"Identifying the Employment and Population Centers at regional and metropolitan scale: The Case of Catalonia and Barcelona"

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ABSTRACT:
Nowadays, the urban structure of the metropolitan areas has led to a polynucleated structure, breaking with the paradigm of the monocentric city. The specialized literature has studied this polynucleated structure by identifying the centers that are within of these urban areas. According to this objective, many approaches have used in order to identify these centers (sub-centres): by analyzing the employment or population density and by studying the mobility flows.
In this paper, the employment and population centers in Catalonia and in the Barcelona Metropolitan Region are identified by taking into account a new mobility approach, focusing on the flows of workers and people. In doing so, this study has carried out a dynamic analysis: from 1981 to 2010 in the case of identifying population centers and from 1991 to 2001 in the case of detecting employment centers at the time that the functional and the administrative boundaries of the Barcelona Metropolitan Region has also taken into account. Then, the influence of these identified sub-centres on the urban spatial structure is analyzed by estimating the evolution of polycentricity level and their influence on the urban hierarchy.
The results by having this dynamic perspective (1981-2010) and (1991-2001) suggest: a more polynucleated structure of the Barcelona Metropolitan Region as well as the Catalan territory, an increment of the influence of the identified sub-centres on the urban hierarchy at the time that these identified centres are more dominant in terms of in-commuting flows, more self-contained in comparison with the sub-centres that are detected by using the standard employment and demographic density functions.

KEYWORDS:
Urban spatial structure, sub-centres, polycentrism, metropolitan areas & new urban economy

JEL CODES: R0, R11, R12 & R14

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1. INTRODUCTION

Polycentricity may be defined as that process by which a city gradually distances itself from a spatial structure characterized by the existence of a single employment centre, moving towards a new one where various employment centres of the same or different hierarchic order coexist. The existence of polycentric urban structures is increasingly evident both in Europe and in the United States. Nevertheless, their origin tends to be different in origin according to Champion (2001) and Clark & Kuijpers-Linde (1994).

In the United States, polycentricity arises mainly from employment decentralisation: new subcentres appear at the periphery, colonising a space that is either normally empty or occupied by dwellings under low-density conditions. This first origin of polycentrism is situated within the framework of the Monocentric city Model studied by Alonso (1964), Muth (1969) and Mills (1972). Thus, for instance references have been included to congestion, the mechanism for fixing equilibrium wages, the spatial impact of agglomeration economics, or to the relationship between the costs of product transport and of commuting. These have been the theoretical framework from which the polycentricity of North American cities has been focused and the most relevant work related to that are the studies of Fujita & Owaga (1982), Sullivan (1986), Wieand (1987), White (1990), Henderson & Slade (1993), Anas & Kim (1996), Anas, Arnott & Small (1998), Anas (2000), Berliant et al. (2002), Fujita & Mori (2005), Berliant & Wang (2008) and Tabuchi (2009) for example.

This rise of polycentric city in North American cities is explained by McMillen (2001a, pg.15): *"theoretical models of urban structure are based on the assumption that all jobs are located in the central business district (CBD). Although this assumption was never literally true, it is useful approximation for a traditional city in which the CBD holds the only large concentration of jobs. As metropolitan areas have become increasingly decentralized, traditional CBD have come to account for a much smaller proportion of jobs than in the past large employment districts have arisen outside of central cities that rival the traditional city center as places of work. When these districts are large enough to have significant effects on urban spatial structure, they are referred to in the urban economics literature as employment subcenters"*, at the time that McMillen & Smith (2003, pg.321) explain the benefits of this new urban spatial structure: *"polycentric urban areas combine many of advantages of big and small urban areas. Whereas the CBD offers firms the advantages of significant agglomerations economies, it also requires high wages to compensate for expansive and time-consuming commutes. Employment subcenters that resemble small CBDs have arisen in the suburbs of many urban areas. When sufficiently large to quality an urban area for the polycentric label, employment subcentres offers firms some of the benefits of agglomeration while reducing commuting costs, wages and land prices.* Edge cities, industrial districts, technology parks, university campuses, peripheral centers of employment in general, collect that which CBD expels. Since the mid-eighties there has appeared a substantial amount of literature propounding different methodologies for identifying subcentres that have emerged over time. Gordon et al. (1986), Heikkila et al. (1989), Giuliano & Small (1991), Song (1994), Clark & Kuijpers-Linde (1994), Gordon & Richardson (1996), McDonald (1987), McDonald & McMillen (1990), McDonald & Prather (1994), McMillen & McDonald (1997, 1998a, 1998b), Cervero & Wu (1997), Bogart & Ferry (1999), Craig & Ng (2001), Anderson & Bogart (2001), Shearmur & Coffey (2002), McMillen & Lester (2003), McMillen (2003a, 2003b, 2004) and Readfearn (2007) among others. The results of this string of applied studies confirm the validity and extension of polycentrism in North American cities, even though the number of subcentres identified in each study may vary considerably depending on the method used or the numerical or statistical reference thresholds.

In the case of Europe, polycentricity has been presented as the result of the evolving of pre-existing hierarchic urban system where the different centres have been functionally integrated due to the reduction of transport costs. Relationships that in the past were of a vertical origin (between centres of a different order) are being increasingly replaced by horizontal relationships (between centres of the same order), which has led to the role played by the different centres making up the system no longer being explained only by the specificity of the services they offer, but rather also by the activity sectors in which they specialize. The metaphor of the hierarchic tree characteristic of the Central Place Theory proposed by Christaller (1933) and then by Lösch (1940) has been replaced by that of the network paradigm proposed by Dematteis (1990, 1991a, 1991b), Emmanuel & Dematteis (1990), Camagni (1993, 1994), Camagni & Salone (1993) and Batten (1995). The idea is that, as previously disconnected labour market areas become integrated functionally, there arises the possibility that the different centres specialize in certain sectors with the aim of making greatest use of the Marshall-like economies of location. Thus, the hierarchic scheme of a system of christallerian type cities is no longer useful, since the horizontal relationships gain importance in relation to the vertical ones.

So, since the middle of the 20th century, regional migratory flows have showed down in Europe, in such a way that big cities seem to have arrived at a stable population size. This is not however strictly true. The city continues expanding spatially, although not so much by a process of absorption, but rather by integration Champion (2001). Those smaller-sized population and activity centres which in the past were able to resist a trajectory of own growth and were situated far enough away are being integrated into the field of influence of the main city as it has explained by Hohenberg & Lees (1995). Cities like Naples, Marseilles, Toulouse, Turin, Florence, Frankfurt, Helsinki, Stockholm, Oslo and Barcelona would be in this group of polycentric cities with an outstanding centre CSD (1999). In other cases, cities of a similar size which by their proximity maintain a relationship based on a certain rivalry, have seen how their areas of worker attraction are overlapping, taking on the form of a city of cities without a clear dominant centre. Holland's Randstad studied by Lambooy (1998), Meijers (2006, 2007, 2008) and Lambregts (2009) and the so-called Belgian diamond studied in this case by Dieleman & Faludi (1998) are two outstanding example where similarly ranked cities merge Champion (2001).

In some sense, the reference theoretical framework has been adapted to the conditions in each place. In the North America case, the creation of subcentres is in general a relatively recent phenomenon linked to the decentralisation trends of population and employment as it is explained for instance by Alperovich (1983), Giuliano & Small (1993, 1999), Small & Song (1994), Coffey & Shearmur (2002), McMillen (2003b) and Leslie (2010). At the other extreme, the subcentres of European polycentric systems tend to be medium sized cities with a long history as Hohenberg & Lees (1995) and Hohenberg (2004) have explained. The problem is that the reality is usually situated somewhere between the two extremes. Not all the subcenters of North American cities are a result of recent employment decentralisation, nor all the subcentres of European urban systems have their origin in a remote past. In that sense Hohenberg (2004, pg. 49) explains that the European urban model from the origin of their cities onward two sets of forces have driven the process of their urban development, expressed respectively in central places and networks: "*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*". To be able to deal with the shades of grey that suggests the need for a detailed examination of the reality of the situation, it would be desirable to integrate both theoretical approaches, but this unfortunately has not occurred yet. One of the effects deriving from the disconnection produced between the two theoretical approaches is that they have generated clearly separate applied research strategies. In the North American instance, the emphasis has been placed on the need to find some methodology that enables subcentres to be identified in a thorough and objective way. In the European case, research was been mainly directed towards the change of economic base of the systems centres as well as towards all that referring to the relationship between centres, whether they belong to the same or different hierarchical order.

Therefore, the aim of this study is identifying subcentres at regional and intrametropolitan scale that are suitable with the hierarchic and complex European urban systems where centres have been emerged mostly as a result of an integration or coalescence process between old and pre-existing cities, Champion (2001) as well as suitable with the decentralisation process from a single and congested Central Business District (CBD). To do so, it is used the functional approach proposed by Masip (2012b, 2012c) to identify subcentres that are "places to work" (employment subcentres) and subcentres that are "places to work and live" (urban subcentres). That means distinguish those sub-centres that only attract workers (in-commuting flows) or retain their resident workers to those sub-centres that are able to attract flows and retain their resident employed population at the same time. Hence, the identification of regional and intrametropolitan subcentres is carried out in this work by analyzing the functional characteristics of places in Catalonia and in the Barcelona Metropolitan Region rather than their morphological features. Thus, in order to identify metropolitan subcentres, (commuting) flows between urban nodes (municipalities) have been analyzed together with the supply of urban functions. The rest of the paper is organized as follows. In section 2 a review of literature is carried out, distinguishing the major static and morphological methodologies in order to identify subcentres, from those that use flows and that are based on an interaction. Section 3 presents the study case and data. Section 4 is devoted to explain the methodology proposed by Masip (2012b, 2012c) to identify and characterize urban subcentres as well as testing its efficacy with other standard density methodologies in the study case of the Barcelona Metropolitan Region from 1991 to 2001. Section 5 identifies the regional centers in terms of employment from 1991 to 2001 and in terms of population from 1981 to 2010 in the Catalan territory. Section 6 gives a detailed empirical work by analyzing the impact of the identified and characterizes subcentres on the population and employment density in the case of Barcelona Metropolitan Region from 1991 to 2001. Finally, Section 7 sets out the main conclusions.

2. LITERATURE REVIEW

The literature on the identification of subcentres has evolved over the years gaining objectivity, thoroughness and replicability. The first studies that identified subcentres by making use of information provided by some official agency as is studied by Greene (1980) and Griffith (1981a, 1981b) or by the fact of being historical areas, Erickson & Gentry (1985) and Heikkila et al. (1989) among others. For example Greene (1980) defines employment centers as areas with double the average employment density. Although this group of studies provided interesting material, it can only be seen as a first step in the expansion of a literature whose aim is an interesting mixture of simplicity and objectivity. Beyond the first attempt at identification, the studies carried out to date can be grouped into five categories:

The first method consists of using consists of using a reference thresholds. The majority of studies that apply this method consider a double threshold, one the number of jobs and another for employment density. In North America, the most relevant work are the studies carried out by Giuliano & Small (1991), Song (1994), Cervero & Wu (1997, 1998), McMillen & McDonald (1997), McMillen & McDonald (1998a, 1998b), Bogart & Ferry (1999), Anderson & Bogart (2001), McMillen & Lester (2003) and McMillen (2003b). Otherwise, in Europe, within the context of the Barcelona Metropolitan Region, the most remarkable works are: Asensio (2000), Martori & Suriñac (2002), Muñiz et al. (2005), Muñiz et al. (2008) and García-Lopez (2007, 2010a). However, there are some studies add an additional threshold for the ratio of jobs per resident population, for example in the study carried out by Shearmur & Coffey (2002) or other studies that combine the using of thresholds with the identification of density peaks, these are the cases of Muñiz et al. (2003b) and García-López (2010b).

Giuliano & Small (1991) define a subcentre as a set of contiguous tracts that have a minimum employment density of 10 employees per acre each and, together have at least 10.000 employees and identifies 32 subcenters in the Los Angeles area. According to McMillen (2001a, pg.17-18) the Giuliano & Small (1991) method to identify subcentres is sensitive to the cutoff point used for minimum employment density and total subcentre employment: "*data sets with small tracts are more likely to have pockets with low employment density, which reduces the number of subcentres identified using the Giuliano & Small procedure" and "local knowledge must guide the choice of cutoff points, limiting the analysis to familiar metropolitan areas"*. This observation led McMillen & McDonald (1998a, 1998b) to work with proximity instead of contiguity: two tracts are proximate to one another if they are within 1,5 miles, but the number of subcentres is again sensitive to the definition of proximity. García-Lopez (2007, 2010a) suggested that subcentres are zones with a density higher than the metropolitan average and at least 1% of metropolitan employment and in the case of Shearmur & Coffey (2002), which –following the idea of McDonald (1987)- identify as subcentres the contiguous TAZs that show an employment to resident worker ratio greater than 1 and a number of jobs of at least 5.000 units. Therefore, the cutoff approach is subject to a certain degree of discretion, since this method is often guided by trials and errors as well as by some local knowledge of the place under analysis as McMillen (2001b, pg.449) has explained. However, a certain degree of discretion is used in every method of identification, even in econometric ones, where certain statistical confidence level has to be chosen.

The second method is based on interaction procedures that seem particularly sound for Europe, which is characterized by a lot of small, historically determined urban centres. European metropolitan areas are formed mostly by three forces or modes as it is explained by Champion (2001, pp.664): the centrifugal mode, the incorporation mode and the fusion mode[1] in which the majority of these metropolitan areas are the result of such process of coalescence and are characterized by a dominant centre, which is surrounded by other smaller centres,

[1] According to Champion (2001): "the centrifugal mode is base on the monocentric city, where the continuing growth of the city imposes such severe strains (for example, escalating land rents in the CBD and growing problems of access to the central area from the ever more distant outer residential areas) that the most affected production and service services are squeezed out to alternative centres that in due course may, in combination or indeed separately, come to rival the original centre size. The incorporation mode consists in a large urban centre expanding its urban field so that it incorporates smaller centres in the surrounding area that had previously been largely self-sufficient in terms of both employment and services, with these other centres then forming a more powerful catalyst for attracting extra non-residential activities than the centres emerging through the centrifugal mode and perhaps providing an ever stronger challenge to the main centre. Finally, the fusion mode is based on the fusion of several previously independent centres of similar size, as a result of their own separate growth in overall size and lateral extent and particularly because the improvement of transport links between them.

forming contemporary polycentric metropolitan areas. As it is said in Section 1, most European metropolitan subcentres did not result from a simple process of decentralisation of the city centre. From this perspective, metropolitan subcentres can be seen as the central places within a given metropolitan area, the places that organize functionally, their surrounding territory. The literature on the identification of subcentres based on the analysis of the data on mobility can be found in America, for example in the work of Bourne (1989) and Gordon & Richardson (1996), in Europe due to the studies of Clark & Kuijpers-Linde (1994) and Veneri (2010) and finally, in the context of the Barcelona Metropolitan Region are relevant the works of ATM (1998), Burns et al. (2001), Roca et al. (2009), Roca et al. (2011), Masip (2011a) and Masip & Roca (2012).

Bourne (1989) visually analyses commuting flows for Canadian cities. Gordon & Richardson 81996) follow a trip-generation density approach for Los Angeles in 1980, analyzing the distribution of traffic flows among TAZs and identifying 18 subcentres. In addition, Gordon & Richardson (1996) argue that with dynamic methodologies it is possible to grasp the role of subcentres not only as employment concentrations, but also as focal points of a metropolitan area, regarding the urban function that subcentres supply to their neighbor territory. In Europe, Burns et al. (2001) identifying subcentres in Spanish metropolitan areas by selecting the municipalities that show a net entry of at least 15%. Roca et al. (2009) and Roca et al. (2011) identify subcentres in the Barcelona Metropolitan System and in Barcelona & Madrid respectively by using an interaction value[2] defined by Roca & Moix (2005). According to Roca et al. (2009, pg. 2860): "*the analysis of mobility allows for the detection of true subcentres, understood as the generators of true metropolitan structure. The subcentres, from this specific point of view cannot only be understood as local peaks in the topography of the employment density surface. Rather, they must configure nodes of the metropolitan structure that imply significant tensions of urban mobility. The subcentres should constitute real poles of influence and territorial reference that surround them in cultural, social and economic aspects. In order to be truly considered as centres, they should generate authentic cities within their surroundings and, therefore configure a metropolis as a city of cities*".

Veneri (2010) identifies subcentres in two Italian Metropolitan Areas by using an interaction procedure based on two interaction indicators: the flow centrality ratio (FCi) and the productive completeness (PCi). The former, according to Veneri (2010) reveals the capacity of a node to dominate its surrounding territory from a functional point of view. The latter, approximates the variety of functions supplied by each urban node, starting from the idea that, besides attracting a great number of commuters a metropolitan subcentre must have a minimum degree of productive variety, which can be thought of a sign of the wide range of urban functions supplied by a given mode. Thus, Veneri (2010) defines as a subcentre those municipalities that both their flow centrality ratio and productive completeness are higher than 1. By using this approach, Veneri (2010) identifies 3 subcentres in the Rome Metropolitan Area and 10 subcentres in the Milan Metropolitan Area.

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[2] The interaction value is expressed as follows: $IV_{ij} = \frac{f_{ij}^2}{RWP_i LTL_j} + \frac{f_{ji}^2}{RWP_j LTL_i}$ where IVij is the interaction value between the zones (i) and (j); (fij) and (fji) are the existing commuting flows; RWP is the resident employed population; and LTL are the locally based workplaces within zones (i) and (j). The interaction value according Roca et al. (2009, pg. 2846) 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 zones. In addition, this weighting is carried out in a 'transitive' way, considering not only the attraction in one direction (e.g. the 'larger' over the 'smaller'), but also in the opposite direction.

More recently, these interaction or functional approaches have been used also for the analysis of spatial configuration at regional urban system, Green (2007), at the level of national urban systems, for example the works of Limtanakool et al. (2007, 2009) or even at the global level, Derudder et al. (2003). The work of Limtanakool propose a set of spatial interaction indices, trying to quantify the symmetry, the strength and the structure of the urban system by using data about commuting flows.

The third group of studies uses a criterion based on the identification of peaks, e.g. set of contiguous census sections that present a local maximum with respect to the area that surrounds them, whether it be employment density as the studies carried out by Gordon et al. (1986), Craig & Ng (2001), Muñiz et al. (2003a) and Readfearn (2007) or the ratio of jobs per resident population as the works of McDonald (1987) and McDonald & McMillen (1990).

Craig & Ng (2001), propose a nonparametric estimation procedure to obtain smoothed employment density estimates for Houston. Using quantile regression approach, they focus on the 95th percentile of the employment density distribution. According to McMillen (2001a, pg.18) Craig & Ng's procedure is not as sensitive to the unit of analysis as the McDonald (1987) and Giuliano & Small (1991) procedures[3]. Muñiz et al. (2003a) follow a similar approach, using estimated spline functions to identify density peaks, but probably the most relevant work is the non-parametric method developed by Readfearn (2007, pg.521) because contrast sharply with McMillen's applications. Readfearn's procedure estimates a non-parametric employment surface occurs locally –with a subsample- that is kept sufficiently small to keep intact the structure of local employment density. According to Readfearn (2007) this is necessary in order to identify subcentres, as the general spatial trends in employment density using a larger windows size largely mask independent local concentrations of employment in which local maxima on the density surface become candidate to subcentre. However, although non-parametric approaches have the advantages that are flexible, allowing the slope of density functions to vary across the metropolitan area as it is explained in McMillen (2001a, pg. 18), these approaches have some problems in terms of F-tests as it is explained in McMillen (1996, pg. 107) as well as they also require some local knowledge when the window size of the local weighted regression (LWR) has to be defined. McDonald (1987, pg.243) gave five definitions of employment subcentres that at first appear to be reasonable: 1) a secondary peak in gross employment density, 2) net employment density, 3) employment-population ratio, 4) gross population density and 5) net population density. Finally, McDonald (1987, pg.245) suggest that local peaks in gross employment density and the employment-population ratio are the best indicator of employment subcenters and McDonald's (1987, pg. 246) subcentre definition is: "*a zone is considered to be an employment subcentre if its value for the measure in gross employment density or employment –population ratio exceeds the value for each contiguous[4] zone*". However, the studies of McDonald (1987) and McDonald & McMillen (1990) define potential subcentres as zones

[3] Though larger tracts lead to smoother employment density functions, larger subcentres will procedure a rise in the function whether the data set includes acres, quarter sections or square miles. However, the Craig & Ng (2001) procedure requires some local knowledge to choose which sites are subcentres within rings around the CBD, and the imposition of symmetry around the CBD is unsuited to cities that are distinctly asymmetric due to varied terrain or multiple subcentres.

[4] According to McDonald (1987), typically a zone has four contiguous zones: one that is closer to the CBD, two that are approximately the same distance from the CBD and one that is further from the CBD. According to this definition given by McDonald, a zone cannot be an employment subcentre if its gross employment density (or employment-population ratio) is equal to or less than that for any of these four zones. In particular, a zone cannot be an employment subcentre if gross employment density (or employment-population ratio) declines with distance to the CBD.

with higher gross employment density than all contiguous tracts, but these approaches are only adequate for large tracts, due to may identify small zones as subcentres when they are surrounded by others with little or no employment.

The fourth method consists of identifying the positive residuals estimated from an exponential employment density function as McDonald & Prather (1994) or with a combination of non-parametrical and semi-parametric methods as McMillen (2001b, 2003a) and finally, the recently study carried out by Leslie (2010) in which identifies subcentres in the city of Phoenix by using Kernel smoothing process for both employment and establishment density.

McDonald & Prather (1994), identify possible employment subcentres by examining the residuals from a monocentric regression model of employment density. After extensive tests[5], McDonald & Prather (1994) conclude that a simple negative exponential employment density function suffices for this purpose and they identify 3 subcentres in Chicago in 1980: O'Hare Airport, Schaumburg and DuPage country. McMillen (2001b, pg. 449), proposed a two-stage non-parametric and semi-parametric for identifying subcentres with the aim to be less sensitive to the unit of measurement than most existing procedures, readily reproducible by other researchers and that it can be applied to metropolitan areas that the researcher does not known well. The first stage of McMillen's procedure is based on a nonparametric estimator, locally weighted regression, to smooth employment density. The estimate of a site's employment density is obtained according to McMillen (2001b) by weighted least squares, with more weight given to nearby tracts. Potential subcentres are sites with significant positive residuals. Thus, *a potential subcentre is a site with unusually large density after broad spatial trends are accounted for*. In the second stage, McMillen (2001b) uses a semi-parametric regression to determine whether the potential subcentres have significant effects on employment density. The non-parametric part of the regression captures the effect of distance from the CBD using a flexible Fourier form. Thus, according to McMillen's procedure the results are conditioned on distance from CBD, but the CBD gradient can vary spatially. The final list of subcenters includes the sites providing significant explanatory power in the employment density function. The procedure according to (McMillen 2001b, pg.449) *captures the idea that a subcentre is an area with an employment density that is significantly higher than would be expected based only on its distance from CBD.* Finally, McMillen (2003a) used hybrid approach to identify subcentres. According to McMillen (2003a, pg.58) this hybrid approach by using contiguity matrices has the advantages over both the Giuliano & Small (1991) and the McMillen (2001b) approaches. In the first stage, the hybrid approach follows Giuliano & Small (1991) and includes tracts that exceed a minimum density level. In the second stage, allows the cut-off points to vary across cities and spatially within a city by using a non-parametric estimator initially to smooth the employment surface. According to McMillen (2003a), *candidate to subcentre sites are tracts with significantly*

[5] McDonald & Prather (1994) tested seven different functional forms of employment density as follows: (1) $D(X) = D_0 - BX + u$. (2) $D(X) = D_0 - BX + AX^2 + u$. (3) $D(X) = D_0 - BX + A\left(\frac{1}{X}\right) + u$. (4) $LnD(X) = LnD_0 - BX + u$. (5) $LnD(X) = LnD_0 - BX + AX^2 + u$. (6) $LnD(X) = LnD_0 - BX + A\left(\frac{1}{X}\right) + u$ and (7) $LnD(X) = LnD_0 - ALnX + u$. The use of a model with D(x) as the dependent variable generates according to McDonald & Prather (1994, pg.205) severe heteroskedasticity problem. The estimated variance of (u) declines with distance to the CBD. Such a result is especially problematic because the identification of employment subcentres is to be based on examination of residuals. After checked for heteroskedasticity in the functions 4-7, McDonald & Prather (1994) claim that the negative exponential function (4) passes these test for unbiasedness and homoskedasticity. The other three functions that use LnD (x) as the dependent variable also pass the test for homoskedasticity but the double-log function (7) does not pass the test of lack of bias. Thus, far the simple negative exponential (4) has emerged as the best functional form.

positive employment density residuals. However, this procedure as cut-off approaches, is sensitive to the cut-off points used to identify candidate subcentres sites and the results also depend critically on the size of tracts, with small tract sizes leading to more subcentres.

Finally, there have recently appeared some studies where elements of spatial econometrics are used in order to identify clusters with higher density than that of surrounding ones. High-density clusters can be considered subcentres since they represent relative concentrations of employment. This approach is based on the Local Indexes of Spatial Autocorrelation (LISA). With these indicators it is possible to quantify the degree of clustering of neighbouring zones with high levels of density. This method has been used among others by Baumont & Le Gallo (2003), Giullian et al. (2004) and Riguelle et al. (2007).

To summarize the literature on the identification of subcentres, the following Table 1 and Table 2 depict the main works of subcentres identification procedures that has been carried out to date in the Barcelona Metropolitan Region –BMR- (study case of this work) and in North America & Europe respectively.

