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**NETWORKS OF CITIES AND GROWTH: THEORY, NETWORK
IDENTIFICATION AND MEASUREMENT OF THE NETWORK
EXTERNALITY**

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Abstract: Traditional regional and urban economics emphasize the relevance of agglomeration on economic growth. The concept of "agglomeration economies" explains the existence of advantages derived from the concentration of population and activity. However, it does not explain the existence of external economies that are spatially dynamic. Network economies generated in networks of cities correspond to this last type, since they are generated from the interaction between urban units linked by a network relationship. A strong implication arises from this hypothesis: networks of cities generate network economies that influence urban growth. Therefore, concentration is not the only way to generate externalities that influences economic growth. The objectives of this paper are to introduce the theory of the networks of cities and to explain the relationship between them, external economies and economic growth. The text is divided in four parts. First, there is an introduction to the paradigm of the networks of cities (theoretical concepts; network of cities and economic growth and network policies). Second, some examples of networks of cities are provided (Piedmont and Lombardy; Randstad; Kansai; France). Third part introduces the case of Catalonia, where networks of cities have been intensely studied, networks advantages measured and policy strategies proposed. Finally, conclusions and implications are exposed.

1. INTRODUCTION

Urban economics has studied the relation between the concentration of the economic activity and the generation of agglomeration economies (Moomaw 1983; Rosenthal and Strange 2003). Agglomeration economies are linked with the urban economic growth. This relation was theoretically explained by Hoover (1937), Hoover and Vernon (1958), Jacobs (1969) and Krugman (1991), and empirically contrasted by Glaeser et al. (1992) and Henderson et al. (1995).

Nevertheless, agglomeration economies are not the only source of urban-based externalities. A different source of externalities is generated from the interaction between economic agents that do not need concentrate in the contiguous space. When these economies are studied from a microeconomic perspective, they are called “cluster economies” (Porter 1996) or “complex economies” (Parr 2002)¹. Urban economics focuses on the study of these economies from the point of view of the urban unit, and they are synthesized in the paradigm of the networks of cities (Pred 1977; Dematteis 1989; Camagni and Salone 1993; Capello 2000). The main hypothesis is that network economies have an important role on the economic growth. However, we know little about how networks economies operate and which their impact on the urban growth is.

2. THE PARADIGM OF THE NETWORKS OF CITIES

2.1. The concept of network of cities

What is a network of cities? It is a structure where the nodes are the cities, connected by links of different nature, through which flows of socioeconomic nature are exchanged. These flows are supported on communication and telecommunication infrastructures.

The main characteristics of the networks of cities are the possibility of hierarchical and non-hierarchical structures, cooperation (or competence – cooperation) among the cities, and the generation of advantages related to the organization of the urban structure.

¹ Porter (1996, p. 87) views diffusion and generalized use of the “agglomeration economies” concept as a weight that limits the right interpretation of the reality: “*It may be time to shed the term ‘agglomeration economies’, because it obscures distinctions that are crucial for economic modelling and public policy*”.

This is a systemic and global definition of a network of cities, and is not utilized for all the researchers. In fact, each researcher uses a particular definition. For example, Camagni and Salone (1993) restrict the concept in order to include only horizontal (non-hierarchical) networks. Boix (2000) provides a revision of this concept in the economic literature (table 1).

Table 1. Different interpretations of the network concept

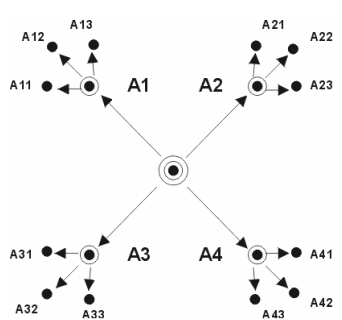
Author	Concept	Principal elements
- Theory of Systems - Westlund (1999) - Casti (1995)	System of objects added to a group of connexions.	- Nodes and links. Associative propriety.
- Dematteis (1990 and 1991)	System of centres (or areal urban systems) related by links.	- Nodes and links.
- Pred (1979)	In an urban system not only vertical relationships (hierarchical) are important, but also the horizontal and cooperative links.	- Nodes and links. Vertical and horizontal relationships.
- Camagni and Salone (1993)	System of horizontal, non-hierarchical relationships among specialised centres providing externalities from complementarity/vertical integration or from synergy/cooperation among centres.	- Nodes and links. - Horizontal relationships. - Synergy and complementarity - Externalities
- Batten (1995)	Two or more previously independent cities, potentially complementary in function, strive to cooperate and achieve significant scope economies aided by fast and reliable corridors of transport and communications infrastructure.	- Cooperation. - Transport and communications infrastructure. - Scope economies.
- Boix (2002)	Structure where the nodes are the cities, connected by links of different nature, through which flows of socioeconomic nature are exchanged. These flows are supported on communication and telecommunication infrastructures. Principal characteristics of the networks of cities are: the possibility of simultaneous hierarchical and non-hierarchical structures, cooperation (or competence – cooperation) between the cities, and the generation of advantages related to the organization of the urban structure.	- Nodes and links. - Transport and communications infrastructure. - Coexistence of hierarchical and non-hierarchical structures. - Generation of advantages (network externalities) related to the urban structure and the interaction between the nodes.
- Vartianen (1997)	Inter-urban cooperation (transnational) of cities and other actors based on the city, with the purpose of use and develops synergetic effects.	- <i>Urban networking</i> as economic and organizational principle - Duality between cities and actors - Network can be a functional network (spontaneous) or a lobby

		- Networks are stable. - Polycentrism.
- Taylor (2001)	A kind of organization where the actors are nodes and the social relationships the links. These social relations are economic links that acts to geographically structure the world economy.	- Nodes and links. - Economics and sociology - Supra-nodal and sub-nodal. - World system.
- Camhis and Fox (1992) - European Commission (1999)	Formal agreement between relevant partners.	- Constitution in organizations. - Defense of interests and promotion of specific networks.

2.2. Typologies of networks of cities

The flexible interpretation of the network concept allows its identification based on different characteristics. This generates a set of typologies. The more utilized are the division in vertical, horizontal and polycentric networks (Dematteis 1990 and 1991) and the division in synergy and complementarity networks (Camagni and Salone 1993). Recently, Trullén and Boix (2001) have incorporated a third classification based on the generation and transmission of knowledge.

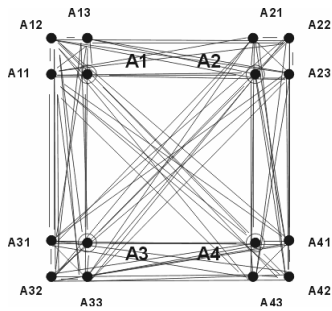
2.2.1. Vertical, horizontal and polycentric (multicentric) networks



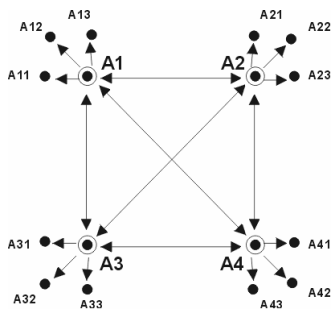
1. *Vertical (hierarchical) networks*: they are the classical networks theorized in the central place models (Christaller 1933; Lösch 1944). The links between the nodes of the network are asymmetric, and the system is “areal”: it implies spatial contiguity and predetermination of the spatial relationships between nodes. This kind of networks describes a territorial system in equilibrium, where all relations are based on

the concepts of “upper and lower range”². Each rank of cities offers diverse goods given their dimension.

² The “upper range” is the farthest distance the dispersed population is willing to go in order to buy a good offered at a central place. The “lower range” (sometimes called “threshold”) is the minimum amount of consumption needed to offer the good.



2. *Horizontal (non-hierarchical) networks*: the links between the nodes of the network are symmetrical or quasi-symmetrical, and the concepts of “upper and lower range” do not operate. There is not an ordination of the goods based on the rank of the cities.



3. *Polycentric (multicentric) networks*: combine vertical and horizontal links. Urban functions are combined in different ways. Major centres tend to generate agglomeration economies and contain high order functions, but “upper and lower range” does not apply in a strict sense, because centres can be specialized regarding the networks.

2.2.2. Synergy and complementarity networks

1. *Synergy networks*: arise between centres with a very similar orientation that interacts in a non-programmed way or collaborate in a planned way. Camagni and Salone (1993) find this behaviour in: high order centres like World Cities or Eurocities along the “Blue Banana”; and in low order centres interested in capturing network effects from the interurban cooperation (Nord-Pas-de-Calais or Wallonia). Other kind of synergy networks are the “innovation networks”, where cities collaborates in order to reach a sufficient critical mass.

