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"Polycentrism and emerging sub-centres in the restructuring of metropolitan systems. The case of Barcelona Metropolitan Region (RMB)"

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ABSTRACT:

Changes in metropolitan areas are characterized by the dispersion and concentrated decentralization of employment and population. These urban dynamics have led to a specialized line of research into polycentric urban systems. The topic is of obvious interest because a perfect polycentric system would offer the two major economic advantages of urban systems: the presence of agglomeration economies, which result in increasing returns for companies, and a potential reduction of transport costs (including time), which lead to a reduction in salaries and land rent. Moreover, this urban model would have social and environmental benefits arising from an improvement in transport planning and a drop in commuting if the network is designed to connect sub-centres. In theory, polycentric systems offer the benefits of large and medium-sized cities by combining the advantages of traditional centralized cities with a decentralized spatial configuration.

In this paper, the current and prospective spatial structure of the Barcelona Metropolitan Region is studied. Firstly, by analyzing employment density and travel-to-work data (Spanish Census 2001) the urban sub-centres are detected at the time that a methodology to classify them into "emerging" and "consolidated" is proposed. Then, this paper is focusing on the prospective urban dynamics (2001-2024) by using a spatial interaction model in order to define, on the one hand, the evolution of polycentrism level; and on the other, the emergence of urban sub-centres due mainly to the effects of the economies of agglomeration and disagglomeration in the regional-urban space.

Results suggest a strengthening process of the level of polycentrism as well as an urban dynamic of emergence of sub-centres, which are concentrating on the intermediate distances instead of in the periphery (edge cities); what it could lead to a restructuring of the Barcelona Metropolitan Region towards a bipolar polycentric model where the complexity of the relations among sub-centres emerges.

Keywords: *Polycentrism, emerging urban sub-centres, spatial interaction model & urban structure*

0. INTRODUCTION

The European Spatial Development Perspective (ESDP), agreed by European Union (EU) Ministers of Planning in Postdam in 1999, proposed a central policy objective of polycentrism: promoting greater polycentricity in the European urban system (European Commission, 1999). But this central term is quite fuzzy. At the EU level, in the ESDP, polycentrism means promoting alternative centres outside the so-called 'Pentagon'[1].

But a regional level, polycentricity refers to outward diffusion from central cities to emergent ones (sub-centres) functionally linked among them, but not necessarily contiguous and reconfiguring different levels of the urban hierarchy (Christaller, 1933) : lower-level service functions are dispersed out from higher-order central cities to lower- order cities, thus altering not only Manuel Castells's celebrated 'space of places' but also his 'space of flows' in the network society (Manuel Castells, 1996). In addition (Manuel Castells, 1996) contrasts our traditional concern for 'spaces of places' (such as countries or cities) with contemporary transnational movements of people, commodities, and especially information, which Castells calls 'space of flows'. This 'space of flows' is today found at a range of different geographical scales ip to and including the global scale o cities within networks and as city regions are the critical hubs and nodes of the space of flows. So, the entire concept of polycentricity proves highly scale-dependent: polycentricity at one scale may be monocentricity at another.

In this paper, the notion of polycentricity is associated with the intrametropolitan scale and the concentrated-decentralization from CBD to sub-centres. In that sense, according to (McMillen, 2001a Op. Cit) "a reasonable

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[1] Bounded by the metropolises of London, Paris, Milan, Munich and Hamburg.

working definition of a sub-centre is a site (1) with significantly larger employment density than nearby locations that has (2) a significant effect on the overall employment density function".

While this latter conceptualization directly derives from the "standard urban model" (i.e. that based on from the theory) and performs well when detecting dense employment zones departing from relatively small areas like census tracts (or even districts within a city), it does not suffices, when study areas have certain demographic, economic and political entity like municipalities, and when what is pursed is not only the detection of employment sub-centres, but truly metropolitan sub-centres.

For that reason, (McMillen, 2003) states two further conditions (3) the necessity that sub-centres – municipalities represent structural elements within metropolitan systems and at the same time (4) are attractive to live and work in. This latter definition of sub-centre is more close to what is pursued in the EU's ESDP.

The aim of this study is to analyse the current spatial urban structure of the Barcelona Metropolitan Region by detecting the urban sub-centres and by proposing a methodology to classify them into "emerging" and "consolidated". Then, by using a spatial interaction model, this paper tries to do a prospective analysis of this metropolitan system for studying the emergence of new sub-centres and the evolution of polycentrism level. The work reported here constitutes the first step of a more comprehensive doctorate research, in which the main objective is study how the prospective urban structure of the metropolitan systems (e.g. sub-centres, polycentrism level) is being restructured and what will be its impact on the territorial cohesion and competitiveness.

The rest of the paper is organized as follows i) firstly, the theory on formation of polycentric structures is presented; ii) secondly, the methodology to identify sub-centres and the proposed method to classify them are discussed; iii) thirdly, the spatial interaction model to detect emerging sub-centres is explained; iv) data and case of study; v) then, the results of sub-centres identification and classification, evolution of polycentrism level and the emergence of new sub-centres (2001-2024) are discussed; vi) and finally, in conclusion, the main findings.

1. THEORY ON FORMATION POLYCENTRIC STRUCTURES

The standard urban model (SUM) as it was shaped by (Alonso, 1964), (Muth, 1969) and (Mills, 1972) with roots in the pioneering work of (Thünen, 1826) and (Launhardt, 1885) is the theoretical framework behind the formation of urban densities. This model, originally conceived for a monocentric city, explains that in achieving locational equilibrium households bid up for land accordingly to expenses saved in commuting. Thus the closer is the residing place to CBD (where all employment is supposed to be) the higher is the rent transferred to land (which capitalizes into higher prices), emerging in that way a land rent gradient. It is the existence of land rent gradients what underlies in density formation in a competitive market scenario. In the monocentric model most of the employment (and services) are located at city centre, and peripheral areas do concentrate housing in low density urban schemes, since the price of unit of land decreases as the distance to CBD increase.

If the monocentric city model is reformulated by introducing the existence not only of agglomeration economies (i.e. scale, localization and urbanization) which induces employment to concentrate in one site, but also the existence of diseconomies of agglomeration (e.g. congestion) which induces employment to decentralize (Henderson et al., 2000), it is possible to get a polycentric city model (White, 1976). In that way polycentrism can be achieved by concentrated decentralization from CBD, in this paradigm economies of agglomeration do exist (explaining why sub-centres do form), nevertheless diseconomies in the large city centre prevent to increase its size.

Another way to reach a polycentric model is by the incorporation of formerly independent urban centers. This latter line is affiliated to Central Place Theory which considers that market areas are defined by the willingness to travel of individuals for achieving the consumption of goods and services centrally distributed (Christaller, 1933). In this respect when travel cost (including time) is reduced (e.g. by the improvement of transport technology) the expansion of market areas allows for integrate central places as sub-centres (Champion, 2001). In this way, previously "independent" cities start to work in a network scheme, in which the externalities emanated from urban sub-centres do influence the urban development of their peripheries consolidating in this way the metropolitan system.

Consequently, the polycentric model concept is a multi-dimensional concept; where the morphological and the functional perspective are coexisting. (Kloosterman and Musterd, 2001) state that the urban polycentric configurations should have the next summarized features:

1. A number of different historical cities.
2. A lack of city-dominant leader.
3. A small number of cities of similar size with each other and a large number of small towns
4. Proximate location between the cities which are constituent of the system (within the maximum commuting distance).
5. Constituent cities are spatially and politically different from one to other.

(Parr, 2004) emphasizes that the polycentric model is related to the plurality of centres. (Parr, 2004) defines the polycentric urban regions as a cluster of similar settlements, separated by open spaces with interactions between them above the average, and having a specialized economic structure. In this line, (Champion, 2001), suggest that there are three basically features that define the polycentric urban region depending on the degree of restriction: 1) a variety of settlements within the region (less restrictive), 2) as above, but with some interaction between the settlements, 3) as above, but each centre has a specialized function within the region (the most restrictive). (Spierkermann and Wegerner, 2004) develop a formal definition of polycentrism based on the rank-size of the settlements of the urban systems. Suggest that polycentrism can be measured from three basic requirements:

1. In a polycentric urban system, there is a distribution of large and small cities.
2. In a polycentric urban system, the rank-size distribution is log-linear.
3. In a polycentric urban system is not dominated by one large city.

In addition, (Paul M Hohenberg, 2004) related to that above, by analysing the urban systems, states that its systemic logic is dual, in that two types of system effectively model urban Europe. (Paul M Hohenberg, Op. Cit.) From the origin of cities onward, two sets of forces have driven the process of urban development, expressed respectively in central places and networks. (Paul M Hohenberg, 2004) analysed these two sets of forces in according to the next way:

1. a) The arrays of central places build toward a pyramidal structure, with many small centres and tiers of, larger, high-order centres culminating in a single capital. These arrays show great spatial and rank stability over time. b) Functionally, central places tend to house diverse service activities, whose range and "level matches the size of the centre, so that high-order places serve as centres of (smaller) centres. c) Population size generally follows their degree of centrality. d) The growth of cities in central places tends to show a bias towards more rapid growth of larger cities, with a frequent tendency to primacy or gigantism in the principal city. Small centres may grow or may fail to grow and in time shrink as they lose all central place-functions. e) In term terms of long-time changes, the central place system has shown much greater stability over time.
2. a) Cities that participate strongly in network relations, on the other hand, from a spatially fluid system where distance as such counts for little. b) Functionally, networks; link specialized cities and zones of production in an inter-urban, often international, division of labour, and thus typically feature a limited range of activities in a single place. c) Population size is an imperfect indicator of role, or importance, in networks, and its growth can be quite irregular; so the dominance or subordination in network cities thus depends on function more than on size. d) The growth in the network system, growth can be rapid and the relation of growth rate to initial size is somewhat negative among network cities. e) In terms of long-term changes in European urban systems, network system logic is behind most structural transformations.

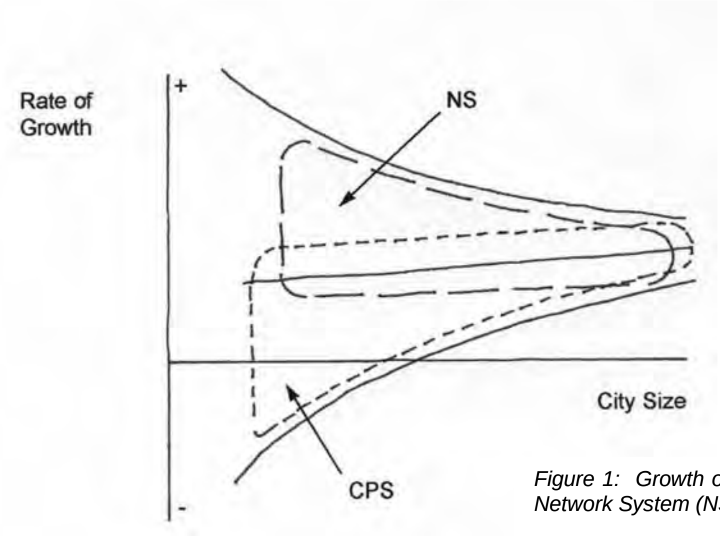

Figure 1: Growth of cities relative to size in Central Place (CPS) and Network System (NS) Source: Hohenberg (2004)

(Paul M Hohenberg, Op. Cit.) concludes: the historic process of urbanization, at least in the central place system, seems akin to the "Big Bang" model of cosmology. All centres were created very early, and their subsequent evolution is principally a structuring and selection to form an orderly hierarchic system. On the other hand, the formation of new centres or sub-centres, of concern to economic geographers and location theorists, responds to the logic of the network system.

Nevertheless, whether polycentric urban structures come from decentralization or integration, the continuing argument in urban economics theory is that both overall land rents and density gradients are conjointly influenced by the proximity to CBD and sub-centres. Sub-centres, therefore, mimic at local scale the influence that is exerted by CBD in the global scale.

1.1. DEFINITION OF SUB-CENTRES

A sub-centre is a point in the metropolitan area characterized not only by having a density significantly higher than the workers of their neighbours, but above all, by being able to exert an influence on their surroundings. This influence can be reflected by the flow of workers and shoppers who visit him from their residences, or by a modification of the mantle value and intensity of land use around it. A sub-centre should also be a reference point in the territory with an intensity that can be recognized for their neighbourhood, but not incorporated the environmental aspect for this urban structure.

Since the early spatial models such as (Thünen, 1826), to those of Krugman and Fujita, self-organization of space has been raised through the integration of three closely interrelated processes, namely: 1) the formation of spatial rent of land, 2) the configuration of land uses, and 3) the intensity of use of space. Value, use and density are, therefore, the three sides of a coin, in which background underlying transport costs and time spent to overcome space and agglomeration externalities, as emergent property, arising from the concentration of locators. In this sense (Bertaud, 2002) has emphasized that the forces that form and maintain the sub-centers are related to the efficiency and effectiveness of the transport system.

(Bertaud, 2002), raises the differences between the monocentric and polycentric cities depend on the level of replacement or substitute destination travel patterns required, and no city is 100% 100% monocentric or polycentric. In an attempt to define a theoretical classification, in 4 groups:

1. A city with a preponderance of the CBD and sub-centers identified, most trips are focused on from the periphery to the CBD. This category would monocentric city.
2. A city where the CBD and sub-centers exert strong bonds of attraction for workers and there is attraction between the sub-centre itself, but to a lesser degree.
3. A city based on a polycentric system equipotential, where there is a preponderance of the CBD with regard to the sub-centre, nor among the latter. This category would be the polycentric city.
4. A town halfway between the monocentric and polycentric. This model is not well defined hierarchies, the CBD maintains its hierarchy attracting travel, but also sub-centres compete with him, but not are equipotential.