Table 1**. Methodologies for subcentre identification: Barcelona Metropolitan Region**

Methodology	Study	Criteria	Year	Subcentres
Thresholds	Asensio (2000)	Employment > 20.000	1996	5
	Martori & Suriñac (2002)	Population > 50.000	1998	11
	Muñiz, Galindo & García-López (2005)	4,5 Employment / ha Employment > 10.000	1996	22
	García-López & Muñiz (2005)	Density > Average Density Employment > 1% Employment	1986	Total 6 Service 4 Manuf. 8
			1996	Total 13 Service 13 Manuf. 12
	Muñiz, García-López & Galindo (2008)	Density > Average Density Employment > 1% Employment	1991 / 2001	9
	García-López & Muñiz (2007, 2010a)	Density > Average Density Employment > 1% Employment	1986 / 1991 / 1996 / 2001	6 / 6 / 7 / 9
Commuting	ATM (1998)	Net commuting in subregional predetermined zones	1996	7
	Burns et al. (2001)	Positve net incommuting > 15% Population > 10.000	1996	7
	Roca et al. (2009, 2011)	Interaction Value	2001	23
	Masip & Roca (2012)	Interaction Value Dominance Index > 1	1991 / 1996 / 2001	3 / 6 / 8
Density Peaks	Muñiz et al. (2003a)	Local maximum in a population density cubic - spline function	1996	7
Thresholds + Density Peaks	Muñiz et al. (2003b)	(1) a. Density > 4,5 Empl / ha	1996	15
		b. Density Peak		11
		c. Positive residuals in a employment exponential density function, and Employment > 10.000		12
		(2) Candidate a+b+c positive effect on a polycentric exponential population density function		13
	García López (2010b)	(1) a.Locally Weighted Regression b. Population > 10.000	1991 / 2005	22 / 23
		(2) a.Locally Weighted Regression b. Population > 1 % Population		8 / 7

Source: Own Elaboration and García-Lopez & Muñiz (2005)

Table 2**. Methodologies for subcentre identification: North America & Europe**

Methodology	Study	Criteria	City - Year	Subcentres
Thresholds	Giuliano & Small (1991)	Density > 25 Empl. / ha Employment > 10.000	Los Angeles 1980	32
	Song (1994)	Density > 37 Empl. / ha Employment > 35.000	Los Angeles 1980	6
	Cervero & Wu (1997, 1998)	Density > 17 Empl. / ha Employment > 10.000	San Francisco 1990	22
	McMillen & McDonald (1997)	Density > 25 Empl. / ha Employment > 10.000 Negative subcentre density gradient	Chicago 1980	20
	McMillen & McDonald (1998a) (1998b)	Density > 25 Empl. / ha Employment > 10.000 Negative subcentre density gradient	Chicago 1990	20
	Bogart & Ferry (1999)	Density > 20 Empl. / ha Employment > 10.000	Cleveland 1990	9
	Anderson & Bogart (2001)	Density > 20 Empl. / ha Employment > 10.000	Cleveland 1990 Indianapolis 1990 Portland 1990 Sant Luis 1990	9 11 11 11
	Shearmur & Coffey (2002)	Employment > 50.000 Employment / Population > 1	Montreal 1996 Toronto 1996 Ottawa-Hull 1996 Vancouver 1996	16 17 7 13
	McMillen & Lester (2003) McMillen (2003b)	Density > 15 Empl. / acre Employment > 10.000	Chicago 1970 Chicago 1980 Chicago 1990 Chicago 2000 Chicago 2020	9 13 15 32 24
Commuting	Bourne (1989)	Commuting Flows	Canada	27
	Clark & Kuijpers-Linde (1994)	Commuting Flows	South. California 1980-1990 Randstad 1980-1990	5 5
	Gordon & Richardson (1996)	Density trop generation > 0,80 Standard deviation	Los Angeles 1980	18
	Veneri (2010)	Flow ratio centrality (FCi) > 1 Productive Completeness > 1	Rome 2001 Milan 2001	3 10
Density Peaks	McDonald (1987)	Density or Employment / Population	Chicago 1970	9
	McDonald & McMillen (1990)	Density or Employment / Population	Chicago 1956 Chicago 1970	8 9
	Gordon et al. (1986)	Employment Density	Los Angeles 1980	18
	Craig & Ng (2001)	Employment Density	Houston	7
	Readfearn (2007)	Employment Density Locally Weigted Regression (LWR)	Los Angeles 2000	41
Residues	McDonald & Prather (1994)	Exponential function	Chicago 1980	3
	McMillen (2001b)	a) Locally Weighted Regression b) Flexible Fourier with subcentre distance	Chicago 1980 Dallas 1980 Houston 1980 Los Angeles 1990 New Orleans 1990 San Francisco 1990	33 28 25 19 2 22
	McMillen (2003a)	Contiguity Matrices a) cut-off points > 10.000 b) Locally Weigted Regression	Atlanta 1990 Baltimore 1990 Boston 1990 New York 1990 Philadelphia 1990	8 /4 18 / 18 9 / 11 27 / 38 8 / 4
Spatial Econometrics	Baumont & Le Gallo (2003)	Local Indexes of Spatial Autocorrelation (LISA)	Dijon 1999	4
	Giullian et al. (2004)	Local Indexes of Spatial Autocorrelation (LISA)	Ile de France 1978 - 1997	3 / 7
	Riguelle et al. (2007)	Local Indexes of Spatial Autocorrelation (LISA)	Brussels 2001 Antwerp 2001 Ghent 2001 Liège 2001	5 2 7 7

Source: Own Elaboration and García-Lopez & Muñiz (2005)

3. STUDY CASE & DATA

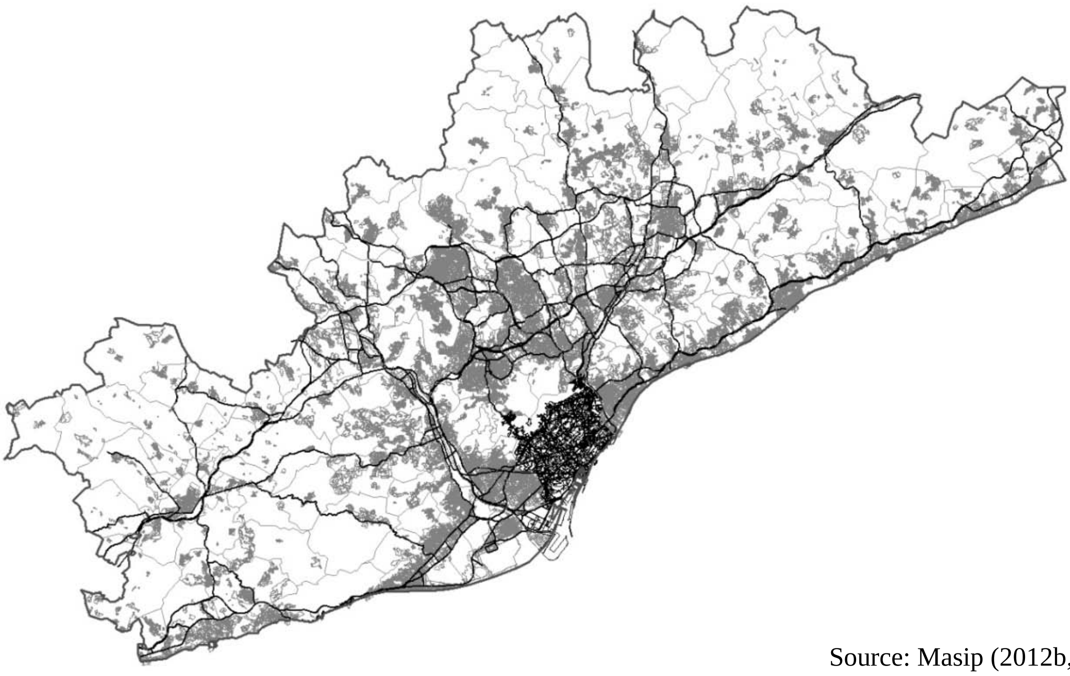
The Catalan regional territory –Figure 1- is one of the most wealthy and prosperous regions in Spain. In 2008 its Regional GDP was €216.9 billion, the highest in Spain and the capita GDP was €30,700 –similar to United Kingdom or Austria for example. Its distribution of economic sectors is: 2,8% primary sector, 37,2% secondary sector (compared to Spain's 29%) and finally 60% tertiary sector (compared to Spain's 67%). Catalonia is organized territorially into 4 provinces: Barcelona, Girona, Lleida and Tarragona, further subdivided into 41 comarques and 947 municipalities. The capital and largest city is Barcelona. Today, Catalonia covers an area of 32.114 km^2 having a population of 7.535.251 in 2011 and 2.615.491 jobs in 2001 (last Spanish census). However, in 1900 the population of Catalonia was 1.984.115 people and in 1970 it was 5.107.606. That increase was produced due to the demographic boom in Spain during the 60s and early 70s and also because of the large-scale internal migration produced from the rural interior of Spain to its industrial cities. In Catalonia that wave of internal migration arrived from several regions of Spain especially from Andalusia, Murcia and Extremadura. These migration flows settled mainly in the Barcelona Metropolitan Region and in its surrounding cities, entailing a process of urban concentration towards these cities: Barcelona, Terrassa, Sabadell, Mataró, Manresa, Igualada and Vic.

Figure 1**. The Catalan Regional Territory**

Source: Own Elaboration

The Barcelona Metropolitan Region (BMR) –Figure 2- was delimited in 1966 by the Esquema Director de l'Àrea Metropolitana. Made up of 164 municipalities, the region covers an area of 323,000 ha in a radius of 55km. Nowadays, the Barcelona Metropolitan Region (BMR) is the second most dense urban area, the fourth most populated and the eight most extensive in Europe. It generates 12% of Spain GDP and more than 20% of Spanish exports. With over 65 per cent of the Catalan population in 2001 (4.390.413 inhabitants) and employment (1.822.000 jobs), the BMR is the main urban agglomeration in Catalonia. The city of Barcelona (marked in dark in Figure 1) is the main centre of the region and the continuous built-up area surpasses its administrative limits, taking in 12 adjacent municipalities[6]. Five outlying municipalities (Mataró, Terrassa, Sabadell, Vilafranca del Penedès and Vilanova i la Geltrú) are medium sized towns which in the past accounted for a significant proportion of the services consumed by nearby towns. Today, they still have a high level of self-containment and a net balance of entries in journeys due to work or study. Since 1980s, population and employment decentralisation towards other cities have entailed that many firms have moved towards the outskirts in search of proximity to access to main roads, entailing that other cities have emerged as an important nodes within the BMR. These are the cases of Granollers, Martorell, Rubí, Sant Cugat del Vallès and Cerdanyola del Vallès.

Figure 2**. The Barcelona Metropolitan Region**



Source: Masip (2012b, 2012c)

In this study, the data of employment come from the forced mobility (residence-to-work) query for the years 1991, 1996 and 2001 at Catalonia scale. The data of population come from the Spanish population census for 1981, 1991 and 2001 and from the municipality register for 1986, 1996, 2006 and 2010, which are produced by the Instituto Nacional de Estadística (INE). The calculation of distances (km) by road between municipalities respect to the CBD-Barcelona and the identified subcentres is carried out using GIS software.

[6] Badalona, Cornellà, Esplugues del Llobregat, L'Hospitalet, Montgat, El Prat de Llobregat, Sant Adrià del Besòs, Sant Boi de Llobregat, Sant Feliu de Llobregat, Sant Joan Despí, Sant Just Desvern and Santa Coloma.

4. A METHODOLOGY TO IDENTIFY AND CHARACTERIZE SUBCENTRES[7]

As we could see in the previous section, there is a vast literature on the identification of subcentres. Each different methodology to identify them entails a different concept about what a subcentre is. In the case of North America as it is explained in the introduction, the majority of works aimed at the identification of employment subcentres adopt morphological and density-based methodologies, which are based on the bid-rent theoretical tradition. These empirical approaches are particularly suitable with the idea that a subcentre emerge as a consequence of processes of employment decentralisation from the Central Business District (CBD) to the hinterland, due to high congestion and land prices.

For example, McMillen (2001a, pg.17) defines employment subcenters "*as nodes that combine many of the advantages of CBD and suburban locations. Highways and public transportation can serve subcenters much as they serve the CBD, bringing in an ample supply of workers from distant locations" and "the diversity of business types may be lower than is the city, but large subcenters sometimes appear to mimic the diversity of CBDs while offering lower land and commuting costs. Large subcentres offer employment and shopping opportunities for which nearby residents are willing to pay a premium. As predicted by the monocentric city model for locations near the CBD, the rise in land values near subcenters leads to configurations with smaller lot sizes and higher population density that look like small cities*" or McMillen & Smith (2003, pg. 322) taking into account the definition of McMillen (2001b, pg. 448) claim "*researchers have been used two criteria to guide subcentre definition, (i) mimicking the traditional definition of an urban area, a subcentre is defined as an area with significantly higher employment densities than surrounding areas and (ii) second, a subcentre should be large enough to have significant effect on the overall spatial structure of the urban area, leading to local rises in population density, land prices and perhaps housing prices*" and finally McMillen (2004, pg.225) "*an employment subcentre is a concentration of firms large enough to have significant effects on the overall spatial distribution of population employment and land prices" and "large subcentres can look remarkably similar to a traditional central business district, with thousands of workers employed in a wide variety of industries*".

In comparison with the North American subcentre conception, that stands for an employment centre, in Europe, the concept of subcentre, is closely link to the concept of urban subcentre: a node that could organize their surrounding territory though a supply of a wider set of urban function or in words of Roca et al. (2009, pg. 2860): "*the subcentres should constitute real poles of influence and territorial reference that surround them in cultural, social and economic aspects. In order to be truly considered as centres, they should generate authentic cities within their surroundings and, therefore configure a metropolis as a city of cities"*. Thus, as it has mentioned in the previous sections, the subcentre definition in Europe is more closely connected with the Central Place theoretical tradition. In fact, European Metropolitan Areas emerge mostly as the result of an integration or coalescence process between old and existing cities, and their urban systems have increasingly become more hierarchical and complex in terms of urban functions, Champion (2001).

In addition, apart from this divergence between the subcentre definitions according to the different methodologies to identify them, another "uncertainty point in the literature" comes out when the researchers try to characterize them into different economic activities or distinguish which subcentres are come from an integration or a decentralisation urban

[7] This section is part of other works carried out by the same author of this paper in order to propose a methodology to identify and characterize simultaneously the urban subcentres (Masip 2012b, Masip 2012c).

process: there is no any methodology in the specialized literature that could identify and characterize the subcentres simultaneously. In that sense, some studies have used the cluster analysis in order to characterize the identified subcentres. For instance Giuliano & Small (1991, pg. 177) have characterized the 32 identified subcentres by using a cut-off approach into five clusters: (i) specialized manufacturing, (ii) mixed industrial, (iii) mixed service, (iv) specialized entertainment, and finally (v) specialized service[8], McMillen & McDonald (1998b, pg.158), classify the 20 identified subcentres for the Metropolitan Area of Chicago into six groups: (i) old satellite cities -3-, (ii) old industrial suburbs -3-, (iii) post World War II industrial suburbs -6-, (iv) newer industrial / retail suburbs -2-, (v) edge cities -3- and finally (vi) service and retail centers -3- or McMillen (2003b, pg. 3) that has categorized subcentres by looking for groups with similar employment compositions, and finding the next sectors: manufacturing, retail, services, transportation, communication and utilities (TCU), finance, insurance, and real estate (FIRE) and government. Other studies have used urban indicators as the location quotients of the identified subcentres in order to characterize them, for example Bogart & Ferry (1999, pg. 2105) characterize the subcentres into three groups: downtown, service provision and manufacturing centres or Coffey & Shearmur (2002, pg. 364) that have classified the subcentres according to their employment-pole structure into primary poles, secondary poles, isolated poles at the time that they also classify them into total employment, FIRE sector and its four individual components and the business service sector and its eight individual components.

In the context of Europe and the Barcelona Metropolitan Region, this question has been analyzed by Muñiz et al. (2005), Muñiz et al. (2008), García-López & Muñiz (2010a) and García-Lopez (2010b). The first attempt has been carried out by Muñiz et al. (2005, pg. 12) in which by using three urban indicators: the coefficient of diversification, the coefficient of location and their population in 1900, they classified the 22 identified subcentres into high level integrated subcentres, decentralized subcentres and low level integrated subcentres[9]. This classification has turned firstly into integrated subcentres and decentralized subcentres in Muñiz et al. (2008) and then into Christallerian subcentres and decentralized subcentres[10] as García-López & Muñiz (2010a, pg.3048) and García-López (2010b, pg.125) have proposed. According to these studies, a Christallerian subcentre consist of medium sized cities which in the past were to some extent functionally autonomous from CBD (Barcelona) and they cannot be classified as dormitory or satellite cities because they have a high job ratio and have a

[8] Giuliano & Small (1991, pg. 179), define (i) the specialized manufacturing subcentres -7- as centres have the smallest shares of retail and service-related employment. They include several areas located near airports and specializing in aerospace manufacturing, and several older, diversified manufacturing centers and these centers tend to be smaller ones all but one being in the bottom half of the size distribution, (ii) mixed industrial subcentres -9- are centres that contain a broad mix of industries with somewhat more production-oriented industries and less service-oriented industries than the average center, but these centers tend to be larger than the average, (iii) the mixed service subcentres -11- are centers that contains what we might term 'traditional downtowns': centers with a broad mix of employment, somewhat weighted toward services. These cities functioned as independent centres and they are dispersed through the region, indicating that they play a role at all scales and locations, (iv) the specialized entertainment subcentres -2- consist of the two major entertainment centers and finally (v) the specialized services subcentres -3- are centres that consist of service industries account for over 90 per cent of their employment.

[9] In the group of high level integrated subcentres, Muñiz et al. (2005) find the subcentres of Vilanova i la Geltrú, Vilafranca del Penedès, Martorell, Sabadell, Terrassa, Granollers and Mataró. These subcentres have high values of the three used indicators. The decentralized subcentres (low values of population in 1900) are: Rubí, Sant Cugat del Vallès, Cerdanyola del Vallès, Montcada, Barberà del Vallès and Santa Perpètua de Mogoda. Finally, the low level integrated subcentres are: Premià de Mar, Arenys de Mar, Calella, Malgrat de Mar, Castelldefels, Sant Sadurní d'Anoia, Sant Pere Riudabitlles, Pineda de Mar and Sant Celoni.

[10] The integrated subcentres according to Muñiz et al. (2008) are: Mataró, Terrassa, Sabadell and Vilanova i la Geltrú meanwhile the decentralized subcentres are: Cerdanyola, Rubí, Martorell, Sant Cugat i Granollers

considerable population (100.000 or more). Thus, these cities are the result of a long period of maturation and are characterized by an urban area largely made up of a historic city core and an urban expansion area as well as showing a diversified production structure, although they still display evidence of a specialization in some economic activities. According to García-López (2010b, pg.126), the second group consists of employment subcentres have arisen from decentralisation rather than integration, due to the process of population suburbanization and employment decentralization what it has entailed that they are also specialized in certain services, owing to their role as service providers to the residents and to business in the municipality and nearby small towns.

Within this context, the methodology proposed by Masip (2012b, 2012c) try to integrate –merge- simultaneously the procedures of subcentres identification and characterization as well as that it takes into account the different origin of the subcentres formation. Thus, it means that the Masip’s procedure to identify and characterize subcentres is suitable with the hierarchic and complex European urban systems where centres have been emerged mostly as a result of an integration or coalescence process between old and pre-existing cities, Champion (2001) as well as suitable with the decentralisation process from a single and congested Central Business District (CBD).

Consequently, the methodology identifies subcentres that are “places to work” (employment subcentres) and subcentres that are “places to work and live” (urban subcentres). That means distinguish those sub-centres that only attract workers (in-commuting flows) or retain their resident workers (significant local labour market) to those sub-centres that are able to attract flows and retain their resident employed population at the same time.

To do so, the procedure of subcentre identification proposed by Masip (2012b, 2012c) is developed following three steps[11]. Firstly, by analyzing the commuting flows of the matrix residence-to-work, the RW (resident workers) Entropy Information and the IF (in-commuting flows) Entropy Information has been calculated for all municipalities. These indicators approximates which municipalities are the most hierarchical and complex in terms of local labor market (RW-resident workers) and in terms of attracting a great number of commuters (IF-incommuting flows), so the municipalities that best fit to the paradigm of European urban systems explained before. To estimate the RW & IF Entropy Information for each municipality –Figure 3-, it is necessary used the following two expressions[12]:

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

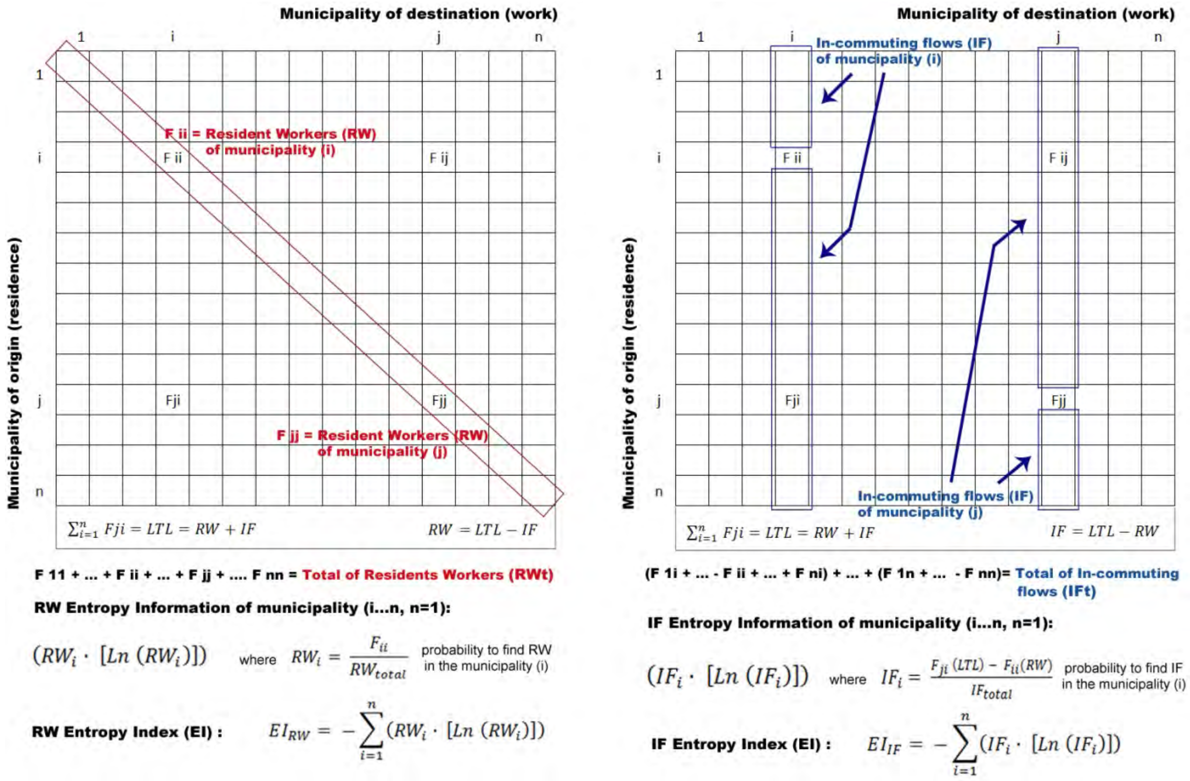
$$EI_{IF} = -\sum_{i=1}^{n}(IF_i \cdot [Ln\,(IF_i)]) \quad (2)$$

[11] The methodology explained in this work, has its origin with the studies of Masip (2011b, 2011c) in which have tried to characterize subcentres after they have been identified into “emerging” and “large-consolidated” by using the RW & IF Entropy Information of each subcentre.

[12] The expressions (1) and (2) are formulated as Shannon Entropy Index by using RW (resident workers) and IF (in-commuting flow) respectively. However, Limtanakool, (2007, 2009) have used 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 (1) and (2) 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, is used the Shannon Entropy Index instead of the Evenness Entropy because there is only one study case (Barcelona Metropolitan Region) and the number of municipalities are constant over the time period of analysis (from 1991 to 2001).

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

Figure 3**. Employment (LTL) Entropy Information: RW + IF Entropy Information**



Source: Masip (2012b, 2012c)

As a consequence, the higher is the RW (resident workers) Entropy Information for a given municipality, the higher is its functional urban hierarchy and complexity in terms of local labour market. Thus, the higher is the capacity of this given municipality to retain its occupied workers and being functionally autonomous from other urban nodes. For the same reason, the higher is the IF (in-commuting flows) Entropy Information for a given municipality, the higher is its capacity to attract workers and being an important node of employment within all the metropolitan area. Thus, after the RW and IF Entropy Information have separately calculated, we can find two types of municipalities:

1. Municipalities that have a higher value of RW and IF Entropy Information. Thus, urban nodes that have a hierarchical local labor market, what it means that they could retain their occupied workers and being enough attractive in residential terms to have population. In addition, these nodes are highly diverse to attract workers from other urban nodes of the metropolitan area.
2. Municipalities that have a higher value of RW or IF Entropy Information. Thus, urban nodes that are functionally hierarchical in terms of their local labor market, or nodes are important "places to work" due to their capacity to attract workers.

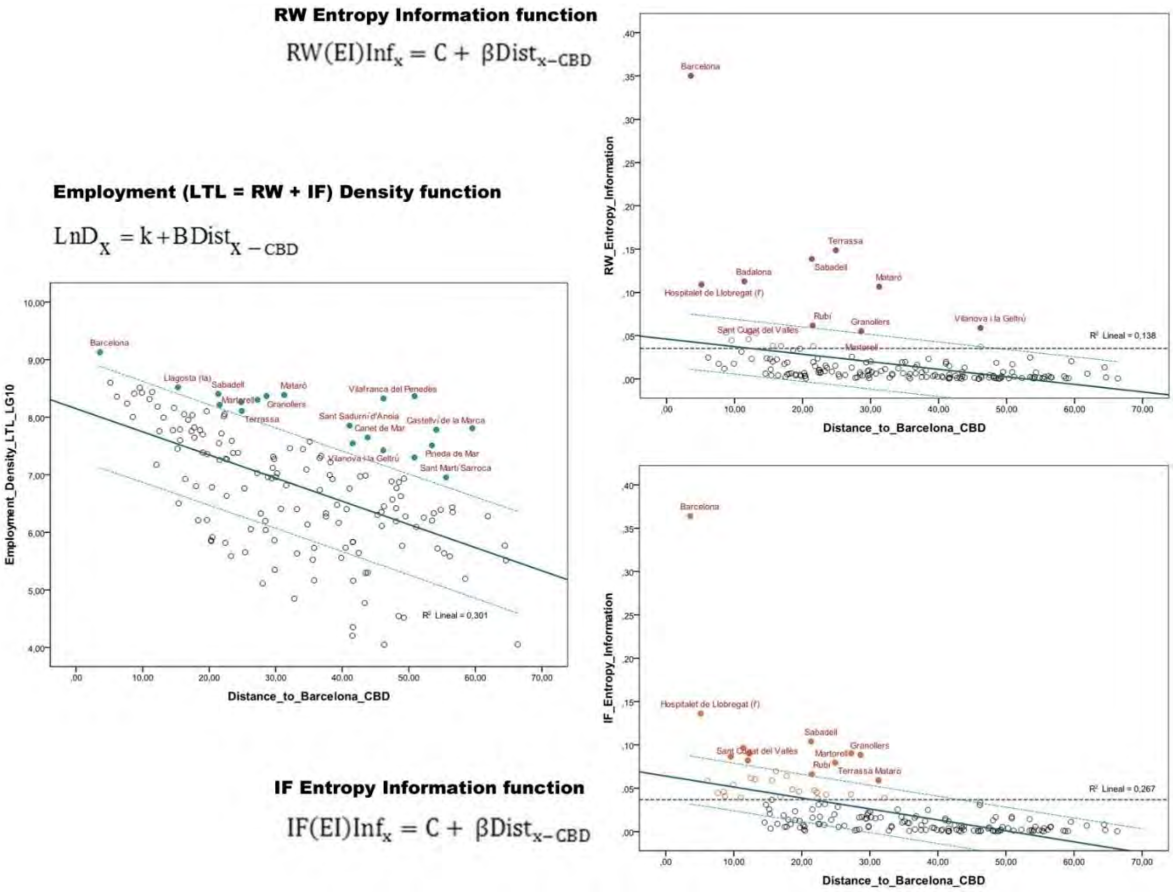
The second step of the identification and characterization procedure is based on identify the positive residuals estimated from an exponential RW Entropy Information function and from an exponential IF Entropy Information function. To do so, is used the exponential function form that McDonald & Prather (1994) has proposed as the best functional form[13]. Thus, these double exponential Employment Entropy Information functions can be formulated as follows:

$$RW(EI)Inf_x = C + \beta Dist_{x-CBD} \qquad (3)$$

$$IF(EI)Inf_x = C + \beta Dist_{x-CBD} \qquad (4)$$

Where $RW(EI)Inf_x$ and $IF(EI)Inf_x$ are the RW and IF Entropy Informations at municipality (x), C is the constant which is argued to be the RW and IF Entropy Informations at CBD and $Dist_{x\text{-}CBD}$ is the distance between CBD and the municipality (x).

Figure 4. **Employment (LTL=RW+IF) Density function versus Double Employment Entropy functions (RW and IF Entropy Information functions)**



Source: Masip (2012b, 2012c)

[13] As it is explained in the previous section, McDonald & Prather (1994), identify possible employment subcentres by examining the residuals from a monocentric regression model of employment density. After tested seven different functional forms of employment density, they conclude that the simple negative exponential has emerged as the best functional form: $LnD_x = k + BD_{x-CBD}$ where D_x is the employment density at municipality (x), K is the constant which is argued to be the density at CBD, and $D_{x\text{-}CBD}$ is the distance between CBD and municipality (x).

In that sense, the Masip's (2012b, 2012c) procedure to identity subcentres has integrated the origin of North-American studies in order to identify subcentres. With computing the RW & IF Entropy Information of each municipality in function of the distance to the CBD, the procedure adopts a morphological methodology which is based on the bid-rent theoretical tradition but in this case instead of using employment density, is used a double employment entropy information (resident workers entropy and in-commuting flows entropy).

In the following Figure 4, for example, it is possible to compare the standard employment density function with the double employment (RW +IF) Entropy information functions for the Barcelona Metropolitan Region in 2001. As the graphics depicted, when it is computed the double Entropy functions it is possible to identify more clearly the nodes that are above of the standard deviation, so the nodes that are more hierarchical and complex in terms of resident workers and in-commuting flows (or in one of these) within the metropolitan area. Meanwhile when it is computed only the standard employment density function, this evidence is less clearly and it is possible to identify as a candidate to subcentre some small municipalities with low employment density but that it appears as a subcentre because their location is too far from the CBD, in our case, from Barcelona. In order to analyze these three models, the next Table 3 contains the results of applying the aforementioned expressions using the Barcelona Metropolitan Region data in 2001[14].

Table 3**. Models with standard Employment Density and RW & IF Entropy Information for the Barcelona Metropolitan Region in 2001**

	Ln Employment Density (2001)	RW (resident workers) Entropy Information (2001)	IF (in-commuting flows) Entropy Information (2001)
Adjusted R2	0,301	0,138	0,267
F	67,103	25,991	58,976
F (sig)	0	0	0
Constant	8,149***	0,046***	0,064***
Constant (t-value)	45,949	7,295	10,535
Constant (sig)	0	0	0
Dist. Bcn-CBD	-0,040***	-0,001***	-0,001***
Dist. Bcn-CBD (t-value)	-8,192	-5,098	-7,680
Dist. Bcn-CBD (sig)	0	0	0

***, **, * variables significant at 99 per cent, 95 per cent and 90 per cent respectively

Source: Masip (2012b, 2012c)

It can be observed that although the three models are significant and have the expect sign: e.g. the bigger is the distance to CBD, the lower is the density, the model which fits better is the standard employment density, since its R^2 and the Anova's F statistics have a higher value in comparison with the RW and IF Entropy Information models. However, that is not meaning that the employment density model is the better model in order to identify urban subcentres: is expected that the functional urban hierarchy and complexity have to be explained by using other explanatory variables than only the distance to the CBD. As we will see in the following sections, the urban subcentres by using this new procedure are more dominant in terms of in-

[14] In this work only is presented the results in 2001. The results of these three models for 1991 and 1996 are not presented because it leads us to the same conclusions.

commuting flows, more self-contained, and their influence on the urban structure are more significant (having a major influence on the overall metropolitan employment).

Finally, the third step of the methodology proposed by Masip (2012b) consists in selecting the positive residuals of the two previous explained Employment Entropy functions (3) and (4). The municipalities that have positive residuals in these two Employment Entropy functions are defined as subcentres and characterized simultaneously with the following conditions:

1. The municipalities that have both positive residuals in the RW and IF Entropy Information functions as defined as “large-consolidated” subcentres[15]. These urban nodes tend to be over-specialized in more than one economic activity, so they are diverse, having a signification population and they are able to retain their occupied workers, so they have an important local labour market as well as being attractive to grasp a higher mass of workers (in-commuting flows) from elsewhere in the metropolitan area. This kind of subcentres, from this point of view are suitable with the McMillen’s (2004, pg. 255) large subcentres definition: “*large subcentres can look remarkably similar to a traditional central business district, with thousands of workers employed in a wide variety of industries*” at the time that they are complex and hierarchical in terms of local market. These subcentres it also satisfy the definition of what a urban subcentre is according to Roca’s et al. (2009, pg 2860) definition: “*the subcentres should constitute real poles of influence and territorial reference that surround them in cultural, social and economic aspects. In order to be truly considered as centres, they should generate authentic cities within their surroundings and, therefore configure a metropolis as a city of cities”*.
2. The municipalities that have positive residuals in RW or IF Entropy Information functions as defined as “emerging” subcentres. These nodes are able to structure and being an important economic node of attraction within the metropolitan area, but they also tend to be mono-specialized and having a small or medium size population due to their origin is the employment and population decentralization from the CBD. Thus, this kind of subcentre fits to the decentralized subcentres definition that García-López & Muñiz (2010a, pg.3048) and García-López (2010b, pg.125) have proposed in their studies.