One may suggest the division of the synergy concept in specialization networks, synergy networks and innovation networks. This is an operative distinction in order to differentiate the productive orientation (industry-based) from other types of synergy.

2. *Complementarity networks*: they are links between specialized centres that contain complementary activities or functions. From a more traditional perspective, this mechanism assures that each city has enough market-share. From a more recent point of view, this is a reflex of the labour division in the network, where some cities can have a strong specialization oriented to the international markets, and other acts as service centres. In fact, the ways of complementarity can be diverse.

Although concepts of vertical and horizontal seem more exclusive, one could find that two cities can have simultaneous specialization (synergy) and complementarity links. This is possible because cities are not mono-specialized or mono-function, but poly-specialized.

2.2.3. Knowledge-based networks of cities

Relations between cities can be specified through information and knowledge flows. This approach allows one to analyze processes of generation and diffusion of knowledge through the urban structure.

Central place models relate the production of innovation to the rank of the city in the urban system (Webber 1972). The amount of cumulate knowledge is ordered in a hierarchic way because depends of the population of each city. Then, innovations and knowledge spread in a hierarchical way from major cities to minor cities.

On the other hand, in the network models knowledge diffusion cannot only be carried out in a vertical way, but also among cities of the same rank and from cities of lower rank to cities of higher rank. Tullén and Boix (2001) use the industry classification of the OECD to distinguish between *high knowledge urban networks* and *low knowledge urban networks*. Classification is not exclusive, and a city can be in a high and a low knowledge network at the same time.

2.2.4. Other typologies of networks of cities

Other typologies of network of cities can derive from the ambit of interaction (local networks; regional and national networks and world city networks), from the principle of formation and exchange (natural networks and cooperation networks) and from the duration of the network (conjuncture networks and stable networks).

Table 2. *Typologies of networks of cities*

Principle	Typology
Articulation of the urban structure (Dematteis 1990 and 1991)	<ul style="list-style-type: none"> • Vertical (hierarchical) networks • Horizontal (non-hierarchical) networks • Polycentric networks
Nature of the network externality (Camagni and Salone 1993)	<ul style="list-style-type: none"> • Complementarity networks • Synergy networks • Innovation networks
Knowledge generation and transmission (Trullén and Boix 2001)	<ul style="list-style-type: none"> • High knowledge urban networks • Low knowledge urban networks
Other typologies	
- Ambit of the network	<ul style="list-style-type: none"> • Local networks • Regional networks • World city networks
- Principle of formation and exchange	<ul style="list-style-type: none"> • Explicit cooperation networks • Natural networks
- Duration	<ul style="list-style-type: none"> • Stable networks • Conjuncture networks

3. NETWORKS OF CITIES AND ECONOMIC GROWTH

After introducing the basic concepts of the network of cities paradigm, we must establish the link between networks of cities and urban growth. The mechanism is simple: networks of cities generate external spatially dynamic economies (network economies). These economies results in increasing returns that influences economic growth.

3.1. Agglomeration economies and network economies

3.1.1. Internal and external economies

Marshall (1920) use the terms “internal economies” and “external economies” to explain that increasing returns in the production can originate in factors that are “internal” and “external” to the firm³. Internal economies

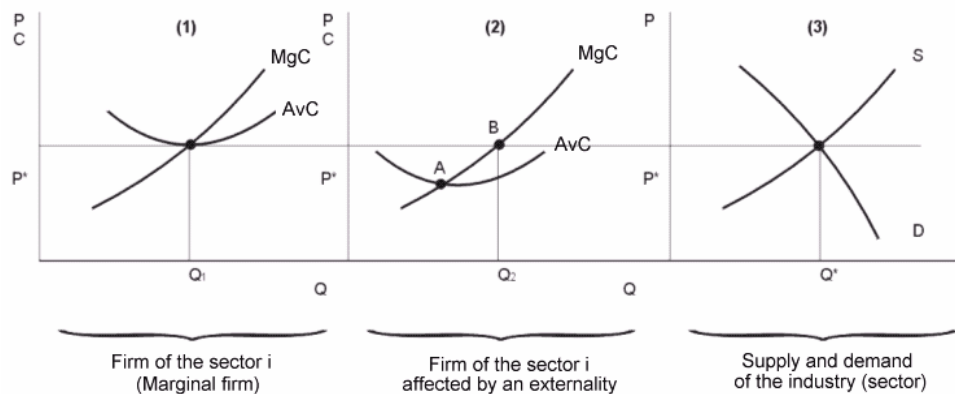
³ [“We may divide the economies arising from an increase in the scale of production of many kind of goods, into two classes – firstly, those dependent on the general development of the industry; and, secondly, those dependent on the resources of the individual houses of business engaged in it, on their organization and the efficiency of their management. We

are produced and appropriated inside the firm. External economies describe a situation where the firms have advantages coming from outside the firm. According to Meade (1952) and Scitovsky (1954), an external economy in the production is generated when the output (y_k) of a firm k depends not only of the factors of production used by the firm (l_k, c_k, \dots), but also of the output ($y_{k'}$) and the factors ($l_{k'}, c_{k'}, \dots$) used by others firms k' ⁴:

$$y_k = F(l_k, c_k, \dots; y_{k'}, l_{k'}, c_{k'}, \dots) \quad \forall k' \neq k \quad [1]$$

The existence of external economies allows increasing returns in an industry (sector) although their firms have perfect competition curves. Figure 1 gives an example. The first firm (marginal firm) is a typical firm in the industry i that operates in a competitive market. The second one is a competitive firm affected by an externality. We see that the average costs curve of this second firm is lower than the average cost curve of the first one. The second firm will produce the amount that equals market price to its marginal cost (above its average cost), and will have extraordinary profits.

Figure 1. Efficiency with external economies



may call the former *external economies* and the latter *internal economies*.”] (Marshall 1920, p.221). Marshall’s original definition do not refers that this industries were concentrated. Later on, Marshall declares his interest about concentration economies: [“...; but we now proceed to examine those very important external economies which can often be secured of the concentration of many small businesses of a similar character in particular localities: or, as is commonly said, by the localization of industry”] (Marshall 1920, p.221).
⁴ Mishan (1971) adds the requirement that the effect would be not foreseen (incidental). The equation corresponds to the “technological external economies” in the article of Scitovsky (1954, p. 145), and its adaptation to “pecuniary economies” is immediate.

3.1.2. Spatially static economies: agglomeration economies

What are agglomeration economies? Urban economics uses the concept of “agglomeration economies” to describe the relation between internal/external economies and the cities. Weber (1929 p.124-168) introduces the generic concept of “factors of agglomeration” to refer to elements that determine the localization of the economic activity related to the advantages that firms obtain from being localized in a densely industrialized area. The base of the mechanism of agglomeration is that under the influence of transportation costs, manufacture firms trend to concentrate in a limited number of places. The objective is minimizing the transportation costs to the sources of raw materials and final markets.

Ohlin (1933, p.203) identifies other advantages derived from concentration that are not necessarily related to differences in transportation costs. These advantages are called “concentration economies”, and we can differentiate three categories: “economies of concentration of industry in general”, “external economies of concentration of a particular industry” and “internal large-scale economies of a producing unity”. Hoover (1937, p. 90-91) popularized Ohlin’s taxonomy using the terms: *large-scale economies* within a firm (generated by the enlargement of the firm’s scale of production at one point), *localization economies* (caused by the total growth of a industry in a place, that affects the firms of this industry) and *urbanization economies* (generated by the enlargement of the total economic size in terms of population, income, output or wealth, that affects all the firms in this place). Hoover’s taxonomy has been the most utilized in urban and regional economics, although additional factors have been incorporated, for example diversity as source of urbanization economies after Chinitz (1961) and Jacobs (1969)⁵.

We can represent agglomeration economies in a generic way:

$$y_{k,i} = F(l_{k,i}, c_{k,i}, \dots; y_{k',i'}, l_{k',i'}, c_{k',i'} \dots \mathbf{q}_j) \quad \forall k' \neq k \quad [2]$$

, k is the firm and i is the sector. If $i=i'$ intra-industry external economies are generated. If $i \neq i'$ inter-industry external economies are generated. The component \mathbf{q}_j incorporates the external economies generated by other urban factors.

⁵ Camagni (1992, p.46-57) provides an actualized and exhaustive recompilation of these factors.