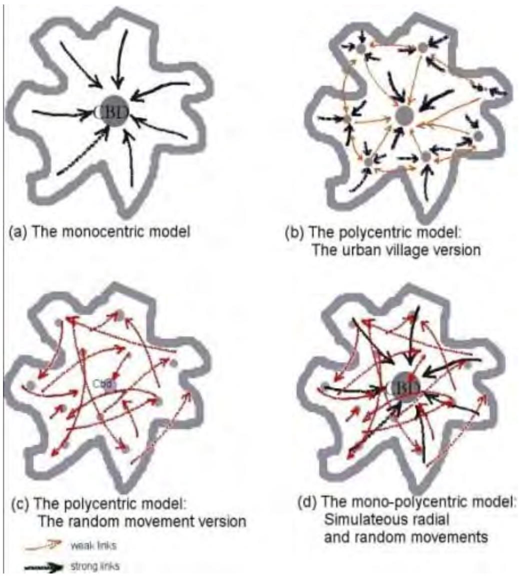

Figure 2: City models, according Bertaud Source: Bertaud (2002)

Besides a metropolitan sub-centre should have a given number of features as:

Diversity in its economical structure, sub-centres should be places that reinforce complex networks of cooperation, complementarily and competence (Rueda, 1996). Diversity understood as complexity, it is to say a group of discrete variables with a significant content of information, about its abundance and interactions (Margalef, 1991).

Concentration of central activities as retailing and office based activities, namely those activities that produce (by means of their market areas) hierarchical relations on the territorial area (Nel·lo, 2001), activities that produce territorial linkages based on services and good distribution (Berry, 1958). Concentration of economical activity but also residence, being able to retain the working population because of their attractive and employment diversification. Sub-centres double attractive as a place to work and live.

As it is evident, such characteristics are consubstantial to the concept of metropolitan sub-centre in the paradigm of European Mediterranean metropolises. Which is quite far from the North American urban paradigm (Dematteis, 1998) where have been envisaged the methods to detect sub-centres. The gap increases when it is realized that an important part of sub-centres in European metropolises are product of functional integration of ancient cities which were originally independents in labour market terms (Muñiz et al., 2003).

2. METHODS TO IDENTIFY SUB-CENTRES & PROPOSED METHOD TO CLASSIFY THEM INTO "EMERGING" AND "CONSOLIDATED"

2.1. METHODS TO IDENTIFY SUB-CENTRES[2]

The vast majority of methodologies have focused on the identification of sub-centres by alternatively studying: a) how dense in employment terms is a site (controlling or not the distance to CBD); or b) the influence of a site in organizing the commuting flows in a more complex urban system. Such criteria have clearly defined two families of sub-centre identification as it will be exposed here.

Methods based on density analysis

The first family, based on the analysis of density, is by far the most widespread. This family has four major methodologies:

1. The first criterion suggested by (McDonald, 1987) is based on the identification of employment density "peaks" (the author suggests that a sub-centre is the second peak beyond the CBD). This criterion consists of analysing density employment to detect local disruptions with the aid of a geographic information system (GIS). Alternatively, the employment/population ratio can be used to detect the areas that have higher relative concentrations of economic activity. (Gordon, Richardson & Wong, 1986) restricted the number of sub-centres to those areas with high t-values; this line of research was continued by (McDonald & McMillen, 1990) and (Craig & Ng, 2001).
2. The second approach consists of using upper and lower cut-offs. This line was originally proposed by (Giuliano & Small,1991), who considered sub-centres to be the contiguous census tracts with a density of more than 10 employees per acre and a total critical mass of at least 10,000 jobs. Therefore sub-centres must to meet density and critical mass criteria. The references of this method are, (Cervero & Wu,1997), (McMillen & McDonald, 1997), (Bogart & Ferry, 1999), (Anderson & Bogart, 2001), (Shearmur & Coffey, 2002) and (Giuliano & Readfearn, 2007). In this line, (García-López, 2007, 2008) and (Muñiz & García-López, 2009), suggested that sub-centres are zones with a density higher than the metropolitan average and at least 1% of metropolitan employment. (Pain & Hall, 2006) have defined "cores" in their Interreg IIIB Polynet Project, as NUTs 5 with 7 or more workers per hectare, and at least 20,000 workers in either single.
3. From an econometric perspective, there is a third methodology that identifies potential sub-centres by analyzing significant residuals in an exponential negative density model (McDonald & Prather, 1994) suggested several models for detecting sub-centres based on the identification of areas with positive residuals that are significant at a 95% confidence level.
4. The fourth approximation (derived from that presented in 3) is based on non-parametric models (e.g., locally or geographically weighted regression –L or GWR-) to detect "peaks" that locally adjust the density function and prioritize the effect of neighbouring municipalities on the adjustment process (McMillen, 2001b; Craig & Ng, 2001; Readfearn, 2007). The main advantage of this method is that it enables local gradients of density reduction to be determined across the metropolitan area. (Suarez & Delgado, 2009) develop a hybrid method, where once that peaks of density have been detected by means of GWR residuals, adjacent census tracks are added to comply with a threshold number of workers and density.

According to (McMillen, 2001b) approaches based on cut-offs are useful because enables a historical analysis of the sub-centre structure. Nevertheless, they excessively rely on local knowledge to calibrate the thresholds of critical mass and density, and this can be a problem when trying to compare different metro areas with different local experts. The work of (García-López, 2007) seems to give a steep forward by relativizing the critical mass

[2] The methods to identify sub-centres are explained in more detail in (Marmolejo, Masip & Aguirre, 2011)

threshold to 1% of metropolitan employment and minimum density to metropolitan average. Nonetheless, such a criterion, in the way operationalized by him, is flawed since the larger the number of spatial units in the metro area, the highest is the difficulty to reach the critical mass criterion, and the most homogeneous is the density function across units, the higher is the probability that a large number of units are above average density. Additionally, cut-offs approach have a more serious defect: they tend to prioritize as subcentres central areas, since they regret what is essential in the standard urban model (i.e. global density is determined by proximity to CBD). Some authors have tried to solve such a problem by manually removing what they consider is the CBD, other have established differentiated thresholds in relation to centrality.

Econometric models have meant a significant advance, in conceptual terms, by controlling the influence on overall density exerted by the CBD, approaching in this way to the central theory behind density formation. Namely the functional form that has been extensively used is the negative exponential. By taking logs it can be formulated as follows:

$$LnD_x = k + BD_{cx} \qquad (1)$$

In (2) *D* is the employment density at municipality *x, K* is the constant which is argued to be the density at *CBD* and *D* is the distance between *CBD c* and municipality *x*.

Sub-centres from this perspective are sites which density is significant above to what is explained by their proximity to CBD. Therefore, one part of their density is endogenously explained, and this piece comes into play in differentiating them from other sites. Nonetheless almost all of the econometric methods have failed in constraining the complexity of metropolitan areas to one dimension: the distance to CBD. Notably the density function is affected by specificities lying in three dimensions. Some studies have broken down this limitation by analysing metropolitan corridors, nevertheless the result of such analyses are difficult to be conjointly interpreted. Advances in spatial modelling have solved such an issue by explicitly introducing the effect of bi-dimensional space, like in the locally or weighted non parametric models.

Methods based on the analysis of functional relations

The second family of methods is based on the understanding that sub-centres are not only abnormally dense zones in the metropolitan space, but also structural nodes that can strengthen the functional relationship with their surrounding municipalities. *In that sense, this approach is closer to the conception that centres in a network of cities function as nodes, without the necessity of being dense spots*. The methods based on the analysis of functional interactions were designed to delimit territorial systems (Nel·lo, 2001), including *Travel To Work Areas* in England, *Statistical Metropolitan Areas* in the USA and *Functional Urban Areas*, and some focused on detecting sub-centres that structure such territorial systems. References in this field include (Bourne, 1989), (Gordon & Richardson, 1996), and the revised literature in section 2.

The methodology proposed by (Roca *et al*., 2009) and used by (Roca, Arellano & Moix, 2011) for the purpose to delimit metropolitan areas, also allows for detect urban sub-centres. This methodology that at the same could delimit metropolitan areas and identify sub-centres within them is based on in travel-to-work data, having as a particularity that reflexive (transitive) interactions are conjointly considered; it is to say the bidirectional relation between municipalities. By doing so, it is possible to integrate in one municipality which result complementary including peripheral municipalities specialised in economic activities (i.e. employment agglomerations) in which work people residing in other municipalities. This transitive integration is possible thanks to the interaction value. As defined by (Roca & Moix, 2005), following (Coombes & Openshaw, 1982), the interaction value (IV) between two municipalities can be expressed as follows:

$$IV_{ij} = \frac{f_{ij}^2}{RWP_i LTL_j} + \frac{f_{ji}^2}{RWP_j LTL_i} \qquad (2)$$

Where IVij is the interaction value between the municipalities i and j, where fij and fji are the existing flows, and where RWP is the resident working population and LTL are the localised work places within municipalities i and j. The interaction value has a special interest over other indicators of urban interaction; given that it weights the flows by virtue of the totality of the “masses” of the municipalities in relation. In addition, this weighting is carried out in a ‘transitive’ way, considering not only the attraction in one direction (i.e. the ‘larger’ over the ‘smaller’), but also in the opposite direction.

The first step in detecting metropolitan limits (and then sub-centres) consists in detecting proto-systems as follows:

1. The joining up of the metropolitan municipalities as a function of their maximum *interaction value*. This determines, as a general rule, the joining together of the municipalities with the greatest number of LTL with those to which they are most linked.
2. The formation of these groupings in *protosystems*. The previous joining up process culminates when a *closed* system is achieved. Thus, for example, if *A*, *B* and *C* have a maximum relation with *D*, they will conform a protosystem only if *D* has its maximum relation with *A* or *B* or *C*. By contrast, if *D* has its maximum relation with E, they will all "gravitate" towards *E*, completing the protosystem if *E* has its maximum relation with one of the municipalities aggregated thereto.
3. The protosystems are only consolidated if they are *physically continuous*[3]. Otherwise the discontinuities are corrected, forcing the different municipalities to integrate in the protosystem with which they have the greatest interaction.
4. Likewise, the consolidation requires a *minimum level of 50% self-containment*. In the event that a protosystem does not reach this degree of autonomy, it is aggregated with the protosystem with which it has a maximum level of interaction, and this continues in an iterative form until the resultant protosystem guarantees this condition of self-containment. In this case it is consolidated as a *metropolitan sub-system* (the municipality leading each metropolitan sub-system it is considered as a sub-centre, namely the most important municipality inside of each sub-system, it is to say the municipality with the highest interaction value with the remaining municipalities of a given sub-system)

The second step in metropolitan delimitation has consisted in aggregate sub-systems according to the interaction value among them. In polycentric metropolitan areas the aggregation is a gradual process: first important sub-centres attract peripheral sub-systems before gravitate towards the central sub-system (that in which central municipality is contained in). In our case, the iterative process is stopped in a threshold of an interaction value equivalent to 1/1,000. [4]

In this paper 4 ways to detect sub-centres has been tested:

1. Using the classical approach, it is to say using the classic density (LTL/a) and functional form explained in (1) $LnD_x = k + BD_{cx}$
2. Using the cut-off approach in the way as has been used by (García-López, 2007)
   $$LTL \geq 1\% \sum LTL_{BMR} \qquad D_{ltl} \geq D_{Average\_BMR}$$
3. Considering as candidate to sub-centre to those municipalities leading each sub-system as suggested by (Roca *et al*., 2009).
   $$IV_{ij} = \frac{f_{ij}^2}{RWP_i LTL_j} + \frac{f_{ji}^2}{RWP_j LTL_i}$$
4. Using an approach based on functional relations and density analysis (a combination of way 2 and 3): considering as a candidate to sub-centre the protosystems[5] that satisfy the criteria of using cut-off approach. In that sense, this "new approach" could identify centres in a network of cities function as nodes that at the same time they also are dense spots.

[3] It needs to be pointed out that the physical discontinuities resulting from the process of aggregating the municipalities to the protosystems are minimal. The interaction algorithm shows its extreme potential, though not requiring in practice, the assumption of additional geographical requirements.

[4] In establishing such a stop-value the formation process of the metropolitan area (MA) studied in this paper was analyzed in detail. After an interaction value of 1/1.000 it is necessary to wait a significative number of interactions to aggregate more protosystem to the MA.

[5] According to (Roca et al. 2009) there are 44 protosystems and 24 metropolitan subsystems (consolidated protosystems, more than 50% of self-containment) for the Barcelona Metropolitan Region. In this approach, is used the 44 protosystems: Arenys, Barcelona, Begues, Bigues i Riells, Cardedeu, Corbera de Llobregat, Cornella de Llobregat, La Garriga, Gelida, Granollers, Malgrat de Mar, Martorell, Masnou, Mataró, Mollet del Vallés, Montornés del Vallés, Palau-solità I Plegamans, Parets del Vallès, Piera, Pineda de Mar, Pontons, Premià de Mar, Rubí, Sabadell, Sant Andreu de la Barca, Sant Antoni de Vilamajor, Sant Boi de Llobregat, Sant Celoni, Sant Feliu de Llobregat, Sant Pol de Mar, Sant Sadurní d'Anoia, Santa Perpètua de Mogoda, Sant Vicenç dels Horts, Sant Vicenç de Montalt, Cerdanyola del Vallès, Terrassa, Vallirana, Vilafranca del Penedès, Vilanova i la Geltrú, Blanes, Breda, Hostalric, Arboç and Vendrell.