Summarizing, the methodology proposed by Masip (2012b, 2012c), in order to identify and characterize simultaneously the urban subcentres is an objective procedure in which there is no local knowledge in the identification criterions in comparison with other methodologies explained before at the time that it tries to be replicable to other metropolitan areas.

4.1. Results: Testing its efficacy with other standard density methods

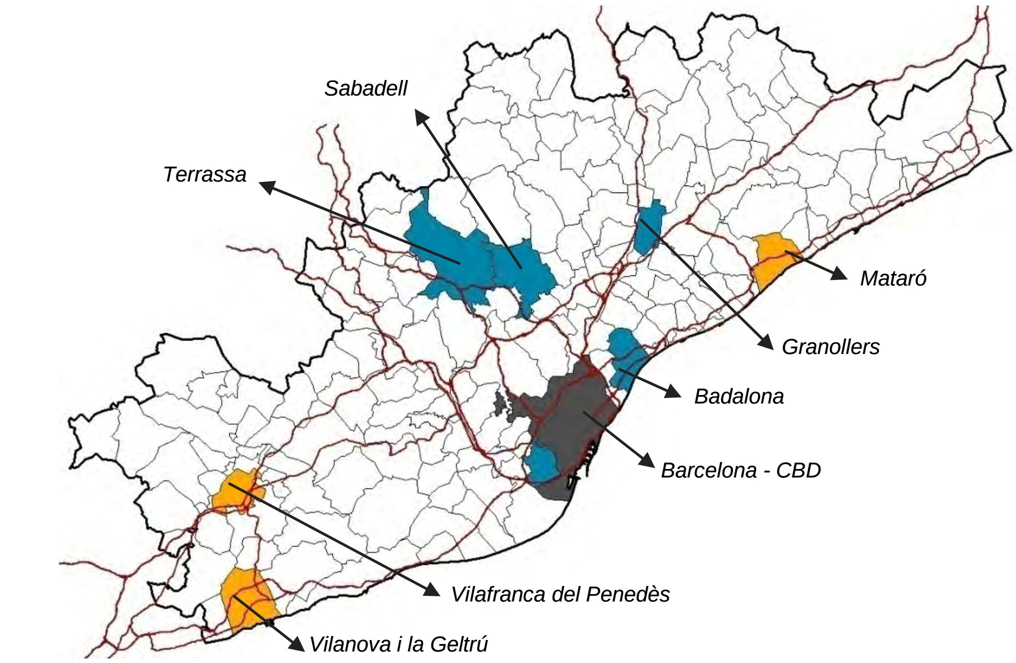
In this section the results of the above-mentioned procedure are reported and compared with those emerging using the traditional density-based method of Giuliano & Small (1991) but using the thresholds proposed by García-López & Muñiz (2005, 2007, 2010a)[16] and the density method of McDonald & Prather (1994). To do so, this work takes as study case the Barcelona Metropolitan Region (administrative limit) from 1991 to 2001.

[15] The subcentres defined as “large-consolidated” are fit to the definition of Christallerian subcentres that Muñiz et al. (2008) have proposed.

[16] Is used the employment thresholds proposed by García-López & Muñiz (2005, 2007, 2010a) instead of the Giuliano & Small’s thresholds because the García-López & Muñiz studies are focused on the Barcelona Metropolitan Region (the same study case of this work).

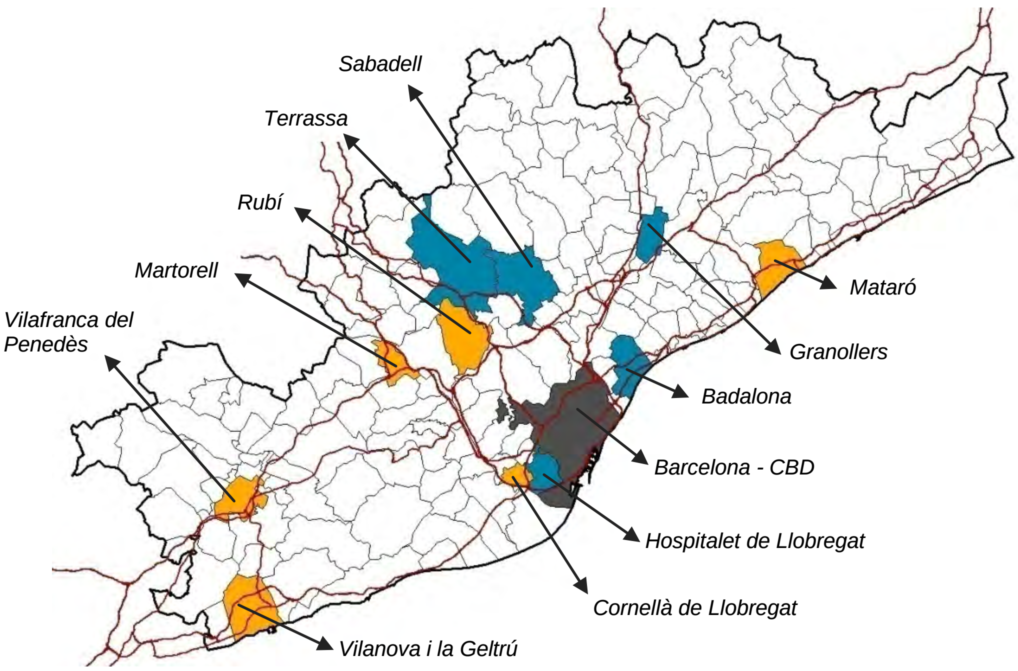
As regards of the methodology proposed by Masip (2012b, 2012c), the following Figures 5-7 and Table 4, represent the identified "large-consolidated" and "emerging" subcentres from 1991 to 2001 in the Barcelona Metropolitan Region.

Figure 5**. Municipalities identified as possible subcentres in 1991 for the Barcelona Metropolitan Region**



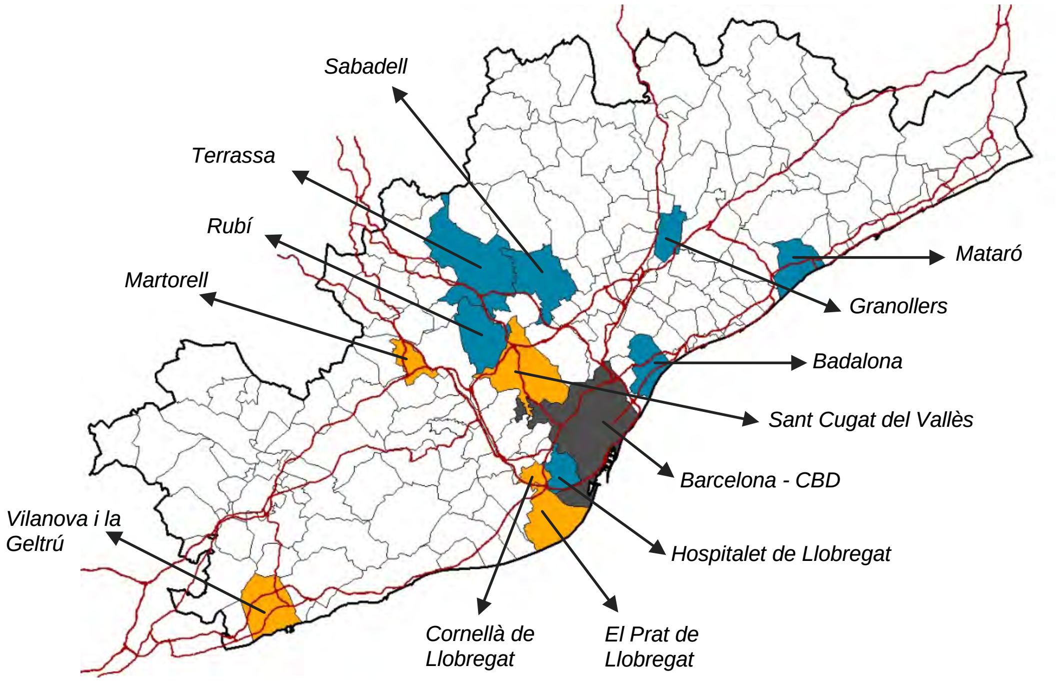
Source: Masip (2012b, 2012c)

Figure 6**. Municipalities identified as possible subcentres in 1996 for the Barcelona Metropolitan Region**



Source: Masip (2012b, 2012c)

Figure 7. **Municipalities identified as possible subcentres in 2001 for the Barcelona Metropolitan Region**



Source: Masip (2012b, 2012c)

Table 4. **Municipalities identified as possible subcentres from 1991 to 2001 in the Barcelona Metropolitan Region**

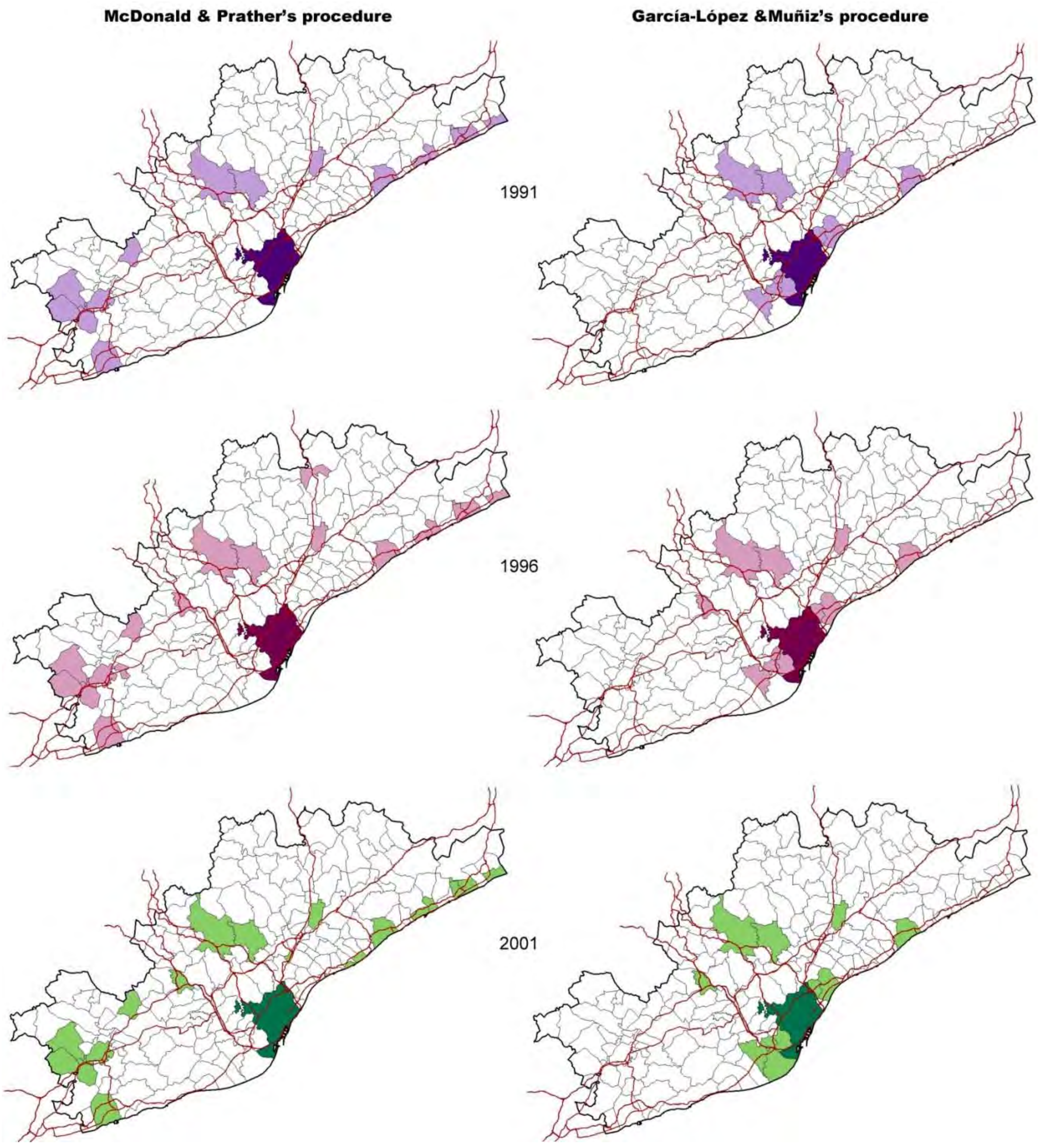
Municipality (name)	1991	1996	2001	% Increment LTL (2001-1991) in comparison with their LTLs in 1991	Distance to CBD (Barcelona)
Barcelona	CBD	CBD	CBD	-0,36%	-
Sabadell	Large-Consolidated	Large-Consolidated	Large-Consolidated	10,19%	21,36
Terrassa	Large-Consolidated	Large-Consolidated	Large-Consolidated	26,05%	24,90
Mataró	Emerging	Emerging	Large-Consolidated	16,15%	31,26
Badalona	Large-Consolidated	Large-Consolidated	Large-Consolidated	10,57%	11,43
Hospitalet de Llobregat (L')	Large-Consolidated	Large-Consolidated	Large-Consolidated	4,08%	5,14
Vilanova i la Geltrú	Emerging	Emerging	Emerging	29,40%	46,17
Granollers	Large-Consolidated	Large-Consolidated	Large-Consolidated	25,69%	28,62
Vilafranca del Penedès	Emerging	Emerging		23,88%	46,21
Rubí		Emerging	Large-Consolidated	43,82%	21,47
Martorell		Emerging	Emerging	139,67%	27,26
Cornellà de Llobregat		Emerging	Emerging	25,35%	9,56
Prat de Llobregat (El)			Emerging	38,11%	12,25
Sant Cugat del Vallès			Emerging	86,04%	12,07
	8 urban sub-centres	11 urban sub-centres	12 urban sub-centres	Average (14,95%)	Average (33,73)

Source: Masip (2012b, 2012c)

The last Figures 5-7 and Table 4 highlight that from 1991 to 2001 in the Barcelona Metropolitan Region, there has been a process of emergence of subcentres linked to the infrastructure nodes (Martorell, Rubí) as well as in the north of the CBD-Barcelona (Sant

Cugat del Vallès and Rubí). This process of emergence has been more significant from 1991 to 1996 than 1996 to 2001 (during the period of 1991 to 1996 there was an increment of three identified subcentres, meanwhile from 1996 to 2001 this increment it was only one subcentre) at the time that the subcentres identified as "emerging" are the subcentres that most increased their LTL (localised workplaces: resident workers and incommuting workers) in comparison with their LTL in 1991. These are the cases of Martorell (139,67%), Sant Cugat del Vallès (86,04%), El Prat de Llobregat (38,11%). Otherwise, the "large-consolidated" subcentres have had a more constant LTL increment: for example Sabadell 10,19%, Terrassa 26,05%, Badalona 10,57%, L'Hospitalet de Llobregat 4,08%.

Figure 8**. Municipalities identified as possible subcentres from 1991 to 2001 in the Barcelona Metropolitan Region by using McDonald & Prather (1994) and García-Lopez & Muñiz (2005, 2007, 2010a) approaches**



Source: Masip (2012b, 2012c)

Figure 8 shows the identified subcentres by using two traditional density-based methods: identifying positive residuals as McDonald & Prather (1994) and using thresholds in the way that García-López & Muñiz (2005, 2007, 2010a) has been proposed[17]. Comparing the results of these two methodologies with the Masip (2012b, 2012c) procedure, it lead us to conclude that the Masip's methodology have both advantages of these procedures: (i) identifying subcentres with a significant mass critic in terms of employment (advantage of using a correct thresholds) and identifying subcentres in function of their distance from the CBD (advantage of McDonalds & Prather's procedure and one of the drawbacks of cut-off approaches).

However, in order to compare in more detail the identified subcentres according to these three approaches and testing the "validity" of the Masip's methodology it has been calculated the following urban indicators using data from the Barcelona Metropolitan Region at municipal level in 2001. The indicators are:

1. Dominance Index (DI)[18]: it determines the capacity of a subcentre to attract workers from the whole of the metropolitan area and being a dominant employment node.
2. Diversity Index[19]: is expected that subcentres with centrality functions are diversified
3. Location coefficient (LC)[20]: is calculated the (LC) of FIRE (finance, insurance and real estate) activities, the LC of retail activities and the LC of qualified manufacturing. It is expected to find that subcentres specialized in these economic activities.

Table 5. **Subcentres by using Masip's (2012b) procedure in 2001: urban indicators**

Municipality (name)	LTL (localised workplaces)	Population	Dominance Index (DI)	Diversity Index	Location coefficient (LC) FIRE	Location coefficient (LC) Retail	Location coefficient (LC) Manufacturing
Barcelona (CBD)	743.594	1.505.325	51,78	2,414	1,415	0,958	0,573
Sabadell	68.401	185.170	4,83	2,275	1,084	1,093	1,014
Terrassa	66.510	174.756	3,35	2,206	0,802	1,117	1,108
Mataró	41.997	107.191	2,26	2,195	0,748	1,114	1,223
Badalona	54.381	208.994	4,36	2,243	0,712	1,274	0,973
Hospitalet de Llobregat (L')	65.642	242.480	7,11	2,288	0,793	1,209	0,879
Vilanova i la Geltrú	18.730	53.421	0,98	2,284	0,675	1,263	0,929
Granollers	31.047	53.681	3,87	2,165	0,800	1,090	1,260
Rubí	27.282	60.303	2,62	1,768	0,530	0,823	2,014
Martorell	23.555	22.537	3,98	1,562	0,524	0,576	2,355
Cornellà de Llobregat	27.385	81.145	3,76	2,172	0,910	1,442	1,040
Prat de Llobregat (El)	31.362	63.139	3,97	2,113	0,770	0,978	1,095
Sant Cugat del Vallès	26.593	55.825	3,50	2,350	1,370	0,868	0,847

Source: Masip (2012b, 2012c)

[17] To know the criterions of these two methodologies to identify subcentres, see Table 1 and Table 2.

[18] The DI is calculated as follows: $DI_{u-sub} = \frac{IF_{(i)}}{\frac{IF_{ma}}{n}}$ where $IF_{(i)}$ are the in-commuting flows of a given municipality, IF_{ma} are the total in-commuting flows of a given metropolitan area, (n) are the total number of municipalities and $\frac{IF_{ma}}{n}$ is the average attractiveness in terms of in-commuting flows. Thus if a municipality its DI > 1, it can be considered as a dominant node within this given metropolitan area.

[19] It has been used the Shannon Index: $H = -\sum_{i=1}^{n} Ln(P_i x) * P_i(x)$, where $P_i(x)$ is the probability to find a (x) element (e.g.: employment in a given retail firm) in municipality (i). The sum is multiplied by (-1) in order to get a positive indicator. Thus, the bigger is H, the higher the diversity.

[20] The LC is calculated as follows: $LC = \frac{\frac{LTLx\ i}{LTLi}}{\frac{\sum_i^n LTLxi}{\sum_{ix}^n LTLxi}}$ where LTL are the localized workplaces, (x) is a given industry of economical activity and (i) is a given municipality of the metropolitan area.

Comparing the Tables 5 and 6, the results show that the 12 subcentres identified by using Masip (2012b, 2012c) methodology are: (i) more dominant in terms of in-commuting flows (most subcentres identified by using McDonald & Prather's method their Dominance Index are < 1, for example: Castellví de la Marca, Sant Martí Sarroca or Canet de Mar), (ii) more specialized in FIRE and retail economic activities (e.g. Sant Cugat del Vallès and Badalona, L'Hospitalet de Llobregat and Cornellà del Llobregat respectively) and finally (iii) more significant in terms of employment and population mass critic (e.g. Castellví de la Marca and Sant Martí de Sarroca have less than 750 localised workplaces and 5000 population).

Table 6**. Subcentres by using McDonald & Prather's method in 2001: urban indicators**

Municipality (name)	LTL (localised workplaces)	Population	Dominance Index (DI)	Diversity Index	Location coefficient (LC) FIRE	Location coefficient (LC) Retail	Location coefficient (LC) Manufacturing
Barcelona (CBD)	743.594	1.505.325	51,78	2,414	1,415	0,958	0,573
Arenys de Mar	4.031	12.819	0,31	2,451	0,596	1,001	0,701
Calella	5.213	13.814	0,48	2,341	0,644	1,189	0,364
Canet de Mar	2.812	10.585	0,14	2,212	0,628	0,946	1,222
Castellví de la Marca	470	1.434	0,04	1,923	0,270	0,496	1,532
Granollers	31.047	53.681	3,87	2,165	0,800	1,090	1,260
Llagosta (La)	4.576	12.124	0,60	1,835	0,473	0,800	1,916
Malgrat de Mar	5.083	14.246	0,29	2,224	0,490	1,122	0,955
Martorell	23.555	22.537	3,98	1,562	0,524	0,576	2,355
Mataró	41.997	107.191	2,26	2,195	0,748	1,114	1,223
Pineda de Mar	6.547	20.871	0,39	2,235	0,665	0,963	1,078
Premià de Mar	5.596	26.555	0,45	2,361	0,785	1,229	0,794
Sabadell	68.401	185.170	4,83	2,275	1,084	1,093	1,014
Vilassar de Mar	5.304	17.374	0,58	2,373	0,762	1,199	0,779
Sant Martí Sarroca	720	2.512	0,08	2,245	0,401	0,913	0,947
Sant Sadurní d'Anoia	4.762	9.805	0,35	1,909	0,382	0,974	1,772
Santa Margarida i els Monjos	3.165	4.834	0,42	1,489	0,304	0,654	2,444
Terrassa	66.510	174.756	3,35	2,206	0,802	1,117	1,108
Vilafranca del Penedès	13.000	30.807	1,10	2,295	0,989	1,317	0,841
Vilanova i la Geltrú	18.730	53.421	0,98	2,284	0,675	1,263	0,929

Source: Masip (2012b, 2012c)

However, when it is compared the results of Tables 5 and 7, the differences between the 12 subcentres identified by Masip's methodology and the identified subcentres by using the cut-off approach proposed as García-López & Muñiz are less significant: (i) in terms of employment and population mass critic the identify subcentres by using both approaches are similar, (ii) in terms of being a dominant nodes it may be that the identified subcentres by using the Masip's (2012b) procedure are quite more dominant, e.g. Sant Cugat del Vallès with a Dominance Index of 3,50 it has not been identified by using the cut-off approach and finally (iii) in terms of Diversity Index and the three analyzed Location coefficients both subcentres by using the two approaches obtain similar results but with the exception again of Sant Cugat del Vallès (subcentre with a higher value of specialization -1,370- in FIRE activities).

In conclusion, after being analyzed the identified subcentres by using the selected urban indicators, is clear that the Masip's (2012b, 2012c) methodology, could identify subcentres that are more dominant, with a higher mass critic in terms of population and employment, are diverse and specialized in central economic activities such as FIRE, retail and qualified manufacturing.

Table 7**. Subcentres by using García-López & Muñiz's method in 2001: urban indicators**

Municipality (name)	LTL (localised workplaces)	Population	Dominance Index (DI)	Diversity Index	Location coefficient (LC) FIRE	Location coefficient (LC) Retail	Location coefficient (LC) Manufacturing
Barcelona (CBD)	743.594	1.505.325	51,78	2,414	1,415	0,958	0,573
Badalona	54.381	208.994	4,36	2,243	0,712	1,274	0,973
Cornellà de Llobregat	27.385	81.145	3,76	2,172	0,910	1,442	1,040
Granollers	31.047	53.681	3,87	2,165	0,800	1,090	1,260
Hospitalet de Llobregat (L')	65.642	242.480	7,11	2,288	0,793	1,209	0,879
Martorell	23.555	22.537	3,98	1,562	0,524	0,576	2,355
Mataró	41.997	107.191	2,26	2,195	0,748	1,114	1,223
Prat de Llobregat (El)	31.362	63.139	3,97	2,113	0,770	0,978	1,095
Sabadell	68.401	185.170	4,83	2,275	1,084	1,093	1,014
Sant Boi de Llobregat	23.239	79.463	2,33	2,188	0,636	1,281	1,102
Santa Coloma de Gramanet	19.078	116.064	1,41	2,321	0,705	1,409	0,664
Terrassa	66.510	174.756	3,35	2,206	0,802	1,117	1,108

Source: Masip (2012b, 2012c)

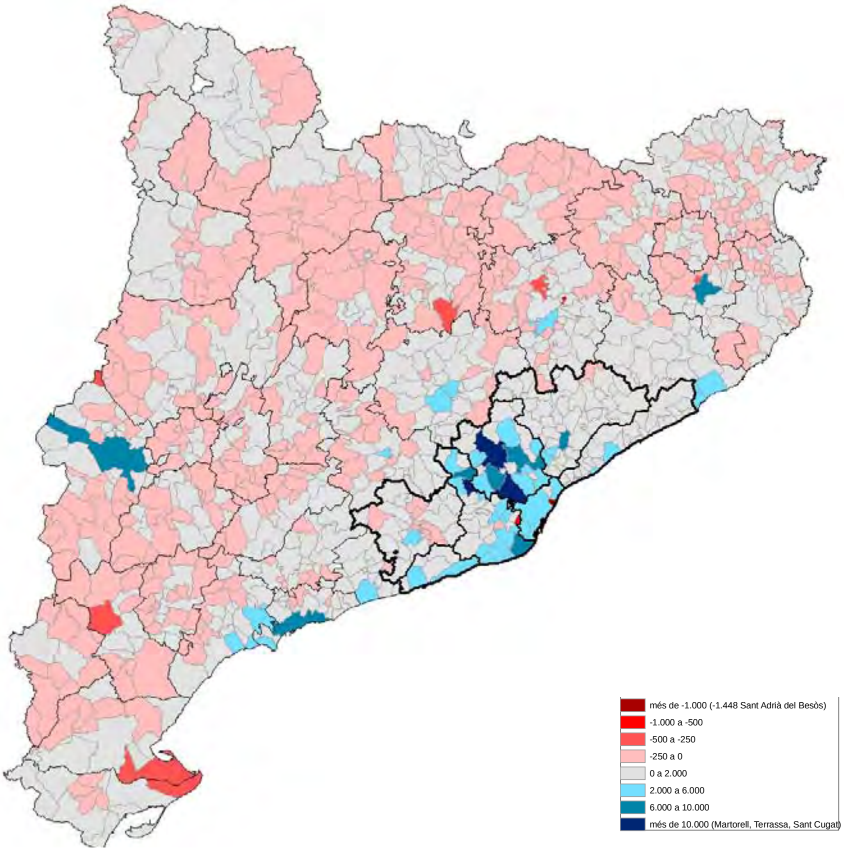
5. IDENTIFYING THE EMPLOYMENT AND POPULATION CENTERS WITHIN THE CATALAN TERRITORY

In this section, by using the methodology proposed by Masip (2012b, 2012c) to identify subcentres, the employment and population centres for the whole of the Catalan territory are identified. In the first case, the analysis takes a time period of ten years, from 1991 to 2001 and in the case of identifying the population centres; the empirical work takes a time period of thirty years from 1981 to 2010.

5.1. Employment centers from 1991 to 2001 at regional scale: Catalan territory

In the following, Figure 9 and Table 8, the employment growth rate from 1991 to 2001 is depicted at municipal level. As the Figure 9 depicts, from 1991 to 2001, there was an urban dynamic in terms of employment growth that has consist in: a) apart from the capital city of Barcelona, a clear employment growth of the rest of province capitals: Tarragona (9.415 LTL), Girona (7.844 LTL) and Lleida (7.188 LTL); b) a prominent employment growth in the municipalities located in the county of Vallès Occidental, for example the cases of Sant Cugat del Vallès (12.624 LTL), or Terrassa (14.225 LTL) and in less extent the cases of Rubí (8.479 LTL) or Sabadell (6.619 LTL); c) a significant growth of other important metropolitan cities such as Martorell (14.400 LTL) and Granollers (6.551 LTL); and finally d) a process of losing in terms of employment of the majority of the rural municipalities in comparison to the metropolitan and coast municipalities. The combination of the previous trends, suggest that from 1991 to 2001 in terms of employment the Barcelona Metropolitan Region has become a more structural pole within the Catalan territory at the time that the county of Vallès Occidental has emerged as a second capital of Catalonia. This observation is explained in more detail by Masip & Roca (2012d) in which by analyzing the demographic trends from 1981 to 2010 suggest a new paradigm for the Catalan territory: towards a Catalan and Metropolitan Bicapital?