3.1.3. Spatially dynamic economies: network economies

Following Hoover (1937), agglomeration economies show two characteristics: they are *temporally static* and they are *spatially static*. The former is studied by Glaeser et al. (1992) that introduce the distinction between static and dynamic external economies⁶. The latter (spatial dynamics) is present when we approach the city as a node in a system of cities, and not as an isolated entity. Regional and urban economics and traditional economic geography synthesize this approach in the central place models. The main feature of these models is to explain the organization of the urban systems forming nested hierarchies of centres. In their early versions (Christaller 1933; Lösch 1944), the relation with agglomeration economies was based on the internal scale economies generated by firms located in the main cities of the system when market size increases. Recent elaborations (Fujita, Krugman and Mori 1999) include localization economies and congestion diseconomies in hierarchical urban systems.

Generation of external economies related to the interaction between cities, and therefore spatially dynamic, is studied by the theories of the *network of cities* (Pred 1977; Dematteis 1989; Camagni and Salone 1993). The central theory of this paradigm is that there are economies/diseconomies associated to the existence of networks of cities. These economies depend on the characteristics of the nodes and the interaction. Network economies can be generated from the supply side (production) or from the demand side. They are a source of increasing returns and competitive advantages, and contribute to the growth of urban economies. We can incorporate an additional term to the previous equations⁷:

$$y_{k,i,j} = F(\underbrace{l_{k,i,j}, c_{k,i,j}, \dots}_{\text{Internal economies}}; \underbrace{y_{k',i',j'}, l_{k',i',j'}, c_{k',i',j'}, \dots, \mathbf{q}_j}_{\text{External agglomeration economies}}; \underbrace{y_{i',j'}, l_{i',j'}, c_{i',j'}, \dots, \mathbf{q}_{j'}}_{\text{External network economies}}) \quad \forall k' \neq k \quad y_{j'} \neq j \quad [3]$$

⁶ Theories of (temporally) dynamic externalities explain simultaneously how the cities are born and grow. Theories of (temporally) static externalities, represented by the traditional conception of localization and urbanization economies, explain the formation of cities and their specialization but not their growth. From this approach we can differentiate between localization *economies* (temporally static) and *MAR externalities* (temporally dynamic), and between *urbanization economies* (temporally static) and *Jacobs economies* (temporally dynamic) (Glaeser et al. 1992, p.1128).

⁷ Suffix *k'* is omitted from the third term of the equation. Therefore, we can capture the aggregate effect of a generic urban unit on the unit of reference, and not the individual effect of a firm located in another different urban unit.

Table 3. External and internal economies regarding the space-territorial unit

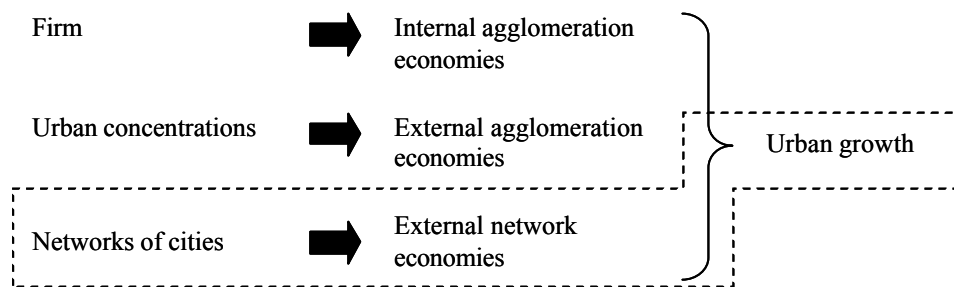
	Internal to the firm		External to the firm		
	Internal to the plant	External to the plant	Internal to the industry	External to the industry	
Internal to the city	I1 (Internal economies)	I2	I3 (Localization economies)	I4 (Urbanization economies)	Hoover's agglomeration economies (I1+I3+I4)
External to the city		E2	E3	E4	Network external economies (E3+E4)
	Hoover's internal economies	Network firm Network of firms	Marshallian industrial district		

, k is the firm, i is the industry and j the localization (city). Therefore, we can offer an additional element to explain the process of growth and development of the cities⁸.

3.2. Networks of cities and urban growth

Equation 3 provides an immediate way to link urban economic growth to internal and external economies. The output of the firms is affected not only by internal factors but also by external advantages located in the same or different cities. Stable network relations among cities provide an additional source of external economies that affects competitive advantages of the firms and generates economic growth.

Figure 2. Urban externalities and growth



Little research has been carried out on the concrete mechanisms of generation of network externalities. We can identify some ways of generation of advantages: size effects, knowledge effects, reduction of transaction costs and organizational advantages.

⁸ Spatially dynamic economies are not a new phenomenon in the economic literature. At the same time that Ohlin and Hoover study concentration economies, Robinson (1931/1958 p.124-127) divide external economies in mobile and immobile. *Immobile economies* belong together with Hoover's localization economies. *Mobile external economies* are generated among specialized places (e.g. cotton industry in Manchester and Liverpool at the end of the XIX century). They do not depend on the size of a particular city, but the size of the industry whole, in a set of linked places. In fact, we can define these mobile economies as the spatially dynamic version of localization economies, where concentration in an only urban unit is not necessary. Thus, firms located in two cities of the network to share the same advantages that if they were concentrated. Notice that although the mobile economies were known by Hoover (1937, p.90 note 4) but regional and urban economies preferred to study concentration economies (spatially static).

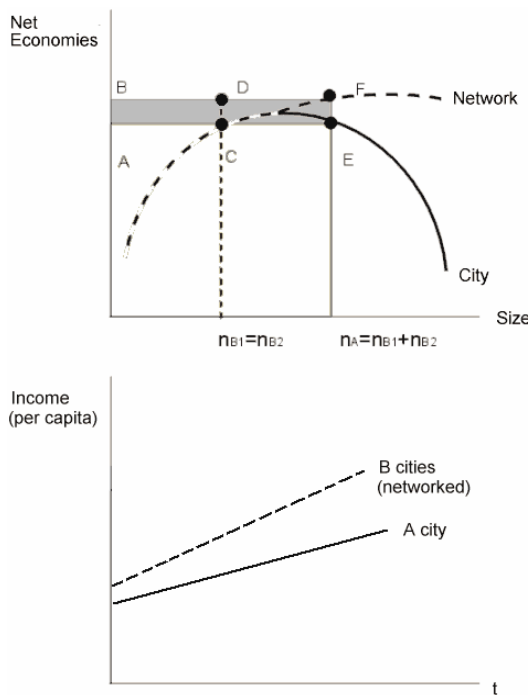
Size effects (mass effect) are one of the more elemental advantages of a network of cities. This is the same mechanism that leads concentration externalities but not in a geographical space but in an economic-relational space. Under this principle, a group of medium-size cities that interacts forming a network can reach the same functional dimension of a large city. These cities can use a system of complementarity and synergy mechanisms that assures a sufficient mass to provide high-level functions and to share indivisibilities from an infrastructural nature.

Knowledge effects arise from the transmission of knowledge's flows through the cities of the network and multiply the amount of knowledge available in each node and the velocity of transmission.

Transaction costs: includes transport costs, communication costs and uncertain. There are external advantages that influence the transaction costs of the firm (Scott 1988): flux standardization, space-time stability of flows, existence of brokers and subcontractors and other advantages in the exchange of intangibles (e.g. face-to-face contacts). Mori and Noshikimi (2002) call these factors "economies of density in transport". They are external to the firm but internal to the concentration of firms and the existence of stable links between cities.

Organizational advantages take place in two ways: from a static point of view, they arise from optimizing the distribution of resources and productions among the cities; from a dynamic approach, the morphology of the interaction between cities affects several mechanisms like knowledge distribution, transaction costs or feedback. Per example, velocity and survival probabilities in the transmission of knowledge are different in a network with shape of tree (Christallerian) from a meshed network.

Figure 3. Spatially static and dynamic economies, urban size and growth



There is a city with size (population) n_A and two identical cities n_{B1} and n_{B2} . We suppose that size $n_{B1} = n_{B2}$ and $n_{B1} + n_{B2} = n_A$ (each B city is 50% of city A). The amount of static agglomeration economies is the same for the three cities, and the area of these economies $n_{B1} + n_{B2} = n_A$. The difference is that B cities are operating on the point C and city A is located at the point E (where congestion effects reduce net benefits of agglomeration). However, n_{B1} and n_{B2} interact and obtain network economies. Then, network curve moves until point D. This point is above points E and C (without network economies). In this case, two smaller cities forming a network reach more external economies than a larger city. These external economies influence the firm's production function (equation 3) and generate additional economic growth.

4. NETWORKS OF CITIES AND ECONOMIC POLICY

4.1. Evolution of the framework and diagnoses

We have explained the theories of networks of cities and their relationship with urban growth through the externalities' mechanism. Now, we provide a brief introduction about the role of networks of cities in the design and implementation of territorial policies.