2.2. A METHDOLOGY TO CLASSIFY SUB-CENTRES INTO "EMERGING" AND "CONSOLIDATED"

The conditions stated by (McMillen, 2001a) "a reasonable working definition of a sub-centre is a site (1) with significantly larger employment density than nearby locations that has (2) a significant effect on the overall employment density function" are extended by adding two further conditions (3) the necessity that they represent structural elements within metropolitan systems and, at the same time (4) are attractive to live and work in.

(McMillen & Smith 2003, Op. Cit) has suggested that "large sub-centres can look remarkably similar to traditional CBD, with thousands of workers employed in a wide variety of industries "and according to (McMillen, 2001a) " the diversity of business types may be lower than in the city, but large sub-centres sometimes appear to mimic the diversity of CBD. If sub-centres are expected to offer a real –albeit modest- alternative to the CBD they also have to be diverse, not only to increase the probability to retain their working population (i.e. widening the probability to match workers abilities and firms necessities), but also to increase the probability to interact with other sub-centres and the hinterland, as it is pursued in the ESDP.

In order to purpose a methodology to classify sub-centres intro "emerging" and "consolidated", this study defines a "emerging" sub-centre" as one who can be able to structure and be an important economic pole of attraction within the metropolitan system, but also it tends to be monospecialized, with a no significant enough population and economic diversity due to its main origin is a result of the outsourcing of a particular "production unit" outside of CBD. So, it is logical to think that an "emerging subcentre" will be significant in terms of IF (in-commuting flows, capacity of a given municipality to attract workers) but will not be in terms of RW (resident workers, the capacity of a municipality to retain its employed residents) because it doesn't have a relevant population yet, or it is not enough diverse neither it could retain a considerable resident working population.

In contrast, a "consolidated - large sub-centre" is one who is over-specialized in more than one economic activity, so it is very diverse and has a significant population at the same time that on the one hand it could retain the most of its resident working population and on the other it could attract a higher mass of workers (in-commuting flows – IF).

In that sense, this study, defines that by using Entropy Index, is possible to classify the sub-centres into "consolidated" and "emerging": A "consolidated sub-centre" within the metropolitan system, is one who its RW (resident workers) Entropy information by using RW Entropy Index and its IF (in-commuting flows) Entropy Information by using IF Entropy Index are considerably significant (for example above the standard deviation). As a result, compared to a "consolidated subcentre", an "emerging subcentre" is one who is only considerably significant in terms of IF (in-commuting flows) Entropy Information.

The RW Entropy Index and IF Entropy Index can be formulated as follows[6]:

$$EI_{RW} = -\sum_{i=1}^{n}(RW_i \cdot [Ln\,(RW_i)]) \qquad (3)$$

$$EI_{IF} = -\sum_{i=1}^{n}(IF_i \cdot [Ln\,(IF_i)]) \qquad (4)$$

Where $(RW_i \cdot [Ln\,(RW_i)])$ & $(IF_i \cdot [Ln\,(IF_i)])$ are the RW Entropy Information & IF Entropy Information for each municipality and EI_{RW} & EI_{IF} are the RW Entropy Index & IF Entropy Index for the whole of the metropolitan system. Higher RW Entropy Information & IF Entropy Information for (x) municipality higher is the weight of this (x) municipality in terms of RW & IF in the whole of the metropolitan area because RW_i & IF_i are the probability (proportion) to find RW & IF in the municipality (i) within the metropolitan system.

[6] The expressions (11) and (12) are formulated as Shannon Entropy Index by using RW (resident workers) and IF (in-commuting flow) respectively. However, (Limtanakool, 2007,2009) uses the normalized Entropy Index in the Following form: $EI_i = -\sum_{j=1}^{J}\frac{(Xj)\cdot Ln\,(Xj)}{Ln\,(J-1)}$. By using the Entropy Index purposed by (Limtanakool, 2007,2009) the expressions (11) and (12) could be reformulated as: $EI_{RW} = -\sum_{i=1}^{n}\frac{(RW_i)\cdot Ln\,(RW_i)}{Ln\,(n)}$ and $EI_{IF} = -\sum_{i=1}^{n}\frac{(IF_i)\cdot Ln\,(IF_i)}{Ln\,(n-1)}$ .In this study, the results of using Shannon Entropy Index or Normalized Entropy Index is the same because it is only considered "the RW and IF Entropy information" of each municipality in order to determinate the standard deviation for classifying the sub-centres. In comparison with that, in the case of defining the total RW and IF Entropy Index of the metropolitan system, the Shannon Entropy form and the Normalized Entropy form entail different results.

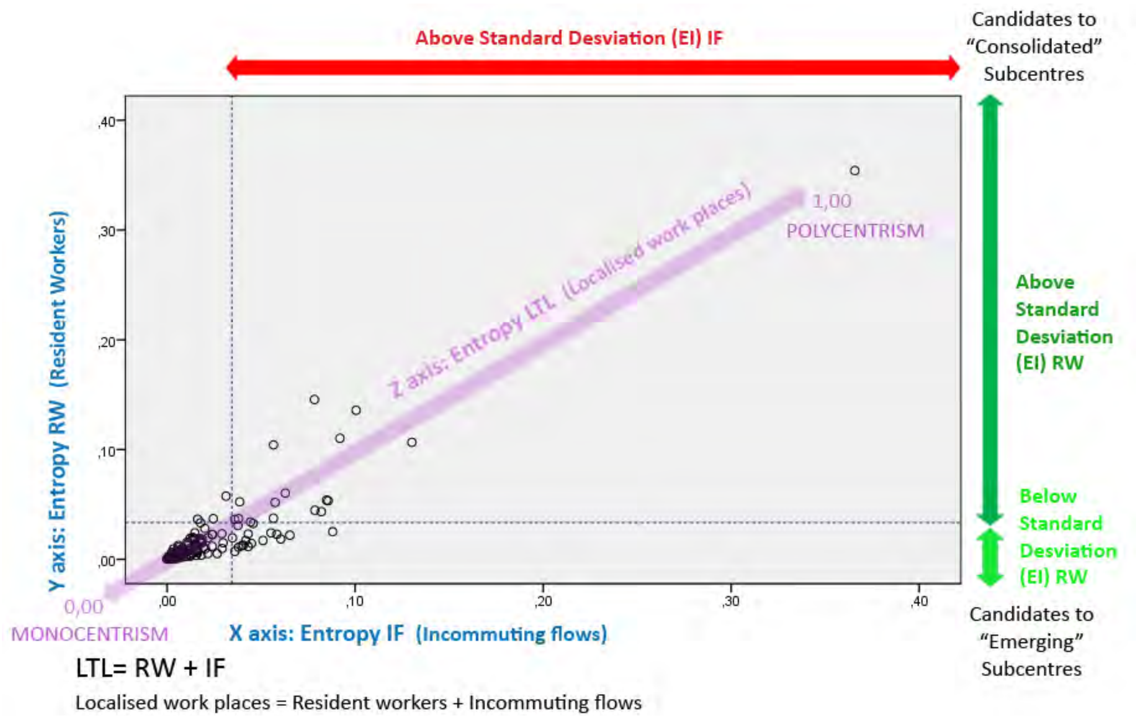

Figure 3: Interpretive scheme of classifying sub-centres into "emerging" and "consolidated"

3. SPATIAL INTERACTION MODEL TO IDENTIFY EMERGING SUB-CENTRES

The literature, which carries on the model of (Harris and Wilson, 1978), has focused primarily on the basis of the attraction that the entities exert on their environment and the role that the distance implies. By applying these mechanisms to models of land use, type-Lowry, we obtain necessarily, agglomerations, although the loss of economies of scale and the weakening of spatial friction may lead to decentralized schemes, as (Lombardo and Rabino, 1984) have demonstrated[7]. However, in order to approach a simulation of contemporary metropolis, characterized by process of decentralization-concentration, is necessary to introduce explicitly repulsive forces, or diseconomies of agglomeration. That arises mainly by the desire for access simultaneously to naturally scarce resources: land, services, infrastructure and generally rich environments with positive externalities. Paradoxically, these centrifugal forces are simultaneous to the centripetal ones and the tension that exists between them, ends up conditioning the spatial distribution of individuals involved (e.g. companies).

In this line of thought (Paul Krugman, 1996), has proposed a spatial interaction model called "edge cities" that combine the influence of centripetal and centrifugal forces on the interdependent decision about the companies locations; complete with the step of the time, the configuration of a polycentric structure from an imperfectly dispersed original distribution[8].

The model of edge cities has its origins in a one-dimensional metropolitan area, which can be represented either by a circumference, or an infinite line. In the case of a finite city, circular features, the line is divided into discrete way; into "n" entities or locations "x", separated from each other at distance 2π/n, the density of companies in each location is represented by λ(x).

The attractiveness of each location depends positively and negatively on the distribution and density of the companies that occurs in other locations. "A" represents the magnitude of the attraction forces and "B" the opposing forces. The dilution of the attractive forces, "r1", is different from the dilution of the repulsive forces, "r2", both being considered as a negative exponential function of the distance that separates the locators. The potential market of each location is determined by:

[7] A gravity-type model in which there are only attractive forces can return, if applied to an OD array temporary type (e.g. an array of intermunicipalities migrations of residence), a process of decentralization. Everything depends on the degree of dilution of the attractive forces, parameter B in ($T_{ij}=A_i \times B_j \times O_i \times D_j \times e^{-Bd_{ij}}$, where B means the friction parameter to overcome the gap between i and j). However the classical interaction models not recognize explicitly the existence of disagglomerative forces, what represents undoubtedly one of its weaknesses.

[8] Krugman, however, does not apply this model to a type of real city, strongly concentrated in origin, with a center and a marked periphery. It remains therefore, unexplained the historical process of emergence of edge cities, which have been derived from an "original state" characterized by a marked inequality in the distribution of externalities.

$$P(x) = \int_z \left(Ae^{-r_1 d_{xz}} - Be^{-r_2 d_{xz}}\right) \lambda(z) dz \qquad (5)$$

The dynamic mechanism that establish that the firms gradually moving from less suitable locations to the most attractive, the border that separates, it is denominated by “average attractive” de P(x). Krugman defines the average potential market as:

$$\bar{P} = \int_x P(x)\lambda(x)\, dx \qquad (6)$$

Otherwise:

$$\frac{d\lambda(x)}{dt} = \gamma\,[\mathrm{P(x)} - \overline{\mathrm{P}}]\,\lambda(\mathrm{x}) \qquad (7)$$

represents the dynamic rule of the system, while it ensures that the total number of companies in the systems remains constant and prevent that the firms density decreases below zero, ensuring that $\lambda(x) \geq 0$. When the scope of the agglomeration forces is smaller than the repulsive forces, r1<r2 multiples centers emerges. The same occurs if “B” is succulently large in relation to “A”. Thus applying the circular and finite city model, the results are equipotential and equidistant agglomerations, whose number depends on the parameters used and the location of regular undulation implied by the irregularities of the original firms distribution. The frequency with these regular waves occur, determines the rate of growth of each location, and thus the emergence of edge cities.

In development of the model proposed by Krugman, in this paper, is used a fully gravitational algorithm as (Roca and Marmolejo, 2006) explained[9]. There is an intuitive link between the concepts of economies of agglomeration and gravitational attraction. From this point of view, companies (or more generally, “individuals”) would like to be near to other companies (or individuals) in order to take benefits of the positive spillovers of this kind of relationship. Thus, each place in space would bring the group of individuals located in other places according to an attractive (or “gravitational field”) directly proportional to the amount of the product of its “masses” (the number of spatially located jobs, or “population”) and inversely proportional to the distance.

$$AT_{i=} \int_j A \cdot M_i^{k1} \cdot M_j^{k2} \,/\, d_{ij}^{r1} \qquad (8)$$

Being “A” a parameter that quantifies the intensity of gravitational attraction, “M” the population (local workplaces in our case) from the attracted location (i) to (j) the attractors, “k1” and “k2”, the constants of the adjusting model[10], D the distance between the two locations, and “r1” the grade which the attraction is diluted with distance.

The centrifugal forces, or anti-gravity, which for reasons of simplicity it is considered as Krugman suggested: structure or nature identical but with opposite sign. So the equation of the model can be rewritten as follows:

$$AT_{i=} \int_j A \cdot M_i^{k1} \cdot M_j^{k2} \,/\, d_{ij}^{r1} - \int_j B \cdot M_i^{k1} \cdot M_j^{k2} \,/\, d_{ij}^{r2} \qquad (9)$$

Each location of urban regional system will, therefore, an attractive potential (ATP_i) under the average attractive (ATM) of the system. Potential may be positive or negative by virtue of the difference between attractive and the average of the system.

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[9] Although the results are very similar, there no appears to be an absolute identity between the classical and the gravitational algorithm derived from the application of the term EXP (-r1dij). In Physics, the specialized literature tends to understand that the term 1/d (classical gravity) has an infinite effect, otherwise EXP (-d) represents an interaction at close distance. (Roca and Marmolejo, 2006 Op. Cit) prefers, for aesthetic reasons, to recover the original form of the gravitational algorithm. Moreover, the model is built with the “masses” and not with” density” in order to strengthen the gravitational analogy which is intended to achieve. Obviously “mass” and “density” are equivalent concepts if the size of each location is uniform. (Roca and Marmolejo, 2006 Op. Cit) adds that therefore it is assumed that each location has an area equal to 1 and the model leaves the circularity abstract proposed by Krugman and it is replaced by a straight linear city, more according to the physical reality.