Figure 9**. Employment growth from 1991 to 2001 in Catalonia at municipal level**



Source: Own Elaboration

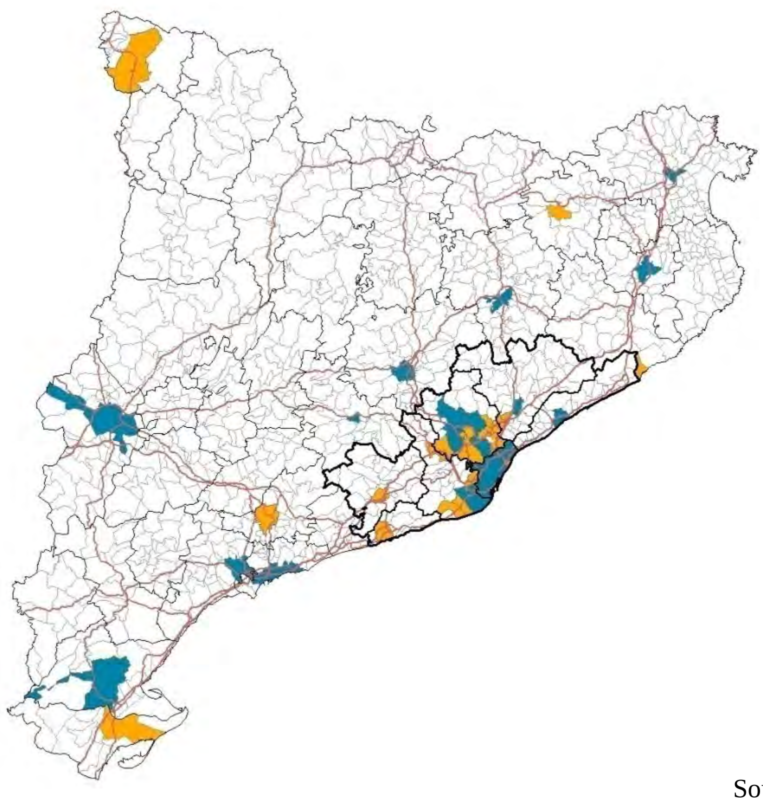
Table 8**. Employment growth from 1991 to 2001 in Catalonia at municipal level**

Municipality	County	RMB	LTL 1991	LTL 1996	LTL 2001	% Variació LTL 1996-1991	% Variació LTL 2001-1996	% Variació LTL 2001-1991	Increment LTL 2001-1991
Martorell	Baix Llobregat	Sí	10.285	18.821	24.685	82,99%	31,16%	140,01%	14.400
Terrassa	Valles Occidental	Sí	53.316	55.219	67.541	3,57%	22,31%	26,68%	14.225
Sant Cugat del Vallès	Valles Occidental	Sí	14.465	17.724	27.089	22,53%	52,84%	87,27%	12.624
Tarragona	Tarragones	No	42.927	42.664	52.342	-0,61%	22,68%	21,93%	9.415
Prat de Llobregat (El)	Baix Llobregat	Sí	22.884	24.436	31.775	6,78%	30,03%	38,85%	8.891
Rubí	Valles Occidental	Sí	19.101	20.703	27.580	8,39%	33,22%	44,39%	8.479
Girona	Girones	No	34.149	34.044	41.993	-0,31%	23,35%	22,97%	7.844
Lleida	Segria	No	44.090	44.416	51.278	0,74%	15,45%	16,30%	7.188
Sabadell	Valles Occidental	Sí	62.641	60.150	69.260	-3,98%	15,15%	10,57%	6.619
Granollers	Valles Oriental	Sí	25.115	24.606	31.666	-2,03%	28,69%	26,08%	6.551
Santa Perpètua de Mogoda	Valles Occidental	Sí	9.050	10.810	15.369	19,45%	42,17%	69,82%	6.319
Abrera	Baix Llobregat	Sí	2.308	3.929	8.421	70,23%	114,33%	264,86%	6.113
Mataró	Maresme	Sí	36.305	32.900	42.304	-9,38%	28,58%	16,52%	5.999
Cornellà de Llobregat	Baix Llobregat	Sí	22.014	23.772	27.751	7,99%	16,74%	26,06%	5.737
Vic	Osona	No	15.097	16.406	20.579	8,67%	25,44%	36,31%	5.482
Badalona	Barcelones	Sí	49.464	47.645	54.821	-3,68%	15,06%	10,83%	5.357
Reus	Baix Camp	No	28.060	27.829	32.975	-0,82%	18,49%	17,52%	4.915
Barcelona	Barcelones	Sí	761.165	659.949	765.898	-13,30%	16,05%	0,62%	4.733
Sant Boi de Llobregat	Baix Llobregat	Sí	18.817	18.674	23.521	-0,76%	25,96%	25,00%	4.704
Sant Andreu de la Barca	Baix Llobregat	Sí	7.540	7.814	12.180	3,63%	55,87%	61,54%	4.640
Barberà del Vallès	Valles Occidental	Sí	12.940	14.290	17.424	10,43%	21,93%	34,65%	4.484
Vilanova i la Geltrú	Garraf	Sí	14.877	15.256	19.271	2,55%	26,32%	29,54%	4.394
Castelldefels	Baix Llobregat	Sí	7.489	7.650	11.817	2,15%	54,47%	57,79%	4.328
Manresa	Bages	No	25.233	24.588	29.544	-2,56%	20,16%	17,08%	4.311
Viladecans	Baix Llobregat	Sí	10.396	11.184	14.608	7,58%	30,62%	40,52%	4.212
Gavà	Baix Llobregat	Sí	10.994	12.020	15.184	9,33%	26,32%	38,11%	4.190
Mollet del Vallès	Valles Oriental	Sí	11.499	12.590	15.229	9,49%	20,96%	32,44%	3.730
Montcada i Reixac	Valles Occidental	Sí	12.077	12.743	15.698	5,51%	23,19%	29,98%	3.621
Palau-solità i Plegamans	Valles Occidental	Sí	5.513	7.365	9.120	33,59%	23,83%	65,43%	3.607
Igualada	Anoia	No	15.910	16.049	19.352	0,87%	20,58%	21,63%	3.442

Source: Own Elaboration

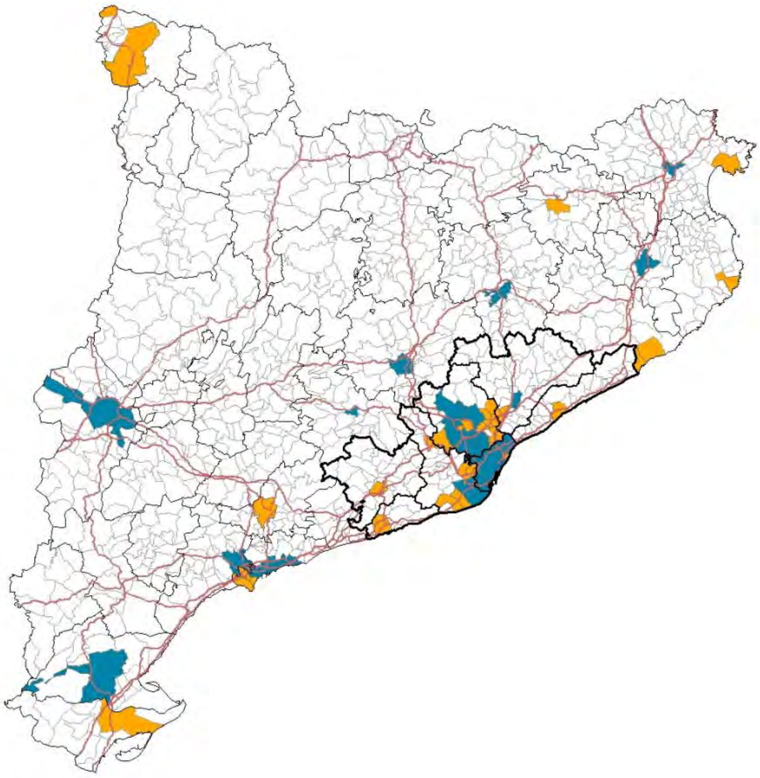
The following Figures 10-12 and Table 9 reports the employment centres identified by using the Masip's (2012b, 2012c) method presented in section 4 and characterized as "large-consolidated" and "emerging". As the Figures 10-12 and the Table 9 present, from 1991 to 2001 there was a process of subcentres emergence what it has entailed the following urban trends: a) a consolidation of the urban centres (large-consolidated centres, centres that are places to live and work) in the province capitals (Barcelona, Girona, Lleida and Tarragona), in the main metropolitan cities: Mataró, Granollers, Sabadell, Terrassa, and Vilafranca del Penedès and in the cities of the Vallès Occidental county: apart from Sabadell and Terrassa, there are the cases of Sant Cugat del Vallès, Cerdanyola del Vallès and Rubí, b) a process of subcentre emergence in the coast of Catalonia at the time that most centres identified as "emerging" in 1991 have turned into "large-consolidated" in 2001. These are the cases of Lloret de Mar, Salou, Roses, Cambrils, Castelldefels, Palafrugell, Vilaseca and Sant Cugat del Vallès and Viladecans respectively and finally c) there was a process of concentration of centres, "large-consolidated" or "emerging" in the north of Barcelona (capital of Catalonia), what it fits with the employment growth from 1991 to 2001 analyzed in the previously. Hence, the centres located in the county of Vallès Occidental and in the B-30 orbital highway: the large-consolidated centres of Sabadell, Terrassa, Sant Cugat del Vallès, Rubí and Cerdanyola del Vallès as well as the emerging centres of Barberà del Vallès, Santa Perpètua de Mogoda, Montacada i Reixac, Castellbisbal, Palau-solità i Plegamans and Polinyà could structure a network of cities that in near future could compete with the Barcelona macrocephalia. In that sense, in terms of employment, the Catalan territory could be understood as a PUR (polycentric urban region) based in a) the capital of Barcelona, b) the other province capitals (Girona, Lleida and Tarragona), c) the main cities of Vallès Occidental mentioned previously and finally d) other county capitals: Manresa, Igualada and Vic.

Figure 10**. Municipalities identified as Employment Centres in 1991 for the Catalan territory by using Masip's (2012b, 2012c) methodology**



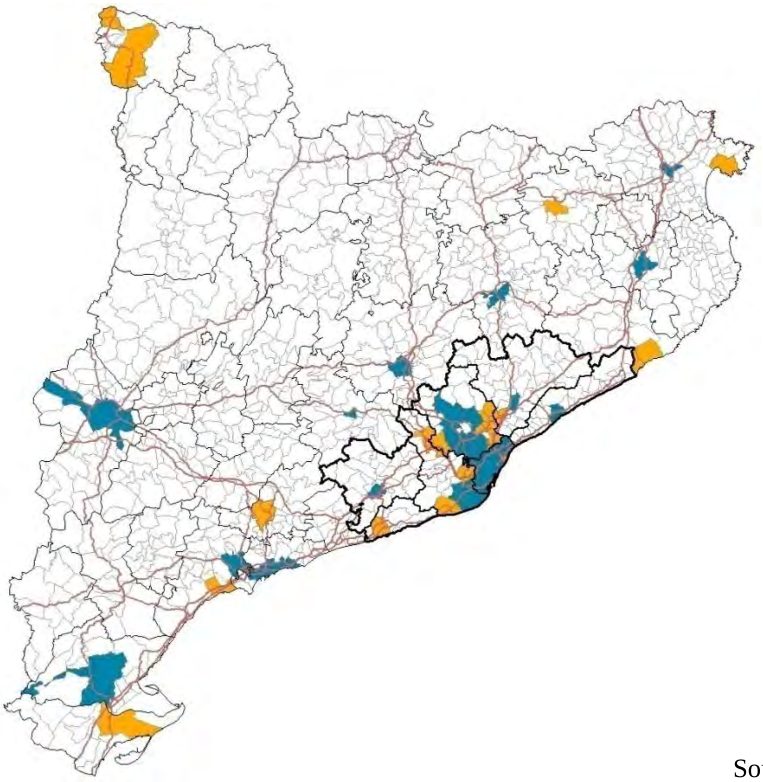
Source: Own Elaboration

Figure 11. **Municipalities identified as Employment Centres in 1996 for the Catalan territory by using Masip's (2012b, 2012c) methodology**



Source: Own Elaboration

Figure 12. **Municipalities identified as Employment Centres in 2001 for the Catalan territory by using Masip's (2012b, 2012c) methodology**



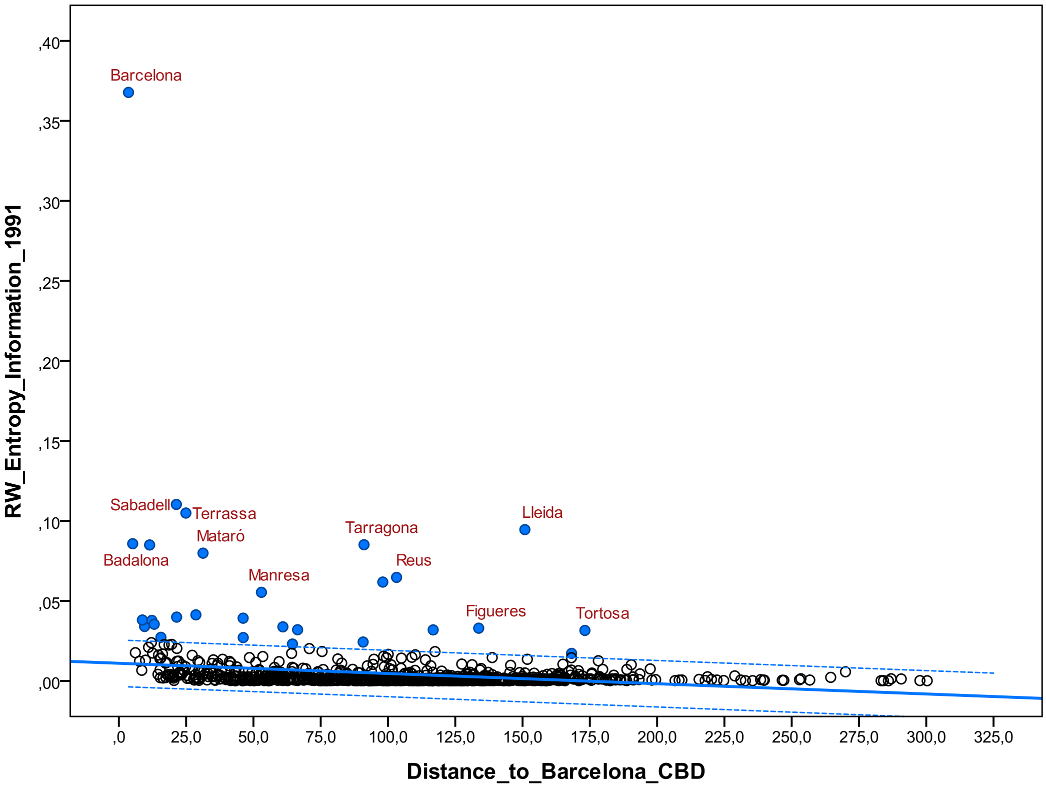
Source: Own Elaboration

Table 9. **Employment Centres in the Catalan territory from 1991 to 2001**

Subcentres 1991	Subcentres 1996	Subcentres 2001	Type of subcentre 1991	Type of subcentre 1996	Type of subcentre 2001
Badalona	Badalona	Badalona	Large	Large	Large
Barcelona	Barcelona	Barcelona	Large	Large	Large
Cornellà de Llobregat	Cornellà de Llobregat	Cornellà de Llobregat	Large	Large	Large
Granollers	Granollers	Granollers	Large	Large	Large
Hospitalet de Llobregat (L')	Hospitalet de Llobregat (L')	Hospitalet de Llobregat (L')	Large	Large	Large
Igualada	Igualada	Igualada	Large	Large	Large
Manresa	Manresa	Manresa	Large	Large	Large
Mataró	Mataró	Mataró	Large	Emerging	Large
Prat de Llobregat (El)	Prat de Llobregat (El)	Prat de Llobregat (El)	Large	Large	Large
Rubí	Rubí	Rubí	Large	Large	Large
Sabadell	Sabadell	Sabadell	Large	Large	Large
Sant Boi de Llobregat	Sant Boi de Llobregat	Sant Boi de Llobregat	Large	Large	Large
Santa Coloma de Gramenet	Santa Coloma de Gramenet	Santa Coloma de Gramenet	Large	Large	Large
Cerdanyola del Vallès	Cerdanyola del Vallès	Cerdanyola del Vallès	Large	Large	Large
Terrassa	Terrassa	Terrassa	Large	Large	Large
Vic	Vic	Vic	Large	Large	Large
Figueres	Figueres	Figueres	Large	Large	Large
Girona	Girona	Girona	Large	Large	Large
Lleida	Lleida	Lleida	Large	Large	Large
Reus	Reus	Reus	Large	Large	Large
Tarragona	Tarragona	Tarragona	Large	Large	Large
Tortosa	Tortosa	Tortosa	Large	Large	Large
Vilafranca del Penedès	Vilafranca del Penedès	Vilafranca del Penedès	Emerging	Emerging	Large
Vilanova i la Geltrú	Vilanova i la Geltrú	Vilanova i la Geltrú	Emerging	Emerging	Emerging
Blanes	Blanes	Blanes	Emerging	Emerging	Emerging
Olot	Olot	Olot	Emerging	Emerging	Emerging
Amposta	Amposta	Amposta	Emerging	Emerging	Emerging
Valls	Valls	Valls	Emerging	Emerging	Emerging
Castellbisbal	Castellbisbal	Castellbisbal	Emerging	Emerging	Emerging
Esplugues de Llobregat	Esplugues de Llobregat	Esplugues de Llobregat	Emerging	Emerging	Emerging
Gavà	Gavà	Gavà	Emerging	Emerging	Emerging
Martorell	Martorell	Martorell	Emerging	Emerging	Emerging
Mollet del Vallès	Mollet del Vallès	Mollet del Vallès	Emerging	Emerging	Emerging
Montcada i Reixac	Montcada i Reixac	Montcada i Reixac	Emerging	Emerging	Emerging
Parets del Vallès	Parets del Vallès	Parets del Vallès	Emerging	Emerging	Emerging
Polinyà	Polinyà	Polinyà	Emerging	Emerging	Emerging
Sant Adrià de Besòs	Sant Adrià de Besòs	Sant Adrià de Besòs	Emerging	Emerging	Emerging
Sant Andreu de la Barca		Sant Andreu de la Barca	Emerging		Emerging
Sant Cugat del Vallès	Sant Cugat del Vallès	Sant Cugat del Vallès	Emerging	Large	Large
Sant Joan Despí	Sant Joan Despí	Sant Joan Despí	Emerging	Emerging	Emerging
Sant Just Desvern	Sant Just Desvern	Sant Just Desvern	Emerging	Emerging	Emerging
Sant Quirze del Vallès	Sant Quirze del Vallès		Emerging	Emerging	
Barberà del Vallès	Barberà del Vallès	Barberà del Vallès	Emerging	Emerging	Emerging
Santa Perpètua de Mogoda	Santa Perpètua de Mogoda	Santa Perpètua de Mogoda	Emerging	Emerging	Emerging
Viladecans	Viladecans	Viladecans	Emerging	Emerging	Large
Vielha e Mijaran	Vielha e Mijaran	Vielha e Mijaran	Emerging	Emerging	Emerging
	Lloret de Mar	Lloret de Mar		Emerging	Emerging
	Palafrugell			Emerging	
	Roses	Roses		Emerging	Emerging
	Palau-solità i Plegamans	Palau-solità i Plegamans		Emerging	Emerging
	Sant Feliu de Llobregat			Emerging	
	Bausen	Bausen		Emerging	Emerging
	Vila-seca			Emerging	
	Salou			Emerging	
		Castelldefels			Emerging
		Abrera			Emerging
		Sant Feliu de Llobregat			Emerging
		Les			Emerging
		Cambrils			Emerging

Source: Own Elaboration

Figure 13. **Lineal Regression: RW (resident workers) Entropy Information function and Distance to Barcelona. Identifying the positive residuals (municipalities) in 1991**



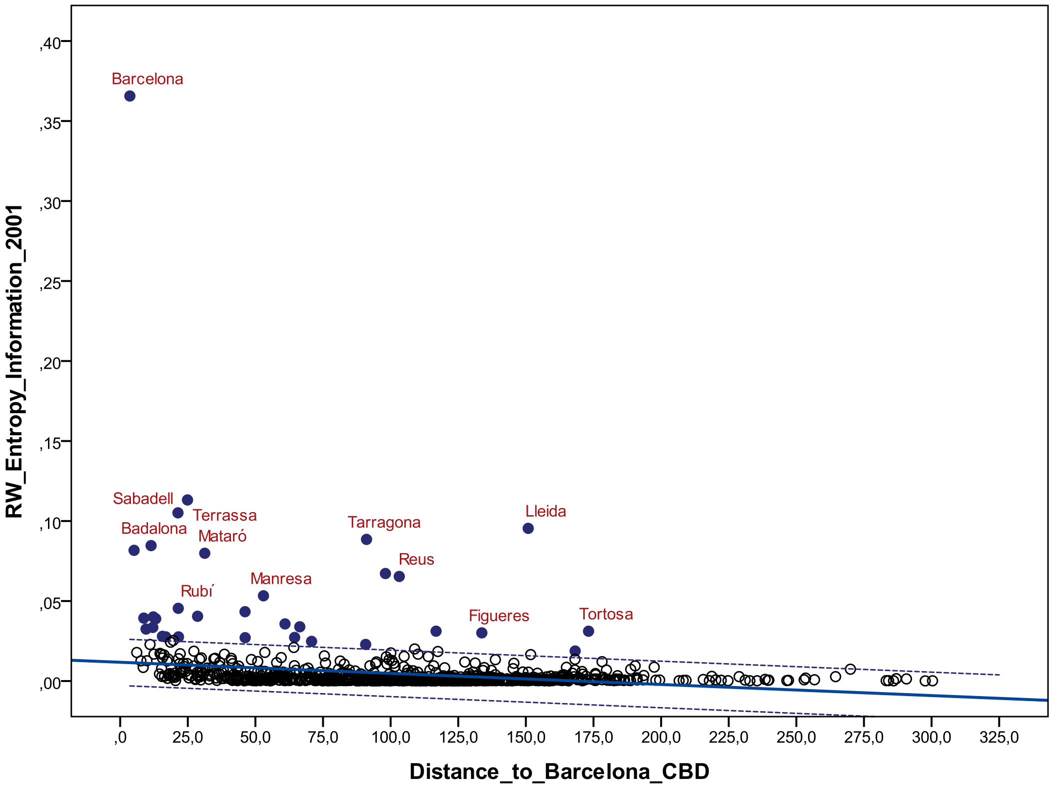
Source: Own Elaboration

Table 10. **Lineal Regression: RW (resident workers) Entropy Information function and Distance to Barcelona. Identifying the positive residuals (municipalities) in 1991**

Municipality	County	RMB	LTL 1991	LTL 2001	Increment LTL 2001-1991	Inf. Entròpica LTL 1991	Inf. Entròpica RW 1991	Distància Barcelona	Residu RW (EI) 1991
Barcelona	Barcelones	Sí	761.165	765.898	4.733	0,3667	0,36780	3,58	0,3570
Sabadell	Valles Occidental	Sí	62.641	69.260	6.619	0,0998	0,11030	21,36	0,1006
Terrassa	Valles Occidental	Sí	53.316	67.541	14.225	0,0888	0,10492	24,90	0,0955
Lleida	Segria	No	44.090	51.278	7.188	0,0771	0,09456	150,86	0,0932
Tarragona	Tarragones	No	42.927	52.342	9.415	0,0756	0,08511	91,09	0,0799
Hospitalet de Llobregat (L')	Barcelones	Sí	63.552	66.490	2.938	0,1009	0,08575	5,14	0,0750
Badalona	Barcelones	Sí	49.464	54.821	5.357	0,0840	0,08497	11,43	0,0747
Mataró	Maresme	Sí	36.305	42.304	5.999	0,0667	0,07984	31,26	0,0708
Reus	Baix Camp	No	28.060	32.975	4.915	0,0547	0,06470	103,19	0,0603
Girona	Girones	No	34.149	41.993	7.844	0,0636	0,06178	98,07	0,0570
Manresa	Bages	No	25.233	29.544	4.311	0,0504	0,05537	52,98	0,0477
Granollers	Valles Oriental	Sí	25.115	31.666	6.551	0,0502	0,04129	28,62	0,0321
Tortosa	Baix Ebre	No	11.986	13.262	1.276	0,0279	0,03155	173,17	0,0316
Vilanova i la Geltrú	Garraf	Sí	14.877	19.271	4.394	0,0332	0,03920	46,17	0,0311
Figueres	Alt Emporda	No	13.066	14.310	1.244	0,0299	0,03295	133,71	0,0305
Rubí	Valles Occidental	Sí	19.101	27.580	8.479	0,0405	0,03988	21,47	0,0302
Olot	Garrotxa	No	11.039	12.470	1.431	0,0261	0,03189	116,79	0,0283
Santa Coloma de Gramenet	Barcelones	Sí	17.930	19.205	1.275	0,0386	0,03807	8,74	0,0276
Prat de Llobregat (El)	Baix Llobregat	Sí	22.884	31.775	8.891	0,0467	0,03780	12,25	0,0276
Igualada	Anoia	No	15.910	19.352	3.442	0,0351	0,03380	60,95	0,0267
Sant Boi de Llobregat	Baix Llobregat	Sí	18.817	23.521	4.704	0,0401	0,03543	13,14	0,0252
Vic	Osona	No	15.097	20.579	5.482	0,0336	0,03198	66,41	0,0252
Cornellà de Llobregat	Baix Llobregat	Sí	22.014	27.751	5.737	0,0453	0,03402	9,56	0,0236
Valls	Alt Camp	No	8.897	9.489	592	0,0219	0,02431	90,76	0,0191
Vilafranca del Penedès	Alt Penedes	Sí	10.921	13.895	2.974	0,0259	0,02709	46,21	0,0190
Cerdanyola del Vallès	Valles Occidental	Sí	16.549	19.099	2.550	0,0362	0,02723	15,63	0,0172
Amposta	Montsia	No	5.520	6.792	1.272	0,0148	0,01719	168,22	0,0169
Blanes	Selva	No	7.414	10.208	2.794	0,0189	0,02304	64,50	0,0161

Source: Own Elaboration

Figure 14**. Lineal Regression: RW (resident workers) Entropy Information function and Distance to Barcelona. Identifying the positive residuals (municipalities) in 2001**



Source: Own Elaboration

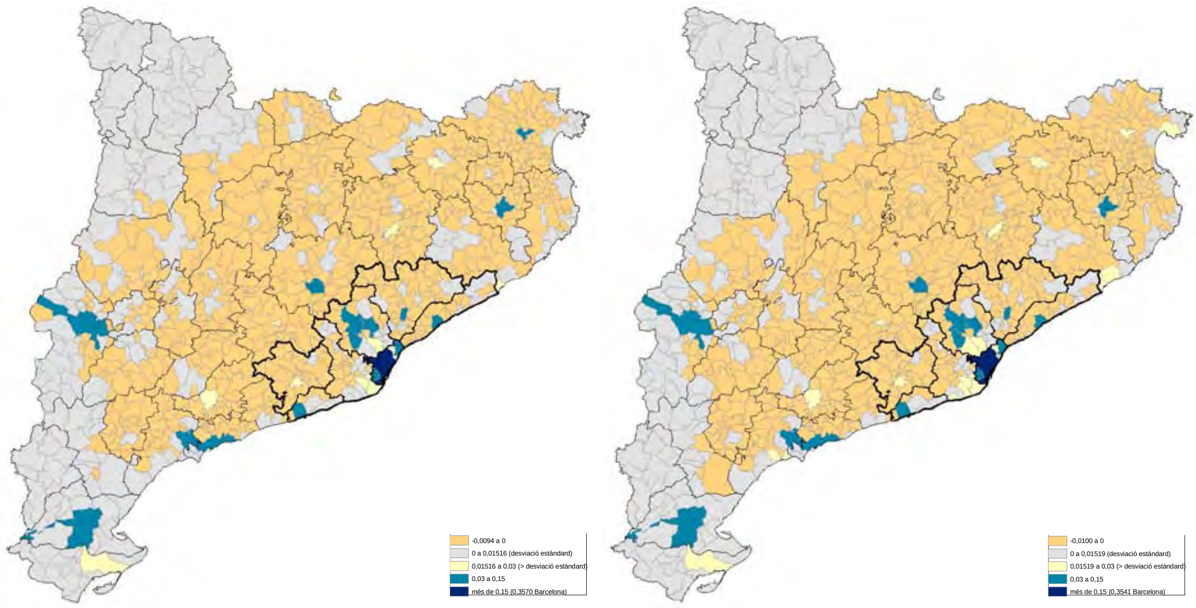
Table 11**. Lineal Regression: RW (resident workers) Entropy Information function and Distance to Barcelona. Identifying the positive residuals (municipalities) in 2001**

Municipiality	County	RMB	LTL 1991	LTL 2001	Increment LTL 2001-1991	Inf. Entròpica LTL 2001	Inf. Entròpica RW 2001	Distància Barcelona	Residu RW (EI) 2001
Barcelona	Barcelones	Sí	761.165	765.898	4.733	0,3596	0,36564	3,58	0,35416
Terrassa	Valles Occidental	Sí	53.316	67.541	14.225	0,0944	0,11318	24,90	0,10318
Sabadell	Valles Occidental	Sí	62.641	69.260	6.619	0,0962	0,10511	21,36	0,09487
Lleida	Segria	No	44.090	51.278	7.188	0,0771	0,09542	150,86	0,09416
Tarragona	Tarragones	No	42.927	52.342	9.415	0,0783	0,08852	91,09	0,08311
Badalona	Barcelones	Sí	49.464	54.821	5.357	0,0810	0,08465	11,43	0,07372
Hospitalet de Llobregat (L')	Barcelones	Sí	63.552	66.490	2.938	0,0934	0,08169	5,14	0,07031
Mataró	Maresme	Sí	36.305	42.304	5.999	0,0667	0,07985	31,26	0,07029
Girona	Girones	No	34.149	41.993	7.844	0,0663	0,06719	98,07	0,06227
Reus	Baix Camp	No	28.060	32.975	4.915	0,0551	0,06537	103,19	0,06080
Manresa	Bages	No	25.233	29.544	4.311	0,0506	0,05327	52,98	0,04522
Rubí	Valles Occidental	Sí	19.101	27.580	8.479	0,0480	0,04544	21,47	0,03520
Vilanova i la Geltrú	Garraf	Sí	14.877	19.271	4.394	0,0362	0,04333	46,17	0,03480
Tortosa	Baix Ebre	No	11.986	13.262	1.276	0,0268	0,03114	173,17	0,03142
Granollers	Valles Oriental	Sí	25.115	31.666	6.551	0,0534	0,04048	28,62	0,03073
Prat de Llobregat (El)	Baix Llobregat	Sí	22.884	31.775	8.891	0,0536	0,04007	12,25	0,02919
Santa Coloma de Gramenet	Barcelones	Sí	17.930	19.205	1.275	0,0361	0,03931	8,74	0,02819
Igualada	Anoia	No	15.910	19.352	3.442	0,0363	0,03569	60,95	0,02819
Sant Boi de Llobregat	Baix Llobregat	Sí	18.817	23.521	4.704	0,0424	0,03893	13,14	0,02811
Figueres	Alt Emporda	No	13.066	14.310	1.244	0,0285	0,03010	133,71	0,02764
Olot	Garrotxa	No	11.039	12.470	1.431	0,0255	0,03115	116,79	0,02753
Vic	Osona	No	15.097	20.579	5.482	0,0381	0,03389	66,41	0,02676
Sant Cugat del Vallès	Valles Occidental	Sí	14.465	27.089	12.624	0,0473	0,03351	12,07	0,02261
Cornellà de Llobregat	Baix Llobregat	Sí	22.014	27.751	5.737	0,0482	0,03249	9,56	0,02142
Blanes	Selva	No	7.414	10.208	2.794	0,0216	0,02724	64,50	0,01999
Amposta	Montsia	No	5.520	6.792	1.272	0,0155	0,01876	168,22	0,01870
Vilafranca del Penedès	Alt Penedes	Sí	10.921	13.895	2.974	0,0278	0,02709	46,21	0,01856
Lloret de Mar	Selva	No	7.207	9.460	2.253	0,0203	0,02478	70,77	0,01796

