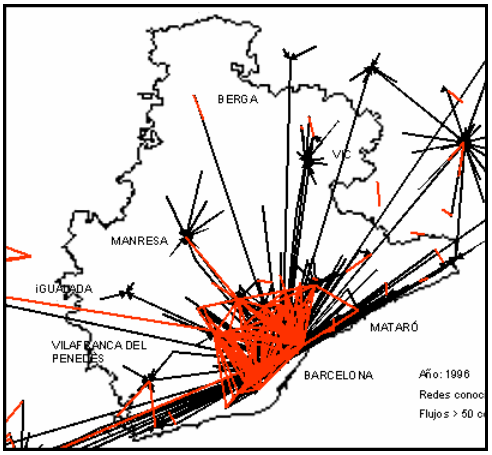
[22] As in the previous cases, it has been proven with other thresholds. The main tendencies revealed by the data don't change significantly.

[23] The amount of low knowledge flows is bigger than the high knowledge one, because it includes a bigger number of sectors.

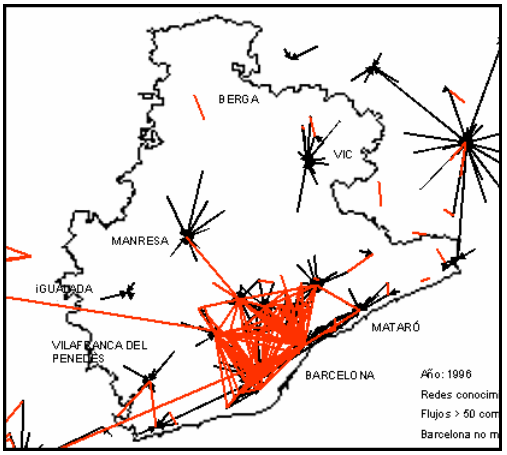
knowledge network we point out the capacity of the horizontal flows to connect different sub-networks, and increase their density.

Figure 6. *High and low knowledge-based networks. Filter above 50 commuters. 1996*

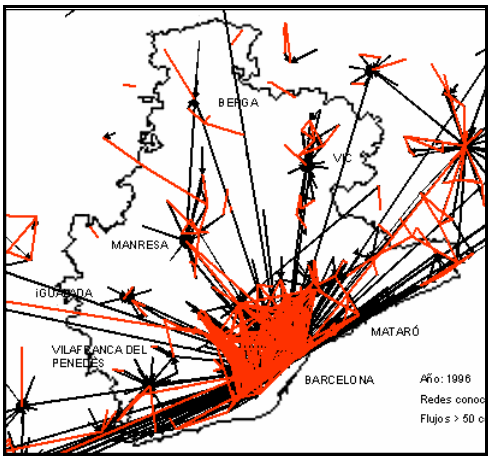
a) High knowledge networks



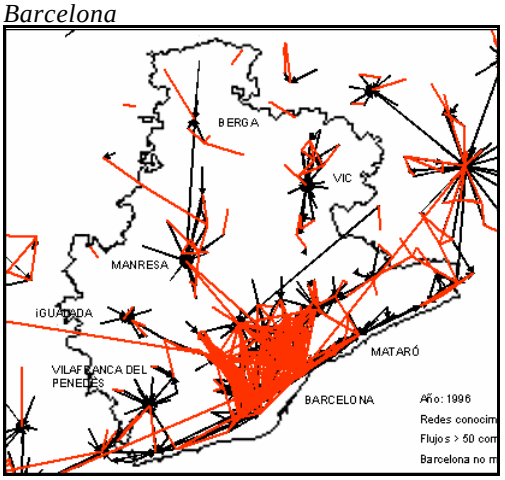
b) High knowledge networks without Barcelona



c) Low knowledge networks



d) Low knowledge networks without Barcelona



Source: Elaborated from Censuses (IDESCAT: http://www.idescat.es).

Elaboration:

1. OECD's classification. To divide the flows: high knowledge and low knowledge.
2. To identify the significant links for each category of knowledge (high and low).
3. OPTIONAL: To divide in vertical and horizontal networks.

4. CONCLUSIONS

The organization of the production in the space-territory is related to the growth and the economic development. This paper is the first stage of a research directed to the identification and measurement of the advantages derived from the economic organization of the relationships among cities in a regional ambit. We consider three complementary approaches. The metropolitan area focuses on a homogeneous and compact ambit, and it is used to carry out the aggregated changes in the scale of the metropolis: we find that Barcelona's metropolis is expanding. The year 1996 it contained above 200 municipalities, 3.500.000 inhabitants and 1.500.000 jobs. We also notice an integration process with the other metropolitan areas of Catalonia.

However, it is necessary a more detailed study of the main metropolitan cities (policentrism approach) and the articulation of the relationships among cities (networks of cities). We identify the metropolitan subcenters, and find that they are specialized or multi-specialized in some sectors, and their diversity is above the mean. This suggests that it would have external economies of concentration, derived from the specialization (localization economies) and the diversity (urbanization).

The theory of the networks of cities suggests that there is a different kind of external economies (network externalities) that is spacely mobile and depends on the articulation of the relationships among the cities of the regional urban network. We identify networks of cities from three approaches: the hierarchy of the network, the economic relationship and the knowledge. We find that the hierarchical relationships coexist with the non hierarchical ones, and that there are some relations of synergy and complementarity. Finally, the knowledge-based approach shows that the high-knowledge networks are concentrated around the subcenters, and the low-knowledge network is denser and more independent of the city of Barcelona. It is necessary to point out that we need more detailed economic flows data to get a better identification of the networks of cities.

We advance that the results of the measurements (not included in this paper) show that Barcelona's metropolis generates strong external economies of concentration and network.

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ANNEX I. APPLICATION OF THE K-MEANS

1. The "k-means" is a cluster methodology that carries out a single partition of the individuals (municipalities) in *k* groups. It uses an algorithm that allows forming relatively homogeneous conglomerates from the characteristics of the individuals. The "k-means" is based on the distance to the nearest centroid. It assigns every individual into a group with regard to minimize its distance to the centre of the conglomerate Dillon and Goldstein 1984 p.186-187; Visauta 1998 p.194).

2. Variables: the sectoral structure (percentage) is introduced as variables (every sector is a variable). They are considered 220 sectors of the 222 possible (for both remaining it doesn't exist data). Every municipality is an individual.

3. Number of groups (clusters): the number of clusters should be determined a priori, although a clear approach doesn't exist to determine it. We use a high number of groups, fixed in 50. This implies that, if all the clusters would have the same number of municipalities, each cluster would have 19 municipalities. In fact, the number of individuals in each group can oscillate among 1 and (N-k-1) municipalities.

4. Reliability of the results: the number of departure groups, as well as the sectoral division (number of variables) may influence the results. We carry out an analysis of sensibility changing the number of sectors and the number of groups. The results were robust.

5. Characterization of the differences intra-groups: after identifying the groups, a variance analysis (ANOVA) allows knowing what variables (productive sectors) offer bigger dispersion. We compare the deviations of each group with regard to the mean of each sector, with the aim of characterize the profile of the municipalities of each group.