[10] The parameters in question are equal to 1 or depending on the type of model desired. a) if we only want to count the mass of each attractive location “i” k1=1 and k2=0, b) if instead it is wanted to count only the mass of each “j”, k1=0 and k2=1, c) finally, in the strictly gravitational case, k1=1 and k2=1.

$$ATP_{i=}\ AT_i - ATM \qquad (10)$$

$$ATM_{=}\ \int_j\ AT_i \cdot\ M_i \cdot di \qquad (11)$$[11]

Finally, the dynamic nature of the regional system in the context of modeling proposed, in this study, is the same as (Roca and Marmolejo, 2006) and is obtained from the following algorithm:

$$\frac{dM_i}{dt} = G \cdot (AT_i - ATM)\ /\ ATM\ \cdot\ M_i \qquad (12)$$

Therefore, the workers will tend to mode gradually from the locations with lower potential attractive in comparison with the average towards the location with higher attractive. In (12) G is the acceleration of the temporary change of the masses. So, a higher "G", will represent, for a defined period of time, a velocity of evolution of the mass, either increases or reductions, higher.

4. DATA & CASE OF STUDY

Our case of study is the metropolitan area of Barcelona which has 184 municipalities, 3760 square kilometers and 745 square kilometers of artificialised land. In this study, is carried out a cross to the information of workplaces are located at the level of municipalities (denominated working places or LTL, in Spanish) obtained based on the mobility of labour found in the Census of Population and Housing, conducted by INE in 2001.

Figure 3: Barcelona Metropolitan Region: metropolitan delimitation based on criteria suggested by Roca et al (2009; 2011)

	Number of municipalities	Number of consolidated protosystems	Artificialised land	LTL (working places)	Population	Density
			a	b	c	.=(b+c)/a
Barcelona Metropolitan Region	184	24	744,99	1903867	4530164	8636

Source: Corine Land Cover & National Census 2001 (ICN, INE)

[11] In the equation the masses have been standardized, hence the average attractive (ATM) can be calculated with an integral. In addition, the average attractive (ATM) may be positive or negative, depending on the predominance of the forces of agglomeration or disagglomeration.

In order to examine the artificial surfaces of all the municipalities, in this paper are used the data of Corine Land Cover 2000, but with the next considerations:

1. Be considered for the analysis, the next artificial surface uses: continuous urban fabric (11100), discontinuous urban fabric (11210), discontinuous green urban areas (11220), industrial areas (12110), commercial and service areas (12110), port areas (12300), green urban areas (14100), courses field areas (14210) and rest of sport and leisure facilities (14220).
2. Not completely counting the artificial surface for the next two uses: airports (12400) and construction sites (13300). In the case of airport areas, in order to calculate the total area for this use; this study has carried out an average proportion between the occupation of the airport runways in relation to the total airport area. In addition, related to the construction sites, it has deducted the areas which are roads, highway networks and railroad networks from the total area of the construction sites.
3. Not taking into account the following artificial surface uses: road and highway networks and associated land (12210), railroad networks (12220), mineral extraction sites (13100) and dump sites (13200).

Related to the interaction spatial model, it is used the Census of Population and Housing conducted by INE in 1991 in order to define the origin of the model and then could evaluate the absolute error of the model with the Census of Population in 2001. In addition, the values of the parameters that are used by calibrate the spatial interaction model (and having the less possible error in comparison with Census 2001) are the following: k1 and k2=1 (strictly gravitational case), A=0,01 (quantifies the intensity of gravitational attraction), B=1,50 (quantifies the intensity of "antigravitational attraction" or disagglomerative forces), R1=1,11 (grade which the attraction is diluted with distance), R2=3,18 (grade which the disaggomerative force is diluted with distance) and finally G=0,08 (value of the acceleration of the temporary change of the masses).

5. RESULTS

Results of sub-centres identification by using parametric methods, cut-off approach, functional relations and the mixed-approach based on functional relations and cut-off, are contained in the following graphics and tables:

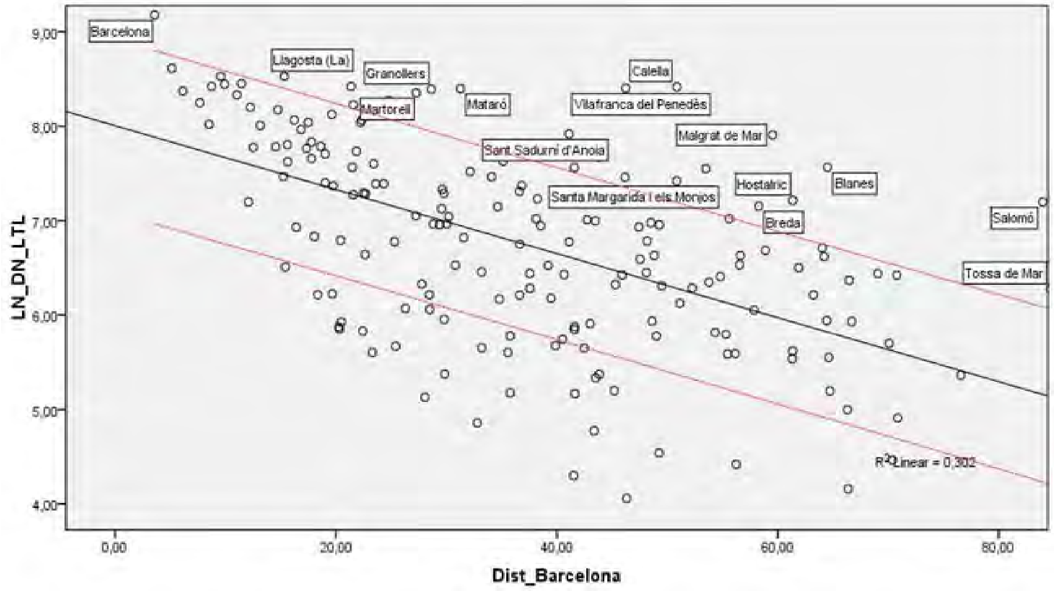
Table 1: Results of sub-centres identification

Parametric methods (1)			Cutt-off approach (2)		Funtional+ Cutt-off approach (4)	
	CL		GL		Protosystem+GL	
	R2 adj	B dist CBD	R2 adj	DNLTL	R2 adj	DNLTL_proto
Barcelona	0,298	-0,034	0,283	21,621	0,60	80,628

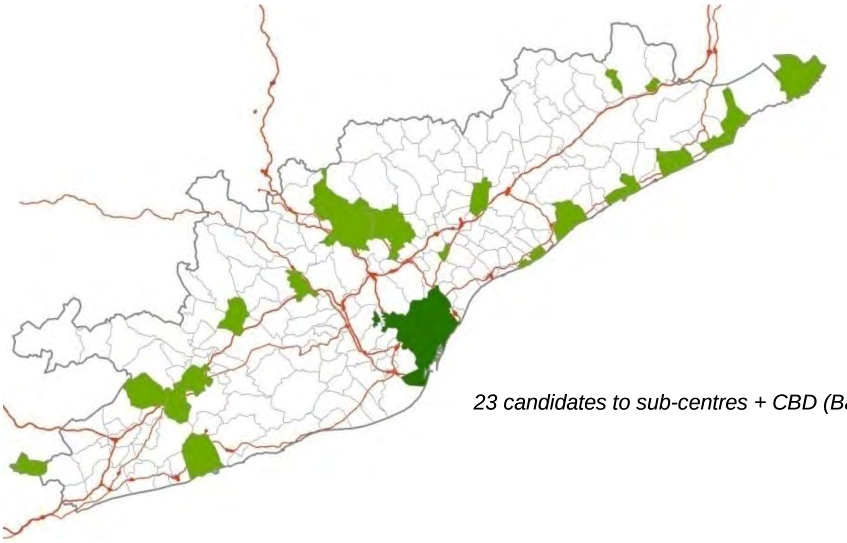
Independent variable: LN_DN_LTL, LTL2001, LTL_2001_proto

(1), (2), (4): related to the used methodology to identify subcentres (page 8 of the paper)

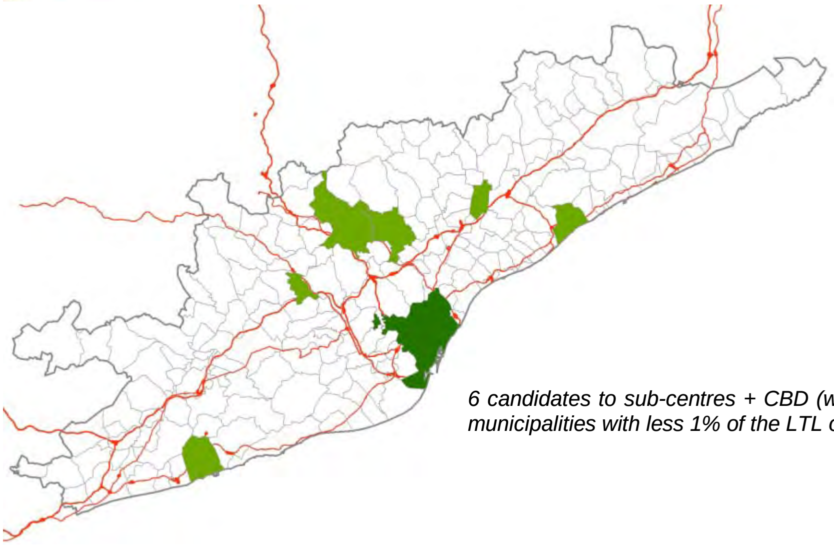
- Parametric method, using functional expression (2) (way 1, page 8 of the paper)



- Candidates to sub-centres, using parametric method (way 1, page 8 of the paper)

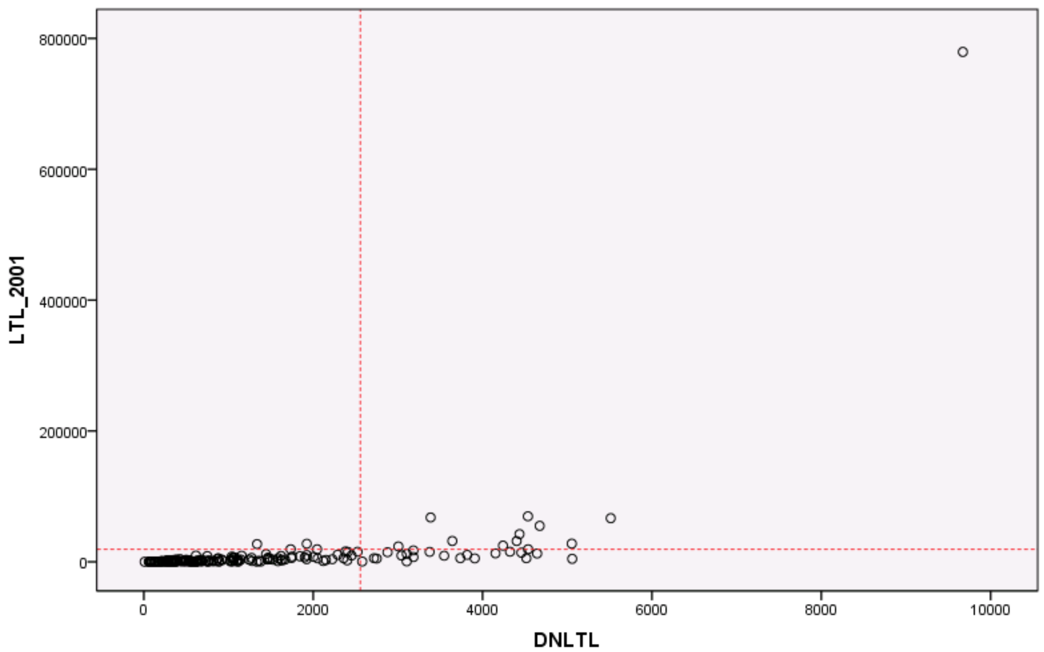


23 candidates to sub-centres + CBD (Barcelona)

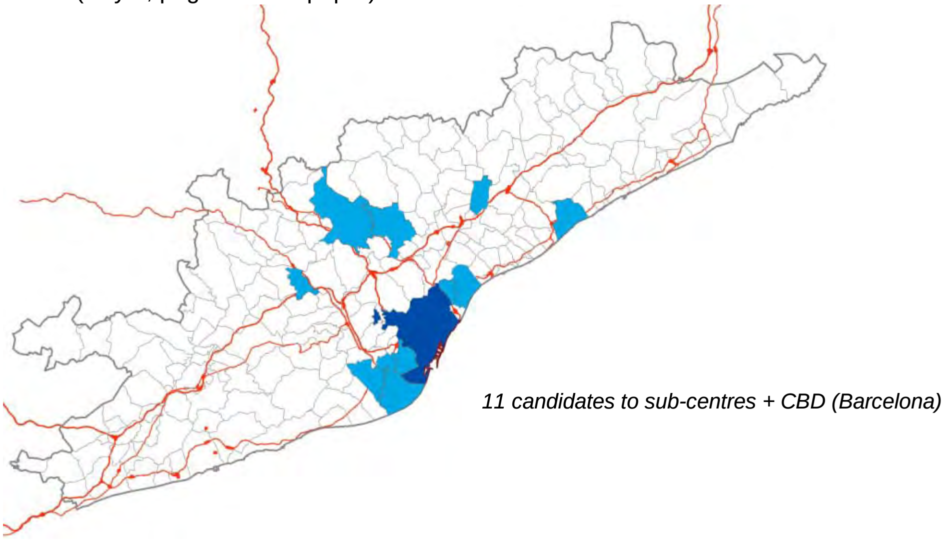


6 candidates to sub-centres + CBD (without taking into account the municipalities with less 1% of the LTL of the metropolitan system)