Source: Own Elaboration

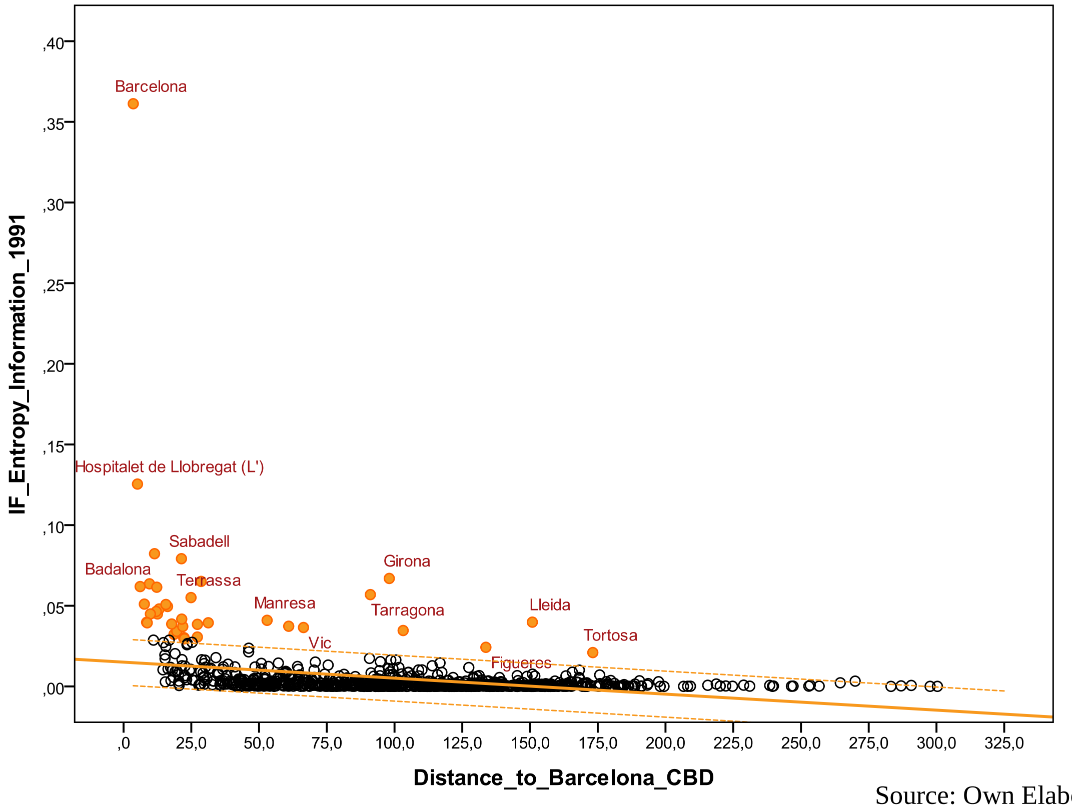
In the Figures 13-14 and Tables 10-11 show the lineal regressions of RW (resident workers) Entropy Information in function of the distance to Barcelona in 1991 (Figure 13 and Table 10) and in 2001 (Figure 14 and Table 11) in order to detect the municipalities which has more urban complexity and hierarchy, in other words, to identify those municipalities (positive residuals) that have more capacity to structure its territory in terms of local labour market. From a perspective of ten years, within the Catalan territory, there were 28 hierarchical municipalities (above the standard deviation, figure 13) in terms of RW in 1991 to 34 (figure 14). As it can observe in the Tables 10 and 11 and then in the following Figure 15 the urban dynamics in terms of local labour market (RW) from 1991 to 2001 has been characterized by: a) a process towards to stabilization (or to a little losing) of urban hierarchy in the municipalities with more urban size. For instance within the Barcelona Metropolitan Region, the city of Barcelona in 1991 its RW Entropy Information was 0,36780 and in 2010 it was 0,36564; Sabadell from 0,11030 in 1991 to 0,10511 in 2001; Terrassa from 0,10492 to 0,11318 as well as it happens in L'Hospitalet de Llobregat and Badalona, from 0,08575 to 0,80169 and from 0,08497 to 0,08465 respectively. Outside the Barcelona Metropolitan Region, these dynamics it also occurs: Lleida and Tarragona for example their RW Entropy Informations were 0,09456 and 0,08511 in 1991 and 0,09542 and 0,08852 in 2001 correspondingly; b) a process of emergence of new prominent municipalities in terms of local labour market within the metropolitan region of Barcelona. These are the cases of Rubí, Sant Cugat del Vallès and el Prat de Llobregat. These municipalities have increased significantly their resident worker Entropy Information: they had 0,03988; 0,02390 and 0,0370 in 1991 respectively and 0,04544; 0,03351 and 0,04007 in 2001; and finally c) as it is shown clearly in the Figure 15 (the more dark color, the highest is the positive residuals of the municipalities in terms of resident workers), the previous urban trends leads to base the urban structure of the Catalan territory in terms of local labour market in the cities of Girona, Manresa, Tarragona, Lleida and Tortosa as well as in the metropolitan cities of Mataró, Granollers and Vilanova i la Geltrú by finally in the duality of Barcelona and the "emerging city" in Vallès (Sabadell, Terrassa, Rubí, Sant Cugat del Vallès and Cerdanyola del Vallès).

Figure 15**. Evolution of the positive residuals (1991-2001) in the Lineal Regression: RW (resident workers) Entropy Information function and Distance to Barcelona.**



Source: Own Elaboration

Figure 16. **Lineal Regression: IF (in-commuting flows) Entropy Information function and Distance to Barcelona. Identifying the positive residuals (municipalities) in 1991**



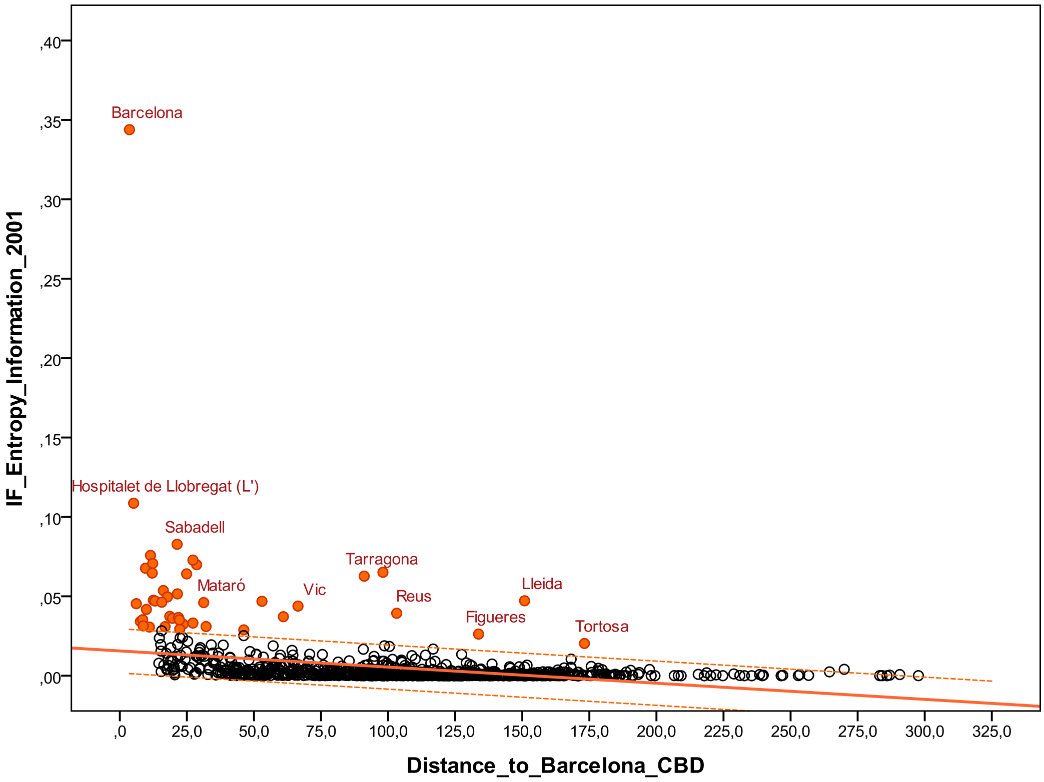
Source: Own Elaboration

Table 12. **Lineal Regression: IF (in-commuting flows) Entropy Information function and Distance to Barcelona. Identifying the positive residuals (municipalities) in 1991**

Municipality	County	RMB	LTL 1991	LTL 2001	Increment LTL 2001-1991	Inf. Entròpica LTL 1991	Inf. Entròpica IF 1991	Distància Barcelona	Residu IF (EI) 1991
Barcelona	Barcelones	Sí	761.165	765.898	4.733	0,3667	0,36124	3,58	0,3466
Hospitalet de Llobregat (L')	Barcelones	Sí	63.552	66.490	2.938	0,1009	0,12545	5,14	0,1109
Badalona	Barcelones	Sí	49.464	54.821	5.357	0,0840	0,08227	11,43	0,0684
Sabadell	Valles Occidental	Sí	62.641	69.260	6.619	0,0998	0,07917	21,36	0,0663
Girona	Girones	No	34.149	41.993	7.844	0,0636	0,06694	98,07	0,0616
Granollers	Valles Oriental	Sí	25.115	31.666	6.551	0,0502	0,06509	28,62	0,0529
Tarragona	Tarragones	No	42.927	52.342	9.415	0,0756	0,05691	91,09	0,0509
Cornellà de Llobregat	Baix Llobregat	Sí	22.014	27.751	5.737	0,0453	0,06360	9,56	0,0495
Prat de Llobregat (El)	Baix Llobregat	Sí	22.884	31.775	8.891	0,0467	0,06149	12,25	0,0477
Esplugues de Llobregat	Baix Llobregat	Sí	16.126	15.361	- 765	0,0354	0,06190	6,13	0,0475
Terrassa	Valles Occidental	Sí	53.316	67.541	14.225	0,0888	0,05507	24,90	0,0425
Lleida	Segria	No	44.090	51.278	7.188	0,0771	0,03984	150,86	0,0398
Cerdanyola del Vallès	Valles Occidental	Sí	16.549	19.099	2.550	0,0362	0,05079	15,63	0,0373
Sant Adrià de Besòs	Barcelones	Sí	11.977	10.529	- 1.448	0,0279	0,05102	7,67	0,0367
Barberà del Vallès	Valles Occidental	Sí	12.940	17.424	4.484	0,0297	0,04955	16,22	0,0361
Sant Boi de Llobregat	Baix Llobregat	Sí	18.817	23.521	4.704	0,0401	0,04801	13,14	0,0343
Sant Cugat del Vallès	Valles Occidental	Sí	14.465	27.089	12.624	0,0325	0,04646	12,07	0,0326
Manresa	Bages	No	25.233	29.544	4.311	0,0504	0,04097	52,98	0,0312
Montcada i Reixac	Valles Occidental	Sí	12.077	15.698	3.621	0,0281	0,04493	12,52	0,0311
Sant Joan Despí	Baix Llobregat	Sí	10.790	12.712	1.922	0,0256	0,04492	9,90	0,0309
Reus	Baix Camp	No	28.060	32.975	4.915	0,0547	0,03466	103,19	0,0298
Rubí	Valles Occidental	Sí	19.101	27.580	8.479	0,0405	0,04171	21,47	0,0288
Igualada	Anoia	No	15.910	19.352	3.442	0,0351	0,03730	60,95	0,0283
Vic	Osona	No	15.097	20.579	5.482	0,0336	0,03651	66,41	0,0281
Mataró	Maresme	Sí	36.305	42.304	5.999	0,0667	0,03945	31,26	0,0275
Martorell	Baix Llobregat	Sí	10.285	24.685	14.400	0,0247	0,03848	27,26	0,0261
Sant Just Desvern	Baix Llobregat	Sí	8.009	9.691	1.682	0,0201	0,03973	8,51	0,0255
Santa Perpètua de Mogoda	Valles Occidental	Sí	9.050	15.369	6.319	0,0222	0,03868	17,76	0,0254

Source: Own Elaboration

Figure 17. **Lineal Regression: IF (in-commuting flows) Entropy Information function and Distance to Barcelona. Identifying the positive residuals (municipalities) in 2001**



Source: Own Elaboration

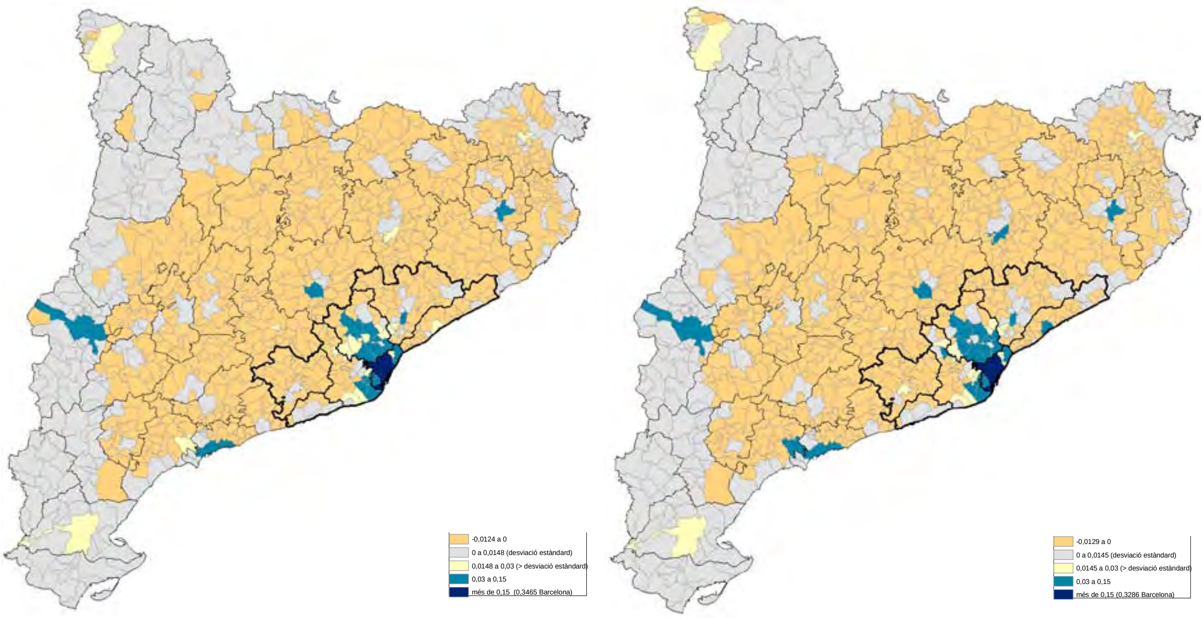
Table 13. **Lineal Regression: IF (in-commuting flows) Entropy Information function and Distance to Barcelona. Identifying the positive residuals (municipalities) in 2001**

Municipality	County	RMB	LTL 1991	LTL 2001	Increment LTL 2001-1991	Inf. Entròpica LTL 2001	Inf. Entròpica IF 2001	Distància Barcelona	Residu IF (EI) 2001
Barcelona	Barcelones	Sí	761.165	765.898	4.733	0,3596	0,34387	3,58	0,32864
Hospitalet de Llobregat (L')	Barcelones	Sí	63.552	66.490	2.938	0,0934	0,10861	5,14	0,09355
Sabadell	Valles Occidental	Sí	62.641	69.260	6.619	0,0962	0,08275	21,36	0,06933
Badalona	Barcelones	Sí	49.464	54.821	5.357	0,0810	0,07575	11,43	0,06132
Martorell	Baix Llobregat	Sí	10.285	24.685	14.400	0,0440	0,07277	27,26	0,05996
Girona	Girones	No	34.149	41.993	7.844	0,0663	0,06512	98,07	0,05950
Granollers	Valles Oriental	Sí	25.115	31.666	6.551	0,0534	0,06990	28,62	0,05722
Tarragona	Tarragones	No	42.927	52.342	9.415	0,0783	0,06269	91,09	0,05636
Prat de Llobregat (El)	Baix Llobregat	Sí	22.884	31.775	8.891	0,0536	0,07067	12,25	0,05633
Cornellà de Llobregat	Baix Llobregat	Sí	22.014	27.751	5.737	0,0482	0,06768	9,56	0,05306
Terrassa	Valles Occidental	Sí	53.316	67.541	14.225	0,0944	0,06413	24,90	0,05107
Sant Cugat del Vallès	Valles Occidental	Sí	14.465	27.089	12.624	0,0473	0,06465	12,07	0,05029
Lleida	Segria	No	44.090	51.278	7.188	0,0771	0,04717	150,86	0,04692
Barberà del Vallès	Valles Occidental	Sí	12.940	17.424	4.484	0,0334	0,05362	16,22	0,03967
Rubí	Valles Occidental	Sí	19.101	27.580	8.479	0,0480	0,05153	21,47	0,03813
Manresa	Bages	No	25.233	29.544	4.311	0,0506	0,04685	52,98	0,03664
Santa Perpètua de Mogoda	Valles Occidental	Sí	9.050	15.369	6.319	0,0302	0,04960	17,76	0,03582
Vic	Osona	No	15.097	20.579	5.482	0,0381	0,04384	66,41	0,03500
Reus	Baix Camp	No	28.060	32.975	4.915	0,0551	0,03933	103,19	0,03423
Mataró	Maresme	Sí	36.305	42.304	5.999	0,0667	0,04605	31,26	0,03364
Montcada i Reixac	Valles Occidental	Sí	12.077	15.698	3.621	0,0307	0,04753	12,52	0,03321
Sant Boi de Llobregat	Baix Llobregat	Sí	18.817	23.521	4.704	0,0424	0,04706	13,14	0,03281
Cerdanyola del Vallès	Valles Occidental	Sí	16.549	19.099	2.550	0,0359	0,04630	15,63	0,03229
Esplugues de Llobregat	Baix Llobregat	Sí	16.126	15.361	- 765	0,0302	0,04534	6,13	0,03038
Igualada	Anoia	No	15.910	19.352	3.442	0,0363	0,03715	60,95	0,02776
Sant Joan Despí	Baix Llobregat	Sí	10.790	12.712	1.922	0,0259	0,04176	9,90	0,02718
Figueres	Alt Emporda	No	13.066	14.310	1.244	0,0285	0,02620	133,71	0,02420
Gavà	Baix Llobregat	Sí	10.994	15.184	4.190	0,0299	0,03736	18,62	0,02366

Source: Own Elaboration

In the last Figures 16-17 and Tables 12-13 show the lineal regressions of IF (in-commuting flows) Entropy Information in function of the distance to Barcelona in 1991 (Figure 16 and Table 12) and in 2001 (Figure 17 and Table 13) in order to detect the municipalities which has more urban complexity and hierarchy, in other words, to identify those municipalities (positive residuals) that have more capacity to attract workers towards its territory in terms of being a an important economic pole. From a perspective of ten years, within the Catalan territory, there were 40 hierarchical municipalities (above the standard deviation, figure 16) in terms of IF in 1991 to 45 (figure 17). As it can observe in the Tables 12 and 13 and then in the following Figure 18 the urban dynamics in terms of in-commuting flows (IF) from 1991 to 2001 has been characterized by: a) a process towards a less hierarchy in terms of incommuting flows in the large cities located in the county of Barcelonès. These are the case of Barcelona that had a IF Entropy Information of 0,36124 in 1991 and 0,34387 in 2001, or L'Hospitalet del Llobregat, 0,12545 in 1991 to 0,10861 in 2001 and Badalona, 0,08227 in 1991 to 0,07575 in 2001; b) an increment of the IF Entropy Information in the main cities located outside of the Barcelona Metropolitan Region: Tarragona had 0,05691 in 1991 and 0,06269 in 2001 or Lleida, 0,03984 in 1991 to 0,04717 in 2001; c) a clear reinforcement of the hierarchy in the cities located in the county of Vallès Occidental, that fits perfectly with the observations in terms of RW Entropy Information or in terms of employment growth that are explained in the previous sections: Sabadell had in 1991 an IF Entropy Information of 0,07917 to 0,08275 in 2001, Barberà del Vallès had 0,04955 in 1991 and 0,05362 in 2001; Sant Cugat del Vallès, 0,04646 in 1991 to 0,05362 in 2001; Montcada i Reixac, 0,04493 in 1991 to 0,04753 in 2001 and Rubí, 0,04171 in 1991 to 0,0513 in 2001; and finally d) as it is shown clearly in the Figure 18 (the more dark color, the highest is the positive residuals of the municipalities in terms of in-commuting flows), the process towards a higher hierarchy in terms of IF flows and being a significant poles in terms of economic activity is concentrated in the cities of Girona, Vic, Manresa, Tarragona, Lleida as well as the capital of Barcelona, the most cities in Vallès Occidental: Terrassa, Sabadell, Cerdanyola del Vallès, Rubí, Sant Cugat del Vallès among others and the cities of Mataró, Granollers and Martorell.

Figure 18**. Evolution of the positive residuals (1991-2001) in the Lineal Regression: IF (in-commuting flows) Entropy Information function and Distance to Barcelona.**

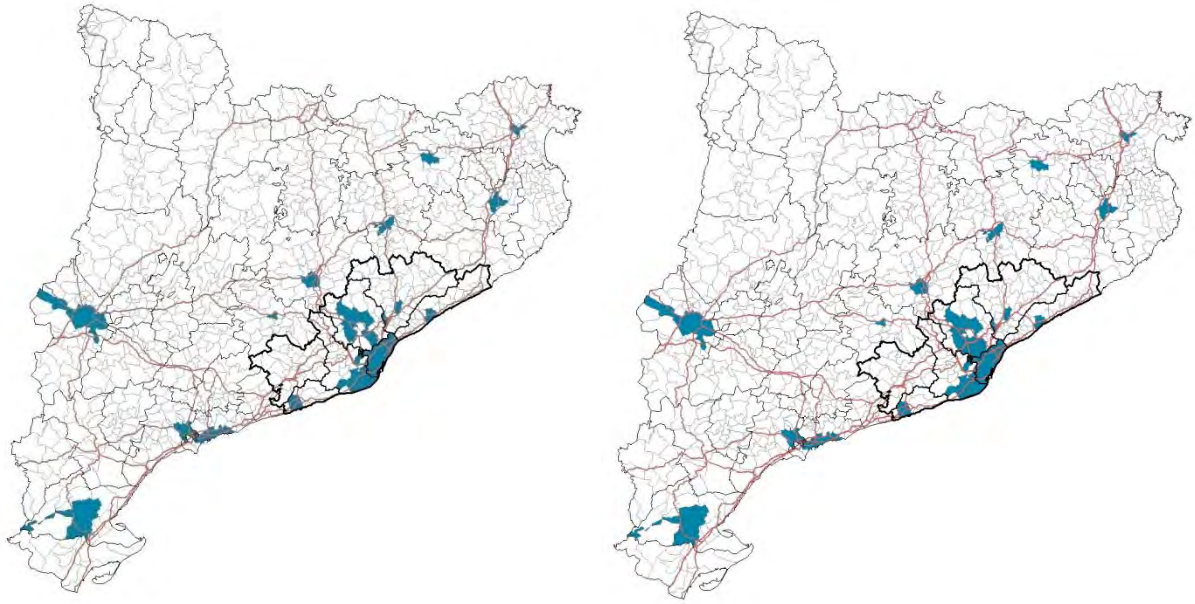


Source: Own Elaboration

5.2. Population centers from 1981 to 2010 at regional scale: Catalan territory

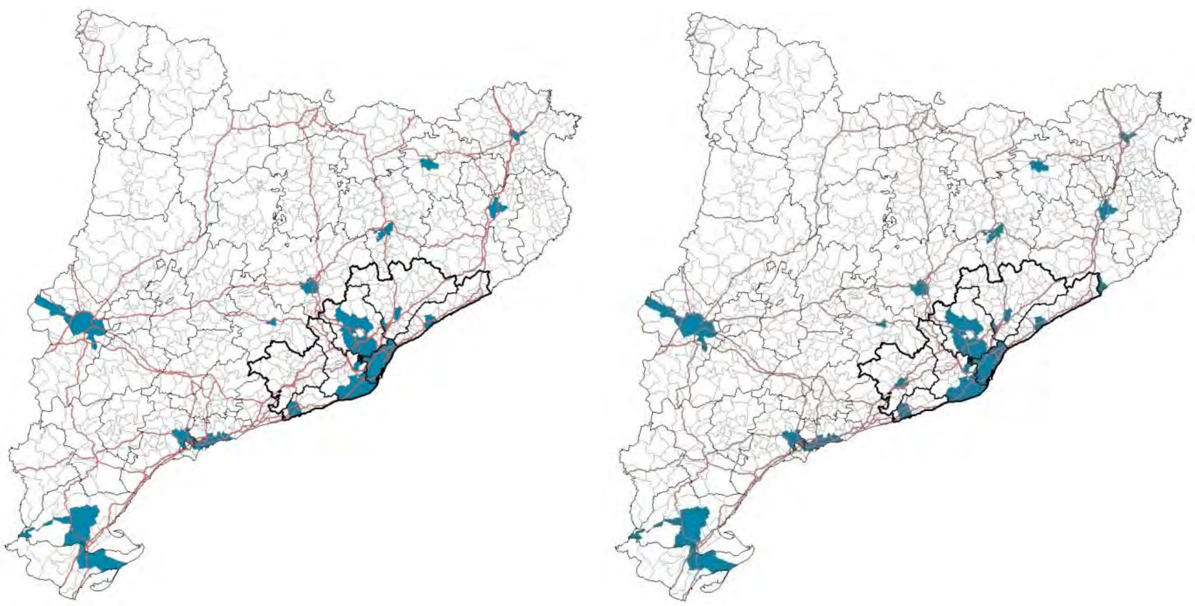
From 1981 to 2010, the demographic dynamics has based on a process towards a concentration in the main cities of the Vallès Occidental county, towards a concentration in the province capitals of Tarragona, Lleida, and Girona and finally an important losing of population in the capital city of Barcelona and in most of the cities in the Barcelonès county. That demographic growth has explained in detail in the work of Masip & Roca (2012d).

Figure 19**. Municipalities identified as Population Centres in 1981 and 1986 for the Catalan territory by using Masip's (2012b, 2012c) methodology**



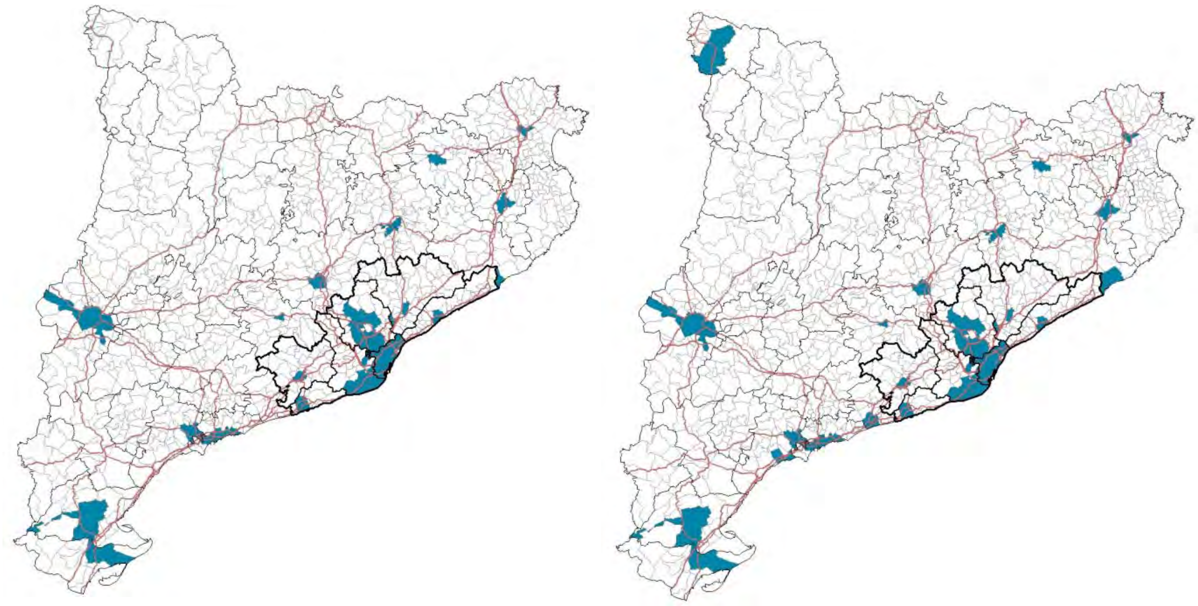
Source: Own Elaboration, population centers in 1981 (left), in 1986 (right)

Figure 20**. Municipalities identified as Population Centres in 1991 and 1996 for the Catalan territory by using Masip's (2012b, 2012c) methodology**



Source: Own Elaboration, population centers in 1991 (left), in 1996 (right)

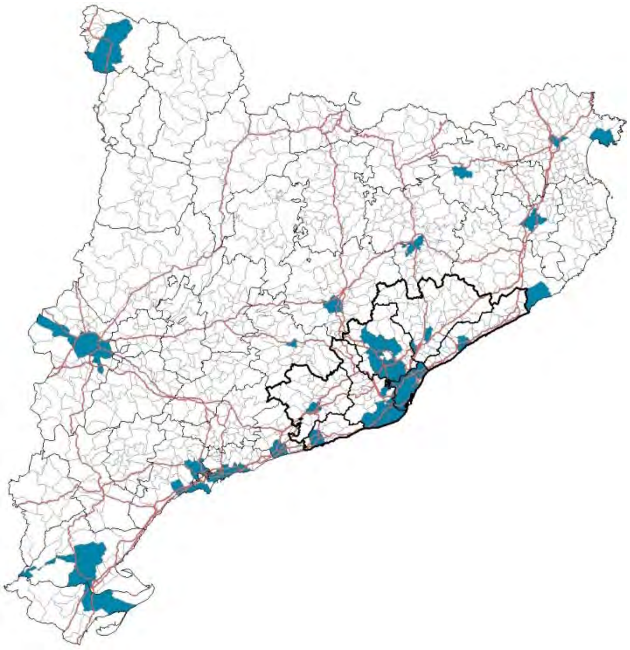
Figure 21**. Municipalities identified as Population Centres in 2001 and 2006 for the Catalan territory by using Masip's (2012b, 2012c) methodology**



Source: Own Elaboration, population centers in 2001 (left), in 2006 (right)

The following Figures 19-22 and Table 14 reports the population centres identified by using the Masip's (2012b, 2012c) method presented in section 4. In that case, instead of using a double Entropy Information function, is used a Population Entropy Information function in the same form that the equation (3) or (4) and then, identifying the positive residuals estimated from the exponential Population Entropy Information function.