Territorial economic policy has evolved since the 1950s. In the 1950s and 1960s the *diagnosis* was territorial disequilibrium in a framework of national economies. The vision of the externalities by Meade and Scitovsky was applied in policies regarding the larger public companies as motor of the regional development. In the 1970s, the diagnosis pointed out the industrial crisis and the exhaustion of the fordist paradigm. New policies were proposed around productive segmentation and flexibility (Piore and

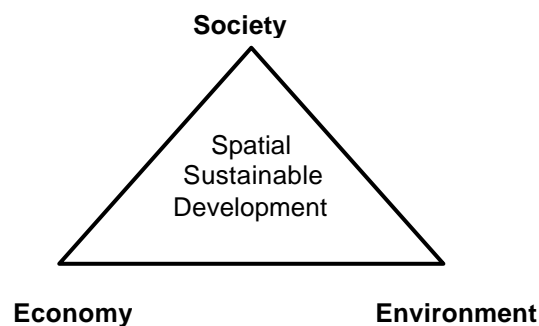
Sable 1984) and alternative ways to the development (Becattini 1975; Brusco 1982; Fuà 1985). In the 1990s, the diagnosis remarks the internationalization process, economic sustainability and knowledge-based economy as well as the cities like unit of application of these policies.

4.2. Objectives

The *objectives* of the territorial policy have also evolved. In the *Barlow report* (1944) they were reduction of chronic unemployment, balanced industrial distribution and dispersion of some industries regarding defensive and strategic purposes (Amstrong and Taylor 1985). In the *European Spatial Development Perspective* (1999, p.10) the aim is balanced spatial development but strengthening social and economic cohesion. This is reflected in a triangle whose vertices are economy, society and environment. Around these vertices the main objectives on the European policy are:

1. Economic and social cohesion (equity);
2. Conservation of natural resources and cultural heritage (sustainability);
3. A more balanced competitiveness of the European territory (competitiveness).

Figure 4. Objectives for a balanced and sustainable development.



Source: ESDP (1999, p.10)

Networks of cities make compatible these three objectives (equity, sustainability and competitiveness) because networks provide a strategy against territorial inequalities, spatial segregation and urban sprawl. In fact, the ESDP (1999, p.11) proposes a spatially-balanced structure based on three main lines: development of balanced polycentric urban systems,

balanced access to knowledge and infrastructures, and sustainable development of nature and cultural heritage.

4.3. Instruments

In an urban framework we must centre on instruments of micro-economic and coordination kind⁹. Micro-economic options related to networks of cities can be divided in *classical* options or *new* options:

Classical options:

1. Attraction of qualified workers;
2. Attraction of capitals;

New options:

3. Policies addressed to improve the organization of the production in the space-territory (this provides advantages from the spatial division of labour among the nodes of the network);
4. Policies addressed to improve the interaction between the cities of the network (e.g. improvement of communication and telecommunication infrastructures or concerted cooperation projects).
5. Technological policies based on technological centres adapted to the particular characteristics of the cities but regarding the network as whole (use of network complementarities).
6. Diffusion of knowledge and information through the network and generation of nodes of specialized knowledge.
7. Coordinated provision of public services.
8. Policies addressed to the integrated management of the land in the cities of the network, in order to obtain a more efficient use of this resource and avoiding urban sprawl.

⁹ Macro-economic instruments seem to be far of the approach of the networks of cities. More detailed revisions of territorial economic policy and its options (instruments) are provided in Armstrong and Taylor (1985) and Camagni and Gibelli (1993)

5. EMPIRICAL EVIDENCE I: EXAMPLES OF NETWORKS OF CITIES

After introducing the paradigm of the networks of cities and its relation with external economies and economic growth, we present a selection of empirical examples of networks of cities documented in the literature. The study of empirical cases is an important tool because supports the theoretical framework and allows corrections and new contributions. We show cases of *natural networks* and *cooperative-policy networks*.

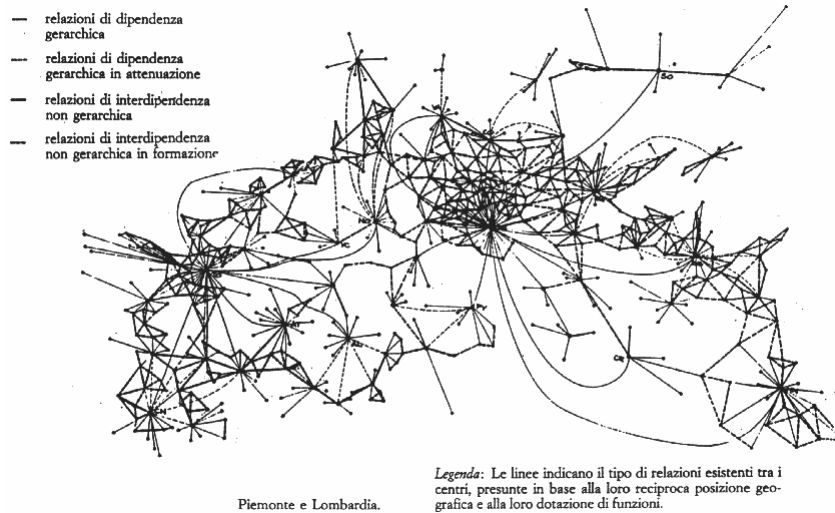
5.1. Networks of cities in the Piedmont and Lombardy

Networks of cities in Piedmont and Lombardy were studied by Emanuel and Dematteis (1990), and Camagni et al. (1994).

Emanuel and Dematteis observe the difference between the theoretical functions of the cities according to their rank and the empirically observed functions. They notice some important differences with the central place models. This study is based on stock data. Emanuel and Dematteis use factorial analysis and two samples: business services and personal services. They identify groups of services spatially related according to their presence or absence in the urban centres and the functional profiles of the municipalities. Results suggest that the distribution of urban functions differs from the central place model. Services seem to cluster not only in a hierarchical way but also according to functional homogeneity and specialization. The design of potential spatial interactions is not the typical figure of a tree but a network¹⁰.

¹⁰ This methodology has two important limitations: first, it uses only service data and cannot capture intra or inter-industry manufacture based on spatial interactions; second, it uses stock data and infers the potential interaction using geographical distance. Boix (2002) compare different approaches and finds that to infer a link from the geographical distance could produce systematic errors. However, this is a feasible approach when no flow data are available at a regional level.

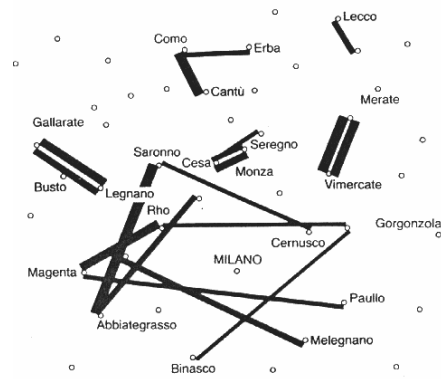
Figure 5. Networks of cities in the Piedmont and Lombardy by Dematteis and Emanuel



Source: Dematteis (1991)

Camagni et al. (1994) use a different approach based on a gravity model. The hypothesis is that central place models (hierarchical paradigm) must be complemented by the network paradigm. They focus on the approach that interaction in a central place model follows a gravitational logic: gravity models postulates a direct relation between intensity of flows and the urban dimension, and an inverse relation with the distance. Then, they use telephonic flows to estimate a gravity model and analyze the residuals. When real flows are above the estimated ones in a significant amount, it would be a non-hierarchical network link. The analysis suggests that vertical and horizontal networks coexist. Hierarchy is dominant in rural areas like Pavia and reticular structures are located in urban zones. Milan acts as a regional gateway and other networks are linked to the presence of specialized districts and multifunctional nodes.

Figure 6. Horizontal networks of cities in Lombardy

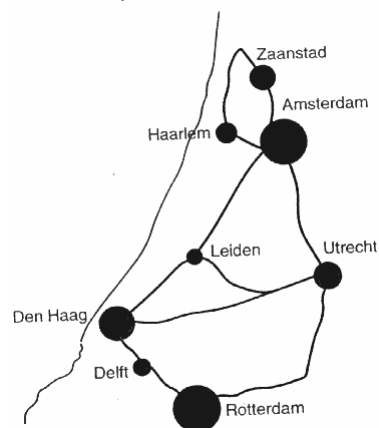


Source: Camagni et al. (1994)

4.2. The Randstad

The Randstad is the more populated zone of Holland. It includes 6 millions inhabitants and 2 millions jobs in 200 municipalities. There are three main conurbations around the cities of Amsterdam, Rotterdam, Den Haag and Utrecht that are complemented with lower nodes in Delft, Haarlem and Zaanstad. The central space is a green belt. The Randstad is a polynucleated network where the cities specialize their functions and operate in a complementary way: port, airport, political functions, international orientation or national orientation. Identity and capacities of each city are viewed as one of the principal potentialities of the network.