- Cut-off approach in the way as has been used by (García-López, 2007) (way 2, page 8 of the paper)

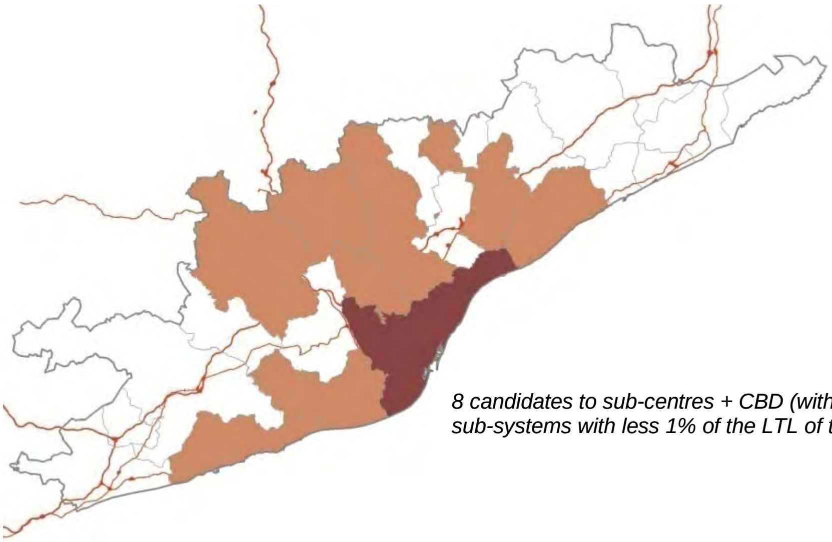


- Candidates to sub-centres, using cut-off approach in the way as has been used by (García-López, 2007) (way 2, page 8 of the paper)



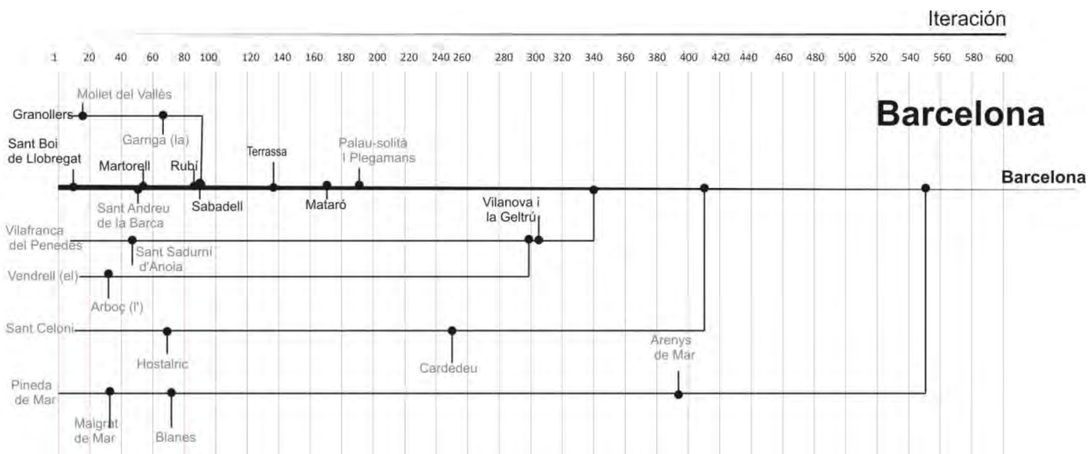
11 candidates to sub-centres + CBD (Barcelona)

- Candidates to sub-centres, considering as candidate to subcentre to those muncipalities leading each protosystem as suggested by (Roca et al., 2009) (way 3, page 8 of the paper)

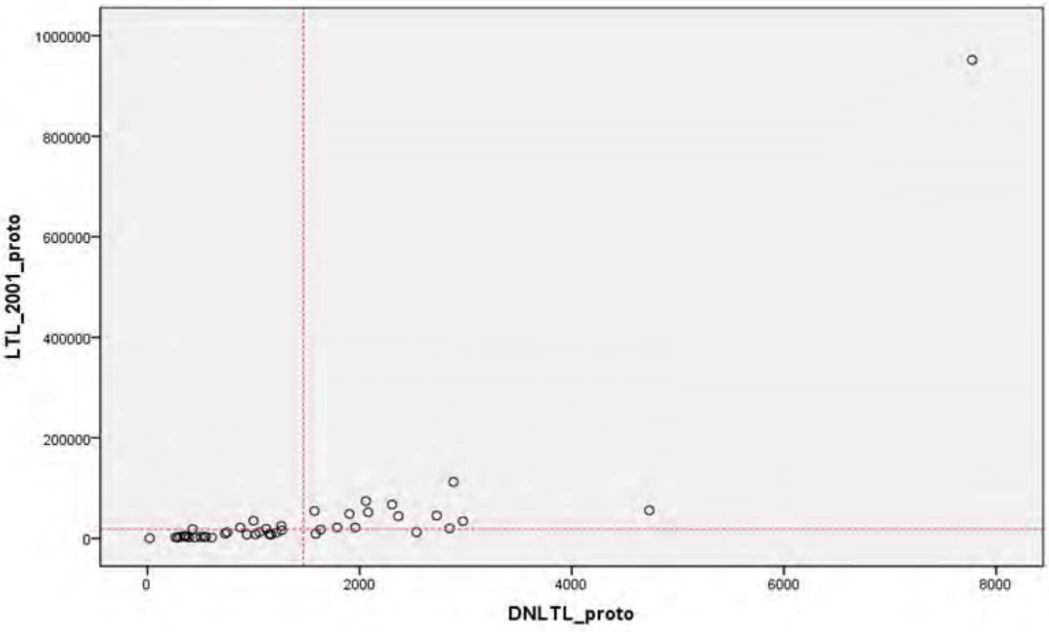


8 candidates to sub-centres + CBD (without taking into account the metropolitan sub-systems with less 1% of the LTL of the metropolitan system)

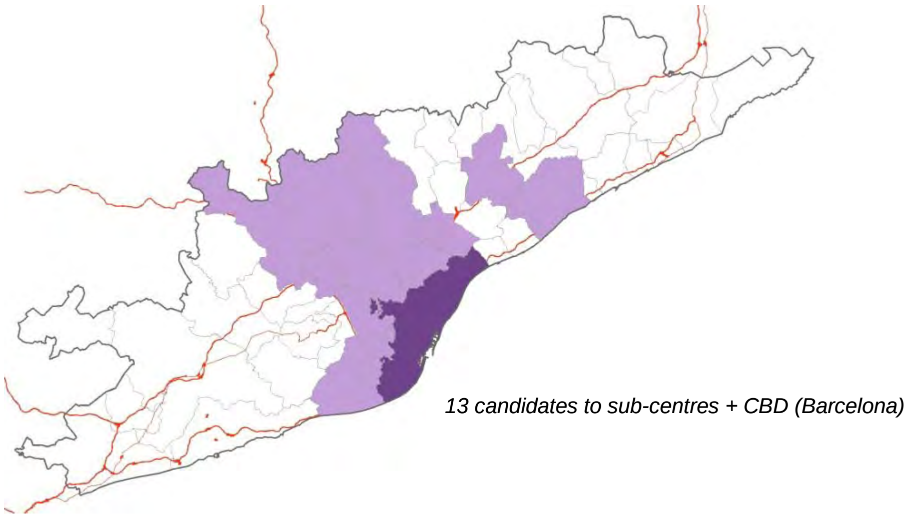
Functional approach also allows studying the complexity in the structuration process of metropolitan areas. It is to say the way in how protosystems (the hinterlands structured by potential subcentres) gravitates toward central protosystems (the subsystems in which CBD is contained). In the following figure the functional tree (suggested in (Roca et al. 2005, 2011) has been reconstructed for the Barcelona metropolitan region, the potential sub-centres, which LTL (localized workers) are superior to 1% are marked in black letters.



- An approach based on functional relations and density analysis, (way 4, page 8 of the paper)



- Candidates to sub-centres, using an approach based on functional relations and density analysis (way 4, page 8 of the paper)



In the following table a comparison is realized using both methodologies, as well it is depicted the employment share that represent the central employment of the central city: Barcelona and the sub-centres beyond it. The employment share that represents the central employment of Barcelona (CBD) can be seen as an indicator of macrocephalia and the employment in subcentres of polycentrism.

Table 2: Barcelona metropolitan region structure according to the different methods to identify sub-centres

			Parametric Method - CL			Cut-off Approach - GL		
	LTL	LTL in CBD (%)	Total nuclei	Nuclei beyond CBD	LTL in nuclei beyond CBD	Total nuclei	Nuclei beyond CBD	LTL in nuclei beyond CBD
Barcelona (BMR)	1903867	40,93%	7	6	13,43%	12	11	24,18%

			Mobility (subsystem) - JR			Mobility (protosystem) + Cut-off - JR+GL		
	LTL	LTL in CBD (%)	Total nuclei	Nuclei beyond CBD	LTL in nuclei beyond CBD	Total nuclei	Nuclei beyond CBD	LTL in nuclei beyond CBD
Barcelona (BMR)	1903867	55,92%	9	8	30,39%	14	13	34,26%

Note: without taking into account the subcentre candidates with less 1% LTL
Source: Own Elaboration

The following table reports the results of sub-centres identification for the Barcelona Metropolitan Region:

Table 3: Sub-centre candidates according to different methods to identify sub-centres
Barcelona Metropolitan Region

	Parametric method	Cut-off	Mobility (subsystems)	Mobility (protosystem)+ Cut-off
Municipality	CL	GL	JR	JR+GL
Badalona	0	1	0	0
Barcelona (CBD)	1	1	1	1
Cerdanyola del Vallès	0	0	0	1
Cornellà de Llobregat	0	1	0	1
Granollers	1	1	1	1
Hospitalet de Llobregat (L')	0	1	0	0
Martorell	1	1	1	1
Mataró	1	1	1	1
Mollet del Vallès	0	0	0	1
Prat de Llobregat (L')	0	1	0	0
Rubí	0	0	1	1
Sabadell	1	1	1	1
Sant Andreu de la Barca	0	0	0	1
Sant Boi de Llobregat	0	1	1	1
Sant Feliu de Llobregat	0	0	0	1
Santa Coloma de Gramanet	0	1	0	0
Santa Perpètua de Mogoda	0	0	0	1
Terrassa	1	1	1	1
Vilanova i la Geltrú	1	0	1	0
Total nuclei	7	12	9	14

Note: without taking into account the subcentre candidates with less 1% LTL

Source: Own Elaboration

Most of municipalities succeed in both methods as candidates to sub-centre like Sabadell, Terrassa, Granollers, Martorell and Mataró. As seen, Barcelona is undoubtedly a polycentric urban system since both methodologies agree in consider most of the candidate to sub-centres.

After identified the candidates to sub-centres according the different used methods, this paper tries to classify the sub-centres candidates into "emerging" and "consolidated" sub-centres regarding to the methodology to classify them explained in section 2.2:

In the following graphs is showed the histograms of RW Entropy Index and IF Entropy Index:

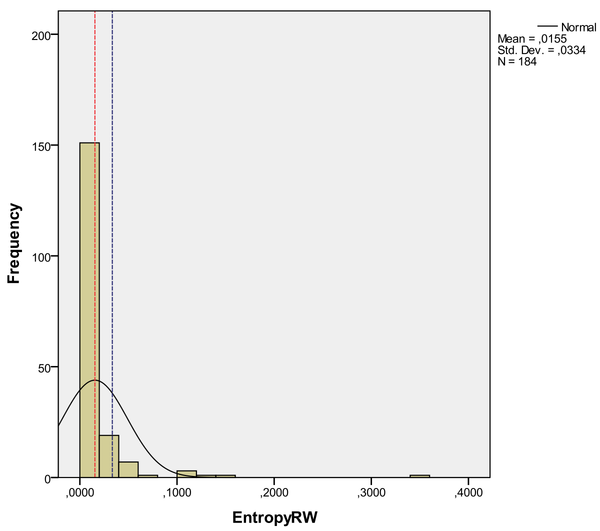


Figure: RW Entropy Histogram
Red line: mean
Blue line: Standard Deviation

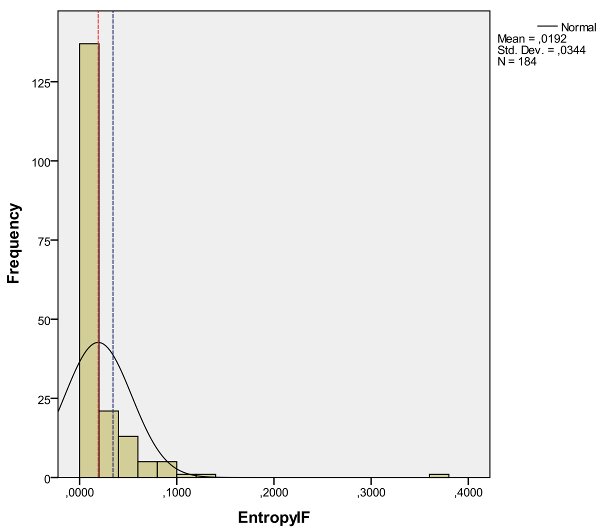


Figure: IF Entropy Histogram
Red line: mean
Blue line: Standard Deviation

In the following tables is exposed the municipalities and the candidates to sub-centres which its RW Entropy Information and IF Entropy Information are above of the standard deviation (value of Std. Dev. in orange):

Table 4: Municipalities and candidates to sub-centres which its "RW entropy information" is above of the standard deviation