Figure 22**. Municipalities identified as Population Centres in 2010 for the Catalan territory by using Masip's (2012b, 2012c) methodology**



Source: Own Elaboration

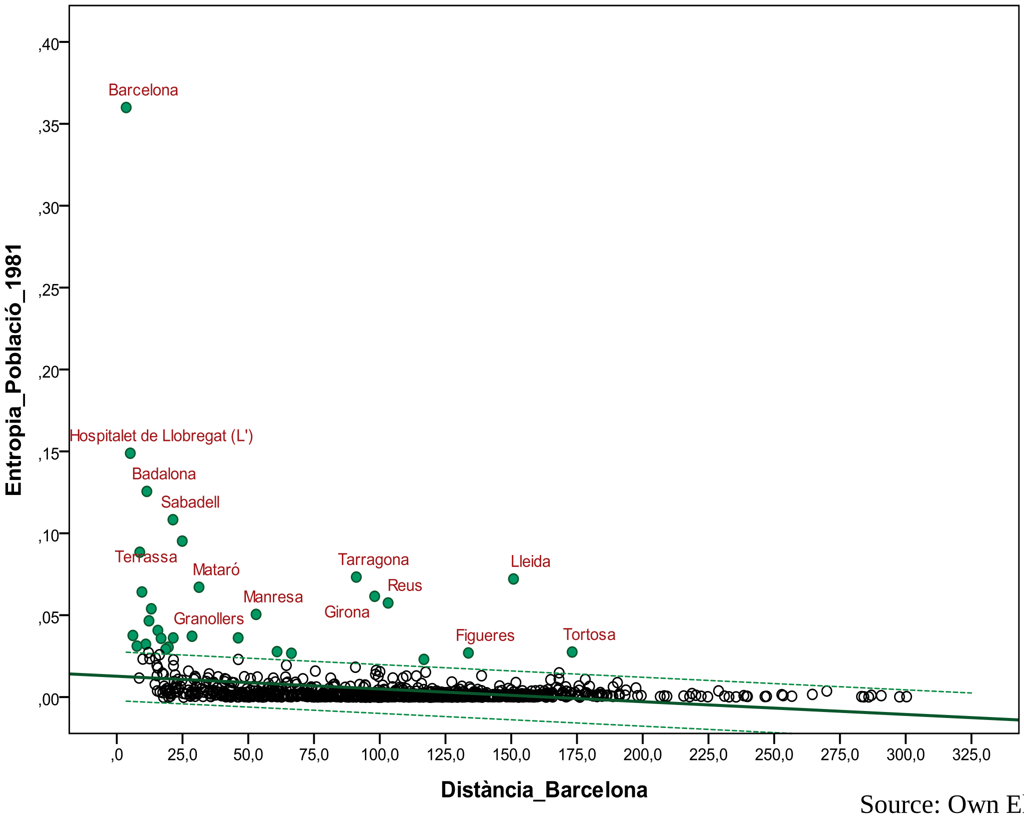
As the Figures 19-22 and the Table 14 present, from 1981 to 2010 there was a strong process of subcentre emergence located in a) the main cities outside the Barcelona Metropolitan Region: Girona, Olot, Vic, Manresa, Igualada, Tarragona, Reus, Lleida, Amposta, Tortosa and Vielha e Mijaran; b) in the main cities of Vallès Occidental (Sabadell, Terrassa, Rubí, Cerdanyola and Sant Cugat); c) in other important cities within the metropolitan region of Barcelona: Granollers, Mataró, Mollet, Vilafranca and Vilanova; and finally d) although they have been lost population, the centers in Barcelonès county still being prominent in terms of population: Barcelona (capital), Badalona and L'Hospitalet de Llobregat among others.

Table 14**. Population Centres in the Catalan territory from 1981 to 2010**

Subcentres 1981	Subcentres 1986	Subcentres 1991	Subcentres 1996	Subcentres 2001	Subcentres 2006	Subcentres 2010
Badalona	Badalona	Badalona	Badalona	Badalona	Badalona	Badalona
Barcelona	Barcelona	Barcelona	Barcelona	Barcelona	Barcelona	Barcelona
Cornellà de Llobregat	Cornellà de Llobregat	Cornellà de Llobregat	Cornellà de Llobregat	Cornellà de Llobregat	Cornellà de Llobregat	Cornellà de Llobregat
Esplugues de Llobregat	Esplugues de Llobregat	Esplugues de Llobregat	Esplugues de Llobregat	Esplugues de Llobregat	Esplugues de Llobregat	Esplugues de Llobregat
Gavà	Gavà	Gavà	Gavà	Gavà	Gavà	Gavà
Granollers	Granollers	Granollers	Granollers	Granollers	Granollers	Granollers
Hospitalet de Llobregat (L')	Hospitalet de Llobregat (L')	Hospitalet de Llobregat (L')	Hospitalet de Llobregat (L')	Hospitalet de Llobregat (L')	Hospitalet de Llobregat (L')	Hospitalet de Llobregat (L')
Igualada	Igualada	Igualada	Igualada	Igualada	Igualada	Igualada
Manresa	Manresa	Manresa	Manresa	Manresa	Manresa	Manresa
Mataró	Mataró	Mataró	Mataró	Mataró	Mataró	Mataró
Mollet del Vallès	Mollet del Vallès	Mollet del Vallès	Mollet del Vallès	Mollet del Vallès	Mollet del Vallès	Mollet del Vallès
Prat de Llobregat (El)	Prat de Llobregat (El)	Prat de Llobregat (El)	Prat de Llobregat (El)	Prat de Llobregat (El)	Prat de Llobregat (El)	Prat de Llobregat (El)
Rubí	Rubí	Rubí	Rubí	Rubí	Rubí	Rubí
Sabadell	Sabadell	Sabadell	Sabadell	Sabadell	Sabadell	Sabadell
Sant Adrià de Besòs	Sant Adrià de Besòs	Sant Adrià de Besòs	Sant Adrià de Besòs			
Sant Boi de Llobregat	Sant Boi de Llobregat	Sant Boi de Llobregat	Sant Boi de Llobregat	Sant Boi de Llobregat	Sant Boi de Llobregat	Sant Boi de Llobregat
Sant Feliu de Llobregat	Sant Feliu de Llobregat	Sant Feliu de Llobregat	Sant Feliu de Llobregat	Sant Feliu de Llobregat	Sant Feliu de Llobregat	Sant Feliu de Llobregat
Santa Coloma de Gramenet	Santa Coloma de Gramenet	Santa Coloma de Gramenet	Santa Coloma de Gramenet	Santa Coloma de Gramenet	Santa Coloma de Gramenet	Santa Coloma de Gramenet
Cerdanyola del Vallès	Cerdanyola del Vallès	Cerdanyola del Vallès	Cerdanyola del Vallès	Cerdanyola del Vallès	Cerdanyola del Vallès	Cerdanyola del Vallès
Terrassa	Terrassa	Terrassa	Terrassa	Terrassa	Terrassa	Terrassa
Vic	Vic	Vic	Vic	Vic	Vic	Vic
Viladecans	Viladecans	Viladecans	Viladecans	Viladecans	Viladecans	Viladecans
Vilanova i la Geltrú	Vilanova i la Geltrú	Vilanova i la Geltrú	Vilanova i la Geltrú	Vilanova i la Geltrú	Vilanova i la Geltrú	Vilanova i la Geltrú
Figueres	Figueres	Figueres	Figueres	Figueres	Figueres	Figueres
Girona	Girona	Girona	Girona	Girona	Girona	Girona
Olot	Olot	Olot	Olot	Olot	Olot	Olot
Lleida	Lleida	Lleida	Lleida	Lleida	Lleida	Lleida
Reus	Reus	Reus	Reus	Reus	Reus	Reus
Tarragona	Tarragona	Tarragona	Tarragona	Tarragona	Tarragona	Tarragona
Tortosa	Tortosa	Tortosa	Tortosa	Tortosa	Tortosa	Tortosa
	Sant Cugat del Vallès	Sant Cugat del Vallès	Sant Cugat del Vallès	Sant Cugat del Vallès	Sant Cugat del Vallès	Sant Cugat del Vallès
		Castelldefels	Castelldefels	Castelldefels	Castelldefels	Castelldefels
		Amposta	Amposta	Amposta	Amposta	Amposta
			Vilafranca del Penedès	Vilafranca del Penedès	Vilafranca del Penedès	Vilafranca del Penedès
			Blanes	Blanes	Blanes	Blanes
					Lloret de Mar	Lloret de Mar
					Salt	Salt
					Vielha e Mijaran	Vielha e Mijaran
					Cambrils	Cambrils
					Vendrell (El)	Vendrell (El)
						Roses
						Salou

Source: Own Elaboration

Figure 23. **Lineal Regression: Population Entropy Information function and Distance to Barcelona. Identifying the positive residuals (municipalities) in 1981**



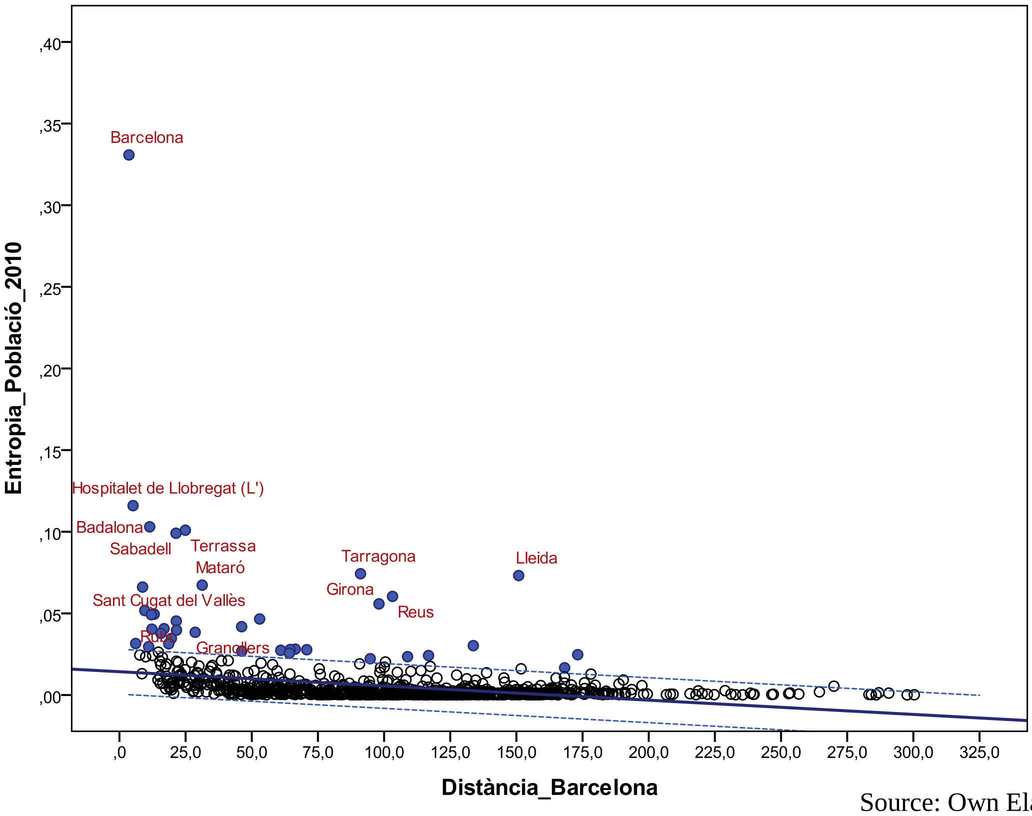
Source: Own Elaboration

Table 15. **Lineal Regression: Population Entropy Information function and Distance to Barcelona. Identifying the positive residuals (municipalities) in 1981**

Municipality	County	RMB	Població 1981	Població 2010	Increment Població 2010-1981	Rank Població 1981	Inf. Entròpica Població 1981	Distància Barcelona	Residu Població (EI) 1981
Barcelona	Barcelones	Sí	1.752.627	1.619.337	- 133.290	1	0,35996	3,58	0,3475
Hospitalet de Llobregat (L')	Barcelones	Sí	295.074	258.642	- 36.432	2	0,14886	5,14	0,1365
Badalona	Barcelones	Sí	229.780	218.886	- 10.894	3	0,12557	11,43	0,1137
Sabadell	Valles Occidental	Sí	186.123	207.338	21.215	4	0,10830	21,36	0,0972
Terrassa	Valles Occidental	Sí	155.614	212.724	57.110	5	0,09522	24,90	0,0844
Santa Coloma de Gramenet	Barcelones	Sí	140.613	120.060	- 20.553	6	0,08844	8,74	0,0764
Lleida	Segria	No	106.814	137.387	30.573	8	0,07211	150,86	0,0711
Tarragona	Tarragones	No	109.112	140.184	31.072	7	0,07327	91,09	0,0676
Mataró	Maresme	Sí	97.008	122.905	25.897	9	0,06706	31,26	0,0568
Girona	Girones	No	86.624	96.236	9.612	11	0,06153	98,07	0,0564
Reus	Baix Camp	No	79.245	106.622	27.377	12	0,05747	103,19	0,0528
Cornellà de Llobregat	Baix Llobregat	Sí	91.563	87.240	- 4.323	10	0,06418	9,56	0,0522
Sant Boi de Llobregat	Baix Llobregat	Sí	72.926	82.411	9.485	13	0,05390	13,14	0,0422
Manresa	Bages	No	67.007	76.209	9.202	14	0,05048	52,98	0,0419
Prat de Llobregat (El)	Baix Llobregat	Sí	60.419	63.434	3.015	15	0,04657	12,25	0,0348
Cerdanyola del Vallès	Valles Occidental	Sí	50.885	58.407	7.522	16	0,04069	15,63	0,0292
Tortosa	Baix Ebre	No	31.188	34.473	3.285	27	0,02750	173,17	0,0283
Vilanova i la Geltrú	Garraf	Sí	43.833	66.532	22.699	20	0,03615	46,17	0,0270
Granollers	Valles Oriental	Sí	45.348	59.691	14.343	18	0,03714	28,62	0,0266
Esplugues de Llobregat	Baix Llobregat	Sí	46.079	46.649	570	17	0,03761	6,13	0,0254
Rubí	Valles Occidental	Sí	43.839	73.591	29.752	19	0,03615	21,47	0,0251
Figueres	Alt Emporda	No	30.412	44.255	13.843	29	0,02695	133,71	0,0246
Viladecans	Baix Llobregat	Sí	43.358	64.077	20.719	21	0,03583	16,85	0,0244
Sant Feliu de Llobregat	Baix Llobregat	Sí	38.004	43.112	5.108	22	0,03225	11,04	0,0204
Igualada	Anoia	No	31.532	39.149	7.617	26	0,02775	60,95	0,0198

Source: Own Elaboration

Figure 24. **Lineal Regression: Population Entropy Information function and Distance to Barcelona. Identifying the positive residuals (municipalities) in 2010**



Source: Own Elaboration

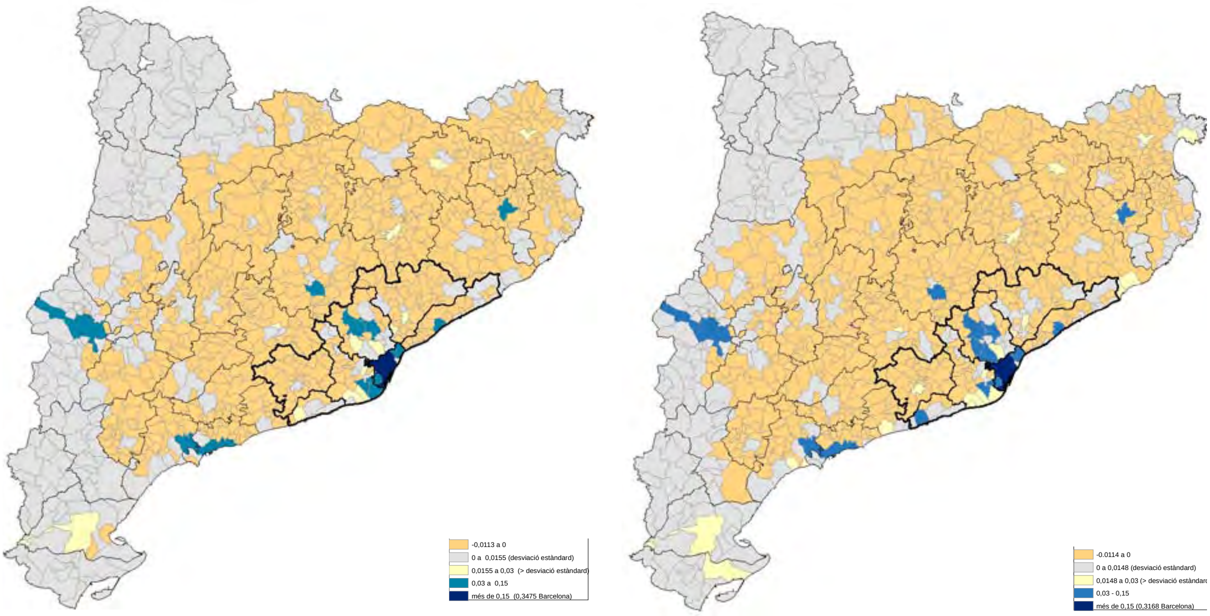
Table 16. **Lineal Regression: Population Entropy Information function and Distance to Barcelona. Identifying the positive residuals (municipalities) in 2010**

Municipality	County	RMB	Població 1981	Població 2010	Increment Població 2010-1981	Rank Població 2010	Inf. Entròpica Població 2010	Distància Barcelona	Residu Població (EI) 2010
Barcelona	Barcelones	Sí	1.752.627	1.619.337	- 133.290	1	0,33078	3,58	0,31681
Hospitalet de Llobregat (L')	Barcelones	Sí	295.074	258.642	- 36.432	2	0,11599	5,14	0,10215
Badalona	Barcelones	Sí	229.780	218.886	- 10.894	3	0,10302	11,43	0,08973
Terrassa	Valles Occidental	Sí	155.614	212.724	57.110	4	0,10093	24,90	0,08882
Sabadell	Valles Occidental	Sí	186.123	207.338	21.215	5	0,09908	21,36	0,08666
Lleida	Segria	No	106.814	137.387	30.573	7	0,07318	150,86	0,07206
Tarragona	Tarragones	No	109.112	140.184	31.072	6	0,07429	91,09	0,06796
Mataró	Maresme	Sí	97.008	122.905	25.897	8	0,06729	31,26	0,05573
Reus	Baix Camp	No	79.245	106.622	27.377	10	0,06039	103,19	0,05511
Santa Coloma de Gramenet	Barcelones	Sí	140.613	120.060	- 20.553	9	0,06611	8,74	0,05258
Girona	Girones	Sí	86.624	96.236	9.612	11	0,05582	98,07	0,05009
Cornellà de Llobregat	Baix Llobregat	Sí	91.563	87.240	- 4.323	12	0,05174	9,56	0,03829
Manresa	Bages	No	67.007	76.209	9.202	15	0,04657	52,98	0,03691
Sant Boi de Llobregat	Baix Llobregat	Sí	72.926	82.411	9.485	13	0,04950	13,14	0,03637
Sant Cugat del Vallès	Valles Occidental	Sí	30.633	81.745	51.112	14	0,04919	12,07	0,03596
Rubí	Valles Occidental	Sí	43.839	73.591	29.752	16	0,04531	21,47	0,03290
Vilanova i la Geltrú	Garraf	Sí	43.833	66.532	22.699	17	0,04186	46,17	0,03160
Viladecans	Baix Llobregat	Sí	43.358	64.077	20.719	18	0,04064	16,85	0,02782
Figueres	Alt Emporda	No	30.412	44.255	13.843	26	0,03025	133,71	0,02763
Castelldefels	Baix Llobregat	Sí	24.697	62.250	37.553	20	0,03972	21,56	0,02732
Prat de Llobregat (El)	Baix Llobregat	Sí	60.419	63.434	3.015	19	0,04031	12,25	0,02710
Granollers	Valles Oriental	Sí	45.348	59.691	14.343	21	0,03842	28,62	0,02663
Tortosa	Baix Ebre	No	31.188	34.473	3.285	35	0,02471	173,17	0,02553
Cerdanyola del Vallès	Valles Occidental	Sí	50.885	58.407	7.522	22	0,03776	15,63	0,02484
Mollet del Vallès	Valles Oriental	Sí	35.480	52.459	16.979	23	0,03467	19,62	0,02209

Source: Own Elaboration

In the last Figures 23-24 and Tables 15-16 show the lineal regressions of Population Entropy Information in function of the distance to Barcelona in 1981 (Figure 23 and Table 15) and in 2010 (Figure 24 and Table 16) in order to detect the municipalities that have more hierarchy and urban complexity, in other words, identifying those municipalities that have more capacity to structure its territory and exert a significance influence to its surrounding urban areas. Hence, from 1981 to 2010, the population centres have increased from 30 to 39 respectively as Figures 23 and 24 present at the time that the demographic dynamic for this time period could summarize in: a) a lost or stabilization of urban hierarchy in the municipalities with more size (population). For instance, in the case of the capital city of Barcelona has decreased its Population Entropy Information from 0,35996 in 1981 to 0,3378 in 2010, the same urban dynamics as the main cities of the Baix Llobregat county, for example in the case of L'Hospitalet del Llobregat, 0,14886 in 1981 to 0,11599 in 2010; Badalona from 0,12557 to 0,10302 and Santa Coloma de Gramanet from 0,0884 to 0,6611; b) the cities outside the metropolitan region of Barcelona this dynamic has been inversed: Tarragona has increased its Population Entropy Information from 0,07327 in 1981 to 0,07429 in 2010, or Lleida from 0,07211 in 1981 to 0,07318 in 2010; and finally c) a process of hierarchical concentration in terms of population in the county of Vallès Occidental due to a significant increment in terms of population in the "emerging" Vallès cities. For instance these are the cases of Sant Cugat del Vallès, Rubí, Terrassa. In that sense, the Figure 25, shows the evolution from 1981 to 2010 of the positive residuals in the lineal regression of the Population Entropy Information in function of the distance to Barcelona, and it is could observe that the municipalities detected as the most hierarchical and significant (the more dark color, the highest is the positive residuals of the municipalities in terms of population) in 1981 (left image in the Figure 25) are mainly: a) Barcelona and its adjacent cities, b) Girona, Lleida, Tarragona and Manresa, c) within the Barcelona Metropolitan Region: apart from the mentioned Barcelona and its adjacent cities, Sabadell, Terrassa and Mataró. In 2010 (right image, Figure 25) the most hierarchical municipalities are the same of 1981 but with the emergence of new hierarchical population centres within the Barcelona Metropolitan Region:

Figure 25**. Evolution of the positive residuals (1981-2010) in the Lineal Regression: Population Entropy Information function and Distance to Barcelona.**



Source: Own Elaboration

These are the cases of Vilanova i la Geltrú, Sant Cugat del Vallès and Rubí. Hence in the Figure 25, shows clearly that the centres that from 1981 to 2010 have been concentrated the most accused growth in terms of population, they are at the same time the nodes that have more increased their capacity to structure the metropolitan and Catalan territory. This conclusion fits perfectly with the observations that the work of Masip & Roca (2012d) have pointed out by analysing the demographic growth in the metropolitan and Catalan territory.

6. SUBCENTRE INFLUENCE ON THE EMPLOYMENT AND POPULATION DENSITY PATTERNS[21]

In this section, it gives a detailed empirical work by analyzing the influence of the identified and characterized ("large-consolidated" and "emerging") subcentres on the population and employment density. To do so, it takes the study case of the Barcelona Metropolitan Region (administrative limit) from 1991 to 2001 and the identified subcentres in the previous section 4 of this paper.

In the literature a usual way to validate the municipalities that are identified as subcentres is to test whether or not they modify the overall employment and population metropolitan density functions after having controlled the distance to CBD. In order to meet the aims of this section (measure the influence of the identified subcentres by using the methodology proposed by Masip 2012b, 2012c) we estimate a polycentric density function with the same objective as the traditional monocentric density function: to explain the value of employment and population density in each municipalities (our case of this work) depending on their location and on their distance to the structuring elements of the city, mainly employment centres (CBD and subcentres). The estimated coefficients of these distances are the so-called gradients and their values and significances measure their influence.

For the case of a polycentric spatial structure, this study has adopted the most commonly model, proposed by McDonald & Prather (1994). This polycentric spatial structure model is formulated as follows:

$$D(d_{CBD}) = D_0 e^{-\alpha d_{CBD} + \beta d_{SUB}^{-1} + \epsilon} \quad (5)$$

Applying neperian logarithm to (5) we obtain:

$$LnD(d_{CBD}) = LnD_0 - \alpha d_{CBD} + \beta d_{SUB}^{-1} + \varepsilon \quad (6)$$

However, the employment and population location is also influenced by the proximity (distance and/or time) of transportation infrastructures. For this reason, in this work, it is computed its effect by extending the previous equation (6) with the average time that the

[21] This section is part of other works carried out by the same author of this paper in order to analyze the subcentre influence on the employment and population patterns. These works are: 1) MASIP TRESSERRA, J. (2012b). Towards a methodology to identify and characterize urban subcentres: Employment Entropy Information versus Density Employment. RSA European Conference 2012: Networked regions and cities in times of fragmentation, developing smart, sustainable and inclusive places. Delft, 13-16 May 2012, pp.1-38 and 2) MASIP TRESSERRA, J. (2012c). Does Employment Density death? Towards a new integrated methodology to identify and characterize Sub-Centres. 52nd European Congress of the Regional Association International (ERSA-RSAI): Regions in Motion, Breaking the Path. Bratislava, 21-25 August 2012, pp.1-36

employed population takes to reach their workplaces from their residences (accessibility to the workplace, residence-to-work commuting time)[22]:

$$\mathrm{LnD}(d_{CBD}) = \mathrm{LnD}_0 - \alpha d_{CBD} + \beta d_{SUB}^{-1} - \mu AT_{R-W} + \varepsilon \quad (7)$$

Where $D(d_{CBD})$ is the employment density at a distance d_{CBD} from the CBD and at a distance d_{SUB} from the subcentre, D_0 is estimated employment density in the CBD, α is the density gradient associated with the distance to the CBD[23], d^{-1}_{SUB} is the inverse of the distance to the nearest subcentre[24], β is corresponding its density gradient[25], AT_{R-W} is the average time of residence-to-work commuting, μ is the density gradient associated with the accessibility to the workplace (infrastructure influence) and ε is the error term.

While the interpretation of the coefficient of the distance to the CBD or the accessibility to the workplace can be done directly, the interpretation of the estimated coefficient for the inverse of the distance of the nearest subcentre is the opposite. For example a positive (negative) coefficient indicates that the employment density growth is less (greater) as we move away from the subcentre under consideration. In addition, a negative and significant accessibility to the workplace gradient ($\mu<0$) would confirm the influence of transportation infrastructure. In that sense, the Figure 26 (appendix 1 of this work) depicts simultaneously the changes in terms of transportation infrastructures and the subcentre identification. The following Table 17 shows the results of the polycentric spatial structure model by using the previous equation (7)[26] according to Masip's (2012b, 2012c) procedure and to the other methodologies to identify subcentres explained in the previous section 4.

The Table 17 highlights all the models are statistical significant and meet the requirements of OLS calibration. The density gradients associated with the distance to the CBD (α) and with the distance to the nearest subcentre (β) are significant for all models and years. The negative sign of (α) gradient implies that the employment density decreases as we move away from the distance to the CBD and the positive sign of (β) gradient also implies that the employment density decreases as we move away from the nearest subcentre. Thus, both CBD and the identified subcentres for all models exert and influence on the employment location pattern and on its density. In addition, the negative and significant accessibility to workplace gradient (μ) for all models and years confirm the influence of transportation infrastructure on the employment location. The negative sign of (μ) gradient entails that the employment density decreases as the average commuting time residence-to-work increases (less accessibility). So, it is expected that the infrastructure gradient and its significance level increase over time showing an increase in their structuring role (the average commuting time residence-to-work in 2001 is low than in 1991 due to the improvements in terms of transportation infrastructure).