Figure 7. The Randstad as a network of cities

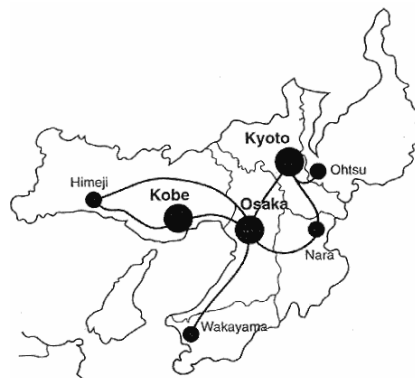


Source : Batten (1995)

4.3. Kansai

Kansai (also called Kinki) is an urban region composed by six prefectures: Osaka, Hyogo, Kyoto, Nara, Wakayama and Siga. The more populated cities are Osaka (2,6 millions), Kyoto and Kobe (more than one million) and there are good transport infrastructures that allow integrating other minor cities (Himeji, Nara, Ohtsu, Wakayama ...). The centre of this network is the metropolitan area of Keihanshin and contains above 18 millions inhabitants. The cities have relevant specializations: Nara and Kyoto were old imperial capitals. Both contain important cultural archives. Kobe and Osaka are port cities with international projection; Kyoto and Kobe have additional specialization as administrative capitals and contain industrial functions. Osaka is the commercial and industrial centre. Integration among the different prefectures generates a network of cities with 21 millions inhabitants. This fact leads to an integrated planning of the area, with projects as the construction of a new international airport and two scientific cities.

Figure 8. Network of Kansai

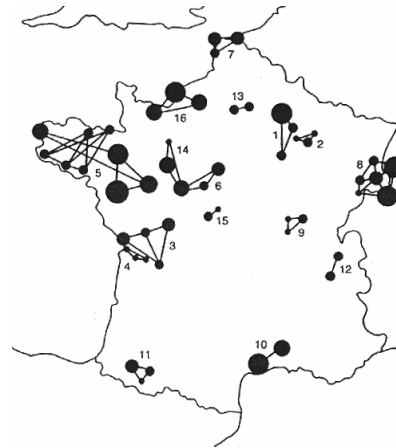


Source: Batten (1995)

4.4. French cooperation networks

Camagni and Salone (1993) and Tesson (1997) provide examples of innovation networks in France. These networks respond to cooperation agreements among local administrations. They are fomented by the DATAR as part of a policy of urbanism and development. The networks are based on the concept of potential community of action and their main characteristics are solidarity and exchange, flexibility and robustness, and efficacy and dynamism. They are based on agreements of cooperation around provision of infrastructures, technological services, educational and cultural programs, tourism management and promotion.

Figure 9. French innovation networks



Source: Camagni and Salone (1993)

These networks contain 63 cities of different sizes and objectives: 41 cities are above 60,000 inhabitants, 8 cities between 50,000 and 60,000 inhabitants, 5 cities between 30,000 and 40,000 inhabitants and 8 cities contains less than 20,000 inhabitants. Networks differ in the number of cities and population (figure 9). They are mainly located in the periphery of big growth poles and in the border across different regions or countries (Tesson 1997).

4.5. Swiss policentric network

The Swiss polycentric network provides an example about the use of networks of cities as key instrument in a spatial development strategy (*Grundzüge der Raumordnung Schweiz* or Guide for the Spatial Swiss Development)¹¹. Main features of this strategy are to reduce negative trends influencing Swiss development, adaptation to market changes in a globalized world, and to improve their competitive position in relation to other European city-regions. The initial diagnosis identifies internal and international deficiencies. Internal problems include concentration of activities in the larger urban centres and an increasing trend towards sprawl. International problems derive from small size of Swiss cities (larger cities

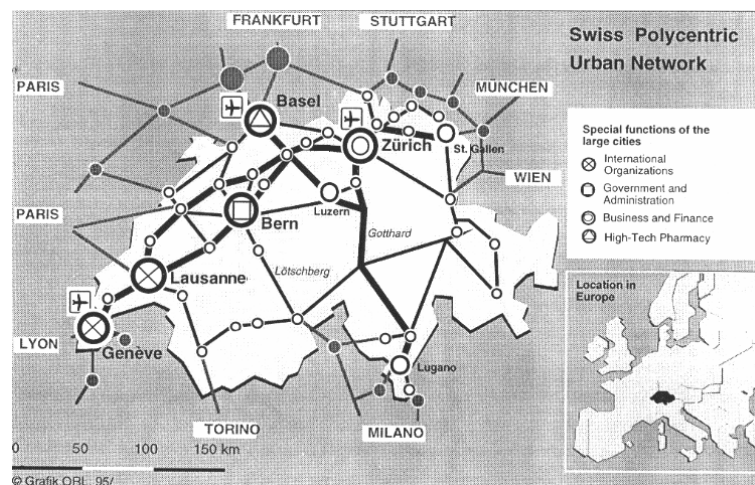
¹¹ Bundesamt Für Raumplanung (1996): "Grundzüge der Raumordnung Schweiz", Bericht v.22, Bern.

are around 1 million inhabitants) that difficult the competition with larger European city-regions.

Thus, the central strategy is the development of a polycentric urban network linking Swiss cities (Ringli, 1997). Swiss urban system contains specialized medium-size cities: Geneva and Lausanne (international headquarters), Bern (Government and Administration); Zurich (Business and Finance) and Basilea (High-tech Pharmacy). There are other minor cities (Lötschberg, Luzen, Gotthard, Lugano, Domodossola, Olten, St.Gallen, Sargans, Chur).

The objective of the strategy is to use this urban basis in order to generate a polycentric network of cities based on functional complementarity. Network can also overcome the handicap of cities' small size and configure a networked space containing 3 millions inhabitants and 2 millions jobs. This dimension allows providing more specialized services and functions avoiding the limitation of individual size. A key feature is the construction of a high-speed railway system linking the centres of the cities.

Figure 10. Project of Swiss polycentric city



Source: Ringli (1997)

5. EMPIRICAL EVIDENCE II: NETWORKS OF CITIES IN CATALONIA

5.1. Identification of networks of cities

5.1.1. Data requirements

Since there are several typologies of networks of cities, of sources of data and of research objectives, several methodologies are used in order to identify networks of cities.

The main problem derives from the fact that network identification needs flow data. Intercity flow data are difficult to find. Flows can be material or immaterial. Material flows can be directly observed and measured (e.g. commuting flows, merchandises, etc.). Immaterial flows can be directly observed or not. Observable immaterial flows are information flows transmitted by communications and telecommunications channels (e.g. telephonic flows, e-mail, etc.). Because they are not observable (e.g. knowledge flows) we must make indirect inference¹². These attributes of the flows make network identification very difficult. A good measurement of the network relationships needs several types of flows on a multiplex layer.

If no flow data are available, it is possible to dynamize stock data using physical (kilometres, time), economic (costs) or relational measures. This is not a desirable option but sometimes is the only one available.

5.1.2. Methodologies

So far, researches on the identification of networks of cities have been few and heterogeneous. This heterogeneity arises from the different objectives of the research and data availability. It makes very difficult to compare the results of the different investigations.

We differentiate between indirect and direct methodologies. *Indirect methodologies* try to identify networks of cities using dynamized stock data or contrasting the differences with the Christallerian model. Examples of these methodologies are Dematteis and Emanuel (1989), and Camagni et al. (1994). *Direct methodologies* are based on the direct use of flows: there is a network link between two urban unities A and B when there is a significant flow (cardinal or ordinal) between them. This methodology assumes a systemic approach where the most important is not divergence from Christallerian patterns. Examples of these methodologies are Pred (1977), Trullén and Boix (2001) and Boix (2002).

5.1.3. Network identification by Significant Direct Flows (SDF) and the flow score coefficient (FSC)

¹² Flows can be also classified based on their direction (directed and undirected flows) and weight (weighted and unweighted; ordinal, cardinal or interval weights).