Municipality	Entropy Shannon Information (STD.DEV.=0,0334)	Entropy Shannon (normalized) Information (STD.DEV=0,00642)	More 1 % LTL of the metropolitan system	Candidate Subcentre CL	Candidate Subcentre GL	Candidate Subcentre JR (subsystem)	Candidate Subcentre JR + GL (protosystem+ cut-off)
Barcelona	0,354185898	0,067988644	1	1	1	1	1
Terrassa	0,145593644	0,027947794	1	1	1	1	1
Sabadell	0,135699284	0,026048497	1	1	1	1	1
Badalona	0,110281276	0,021169319	1	0	1	0*	0**
Hospitalet de Llobregat (L')	0,106557732	0,020454557	1	0	1	0*	0**
Mataró	0,104250934	0,02001175	1	1	1	1	1
Rubí	0,060301971	0,011575416	1	0	0	1	1
Vilanova i la Geltrú	0,057567842	0,01105058	1	1	0	1	0**
Granollers	0,053861284	0,010339078	1	1	1	1	1
Prat de Llobregat (El)	0,053331211	0,010237327	1	0	1	0*	0**
Santa Coloma de Gramenet	0,052346091	0,010048225	1	0	1	0*	0**
Sant Boi de Llobregat	0,051842783	0,009951612	1	0	1	1	1
Sant Cugat del Vallès	0,044760889	0,008592189	1	0	0	0*	0**
Cornellà de Llobregat	0,043426339	0,008336012	1	0	1	0*	1
Cerdanyola del Vallès	0,037451597	0,007189115	1	0	0	0*	1
Viladecans	0,036995302	0,007101526	0	0	0	0*	0**
Castelldefels	0,036991644	0,007100824	0	0	0	0*	0**
Blanes	0,036533504	0,007012881	0	1	0	1	0**
Vilafranca del Penedès	0,036327656	0,006973367	0	1	0	1	0**
Mollet del Vallès	0,034026643	0,00653167	0	0	0	1	1
Lloret de Mar	0,033287854	0,006389854	0	0	0	0*	0**
Gavà	0,032566779	0,006251438	0	0	0	0*	0**
Sant Feliu de Llobregat	0,030714942	0,005895964	0	0	0	0*	1
Vendrell (El)	0,028126911	0,005399172	0	0	0	1	0**
Martorell	0,025134829	0,004824819	1	1	1	1	1

Source: Own Elaboration

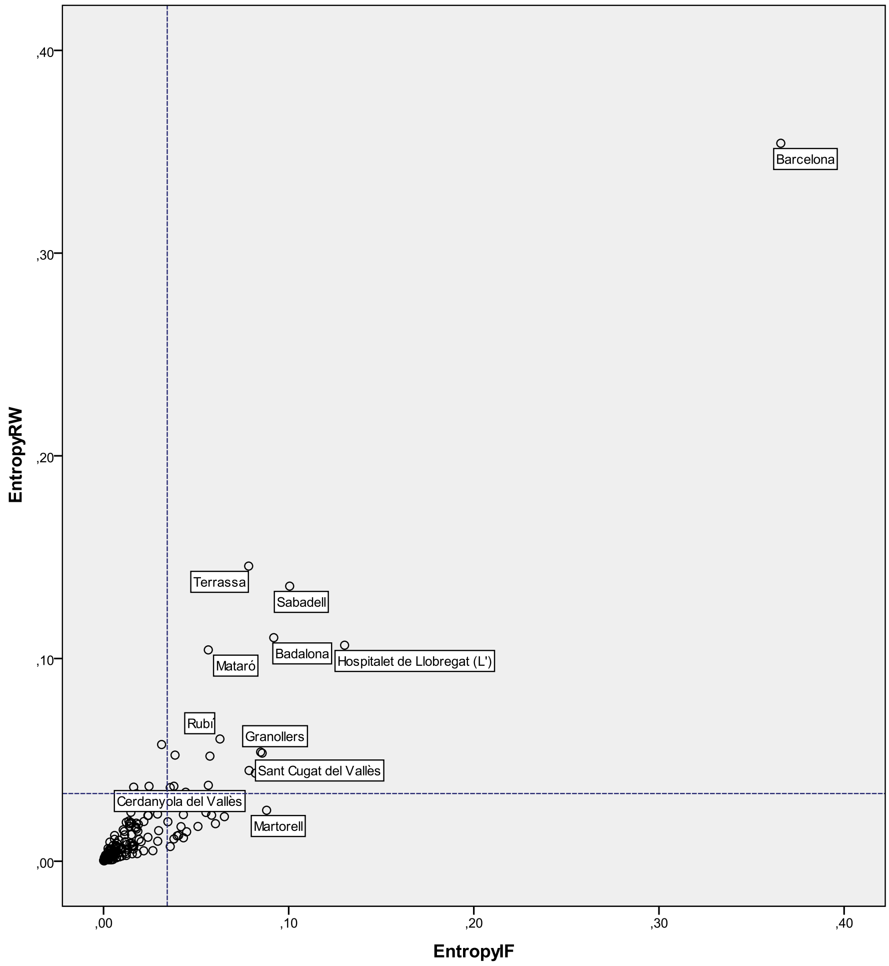
Table 5: Municipalities and candidates to sub-centres which its "IF entropy information" is above of the standard deviation

Municipality	Entropy Shannon Information (STD.DEV.=0,0344)	Entropy Shannon (normalized) Information (STD.DEV.=0,0066)	More 1 % LTL of the metropolitan system	Candidate Subcentre CL	Candidate Subcentre GL	Candidate Subcentre JR (subsystem)	Candidate Subcentre JR + GL (protosystem+ cut-off)
Barcelona	0,36579597	0,070217284	1	1	1	1	1
Hospitalet de Llobregat (L')	0,130198621	0,024992603	1	0	1	0*	0**
Sabadell	0,100528433	0,019297188	1	1	1	1	1
Badalona	0,091938543	0,017648294	1	0	1	0*	0**
Martorell	0,088073491	0,016906368	1	1	1	1	1
Prat de Llobregat (El)	0,085675805	0,016446114	1	0	1	0*	0**
Granollers	0,084839334	0,016285547	1	1	1	1	1
Cornellà de Llobregat	0,082042102	0,015748598	1	0	1	0*	1
Sant Cugat del Vallès	0,07859968	0,015087799	1	0	0	0*	0**
Terrassa	0,078382208	0,015046054	1	1	1	1	1
Barberà del Vallès	0,065283378	0,012531635	0	0	0	0*	0**
Rubí	0,062873081	0,01206896	1	0	0	1	1
Santa Perpètua de Mogoda	0,06044362	0,011602607	0	0	0	0*	1
Montcada i Reixac	0,058366497	0,011203888	0	0	0	0*	0**
Sant Boi de Llobregat	0,057454931	0,011028906	1	0	1	1	1
Cerdanyola del Vallès	0,05660507	0,010865768	1	0	0	0*	1
Mataró	0,056585247	0,010861963	1	1	1	1	1
Esplugues de Llobregat	0,055302884	0,010615804	0	0	0	0*	0**
Sant Joan Despí	0,050993758	0,009788635	0	0	0	0*	0**
Gavà	0,045766819	0,008785285	0	0	0	0*	0**
Parets del Vallès	0,044880182	0,008615088	0	0	0	0*	0**
Mollet del Vallès	0,044365192	0,008516232	0	0	0	1	1
Sant Just Desvern	0,043158273	0,008284555	0	0	0	0*	0**
Sant Andreu de la Barca	0,043123244	0,008277831	0	0	0	1	1
Sant Adrià de Besòs	0,0418423	0,008031944	0	0	0	0*	0**
Castellbisbal	0,040605991	0,007794625	0	0	0	0*	0**
Palau-solità i Plegamans	0,039767212	0,007633615	0	0	0	1	0**
Santa Coloma de Gramenet	0,03861382	0,007412213	1	0	1	0*	0**
Abrera	0,038007726	0,007295869	0	0	0	0*	0**
Viladecans	0,037980309	0,007290606	0	0	0	0*	0**
Sant Feliu de Llobregat	0,037692038	0,00723527	0	0	0	0*	1
Polinyà	0,036030722	0,006916368	0	0	0	0*	0**
Vilafranca del Penedès	0,036012125	0,006912798	0	1	0	1	0**
Molins de Rei	0,034749644	0,006670455	0	0	0	0*	0**
Vilanova i la Geltrú	0,031353052	0,006018454	1	1	0	1	0**

Source: Own Elaboration

In the two previous tables, it showed the municipalities and the candidates to sub-centre ordered by "its RW and IF Entropy information"; where the cutoffs of the standard deviation characterize them as "emerging" or "consolidated" sub-centre. That can be viewed simultaneously in the following graphic:

Graphic: "Emerging" and "consolidate" subcentres by using RW and IF Entropy



Model Summary
Model: 1
R: 0,918
R square: 0,843
Adjusted R square: 0,843
Std. Error of the Estimate: 0,0132593
Predictors (constant): Entropy IF
Dependent variable: Entropy RW

Candidate to "Consolidated" Subcentres
Barcelona (CBD)
Terrassa
Sabadell
Badalona
Hospitalet de Llobregat (L')
Mataró
Rubí
Granollers
Prat de Llobregat (L')
Santa Coloma de Gramanet
Sant Boi de Llobregat
Sant Cugat del Vallès
Cornellà de Llobregat
Cerdanyola del Vallès
Mollet del Vallès
Viladecans

Candidate to "Emerging" Subcentres
Martorell
Sant Feliu de Llobregat
Santa Perpètua de Mogoda
Esplugues de Llobregat
Sant Andreu de la Barca
Barberà del Vallès
Sant Joan Despí
Sant Just Desvern

In blue municipalities that are above of standard deviation but they aren't candidates to sub-centre in any used methodology in order to identify them

By analysing the tables and the graph above, the results are clear. Fristly, the muncipalities that are identified as a candidate to sub-centres according to all used methods (CL, GL, JR, JR+CL) are mostly "consolidated". These are the cases of: Terrassa (RW entropy information:0,145; IF entropy information:0,078), Sabadell (RW entropy information:0,135; IF entropy information:0,100) and Granollers (RW entropy information:0,053; IF entropy information:0,084); Mataró (RW entropy information:0,104; IF entropy information:0,056). On contrary, the unique case of a municipality which is considered as candidate of subcentre acording to all used methods and it is classify into "emerging sub-centre" is Martorell (RW entropy information:0,025; IF entropy information:0,088). It is a quite special case, because although Martorell has a value of RW Entropy Information (0,025) clearly below of the Std. Dev. (0,0334), it has at the same time one of the most higest values in terms of IF Entropy Information (0,088) within the metropolitan system.

Then, it exists, a second family of municipalities which are identifed as sub-centres in accordance with two or more used methodologies and they are significant in terms of RW / IF Entropy Information (above of the Std. Dev., so "consolidated" sub-centres). These are the case of Rubí (RW entropy information:0,060; IF entropy information:0,062), Sant Boi de Llobregat (RW entropy information:0,051; IF entropy information:0,057) and Cornellà (RW entropy information:0,043; IF entropy information:0,082).

Finally, a group of municiaplities which are candidates to sub-centre (identified with only one used method) or simply no sub-centres that are highly significant in terms of RW and IF Entropy Information. These are the case of Badalona, L'Hospitalet de Llobregat, el Prat de Llobregat, Sant Cugat del Vallès and Cerdanyola del Vallès[12].

[12] In that sense, analyzing (e.g. dynamically: 1991-2001) the municipalities which are not sub-centres but at the same time have a significant RW / IF Entropy Information would be a meaningful further research to know their potential to become a sub-centre or to have in a future an important role within the metropolitan system.

Results of the emergence of new sub-centres (1991-2024) by using a spatial interaction model are contained in the following graphics and tables:

In the following table is exposed the results of the spatial interaction model since 1991 (origin model) to 2024. As the table shows, on the one hand, Barcelona loses employment weight within the metropolitan system (in 1991, Barcelona had the 57,34 LTL (localized workers) and by the last period will have had the 32,25% of the total localized workers); on the other hand the sub-centres, where are located on the intermediate distances (15km to 30km from Barcelona-CBD), are increasing considerably their localized workers (LTL) and by 2024 they will have had an important role within the metropolitan system. For instance, it is the case of Sabadell, Terrassa, Rubí, Martorell and Granollers[13].