[22] The data of average time (in minutes) comes from the Spanish population census in 1991 and 2001 and from the municipality register for 1996, which are produced by the Instituto Nacional de Estadística (INE).
[23] The density gradient expresses the density's percentage variation in the event of a marginal increase of the distance to the center. In an exponential function, the gradient is constant for any distance.
[24] The use of an inverted distance enables multicolinearity problems to be eliminated (McDonald & Prather, 1994). For the same reason, and following the example of studies like those of McMillen & McDonald (1998), McMillen & Lester (2003) and McMillen (2004), in this work has used a single variable that adopts the distance to the nearest subcentre.
[25] Observe that working with a direct distance for the case of the CBD and an inverted distance for the nearest subcentre that means recognizing that the CBD's influence (in our case Barcelona) is greater than that of the subcentre for long distances.
[26] The equation (7) is estimated by ordinary least squares.

Table 17. **Influence of the identified subcentres on the overall employment density from 1991 to 2001 in the Barcelona Metropolitan Region**

Methodology:	McDonald & Prahter			García-López & Muñiz			**Methodology proposed by Masip (2012b, 2012c)**		
OLS gradients estimates model (equation 7)	1991 (1)	1996 (2)	2001 (3)	1991 (4)	1996 (5)	2001 (6)	1991 (7)	1996 (8)	2001 (9)
Ln Do (constant)	10,070***	11,377***	10,966***	9,941***	11,297***	10,881***	9,691***	11,106***	10,860***
(t-value)	(15,897)	(19,507)	(22,460)	(16,516)	(19,288)	(20,176)	(15,808)	(18,922)	(19,890)
β (dist. nearest subcentre)	0,196**	0,362***	0,592***	1,168***	1,519***	1,349***	1,578***	1,603***	1,443***
(t-value)	(2,001)	(4,654)	(6,915)	(3,583)	(4,692)	(4,082)	(3,682)	(5,053)	(4,140)
α (distance to BCN - CBD)	-0,045***	-0,060***	-0,058***	-0,036***	-0,047***	-0,045***	-0,040***	-0,051***	-0,046***
(t-value)	(-8,125)	(-11,787)	(-13,225)	(-6,573)	(-8,688)	(-8,537)	(-7,629)	(-9,867)	(-8,961)
µ (time residence-to-work)	-0,075***	-0,122***	-0,116***	-0,090***	-0,144**	-0,134***	-0,074***	-0,131***	-0,130***
(t-value)	(-3,496)	(-5,818)	(-6,084)	(-4,449)	(-7,041)	(-6,566)	(-3,672)	(-6,445)	(6,350)
Adjusted R2	0,298	0,416	0,459	0,340	0,498	0,487	0,355	0,507	0,501
F	22,339	41,448	46,046	26,793	51,036	50,653	27,646	52,691	51,596
F (sig)	0	0	0	0	0	0	0	0	0

***, **, * variables significant at 99 per cent, 95 per cent and 90 per cent respectively

Source: Masip (2012b, 2012c)

However, the municipalities identified as subcentres by using the Masip's (2012b, 2012c) methodology (by using a double RW and IF Entropy Information functions) are more efficient in the explanation of overall metropolitan employment density that those identified by using the other two methodologies. Although from 1991 to 2001, the R^2 of this model has decreased from 0,507 to 0,501, this model has the higher value of R^2 for all analyzed years in comparison with the R^2 of the other two considered models. Furthermore, the density gradient of subcentre (β) is higher in the case of subcentres detected by using the Masip's procedure that from those prioritized by using McDonald & Prather's method and García-López & Muñiz's method, although in this last case this difference is less relevant (1,578***; 1,603***; 1,443*** in relation to 0,196**; 0,362***; 0,592*** and 1,168***; 1,519***; 1,349*** respectively). Therefore, the municipalities identified as subcentres by Masip's (2012b, 2012c) methodology (double RW and IF Entropy Information functions) have a bigger influence on the employment density function. *This observation, could lead us to ask if the Employment density-based methodologies to identify subcentres are enough efficient for achieve their goal or on the contrary, if the Employment Entropy that synthesizes the urban hierarchy and complexity of the urban systems has emerged as the best methodology to identify urban subcentres (and also employment subcentres).*

In addition, by analyzing the density gradient of the distance to the nearest subcentre and its significance level it is possible to determine if the spatial structure have become more polycentric or dispersed for the analyzed time period. According to García-López & Muñiz (2007) four situations are possible: (i) an increment of the subcentre gradient value as well as its significance level what it means an increment of polycentricity with low scope, (ii) an increment of the subcentre gradient value but its significance level has decreased what it means a urban dynamic towards a polycentricity with low scope and towards a dispersion (low density), (iii) a reduction of the subcentre gradient value and an increment of its significance level, in this case it means a urban dynamic towards a polycentricity with high scope and finally (iv) a reduction the subcentre gradient value as well as its significance level what it entails an unequivocal process towards dispersion.

By analyzing separately the columns (1) to (3), (4) to (6) and (7) to (9) in the previous Table 17, the urban dynamics from 1991 to 2001 in the Barcelona Metropolitan referring with the García-López & Muñiz's work is clear: there was a process towards a more polycentric spatial structure, but depending on the used methodology to identify subcentres entails a different type of polycentrism. The methodology proposed by Masip (2012b, 2012c) (columns 7 to 9) imply a urban dynamics towards a polycentric structure with a high scope (in 1991 the gradient was 1,578*** and the significance level 3,682 and in 2001 the gradient has decreased to 1,443*** and the significance level has increased to 4,140), meanwhile the other methodologies (columns 1 to 3 and columns 4 to 6) imply a polycentric spatial structure with low scope (an increment of the subcentre gradient value and its significance level as well).

In order to obtain more details about this urban dynamics towards a more polycentric spatial structure and knowing what kind of subcentres are behind of such process by using the Masip's (2012b, 2012c) methodology, the previous equation (7) is reformulated as follows and having two polycentric spatial structure models, one for each type of identified subcentre:

$$\mathrm{LnD}(\mathrm{d_{CBD}}) = \mathrm{LnD_0} - \alpha \mathrm{d_{CBD}} + \beta \mathrm{d^{-1}_{SUB\ LARGE-CONSOLIDATED}} - \mu \mathrm{AT_{R-W}} + \varepsilon \quad (8)$$

$$\mathrm{LnD}(\mathrm{d_{CBD}}) = \mathrm{LnD_0} - \alpha \mathrm{d_{CBD}} + \beta \mathrm{d^{-1}_{SUB\ EMERGING}} - \mu \mathrm{AT_{R-W}} + \varepsilon \quad (9)$$

Where $D(d_{CBD})$ is the employment or population density at a distance d_{CBD} from the CBD and at a distance d_{SUB} from the subcentre (large-consolidated or emerging), D_0 is estimated employment or population density in the CBD, α is the density gradient associated with the distance to the CBD, $d^{-1}{}_{SUB}$ is the inverse of the distance to the nearest subcentre (large-consolidated or emerging), β is corresponding its density gradient, AT_{R-W} is the average time of residence-to-work commuting, μ is the density gradient associated with the accessibility to the workplace (infrastructure influence) and $\mathcal{E}$ is the error terms of the equations (8) and (9).

The Table 18 depicts the results of computing the polycentric spatial structure models taking into account separately the influence of the "large-consolidated" and "emerging" subcentres on the overall employment density. The results show that all models are statistical significant and the density gradients associated with the distance to the CBD (α), with the distance to the nearest subcentre (β) (large or emerging) and with the accessibility to the workplace (μ) are significant and having the expected sign for all analyzed years. Thus, both CBD and the "large" and "emerging" subcentres exert and influence on the employment location pattern and on its density. Apart from observing that the accessibility gradient (μ) and its significance level increase over time showing an increase in their structuring role, what it is interesting to observe is that although, from 1991 to 2001 there was an urban dynamic towards a more polycentric spatial structure with high scope as it has explained before, by having a reading from 1996 to 2001 the urban dynamic is reverse and dispersion is tackling to polycentricity: the subcentre gradient was 1,603*** in 1996 (column 2) and in 2001 it has decreased to 1,443*** (column 3) as well as its significance level (5,053 to 4,140). However, this it could explain by observing simultaneously the "large" and "emerging" subcentres gradients and their significance levels in the columns 5, 6, 8 and 9.

The density gradients and the significance levels of the "large" subcentres have been more or less constant from 1991 to 2001 and only from 1991 to 1996 their density gradients have significantly decreased from 1,663*** to 1,394*** but this has not meant a more dispersed urban structure because for the same period their significance levels have increased from

3,900 to 4,402. Thus, the point is that the "emerging" subcentres have increased extremely their density gradients and their significance levels from 1991 to 1996 (1,578*** to 1,612*** and 3,816 to 5,318 respectively) at the point that its gradient and significance level are higher than the "large" subcentres in 1996 for then loosing these increments during the last time period (1,298*** and 3,972 respectively). Consequently, the reduction of the density gradients and the significance levels of the subcentres from 1996 to 2001 (columns 2 and 3) is explained by the emergence of important "emerging" subcentres in 1996 such as Martorell and Rubí (see Figure 6) and then by the loss of weight in terms of density gradients and significant levels for the "emerging" subcentres in 2001 due to the disappearance of the "emerging" subcentre of Vilafranca del Penedès, the transformation of Rubí into "large" subcentre and the inability to the new "emerging" subcentre of Sant Cugat del Vallès to thwart these urban dynamics (see Figure 6 and 7).

Table 18**. Influence of the "emerging" and "large-consolidated" subcentres on the overall employment density from 1991 to 2001 in the Barcelona Metropolitan Region**

OLS gradients estimates models (equations 7, 8, 9)	1991 (7)	1996 (7)	2001 (7)	1991 (8)	1996 (8)	2001 (8)	1991 (9)	1996 (9)	2001 (9)
Ln Do (constant)	9,691***	11,106***	10,860***	9,743***	11,252***	10,938***	9,926***	11,299***	10,976***
(t-value)	(15,808)	(18,922)	(19,890)	(16,085)	(18,944)	(20,113)	(16,548)	(19,711)	(20,247)
β (dist. nearest subcentre)	1,578***	1,603***	1,443***						
(t-value)	(3,682)	(5,053)	(4,140)						
β (dist. nearest large subcentre)				1,663***	1,394***	1,364***			
(t-value)				(3,900)	(4,402)	(4,002)			
β (dist. nearest emerg. subcentre)							1,578***	1,612***	1,298***
(t-value)							(3,816)	(5,318)	(3,972)
α (distance to BCN - CBD)	-0,040***	-0,051***	-0,046***	-0,038***	-0,051***	-0,047***	-0,043***	-0,052***	-0,048***
(t-value)	(-7,629)	(-9,867)	(-8,961)	(-7,249)	(-9,631)	(-9,148)	(-8,256)	(-10,484)	(-9,489)
μ (time residence-to-work)	-0,074***	-0,131***	-0,130***	-0,078***	-0,134***	-0,131***	-0,077***	-0,135***	-0,130***
(t-value)	(-3,672)	(-6,445)	(6,350)	(-3,888)	(-6,460)	(-6,379)	(-3,838)	(-6,708)	(-6,302)
Adjusted R2	0,355	0,507	0,501	0,348	0,489	0,498	0,346	0,514	0,497
F	27,646	52,691	51,596	28,429	49,125	50,917	28,122	54,285	50,774
F (sig)	0	0	0	0	0	0	0	0	0

***, **, * variables significant at 99 per cent, 95 per cent and 90 per cent respectively

Source: Masip (2012b, 2012c)

The Table 19 presents the results of the influence of the "large-consolidated" and "emerging" subcentres on the overall population density. As previously, the results show that all models are statistical significant and both CBD and the "large" and "emerging" subcentres exert and influence on the population location pattern and on its density. However, as the residential activity tends to more dispersed than the economic activity, the influence of "large" and "emerging" subcentres on the population density are less in comparison with the employment density (Table 18): the R^2 of the population density models are quite low in comparison with the R^2 of the employment density models (for example 0,285; 0,398 and 0,362 in relation to 0,355; 0,507 and 0,501 respectively) as well as in terms of density gradients and significance levels of all subcentres (columns 1 to 3), "large" subcentres (columns 4 to 6) and "emerging" subcentres (columns 7 to 9). For example taking into account all identified subcentres their density gradients and significance levels in terms of population density are 1,504***; 1,389***; 1,155*** and 3,557; 4,375; 3,205 in relation to 1,578***; 1,603***; 1,443*** and

3,682; 5,053 ; 4,140 respectively (Table 18). Thus, the urban dynamic from 1991 to 2001 in the Barcelona Metropolitan Region in terms of population depicts a different situation than in terms of employment: from 1991 to 1996 there was a process towards a polycentricity with a higher scope (a reduction of the subcentre gradient values and an increment of its significance levels) and from 1996 to 2001 there was an urban trend towards dispersion due to the reduction of the subcentre gradient values and its significance levels.

Table 19**. Influence of the "emerging" and "large-consolidated" subcentres on the overall population density from 1991 to 2001 in the Barcelona Metropolitan Region**

OLS gradients estimates models (equations 7, 8, 9)	1991 (7)	1996 (7)	2001 (7)	1991 (8)	1996 (8)	2001 (8)	1991 (9)	1996 (9)	2001 (9)
Ln Do (constant)	9,674***	10,471***	10,297***	9,718***	10,587***	10,340***	9,894***	10,639***	10,400***
(t-value)	(15,997)	(17,823)	(18,246)	(16,278)	(17,919)	(18,470)	(16,738)	(18,500)	(18,563)
β (dist. nearest subcentre)	1,504***	1,389***	1,155***						
(t-value)	(3,557)	(4,375)	(3,205)						
β (dist. nearest large subcentre)				1,604***	1,232***	1,138***			
(t-value)				(3,818)	(3,911)	(3,243)			
β (dist. nearest emerg. subcentre)							1,522***	1,393***	1,012***
(t-value)							(3,735)	(4,581)	(2,997)
α (distance to Barcelona - CBD)	-0,033***	-0,039***	-0,036***	-0,032***	-0,039***	-0,036***	-0,036***	-0,041***	-0,037***
(t-value)	(-6,455)	(-7,693)	(-6,690)	(-6,090)	(-7,536)	(-6,809)	(-7,051)	(-8,190)	(-7,120)
µ (time residence-to-work)	-0,036*	-0,065***	-0,066***	-0,039**	-0,067***	-0,067***	-0,039**	-0,068***	-0,066***
(t-value)	(-1,792)	(-3,189)	(-3,118)	(-1,986)	(-3,253)	(-3,149)	(-1,942)	(-3,383)	(-3,096)
Adjusted R2	0,285	0,398	0,362	0,293	0,384	0,363	0,291	0,404	0,357
F	21,460	33,922	29,104	22,303	32,030	29,226	22,027	34,834	28,472
F (sig)	0	0	0	0	0	0	0	0	0

***, **, * variables significant at 99 per cent, 95 per cent and 90 per cent respectively

Source: Masip (2012b, 2012c)

In order to give more explanations about the urban dynamics from 1991 to 2001 in terms of employment and population patterns, it has been calculated the following urban indicators using data from the Barcelona Metropolitan Region at municipal level in 1991, 1996 and 2001, at the time that these selected indicators has been calculated at a disaggregated level: taking into account the whole of the metropolitan region, the CBD (Barcelona), the identified subcentres and the rest of the metropolitan region. The indicators are:

1. Employment (LTL) Entropy Index[27]: this indicator ranges from 0 to ∞ and it measures how the total flows interaction is distributed among nodes. Values close to 0 means that almost trips are toward a single node, hence the region should be strongly monocentric. Conversely, high values indicate strong entropy of flows, hence a strong interaction among nodes, which is compatible which a polycentric urban structure. However, this very general indicator may not strictly describe the degree of polycentricity in terms of employment, but also the dispersion of activities over the territory, which would even describe features of urban sprawl. For that reason, it is

[27] The Employment (LTL) Entropy Index is calculated as follows: $EI_{LTL} = -\sum_{i=1}^{n}(LTL_i \cdot [Ln\,(LTL_i)])$ where EI_{LTL} is the LTL Entropy Index for the whole of the metropolitan system, $(LTL_i \cdot [Ln\,(LTL_i)])$ is the LTL Entropy Information for each analyzed spatial unit (e.g. municipality) and finally LTL_i is the probability (proportion) to find LTL in the analyzed spatial unit (i) (e.g. municipality) within the metropolitan area.

also computed the % LTL Entropy Information and the % LTL in CBD (Barcelona), in subcentres and in the rest of the metropolitan region.

Table 20**. Urban structure dynamics in Barcelona Metropolitan Region 1991-2001**

Urban Structure (Barcelona Metropolitan Region)	1991	1996	2001
LTL Entropy Index (Metropolitan Region)	2,80311	3,02504	3,11043
Mean	0,01730	0,01856	0,01897
Median	0,00667	0,00799	0,00793
Std.Desv.	0,03499	0,03582	0,03581
Population Entropy Index (Metropolitan Region)	3,06342	3,22943	3,33110
Mean	0,01891	0,01981	0,02031
Median	0,00707	0,00820	0,00902
Std.Desv.	0,03900	0,03857	0,03795
IF Entropy Index (Metropolitan Region)	3,20152	3,38897	3,50235
Mean	0,01976	0,02079	0,02136
Median	0,00687	0,00852	0,00888
Std.Desv.	0,03665	0,03704	0,03673
OF Entropy Index (Metropolitan Region)	3,68177	3,85332	3,99287
Mean	0,02273	0,02364	0,02435
Median	0,00917	0,01073	0,01266
Std.Desv.	0,04040	0,03804	0,03623
IF Entropy Index - OF Entropy Index (difference)	-0,48026	-0,46435	-0,49052
Dominance Index	164	164	164
Mean	1	1	1
Median	0,16103	0,20847	0,22016
Std.Desv.	4,97575	4,42506	4,14021
BARCELONA (Municipality - CBD of the Metropolitan Region)	METHOD TO IDENTIFY SUB-CENTRES: RW & IF Entropy Inf.		
Dominance Index	62,44639	55,30324	51,78247
% Dominance Index	38,55%	33,93%	31,57%
LTL Entropy Information	0,35284	0,36283	0,36507
% LTL Entropy Information	12,59%	11,99%	11,74%
LTL in CBD	746.249	640.357	743.594
% LTL in CBD	47,80%	43,05%	41,43%
Population in CBD	1.643.542	1.508.805	1.505.325
% Population in CBD	38,54%	35,69%	34,29%
Population Entropy Information	0,36747	0,36771	0,36701
% Population Entropy Information	12,00%	11,39%	11,02%
SUBCENTRES (within the Metropolitan Region)	METHOD TO IDENTIFY SUB-CENTRES: RW & IF Entropy Inf.		
Number of Subcentres	8	11	12
Dominance Index	26,79658	37,75792	44,59327
% Dominance Index	16,54%	23,16%	27,19%
LTL Entropy Information	0,71106	0,89531	0,99669
% LTL Entropy Information	25,37%	29,60%	32,04%
LTL in subcentres	312.918	363.217	482.885
% LTL in subcentres	20,04%	24,42%	26,90%
Population in subcentres	1.065.835	1.199.595	1.308.642
% Population in subcentres	24,99%	28,37%	29,81%
Population Entropy Information	0,81277	0,96558	1,04111
% Population Entropy Information	26,53%	29,90%	31,25%
REST OF THE METROPOLITAN REGION	METHOD TO IDENTIFY SUB-CENTRES: RW & IF Entropy Inf.		
Dominance Index	72,75703	69,93884	67,62426
% Dominance Index	44,91%	42,91%	41,23%
LTL Entropy Information	1,73920	1,76690	1,74867
% LTL Entropy Information	62,05%	58,41%	56,22%
LTL beyond nuclei	502.151	483.924	568.307
% LTL beyond nuclei	32,16%	32,53%	31,66%
Population beyond nuclei	1.555.045	1.519.648	1.576.446
% Population beyond nuclei	36,47%	35,94%	35,91%
Population Entropy Information	1,88318	1,89614	1,92299
% Population Entropy Information	61,47%	58,71%	57,73%

Source: Masip (2012b, 2012c)

2. Population Entropy Index[28]: this indicator it also ranges from 0 to ∞ and it measures how the population is distributed among nodes. For the same reason, that the previous indicator, it is calculated the % Population Entropy Information and the % Population in CBD (Barcelona), in subcentres (identified by using the methodology proposed by Masip 2012b, 2012c), and in the rest of the metropolitan region.
3. IF (in-commuting flows) Entropy Index and the OF (out-commuting flows) Entropy Index[29]: these indicators measure the relation between the labour and residential market. The IF Entropy Index considers the capacity of a node (IF Entropy Information) to be hierarchical in terms of being an important node in terms of employment and on the contrary, as the OF Entropy Index considers the workers that are leaving their residence to work in other places, a higher value of OF Entropy Index entails that this node (OF Entropy Information) would be significant in terms of being a residence node. Thus, as the labour market tends to be more concentrated than the residential one (more dispersed), the OF Entropy Index tends to have a higher value of Entropy Index. Therefore the higher is the difference between these two indexes the higher is the separation between the residential and labour markets.
4. Dominance Index (DI): as it has explained in the previous section 4.1.

The previous Table 20 confirms what we have observed previously (Tables 18 and 19) by analyzing the density gradients and the significance levels of the identified subcentres: a more polycentric structure in 2001 but in which this urban dynamic towards polycentrism has been more accentuated from 1991 to 1996 than 1996 to 2001. The increment of Employment (LTL) Entropy Index (2,80311 to 3,11043) and Population Entropy Index (3,06342 to 3,33110) from 1991 to 2001 (Table 11) combined with the increment of % Population, % LTL, and Dominance Index (DI) in the identified subcentres as well as the reduction of these indicators in the CBD (Barcelona) and in the rest of the metropolitan area leads to a more polycentric structure in terms of employment and population. However, in terms of population is where exists a quite difference in comparison with the results that this study has found before (Table 19): meanwhile by analyzing the population density gradients and the significance levels of the identified subcentres the results lead to a more dispersed are from 1996 to 2001, by analyzing the share of population and the share of population Entropy Information in CBD, subcentres and the rest of the metropolitan in the same time period the results entail a reverse conclusion. This it could explain due to from 1996 to 2001 the areas (municipalities) that are nearby of the identified subcentres has been increased more proportionally their population and consequently the population density gradients of the identified subcentres have decreased.

7. CONCLUSIONS

In this work, it has been identified the employment and population centres at regional (Catalonia) and at metropolitan (Barcelona Metropolitan Region) scale by using the methodology to identify subcentres proposed by Masip (2012b, 2012c). Different from other methodologies that are mainly based on morphological measures (e.g. employment density), the method proposed by Masip (2012b, 2012c) focus on the hierarchical functional

[28] The Population Entropy Index is formulated as follows: $EI_{POP} = -\sum_{i=1}^{n}(POP_i \cdot [Ln\,(POP_i)])$ the interpretation of the expression is the same as the Employment (LTL) Entropy Index.

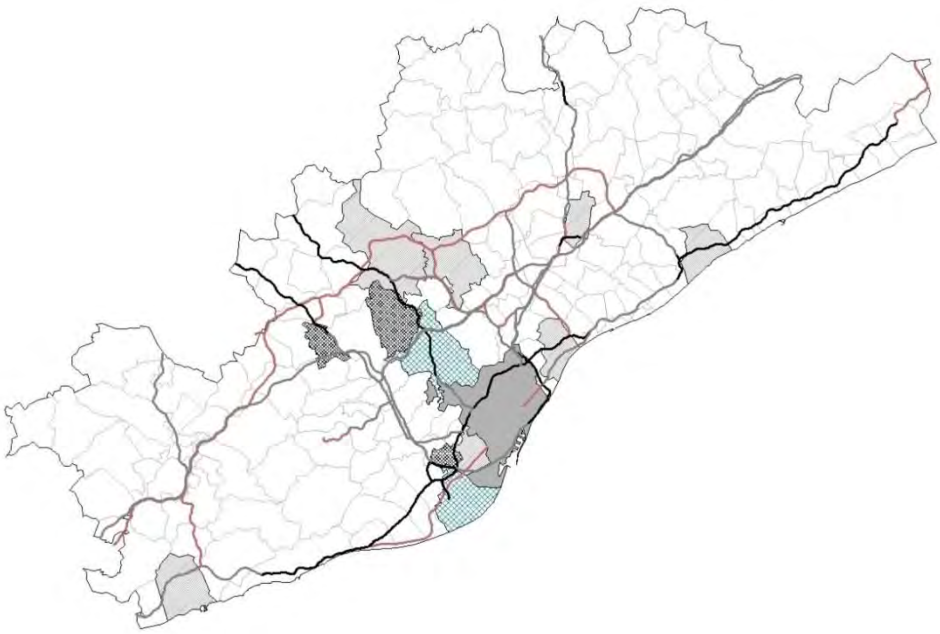
[29] The IF and OF Entropy Index are calculated as follows: $EI_{IN-FLOWS} = -\sum_{i=1}^{n}(IF_i \cdot [Ln\,(IF_i)])$ and $EI_{OUT-FLOWS} = -\sum_{i=1}^{n}(OF_i \cdot [Ln\,(OF_i)])$ the interpretation is the same as the other Entropy expressions.

interactions among nodes and on the different origin of the subcentre formation. Thus, this methodology is suitable with the hierarchic and complex European urban systems where centres have been emerged mostly as a result of an integration or coalescence process as well as suitable with the decentralisation process from a single and congested Central Business District (CBD). Consequently, the Masip's methodology identifies subcentres that are "places to work" (employment subcentres) and subcentres that are "places to work and live" (urban subcentres). That means according to the Masip's methodology, distinguish those sub-centres that only attract workers (in-commuting flows) or retain their resident workers (significant local labour market) to those sub-centres that are able to attract flows and retain their resident employed population at the same time.

The results suggest that in comparison with identifying sub-centres by using the mainly Employment density methodologies, the municipalities identified as sub-centres by using the Masip's (2012b, 2012c) method are more dominant in terms of in-commuting flows, more self-contained, and its influence on the urban structure are more significant, entailing a more polynucleated metropolitan structure. This conclusion, according to Masip (2012b, pàg.32): "could lead us to ask if the Employment density-based methodologies to identify subcentres are enough efficient for achieve their goal and if the Employment Entropy that synthesizes the urban hierarchy and complexity of the urban systems has emerged as the best methodology to identify urban subcentres. *So, does employment density death to identify urban subcentres?"*.

8. APPENDIX 1

Figure 26**. Subcentres and changes of transportation infrastructure from 1991 to 2001 in the Barcelona Metropolitan Region**



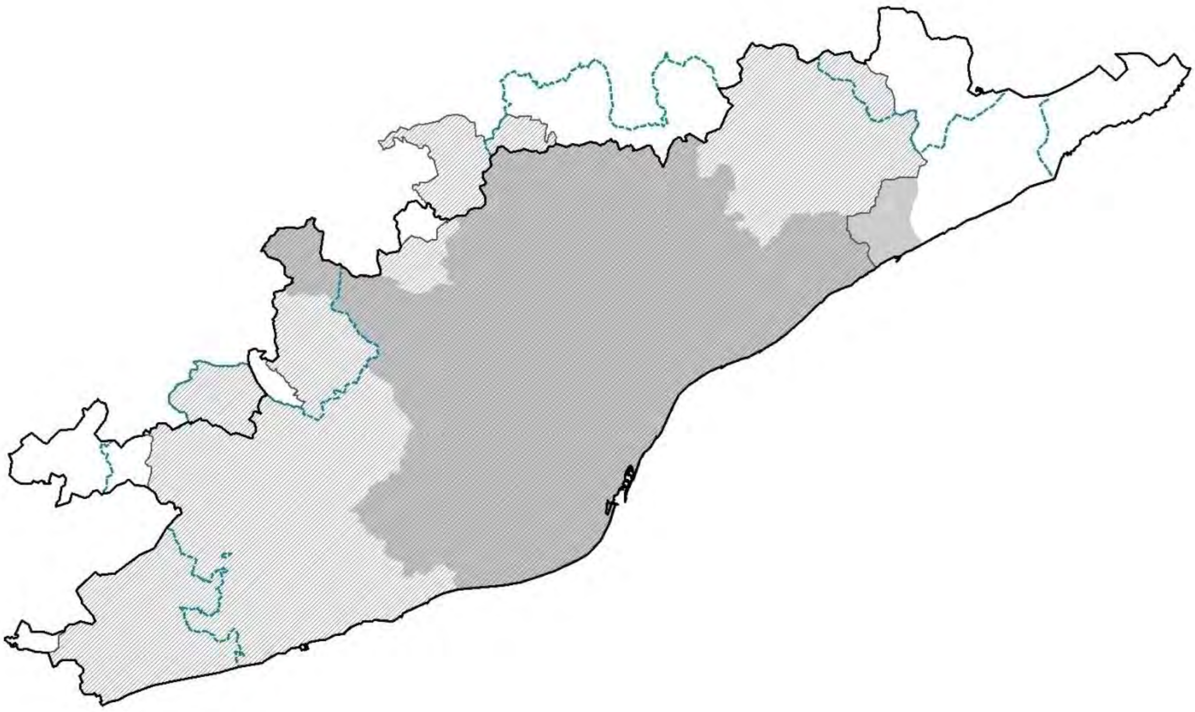
Note: in grey, highways and freeways in 1991; in dark, highways and freeways in 1996 and in red, highways and freeways by 2026 according to the Territorial Plan of Barcelona Metropolitan Region. Referring with the subcentres identified in 2001: in grey, the subcentres and CBD (Barcelona) in 1991, in dark the subcentres that appeared in 1996 and in blue, the last two new subcentres identified in 2001.