We use the municipality (city or town) as spatial unit of analysis. This is not an ideal unit of analysis, but the use of other unities like labour markets or metropolitan (micropolitan) areas imply aggregation. On the other hand, the use of the municipality has some advantages: it is a disaggregate nodal urban unit and has administrative autonomy. Catalonia had 944 municipalities in 1996. Around 80% of the population lives in unities above 10,000 inhabitants (10% of the municipalities). The largest city is Barcelona, with 1.5 millions inhabitants. The distribution of the activity follows similar rules. Barcelona contains 30% of the jobs. The more important cities are distributed in the central nucleus of the Metropolitan Region of Barcelona surrounding the old industrial subcentres or through motorway corridors along the coast.

Since no other data flows are available, we use commuting data (house to work) to identify the structure of the network. These data are related to social relations and infrastructural endowment. Previous researches showed the capacity of this kind of flows to reveal the urban structure¹³.

In 1986, there were 528,030 inter-municipality commuters (in 24,939 pairs of connexions $A \rightarrow B$). In 1996, there were 932,789 commuters (in 38,364 pairs of connexions). However, a great number of these flows are of low volume. This derives from the small dimension of many municipalities. These low amount flows tend to be scarcely significant for the detection of the urban structure. For example, if we apply a filter of minimum 50 commuters it remains only 1,228 pairs of connexions that embrace 429,099 commuters in 1986, and 2,200 pairs of connexions that embrace 752,219 commuters in 1996. This means that 80% of commuters move in 5.7% of intermunicipality relationships.

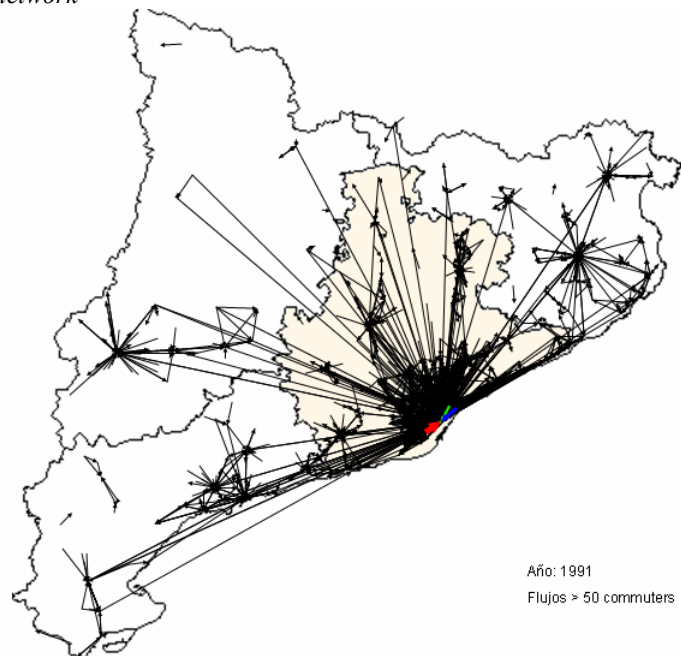
a) We use the *significant flow* methodology as a simple approach to network identification. We fix a minimum threshold (50 commuters) and consider that above this threshold the flow is significant. This provides a first approximation to the principal structure of the network (figure 10). The results of this methodology (year 1991) show a network with a much dense nucleus in the centre of the Metropolitan Region of Barcelona (RMB), and links connecting this centre with other local subsystems (Tarragona, Lleida, Igualada, Manresa, Vic and Girona). We can observe “tree-shaped” patterns (in a Christallerian way) and more meshed patterns (non hierarchical networks)¹⁴.

¹³ In a regional context, commuting flows are strongly correlated with telephonic and retail flows. For a meticulous study of the productive relations would be preferable to have additional types of flows like interfirm transactions.

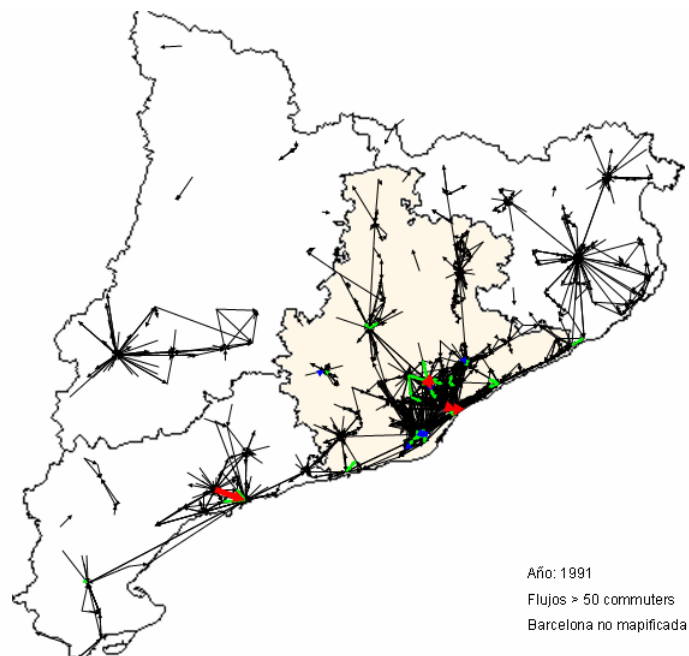
¹⁴ Principal network can be divided in vertical/horizontal networks and synergy/complementarity networks.

Figure 11. Networks of cities (principal structure). Year 1991. Significant flow methodology (minimum threshold=50 commuters)

a) Principal network



b) Principal network without Barcelona



Source: Elaboration from Censuses (IDESCAT)

b) We repeat the same methodology using sector flows. However, the shape of the sectoral networks resembles the figure 10. A problem of the significant flow methodology is that, even with sector flows, it cannot weight the mass of the larger cities. This is problematic if our objective is to differentiate productive relationships using this commuting data. A possibility is use a *Flow Score Coefficient (FSC)*. This coefficient is a translation to a flow context of the coefficient of localization:

$$LC_{i,j}^s = \frac{\frac{F_{i,j}^s}{F_i}}{\frac{F^s}{F}} \quad [4]$$

, where F = external commuting flow; s = sector; i = city of origin; j = city of destination.

A FSC coefficient above 1 indicates relative specialization in the structure of fluxes¹⁵. Thus, FSC imposes a double restriction: emitting city has a relative specialization in this sector related to its labour force, and attractor city may have a relative specialization in the sector in order to originate a differential of attraction. The results of applying the FSC to a standard 10 sectors disaggregation show that this is a powerful tool for differentiate specialized flows (figures 11 and 12)¹⁶. The main feature is that in industrial sectors¹⁷ the FSC coefficient filters most of the flows with Barcelona. It remarks a non-hierarchical structure of flows between specialized municipalities. On the other hand, construction and service activities show more centralized and vertical structures. It remarks Barcelona and other important subcentres¹⁸. Overlapping sector specialized networks, we obtain the principal structure of the network of cities. The main differences with the significant flow methodology are in the nucleus of the Metropolitan Region of Barcelona and in the south of Tarragona (around Gandesa and Amposta-Tortosa)¹⁹.

¹⁵ Researchers use to filter for coefficient larger than one. Thus, we apply the filter above 1.25. Additionally, we impose two restrictions in order to remove non significant or stochastic behaviours in the smaller municipalities: flows above 10 commuters and that the flux account for minimum 1% of the total jobs in the city.

¹⁶ Agriculture is excluded of the analysis.

¹⁷ Electricity, gas and water supply; Mining, quarrying and chemicals; Manufacture of basic metals and fabricated metal products; other manufacturer industries.

¹⁸ Wholesale, repair, hotels and restaurants shows a mixed network structure.

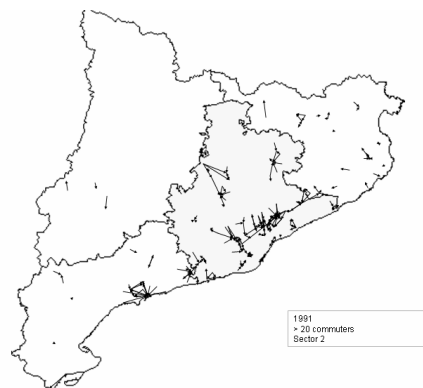
¹⁹ After the identification of the principal structure of the network, it is possible to divide the flows in vertical and horizontal.

Figure 12. Sectoral networks using the FSC coefficient. Industrial sectors. Year 1991.