Table 6: Employment structure in the Barcelona Metropolitan Region by protosystems 1991-2024

Protosystem	Barcelona Distance	% LTL1991 (model origen) (a)	% LTL 2001	% LTL 2009	% LTL 2014	% LTL 2019	LTL 2024	% LTL 2024 (b)	% LTL 2024-1991 (b-a)
Barcelona (CBD)	0,00	57,34%	50,46%	44,32%	40,47%	36,45%	862572	32,25%	-25,08%
Cornellà de Llobregat	10,50	3,02%	2,96%	2,77%	2,44%	2,11%	46916	1,75%	-1,26%
Sant Feliu de Llobregat	11,52	1,64%	1,82%	2,02%	2,12%	2,22%	62135	2,32%	0,68%
Sant Boi de Llobregat	14,43	3,09%	3,58%	4,08%	4,41%	4,75%	136578	5,11%	2,02%
Rubí	16,54	2,07%	2,90%	3,29%	3,55%	3,82%	109787	4,10%	2,03%
Sant Vicenç dels Horts	16,79	0,52%	0,61%	0,68%	0,73%	0,77%	21980	0,82%	0,30%
Masnou (el)	17,29	0,38%	0,46%	0,51%	0,55%	0,58%	16443	0,61%	0,24%
Cerdanyola del Vallès	18,66	2,26%	2,34%	2,64%	2,83%	3,02%	86218	3,22%	0,96%
Santa Perpètua de Mogoda	18,86	0,79%	1,06%	1,17%	1,22%	1,27%	35450	1,33%	0,53%
Mollet del Vallès	20,67	1,04%	1,14%	1,28%	1,35%	1,42%	40125	1,50%	0,46%
Premià de Mar	21,29	0,76%	0,93%	1,04%	1,10%	1,17%	33044	1,24%	0,47%
Sabadell	22,30	5,79%	5,97%	6,95%	7,76%	8,61%	253771	9,49%	3,70%
Parets del Vallès	22,49	0,91%	1,01%	1,13%	1,20%	1,28%	36341	1,36%	0,45%
Sant Andreu de la Barca	22,79	0,84%	1,14%	1,28%	1,36%	1,44%	40613	1,52%	0,67%
Corbera de Llobregat	23,77	0,07%	0,12%	0,19%	0,20%	0,22%	6175	0,23%	0,16%
Montornès del Vallès	24,74	0,61%	0,65%	0,74%	0,79%	0,84%	23924	0,89%	0,29%
Palau-solità I Plegamans	25,81	0,64%	0,83%	0,94%	1,01%	1,08%	30747	1,15%	0,51%
Martorell	26,75	1,34%	2,58%	2,93%	3,17%	3,43%	98711	3,69%	2,35%
Terrassa	28,01	3,41%	3,93%	4,52%	4,96%	5,42%	157886	5,90%	2,49%
Begues	28,31	0,04%	0,07%	0,07%	0,08%	0,08%	2381	0,09%	0,05%
Mataró	29,91	2,69%	2,76%	3,13%		3,65%	105118	3,93%	1,24%
Vallirana	30,00	0,19%	0,24%	0,27%	0,29%	0,31%	8880	0,33%	0,14%
Granollers	30,04	2,16%	2,41%	2,73%	2,94%	3,16%	90545	3,39%	1,23%
Gelida	34,14	0,11%	0,15%	0,17%	0,18%	0,19%	5382	0,20%	0,10%
Garriga (la)	37,56	0,33%	0,41%	0,46%	0,49%	0,52%	14836	0,55%	0,22%
Bigues i Riells	37,64	0,11%	0,17%	0,19%	0,21%	0,22%	6237	0,23%	0,12%
Sant Vicenç de Montalt	39,16	0,05%	0,08%	0,09%	0,09%	0,10%	2851	0,11%	0,05%
Cardedeu	39,56	0,36%	0,42%	0,47%	0,50%	0,54%	15291	0,57%	0,22%
Arenys de Mar	40,40	0,46%	0,49%	0,55%	0,59%	0,63%	17869	0,67%	0,21%
Sant Sadurní d'Anoia	42,69	0,38%	0,40%	0,45%	0,49%	0,52%	14731	0,55%	0,17%
Sant Antoni de Vilamajor	43,29	0,07%	0,10%	0,12%	0,12%	0,13%	3755	0,14%	0,07%
Piera	44,21	0,19%	0,23%	0,25%	0,27%	0,29%	8212	0,31%	0,12%
Vilanova i la Geltrú	45,39	1,52%	1,86%	2,11%	2,27%	2,43%	69693	2,61%	1,08%
Sant Pol de Mar	47,47	0,06%	0,09%	0,11%	0,11%	0,12%	3389	0,13%	0,07%
Vilafranca del Penedès	47,50	1,13%	1,31%	1,48%	1,59%	1,71%	48913	1,83%	0,70%
Pineda de Mar	54,48	0,61%	0,64%	0,72%	0,76%	0,80%	22716	0,85%	0,24%
Sant Celoni	56,64	0,47%	0,50%	0,56%	0,59%	0,63%	18064	0,68%	0,20%
Malgrat de Mar	58,93	0,48%	0,65%	0,73%	0,78%	0,83%	23648	0,88%	0,40%
Arboç (l')	59,28	0,17%	0,16%	0,18%	0,19%	0,20%	5665	0,21%	0,04%
Vendrell (el)	63,22	0,69%	0,97%	1,10%	1,17%	1,25%	35788	1,34%	0,65%
Breda	64,16	0,08%	0,10%	0,11%	0,12%	0,12%	3552	0,13%	0,05%
Blanes	64,41	0,97%	1,14%	1,28%	1,37%	1,46%	41754	1,56%	0,59%
Hostalric	64,84	0,13%	0,15%	0,17%	0,18%	0,20%	5589	0,21%	0,08%
Pontons	67,64	0,01%	0,01%	0,01%	0,01%	0,01%	278	0,01%	0,00%
Total LTL Barcelona Metropolitan Region		1621451	2014738	2495534	2473496	2542025	2674554		

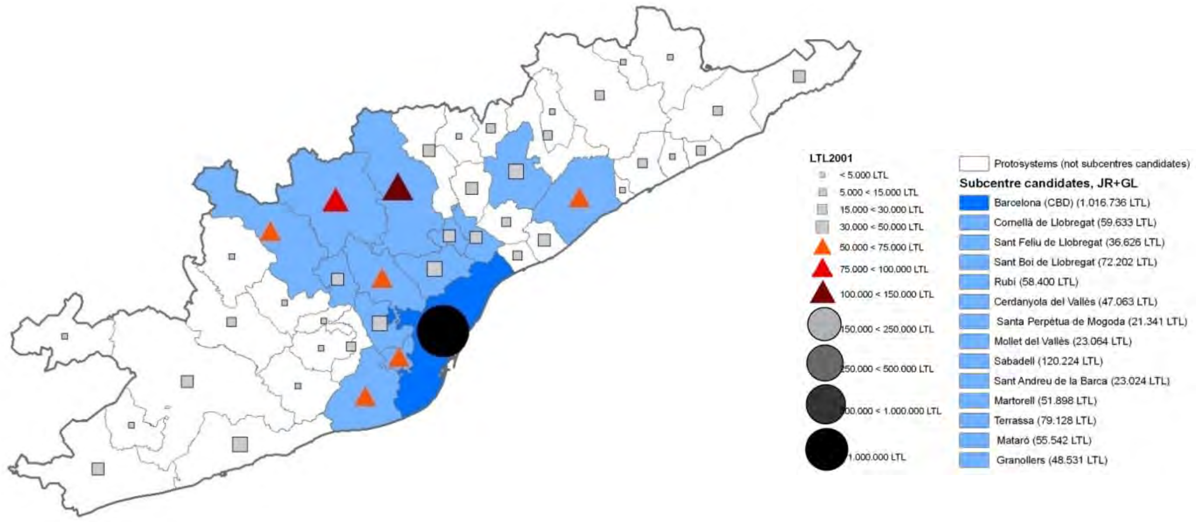
Candidate Subcentres JR+GL

Source: Own Elaboration

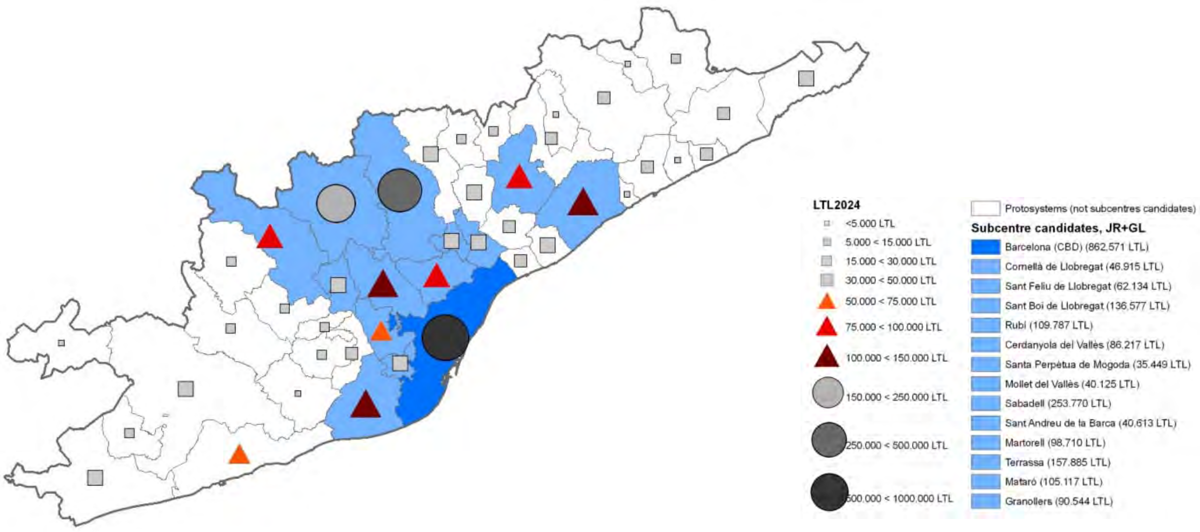
[13] The sub-centre which more increase its % LTL 2024-1991 within the metropolitan system is Sabadell (characterized by "consolidated" sub-centre according to the proposed methodology, page 17&18) with an increment of the 3,70%. Then, the sub-centres which more increase its LTL weight are Terrassa ("consolidated" sub-centre) and Martorell ("emerging" sub-centre") with an increment of 2,49% and 2,35% respectively

Spatially, the results contained in the previous table are expressed in the next maps:

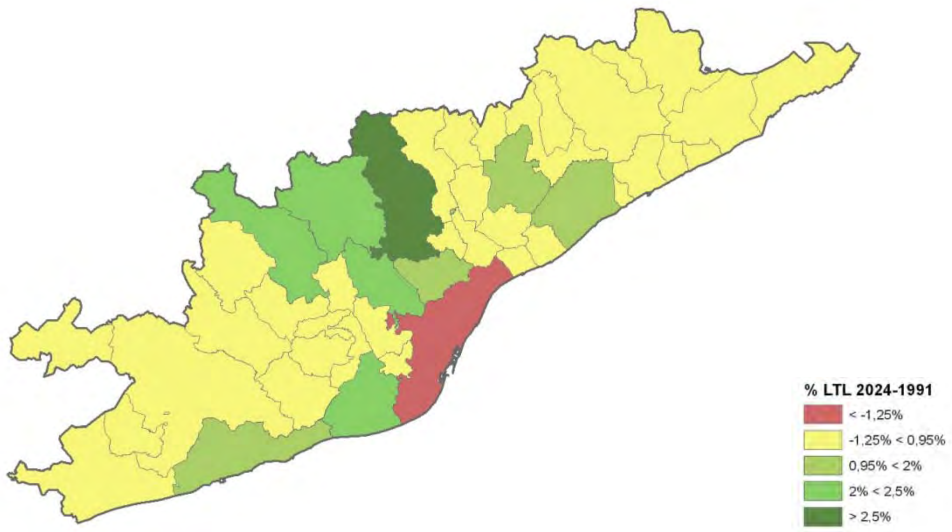
- Localized workers (LTL) in the candidates sub-centres (by using JR+GL method, way 4, page 8 of the paper) in 2001.



- Localized workers (LTL) in the candidates subcentres (by using JR+GL method, way 4, page 8 of this paper) in 2024.



- Increases or decresases of the proportion of localized workers (LTL) that the protosystems of the Barcelona Metropolitan Region will have experimented by 2024.



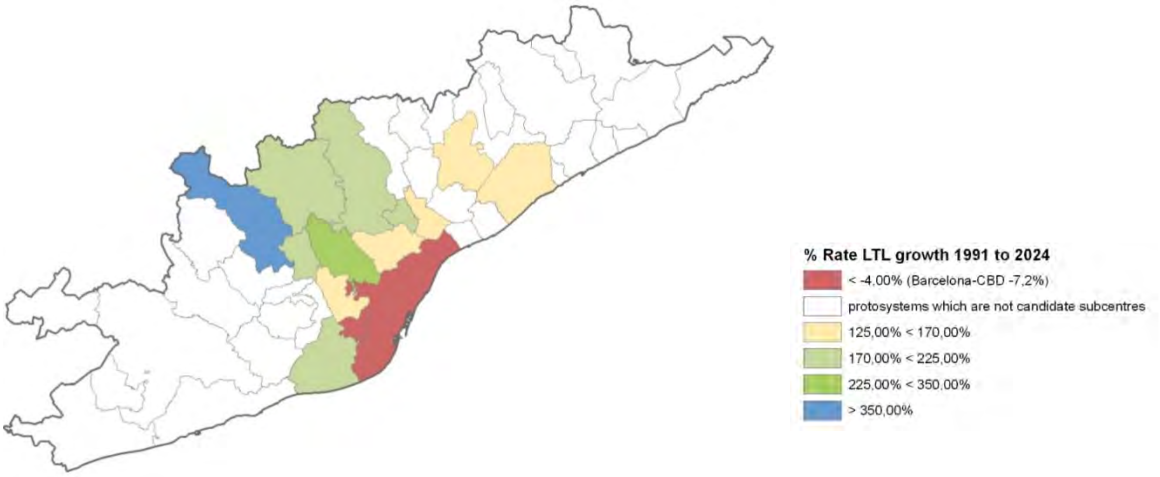
In the following table and maps is exposed a) % rate growth of localized workers (LTL) since 1991 to 2024, and b) entropy index (EI), (Limtanakool, 2007, 2009) and its % rate growth since 1991 to 2024 for the sub-centres identified by using an approach based on functional relations and density analysis[14] (way 4, page 8 of the paper):

Table 7: Relationship between % Rate LTL Growth 1991-2024 and % Rate Growth Entropy 1991-2024

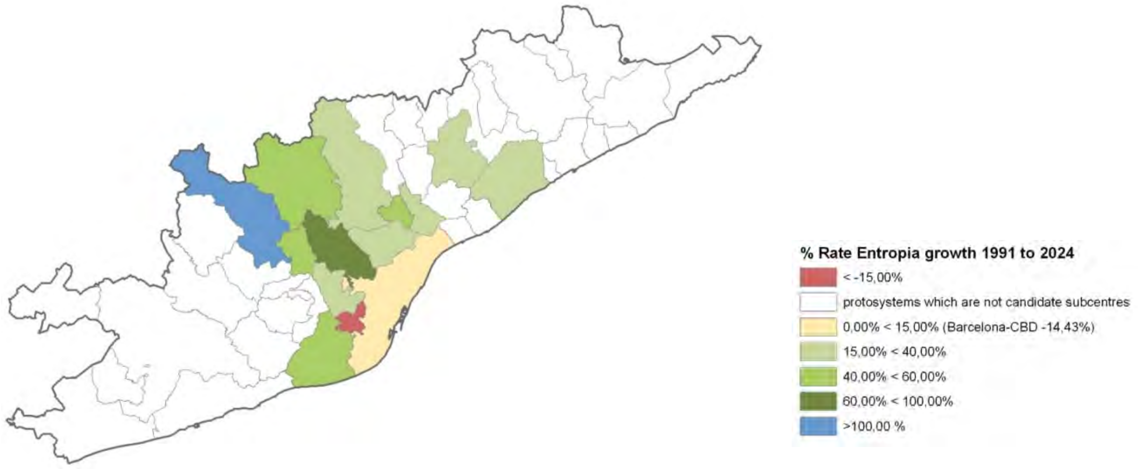
Protosystem	LTL 1991 (model origen) (a)	LTL 2024 (b)	% Rate LTL Growth 2024-1991 [(b-a)/(a)]	Entropy 1991 (model origen) (c)	Entropy 2024 (d)	% Rate Growth Entopia 2024-1991 [(c-d)/(c)]
Barcelona (CBD)	929672	862572	-7,2%	0,084278937	0,096443160	14,43%
Cornellà de Llobregat	48930	46916	-4,1%	0,027915901	0,018742018	-32,86%
Sant Feliu de Llobregat	26668	62135	133,0%	0,017852670	0,023097045	29,38%
Sant Boi de Llobregat	50117	136578	172,5%	0,028397337	0,040141221	41,36%
Rubí	33566	109787	227,1%	0,021212006	0,034635852	63,28%
Cerdanyola del Vallès	36708	86218	134,9%	0,022662268	0,029258804	29,11%
Santa Perpètua de Mogoda	12856	35450	175,7%	0,010135125	0,015143239	49,41%
Mollet del Vallès	16900	40125	137,4%	0,012569936	0,016649317	32,45%
Sabadell	93859	253771	170,4%	0,043584774	0,059051105	35,49%
Sant Andreu de la Barca	13688	40613	196,7%	0,010651147	0,016803200	57,76%
Martorell	21664	98711	355,6%	0,015236509	0,032178694	111,19%
Terrassa	55366	157886	185,2%	0,030472758	0,044142234	44,86%
Mataró	43558	105118	141,3%	0,025676612	0,033614112	30,91%
Granollers	35028	90545	158,5%	0,021892530	0,030289125	38,35%

Source: Own Elaboration

- Spatial distribution of % Rate Growth of localized workers (LTL) for 1991-2024:



- Spatial distribution of % Rate Growth of Entropy Index (Limtanakool, 2007, 2009) for 1991-2024:



[14] The sub-centre of Martorell (characterized as "emerging" sub-centre, page 17&18) is the sub-centre which has the higher % Rate LTL Growth 1991-2024 and the higher % Rate Growth Entropy 2024-1991. Note that the "consolidated" sub-centres of Sabadell and Terrassa their % Rate Entropy growth until 2024 increase slowly in comparison with Rubí (candidate to a sub-centre according to the JR and JR+GL methods) which its RW / IF Entropy Information in 2001 (see page 17) was clearly below to them.

Results of the evolution of polycentrism level (2001-2024) by using a spatial interaction model are contained in the following graphics and tables:

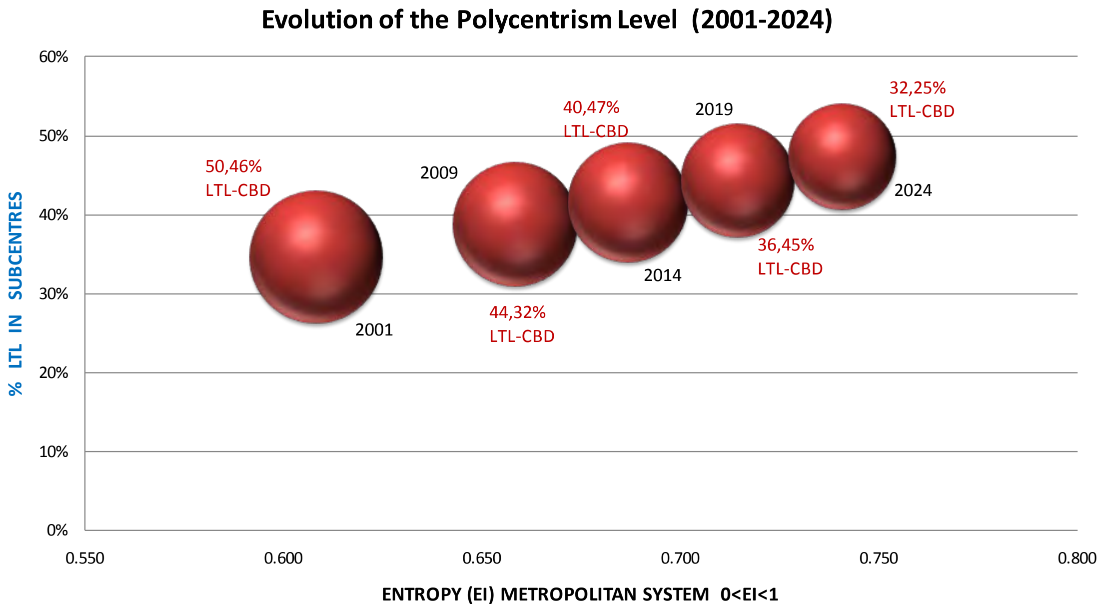
In the following table depicts the evolution of the employment share in the central employment of the central city: Barcelona (CBD) and the sub-centres beyond it. In addition, the next table also represents the dynamics of Entropy Index–EI, (Limtanakool, 2007,2009) during the period 2001-2024 for the central city of Barcelona (CBD), for the sub-centres beyond it, and finally for the Metropolitan System. The results suggest clearly, an increment of the polycentrism level within the Metropolitan System since 2001 to 2024: the entropy index for the metropolitan system will be increased by "0.608" in 2001 to "0,741" in 2024. As a result, the employment share of Barcelona (CBD) is decreasing in favor of the employment share of the sub-centres beyond it.

Table 8: Evolution of: localized workers (LTL), the employment share and Entropy Index in the central city of Barcelona (CBD) and in the sub-centres beyond it

	LTL in subcentres	LTL in CBD	% LTL in subcentres	% LTL in CBD	Entropy (EI) in subcentres	Entropy (EI) in CBD	Entropy (EI) Metropolitan System
2001	696676	1016736	34,58%	50,46%	0,321	0,091	0,608
2009	967912	1106086	38,79%	44,32%	0,348	0,095	0,658
2014	1026194	1001060	41,49%	40,47%	0,363	0,097	0,687
2019	1126318	926603	44,31%	36,45%	0,379	0,097	0,714
2024	1263852	862572	47,25%	32,25%	0,394	0,096	0,741

Note: Candidate Subcentres JR+CL (way 4, page 8 of the paper)
Source: Own Elaboration

In the following figure is exposed, according to the previous table, the evolution of the polycentrism level (2001-2024) in the Barcelona Metropolitan Region. In the X axis is represented the dynamics of the Entropy Index (EI)[15] for the Metropolitan system and in the Y axis the share of employment (LTL) contained in such potential sub-centres during the period 2001-2024. The size of the sphere represents the share of employment located at the CBD.



[15] Note that by analyzing the evolution of polycentrism level since 2001 to 2024 it is used the dynamics of the Entropy Index (EI) and not the number of nuclei. The spatial interact model defines by an origin (1991, in this study) the LTL (localized workers) for each time (2001, 2009, 2014, 2019 and 2024) and it could not define the evolution of artificial surfaces that is used for calculating the density of employment and consequently the potential sub-centres. Definitely, a meaningful further research step will be the analysis of the artificial land dynamics by using for example Markov chains and then, locate it spatially by using Economic Agents or Cellular Automata.

6. CONCLUSIONS

In the first part of the paper, in order to detect sub-centres two families of methods used in literature has been implemented. From the perspective of employment density, analysis econometric models using “classic density” (that only considers employment without considerate mobility) has been used; as well as cut-off approach as it has been used by (García-López, 2007). From the perspective of mobility analysis subcentres has been detected by analysing the densest municipality inside each sub-system having the most intense functional relations with the remaining municipalities in the sub-system.

On the one hand, meanwhile econometric approach and cut-off approach detect dense and relatively big municipalities (without regarding their paper as nodes in the articulation of urban life), in the mobility approach detects nodes that articulate travel-to-works area (without regarding their density and size). So econometric models and cut-off approaches are oriented to detect top-hierarchy areas (although there is no guarantee that dense and big municipalities exert any influence on their hinterland) and mobility approach is oriented to detect nodes inside network systems. For these reasons, in this paper, it has introduced another way to detect sub-centres: a combination of functional methods and density analysis: considering as a candidate to sub-centre, the protosystems that satisfy the criteria of using the cut-off approach. In that sense, this “new approach” could identify centres in a network of cities function as nodes that at the same time they also are dense sports.

On the other hand, comparing these four ways to detect sub-centres; the last methodology (functional+cut-off approach) is the method whose model obtains a higher value of adjusted R square (R^2): 0,60. The parametric model using “classic density” (way 1 to detect sub-centres) obtains a value of 0,298 and the cut-off approach (way 2 to detect sub-centres) gets a value of 0,283. In addition, in order to evaluate the polycentrism level in accordance with the different used methodologies to detect sub-centres, the last methodology (JR+GL) is also the methodology which depicts a more polycentric region, with a total of 13 nuclei beyond Barcelona (CBD) and a share of employment in the potential sub-centres of 34,26%. The parametric method (CL) shows a metropolitan system of 6 nuclei beyond CBD with a share of employment in the sub-centres of 13,34%. The cut-off approach (GL) in its case, defines a urban system of 11 nuclei beyond Barcelona with a share of employment in the sub-centres of 24,18%. Finally, the mobility approach (JR) depicts a metropolitan area with 9 nuclei beyond the central city with a share of employment in the sub-centres of 30,39%.

In the second part of the paper, the emergence of sub-centres and the evolution of polycentrism level by using a spatial interaction model are analysed. The spatial interaction model depicts a prospective metropolitan structure where the central city of Barcelona has significantly lost its prominent role in the metropolitan system. In 2001, the share of employment concentrated in Barcelona (CBD) was 50,46% and by 2024 this share will have decreased to the 32,25%. In addition, this process of decentralization, combines a process of emergence of subcentres on the intermediate distances instead of the periphery (edge cities).

It is the case of the protosystems of Rubí, Sabadell, Terrassa and Martorell. Rubí (16,54 kilometres from Barcelona) had 33.566 LTL in 1991 (localized workers) and by 2024 will have had 109.787 LTL (what means an increment of 227,1%). Sabadell (22,30 kilometres) had 93.859 LTL in 1991 and by 2024 will have had 253.771 LTL (an increment of 170,4%) or Terrassa (28,01 kilometres) which had 55.366 LTL and by 2024 will have had 157.886 (an increment of 185,20 %). However, the protosystem which emerges with most energy is Martorell (26,75 kilometres from Barcelona) which had only 21.664 in 1991 (1,34% of the total employment) and by 2024 will have increased its LTL to 98.711 (an increment of 351,6%). That results, suggest that the potential candidate to sub-centres identified in the first part of the paper that will have an important role in order to articulate the prospective Barcelona metropolitan region will be the subcentres which most increase its LTL (localized workers).

The analysis of the evolution of polycentrism level (2001-2024) confirms that suggestion. In 2001, the central city (Barcelona) concentrated the 50,46% of the localized workers (LTL); the share of employment in sub-centres were 34,58%; and the Entropy Index (EI) (Limtanakool, 2007,2009) of the metropolitan system was 0,608. Compared to “this situation” by 2024, the metropolitan system will have turned into a more polycentric region, where Barcelona (CBD) will have decreased its share of employment to 32,25%, the share of employment in the sub-centres will have increased to 47,25% and the Entropy Index to 0,741. Thus, this process of employment decentralization of the central city towards the rest of the metropolitan territory is closed linked with a process of strengthen of polycentrism and not with a process of urban sprawl.

However, this prospective metropolitan dynamics, not only could it mean a strengthening process of polycentrism level and a process of emergence of sub-centres on the intermediate distances but also it might lead to a restructuring of the Barcelona metropolitan region towards a bipolar polycentric model (Barcelona and a metropolitan subsystem formed by Rubí-Terrassa-Sabadell), where the complexity of the relations among subcentres emerges. The reasons: 1) a process of employment decentralization of the central city 2) combined with an emergence of sub-centres on the intermediate distance and a lack of prominent sub-centres in the periphery (edge cities) and finally, 3) a strongly increment of polycentrism level consequently of the emergence of these sub-centres.

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