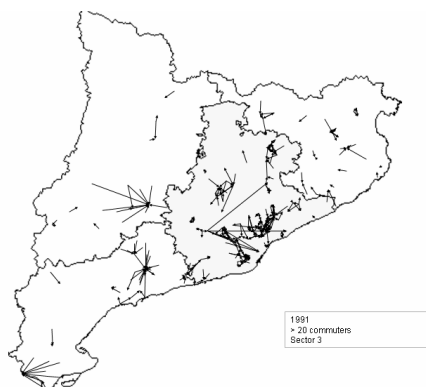
1. Electricity, gas and water supply



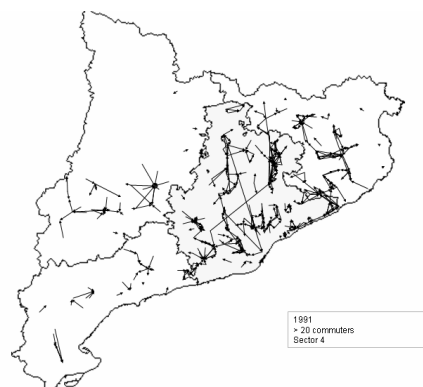
2. Mining, quarrying and chemicals



3. Manufacture of basic metals and fabricated metal products



4. Other manufacturer industries



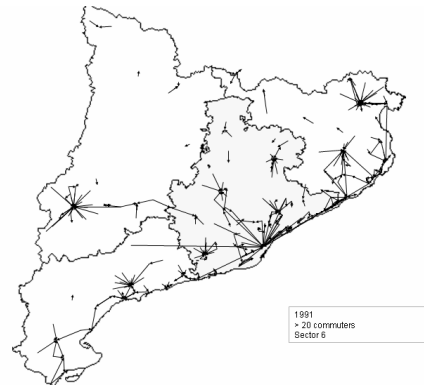
Source: Elaborated from Censuses (Idescat)

Figure 13. Sectoral networks using the FSC coefficient. Construction and service sectors. Year 1991.

5. Construction



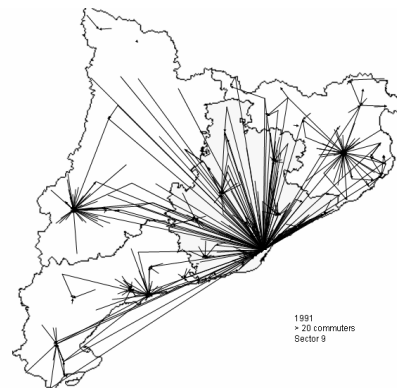
6. Wholesale and retail trade; Repair; Hotels and restaurants



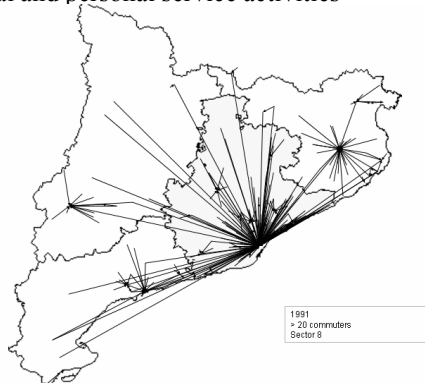
7. Transport, storage and communication



8. Financial intermediation; Real estate, renting and business activities



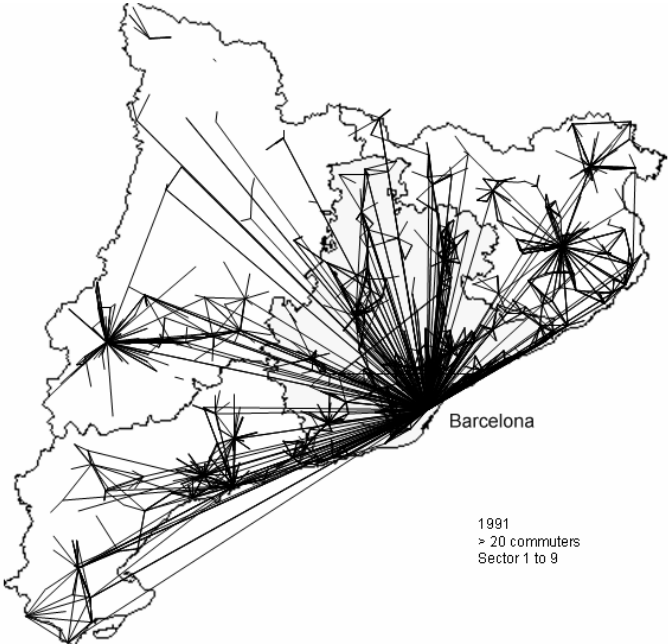
9. Public administration and defence; compulsory social security; Education; Health and social work; Other community, social and personal service activities



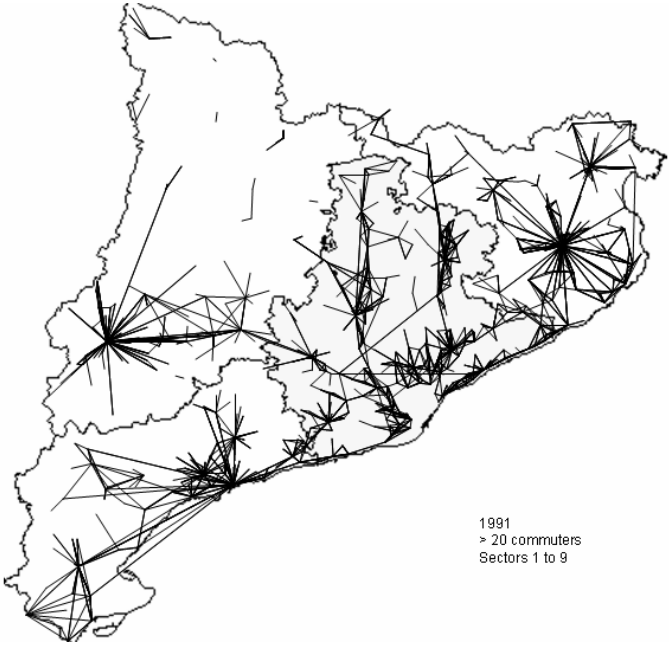
Source: Elaborated from Censuses (Idescat)

Figure 14. Networks of cities using the FSC coefficient. Sectoral maps overlapped. Year 1991.

a) Principal network



b) Principal network without Barcelona



5.2. Capturing network externalities on the economic growth

In the 1970s, the first empirical works started to measure *agglomeration economies* using neoclassical production functions²⁰. Recent researches are influenced by Glaeser et al. (1992) and Henderson et al. (1995). The measurement of the *network externalities* has been approached by Capello (2000) and Trullén and Boix (2001)²¹. Capello tries to provide a quantitative measure of the advantages of the network behaviour in a cooperation network (Health City Network). Trullén and Boix combine the paradigms of the network of cities and the knowledge-based economy. The measurement is carried out on a regional network of cities.

Boix (2003) explores a diverse approach to the network externalities using the model of Glaeser et al. (1992) and spatial econometrics. This framework allows differentiating the effects of agglomeration and network externalities on the urban growth. The network specification used is the *significant flow* for 1986. The dependent variable is the growth ratio of the city employment for each sector. Thus, the model explains why sector jobs grow more in a city than in another²². The results show significant positive and negative agglomeration and network economies (figure 15)²³. Each sector has different response to these advantages. Agglomeration economies seem to be more important than network economies, but network economies are significant²⁴.

²⁰ Moomaw (1983) offers a revision of this literature.

²¹ Other researches introduce spatial externalities using the geographical distance. This is a more limited approach. Rosenthal and Strange (2003) provides a revision of these works.

²² The model explains growth differentials. This is different from explain why a city grows.

²³ Boix (2003) uses a linear econometric regression introducing as agglomeration economies: firm size; initial jobs; initial specialization (location coefficient); initial urban diversity (inverse of the Henderson-Hirschmann-Herfindahl); initial population in the city; initial human capital (mean of years of education); and inter-sector drag effects (growth of the other sectors in the city). Network externalities include the agglomeration variables spatially lagged (multiplied by the binary network matrix) and the lag of the dependent variable (growth of the sector jobs in the municipalities of the network). All variables are in neperian logarithms. Because regression includes a spatially lagged dependent variable, we cannot use a standard OLS estimation. Then, a bayesian heteroskedastic spatial model is carried out producing consistent and efficient estimation of the parameters (LeSage 1999).

²⁴ Low coefficients are associated with network specification as significant flow.

Preliminary experiments using FSC sector network suggest that coefficients increases in a significant way.

Table 4. Estimates of urban network externality measurement in Capello (2000)

	First regression		Second regression	
	β	t	β	t
Constant	0.08	(-1.09)	-0.05	(-0.55)
Network connectivity	0.005	(2.21)	0.006	(2.51)
Intensity of use of the network			0.47	(2.23)
R ²		0.12		0.25

Dependent variable: urban performance in terms of local policies implemented thanks to the network
 β = coefficient; t = student-t
 OLS regression

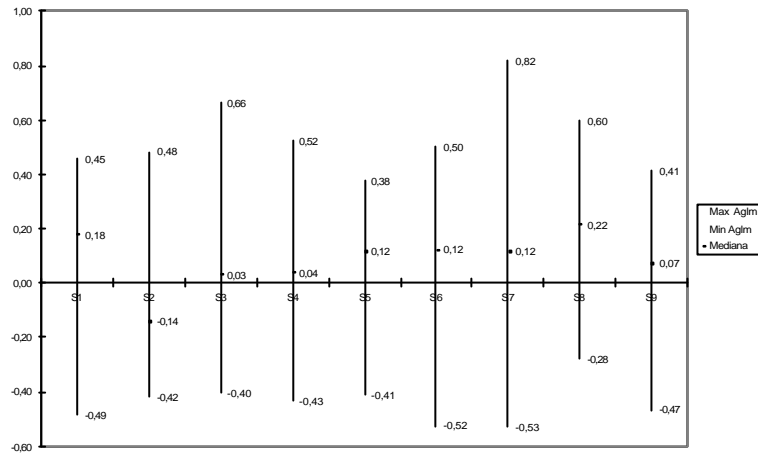
Table 5. Estimates of urban network externality measurement in Trullén and Boix (2001)

	(1)		(2)		(3)		(4)	
	β	t	β	t	β	t	β	t
Constant	471.32	3.59	137.89	1.81	-16.32	-0.15	8.57	0.08
High Knowledge Employment ₁₉₉₁	1.30	608.08	1.42	27.20	1.26	96.83		1.2783.06
Specialization (location Coefficient)	-730.09	-3.87	-251.30	-2.51	-48.52	-0.36		-74.3-0.59
Firm dimension	15.97	4.09	12.87	3.8	12.15	4.02	11.17	4.12
Dummy Barcelona			-45201.30	-2.30				
Principal networks					65.88	2.91		
Vertical networks							37.08	1.31
Horizontal networks							107.14	1.74
R ² Adjusted		0.9990		0.9992		0.9991		0.9992
DW		1.9408		2.6062		2.3126		2.2483

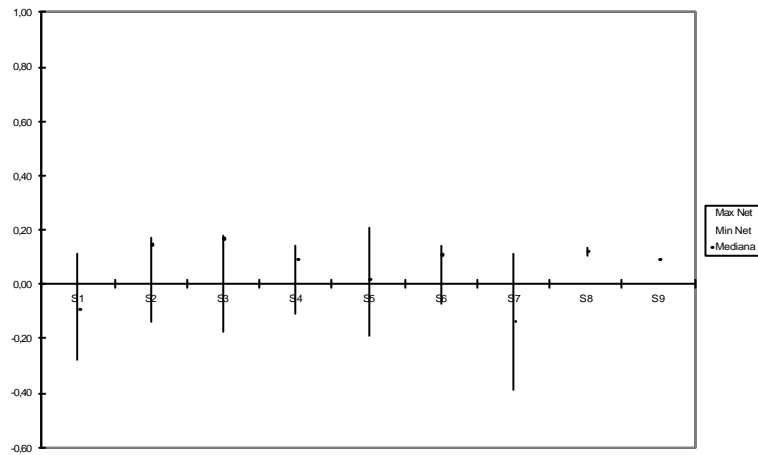
Dependent variable: Total variation in high knowledge employment 1991-2000
 β = coefficient; t = student-t
 IV regression. White heteroskedasticity correction.

Figure 15. Agglomeration and network economies in Catalonia

a) Agglomeration economies (elasticities)



b) Network economies (elasticities)



Source: Elaborated from Boix (2003)

5.3. Network policies

We provide two examples of policy strategies for Catalonia based on the works of Trullén (1999, 2001 and 2002).

5.3.1. Catalonia-Cities

Catalonia-Cities (Trullén 1999 and 2001) proposes a change in the territorial model of Catalonia for the XXI Century. The aim is to incorporate the new features of economic and social basis that are rooted in the cities and use the network of cities like a key tool for a new territorial strategy. The main objectives for this strategy are equity, sustainability, efficient management, and competitiveness.

Networks of cities and polycentrism have an important role:

1. Substitution of the Christallerian approach in the provision of infrastructures and services for a coordinate provision in a non-hierarchical view. The aim is to use the advantages associated with the mass-effect of the network of cities and expand this effect in an efficient way.
2. Substitution of competition for scarce resources inside the urban system (that fragments the supply and diminish the scope) for vertical and horizontal cooperation based on trust and co-responsibility.
3. Improvement of the urban nucleus avoiding urban sprawl and urbanization along the communication's axis.
4. Improvement of the external connection between Catalanian cities through high-velocity railway infrastructures; port and airport infrastructures and high-velocity telecommunications.

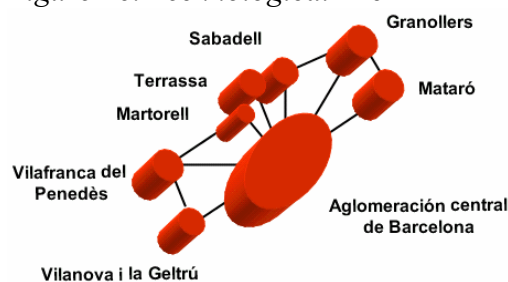
5.3.2. Technological Arc

The "Technological Arc" is a recent proposition of Trullén (2002) based on the identification of two facts:

1. Metropolitan Region of Barcelona is polycentric. It contains a central agglomeration around Barcelona and a system of subcentres that are medium-size cities of industrial tradition. These cities are in process of technological transformation toward a knowledge basis (Technological Arc), and contain 1.5 millions inhabitants and 0.5 millions jobs.

2. Direct connexions between these subcentres have a low quality, hindering direct interaction between them. Traditional diagnoses have identified this space (Technological Arc) as an aggregated external belt. However, it is easy to see (figure 13) that this space is a network of cities. Thus, the suggestion is to develop a better direct connection between subcentres, using high-velocity railway and telecommunication infrastructures.

Figure 16. Technological Arc



Source: Elaborated from Trullén (2002)

7. CONCLUSIONS

1. A network of cities is a structure where the nodes are the cities, connected by links of different nature, through which flows of socioeconomic nature are exchanged. Flows are supported on communication and telecommunication infrastructures. The main characteristics of the networks of cities are the possibility of simultaneous hierarchical and non-hierarchical structures, cooperation (or competence – cooperation) between the cities, and the generation of advantages related to the organization of the urban structure.

2. Several types of networks can be founded: vertical, horizontal and polycentric networks; synergy and complementarity networks; knowledge-based networks (high and low knowledge); regional, national and world cities; natural or cooperation networks; and stable or conjuncture networks.

3. Urban growth is related to the generation of internal and external economies. They produce increasing returns that are compatible with the hypothesis of competitive firms. Marshall differentiates between internal and external economies. Internal economies are generated inside the firms. External economies can derive from the localized concentration of population and activity (spatially static) or from the interaction between agents localized in different urban unities (spatially dynamic). The concept of agglomeration economies includes internal economies and external spatially static economies. Network economies result from the interaction between cities, and are spatially dynamic.

4. The sources of the interurban network externalities have been little studied. Sources of network externalities may be: size effects, knowledge effects, transaction costs and organizational advantages. When net agglomeration economies are decreasing, network externalities could provide an additional source of advantages that influences urban competitiveness and growth.

5. Networks of cities have been documented in the economic and geographic literature. We provide examples for Piedmont and Lombardy, Randstad, Kansai, France and Swiss, but there are other networks documented. Different sources of data, network definitions and methodologies of identification make very difficult to compare these researches.

6. We identify networks of cities in Catalonia using two different methodologies: the Significant Flow and the Flow Score Coefficient (FSC). Results show that both methodologies produce a similar aggregated network, but only the FSC produces a careful identification of sectoral networks.

7. Few studies have measured the network externality in networks of cities. A first generation of studies (Capello 2000; Trullén and Boix 2001) uses static indexes for the measurement. Boix (2003) introduces a new approach using spatial econometrics in order to obtain a spatially dynamic measurement. A variation of the Glaeser et al. (1992) growth model allows linking agglomeration and network externalities with urban growth. Results show that there are positive and negative agglomeration and network economies. Agglomeration economies show larger coefficients than network economies. An additional feature is that each sector shows a different sensibility to these economies.

8. We can use theoretical and empirical advances in the network theories in order to improve network policies. Networks of cities provide a powerful tool for economic policies of territorial basis proposing new strategies regarding to the objectives of equity, sustainability and competitiveness.

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Annex I. Catalonia: main municipalities