Source: Masip (2012b, 2012c)

9. APPENDIX 2

In this section, by using the methodology to identify subcentres proposed by Masip (2012b, 2012c) the subcentres in the Barcelona Metropolitan Region (functional limit) from 1991 to 2001 are detected. In order to define these functional limits of the Barcelona Metropolitan Region has used the functional delimitations used in Masip (2011a) and Masip & Roca (2012a). These functional delimitations of the Barcelona Metropolitan Region from 1991 to 2001 defined in Masip (2011a) and Masip & Roca (2012a) are based on the interaction value proposed by Roca & Moix (2005).

Figure 27**. Functional Limits of the Barcelona Metropolitan Region from 1991 to 2001 by using the Interaction Value proposed by Roca & Moix (2005)**



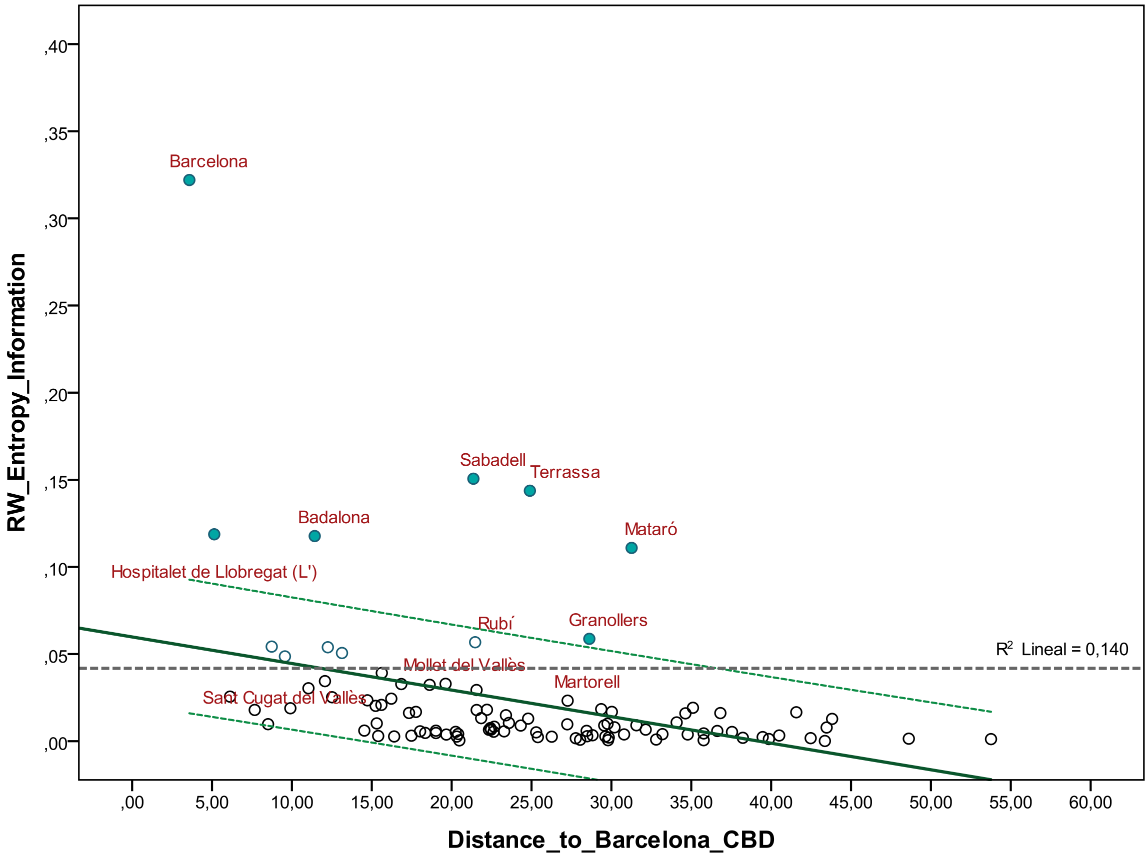
Metropolitan Limit	Area (km^2)	Population	LTL (working places)	nº subsystems	nº protosystems	nº municipalities
1991	1807,83	4.018.099	1.467.321	16	29	100
1996	3332,85	4.200.997	1.478.154	22	38	164
2001	3759,96	4.530.254	1.854.082	24	44	184
RMB						164

Source: Own Elaboration

Source: Masip (2011a) and Masip & Roca (2012a)

In the following Figures 28–39 and Table 21, the results suggest a) in increment of the identified subcentres (from 7 in 1991 to 14 in 2001), due mainly to the extensions of the metropolitan region of Barcelona, b) a more polycentric metropolitan region: the process of descentralization leads to urban dynamics of concentrated descentralization instead of dispersion, (see Figures 28-39 and Table 21), and finally c) in increment of the existence separation between the two main urban markets: the residential and the job market, due to the more proportional increment of the OF (out-commuting flows) Entropy Index in comparison with the IF (in-commuting flows) Entropy Index from 1991 to 2001 (see Table 21).

Figure 28. **Lineal Regression: RW (resident workers) Entropy Information function and Distance to Barcelona. Identifying the positive residuals (municipalities) in 1991**



Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	,060	,010		5,874	,000
	Distance_to_Barcelona_CBD	-,002	,000	-,375	-4,000	,000

a. Dependent Variable: RW_Entropy_Information

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	,024	1	,024	15,997	,000[a]
	Residual	,149	98	,002		
	Total	,173	99			

a. Predictors: (Constant), Distance_to_Barcelona_CBD
b. Dependent Variable: RW_Entropy_Information

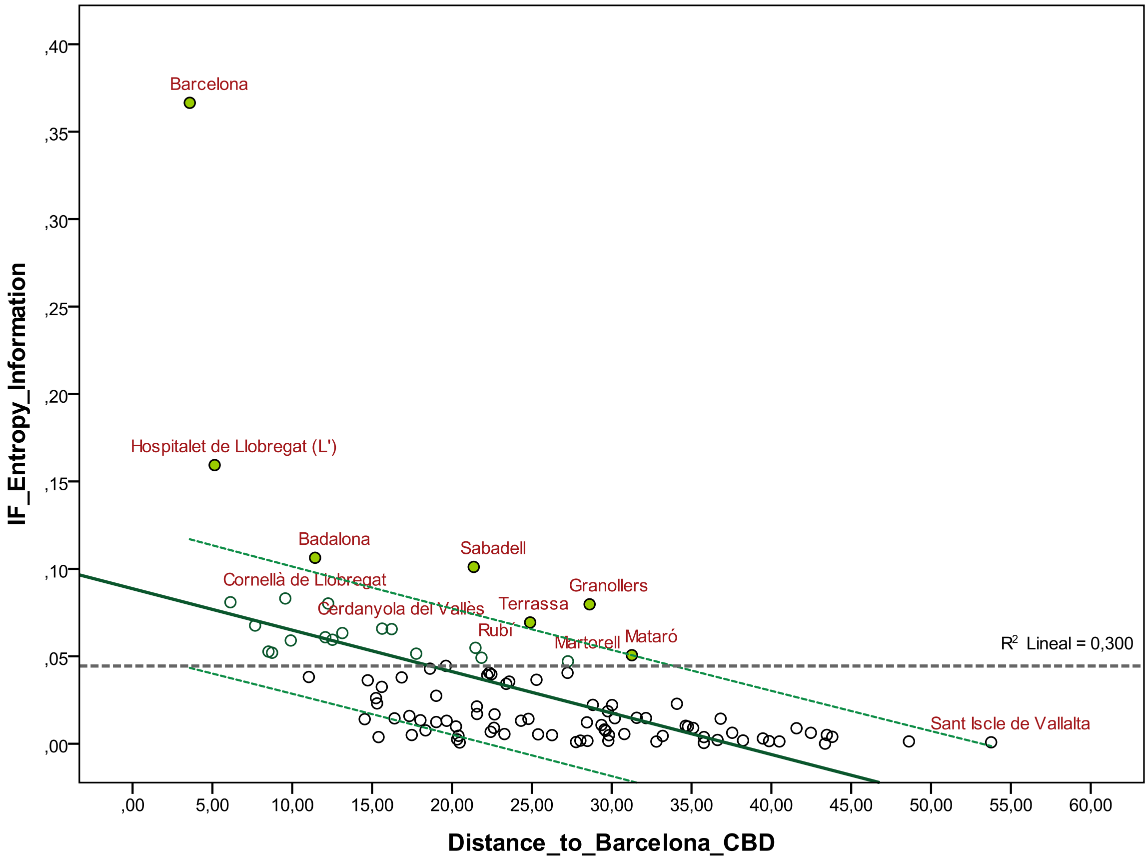
Residuals Statistics[a]

	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	-,022140	,054362	,022188	,0156694	100
Residual	-,0370913	,2676533	,0000000	,0387837	100
Std. Predicted Value	-2,829	2,053	,000	1,000	100
Std. Residual	-,952	6,866	,000	,995	100

a. Dependent Variable: RW_Entropy_Information

Source: Own Elaboration

Figure 29. **Lineal Regression: IF (in-commuting flows) Entropy Information function and Distance to Barcelona. Identifying the positive residuals (municipalities) in 1991**



Coefficients[a]

Model		Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.
1	(Constant)	,089	,010		9,079	,000
	Distance_to_Barcelona_CBD	-,002	,000	-,548	-6,485	,000

a. Dependent Variable: IF_Entropy_Information

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	,059	1	,059	42,060	,000[a]
	Residual	,137	98	,001		
	Total	,196	99			

a. Predictors: (Constant), Distance_to_Barcelona_CBD
b. Dependent Variable: IF_Entropy_Information

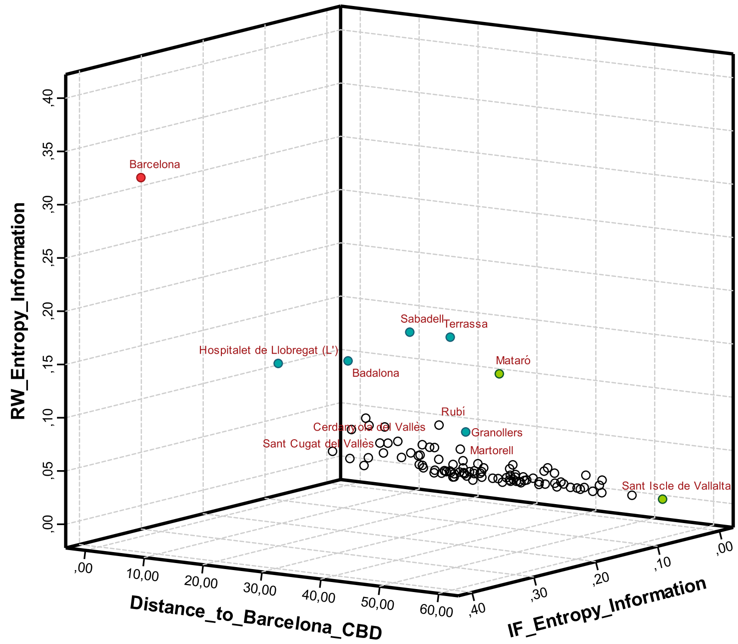
Residuals Statistics[a]

	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	-,038765	,080176	,030153	,0243619	100
Residual	-,0483266	,2863296	,0000000	,0371866	100
Std. Predicted Value	-2,829	2,053	,000	1,000	100
Std. Residual	-1,293	7,661	,000	,995	100

a. Dependent Variable: IF_Entropy_Information

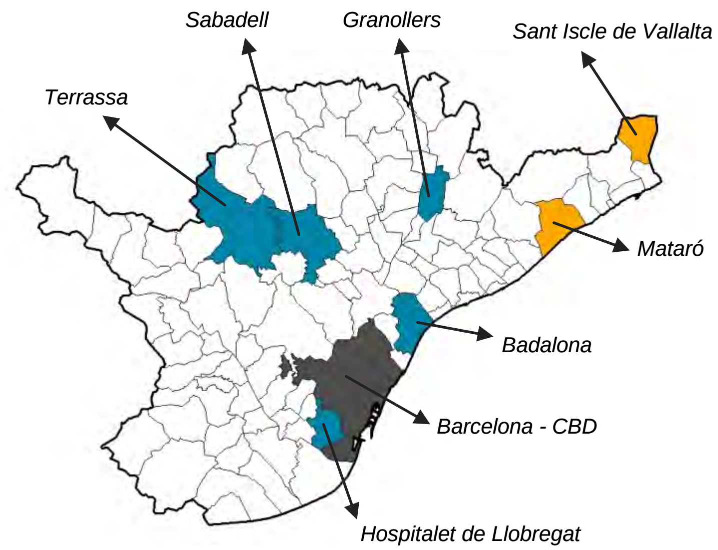
Source: Own Elaboration

Figure 30. **Subcentres and their characterization in "emerging" and "large-consolidated" for the Barcelona Metropolitan System in 1991 by using Masip's (2012b, 2012c) method**



$$RW(Entropy)Inf._x = C + \beta Distance_{x-CBD}$$

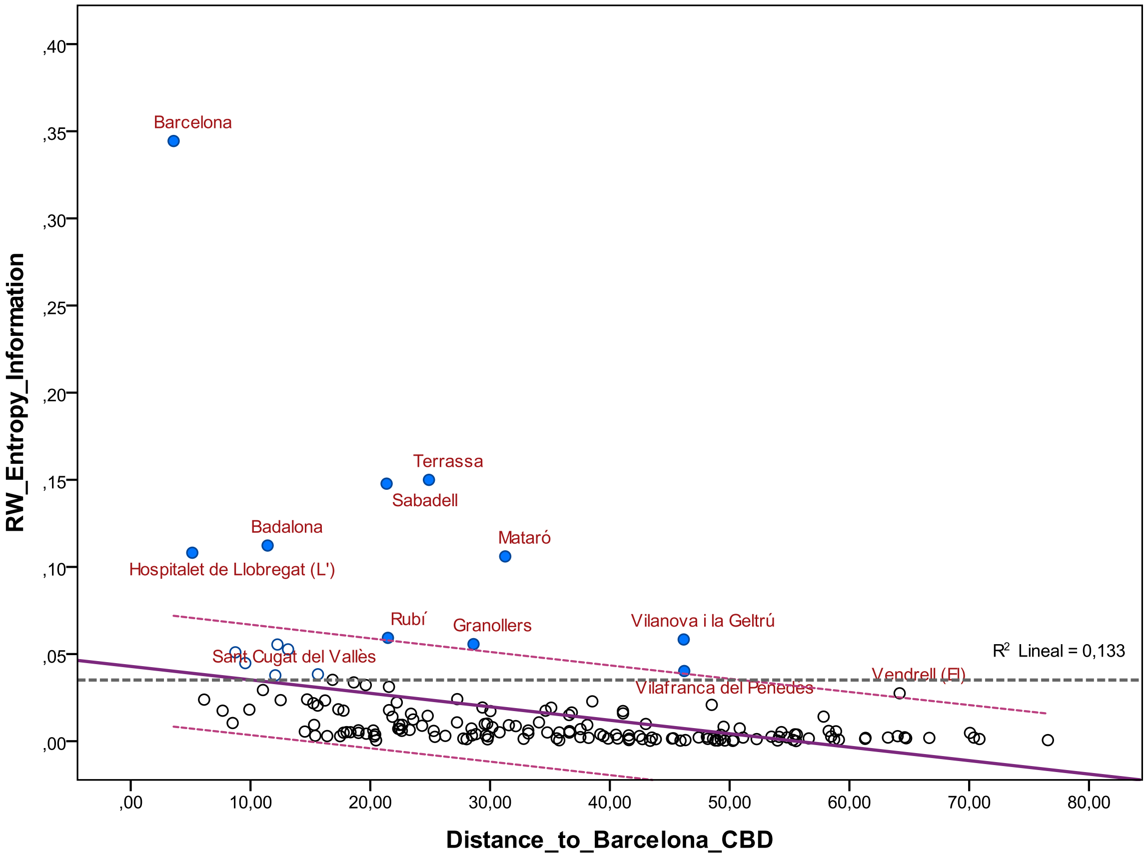
$$IF(Entropy)Inf._x = C + \beta Distance_{x-CBD}$$



Barcelona Metropolitan System 1991	Municipality (name)	RW Entropy Information	IF Entropy Information	Sub-centre Category
	Barcelona	1	1	CBD
	Sabadell	1	1	Large-Consolidated
	Terrassa	1	1	Large-Consolidated
	Mataró	1	0	Emerging
	Badalona	1	1	Large-Consolidated
	Hospitalet de Llobregat (L')	1	1	Large-Consolidated
	Granollers	1	1	Large-Consolidated
	Sant Iscle de Vallalta	0	1	Emerging
	7 urban sub-centres + CBD	5 "Large-Consolidated" and 2 "Emerging" identified urban sub-centres		

Source: Own Elaboration

Figure 31. **Lineal Regression: RW (resident workers) Entropy Information function and Distance to Barcelona. Identifying the positive residuals (municipalities) in 1996**



Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	,043	,006		7,161	,000
	Distance_to_Barcelona_ CBD	-,001	,000	-,365	-4,985	,000

a. Dependent Variable: RW_Entropy_Information

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	,027	1	,027	24,849	,000[a]
	Residual	,174	162	,001		
	Total	,201	163			

a. Predictors: (Constant), Distance_to_Barcelona_CBD
b. Dependent Variable: RW_Entropy_Information

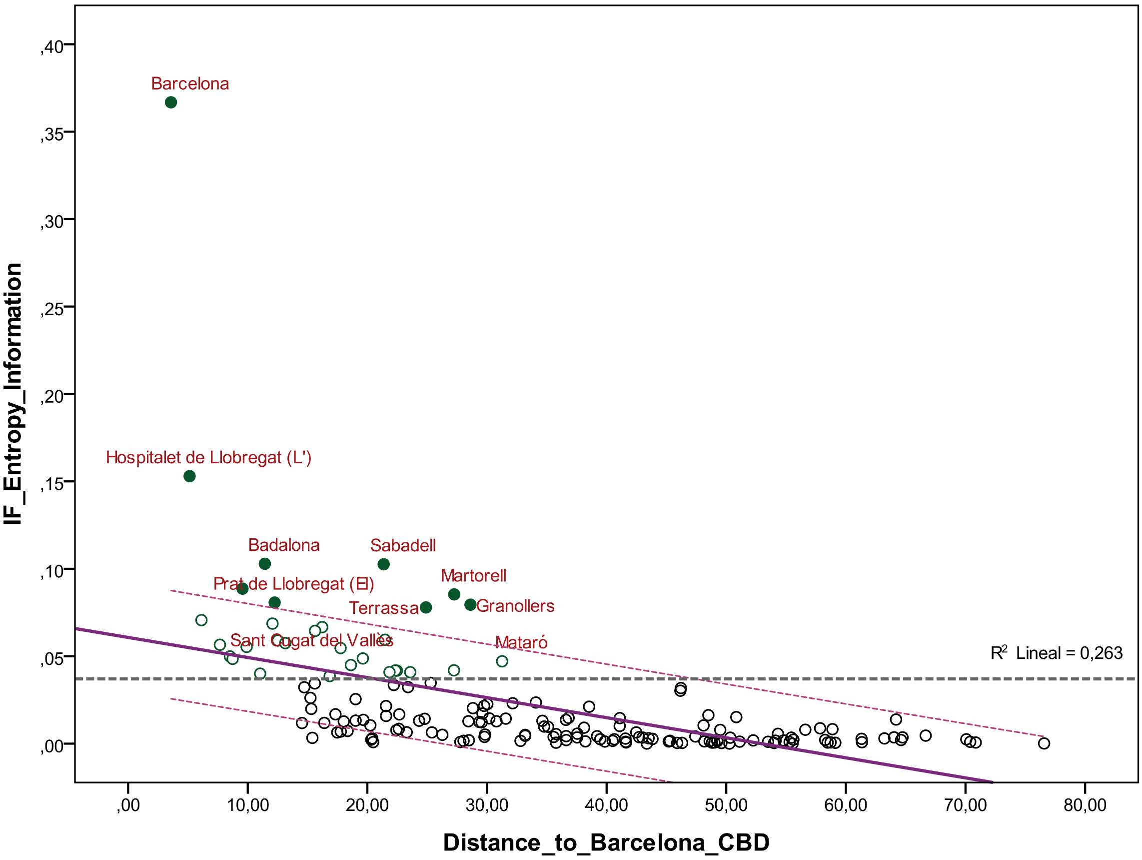
Residuals Statistics[a]

	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	-,016229	,040156	,015904	,0127988	164
Residual	-,0278877	,3042377	,0000000	,0326796	164
Std. Predicted Value	-2,511	1,895	,000	1,000	164
Std. Residual	-,851	9,281	,000	,997	164

a. Dependent Variable: RW_Entropy_Information

Source: Own Elaboration

Figure 32**. Lineal Regression: IF (in-commuting flows) Entropy Information function and Distance to Barcelona. Identifying the positive residuals (municipalities) in 1996**



Coefficients[a]

Model		Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.
1	(Constant)	,061	,006		10,415	,000
	Distance_to_Barcelona_CBD	-,001	,000	-,513	-7,610	,000

a. Dependent Variable: IF_Entropy_Information

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	,059	1	,059	57,907	,000[a]
	Residual	,165	162	,001		
	Total	,224	163			

a. Predictors: (Constant), Distance_to_Barcelona_CBD
b. Dependent Variable: IF_Entropy_Information

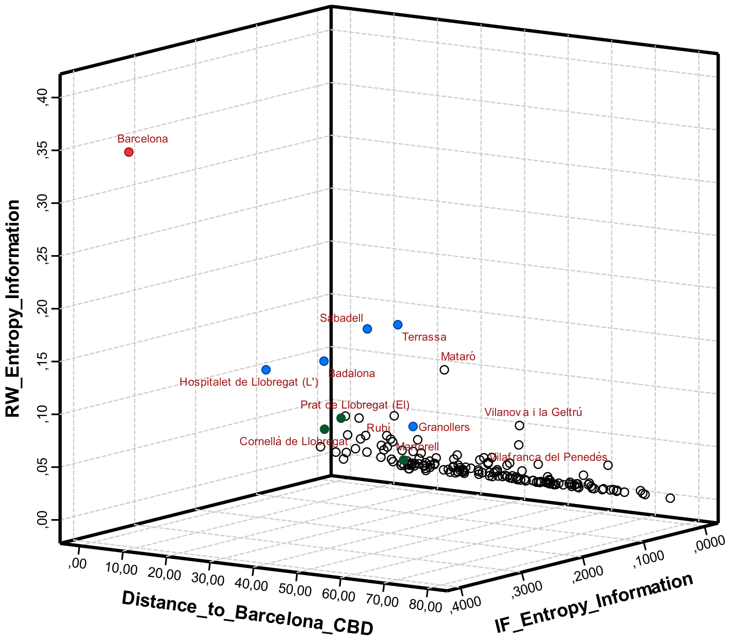
Residuals Statistics[a]

	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	-,027118	,056630	,020609	,0190098	164
Residual	-,0397604	,3101651	,0000000	,0317957	164
Std. Predicted Value	-2,511	1,895	,000	1,000	164
Std. Residual	-1,247	9,725	,000	,997	164

a. Dependent Variable: IF_Entropy_Information

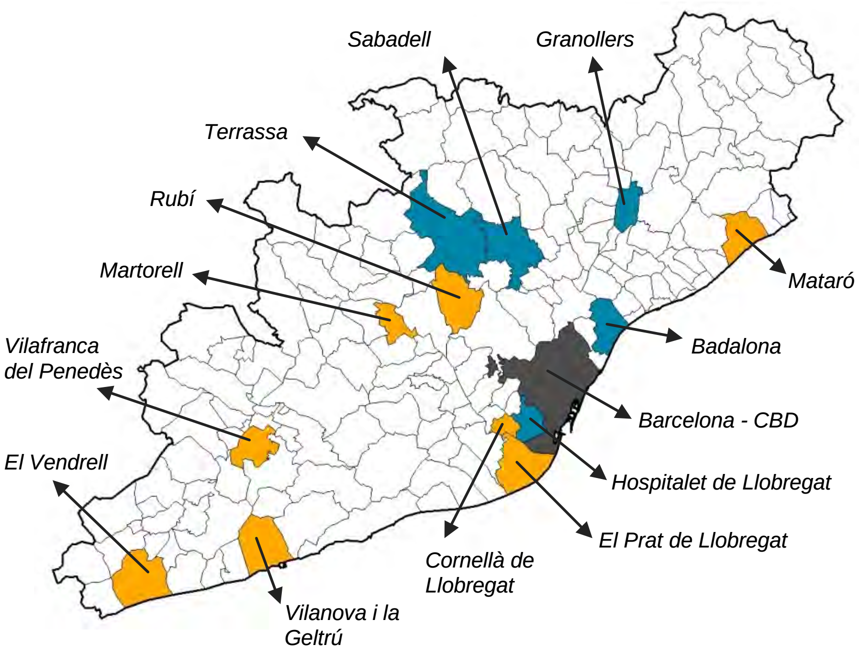
Source: Own Elaboration

Figure 33. **Subcentres and their characterization in "emerging" and "large-consolidated" for the Barcelona Metropolitan System in 1996 by using Masip's (2012b, 2012c) method**



$$RW(Entropy)Inf._x = C + \beta Distance_{x-CBD}$$

$$IF(Entropy)Inf._x = C + \beta Distance_{x-CBD}$$

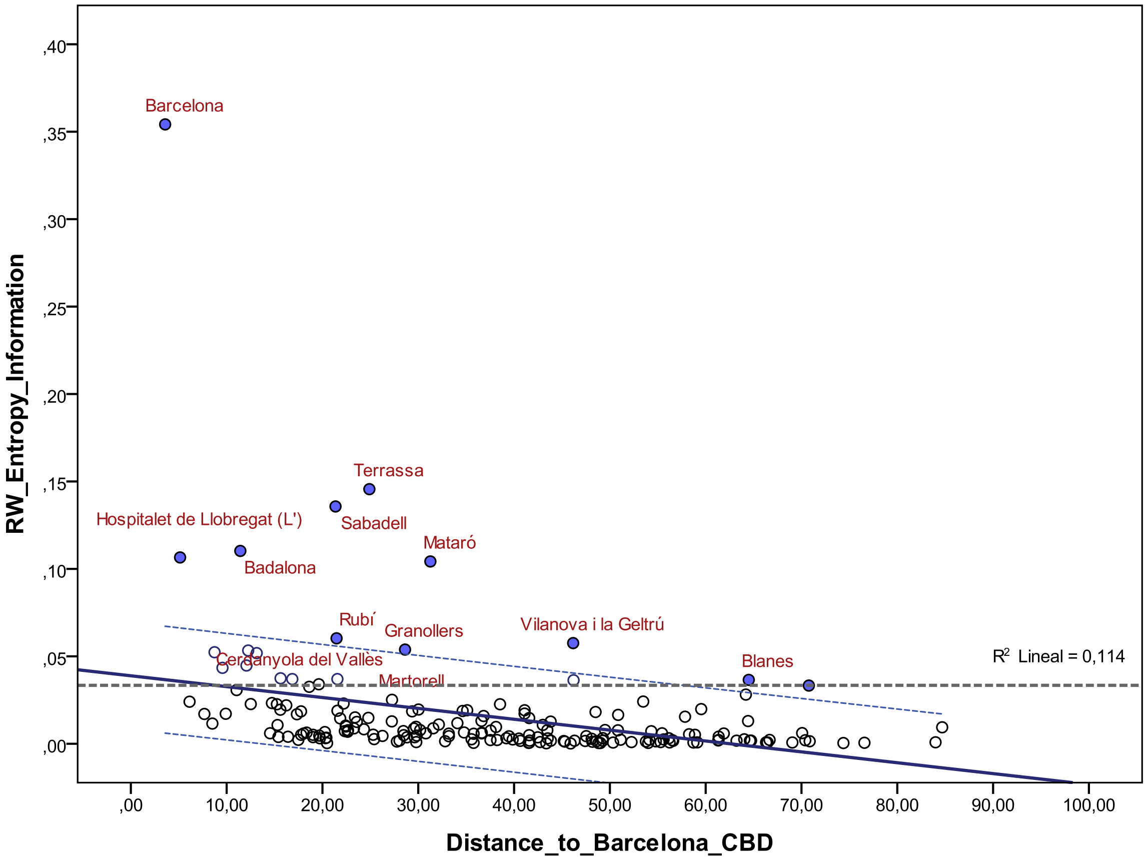


Barcelona Metropolitan System 1996

Municipality (name)	RW Entropy Information	IF Entropy Information	Sub-centre Category
Barcelona	1	1	CBD
Terrassa	1	1	Large-Consolidated
Sabadell	1	1	Large-Consolidated
Mataró	1	0	Emerging
Badalona	1	1	Large-Consolidated
Hospitalet de Llobregat (L')	1	1	Large-Consolidated
Vilanova i la Geltrú	1	0	Emerging
Granollers	1	1	Large-Consolidated
Vendrell (El)	1	0	Emerging
Vilafranca del Penedès	1	0	Emerging
Rubí	1	0	Emerging
Martorell	0	1	Emerging
Cornellà de Llobregat	0	1	Emerging
Prat del Llobregat (El)	0	1	Emerging
13 urban sub-centres + CBD	5 "Large-Consolidated" and 8 "Emerging" identified urban sub-centres		

Source: Own Elaboration

Figure 34. **Lineal Regression: RW (resident workers) Entropy Information function and Distance to Barcelona. Identifying the positive residuals (municipalities) in 2001**



Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients		
		B	Std. Error	Beta	t	Sig.
1	(Constant)	,039	,005		7,239	,000
	Distance_to_Barcelona_CBD	-,001	,000	-,337	-4,833	,000

a. Dependent Variable: RW_Entropy_Information

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	,023	1	,023	23,357	,000[a]
	Residual	,181	182	,001		
	Total	,204	183			

a. Predictors: (Constant), Distance_to_Barcelona_CBD
b. Dependent Variable: RW_Entropy_Information

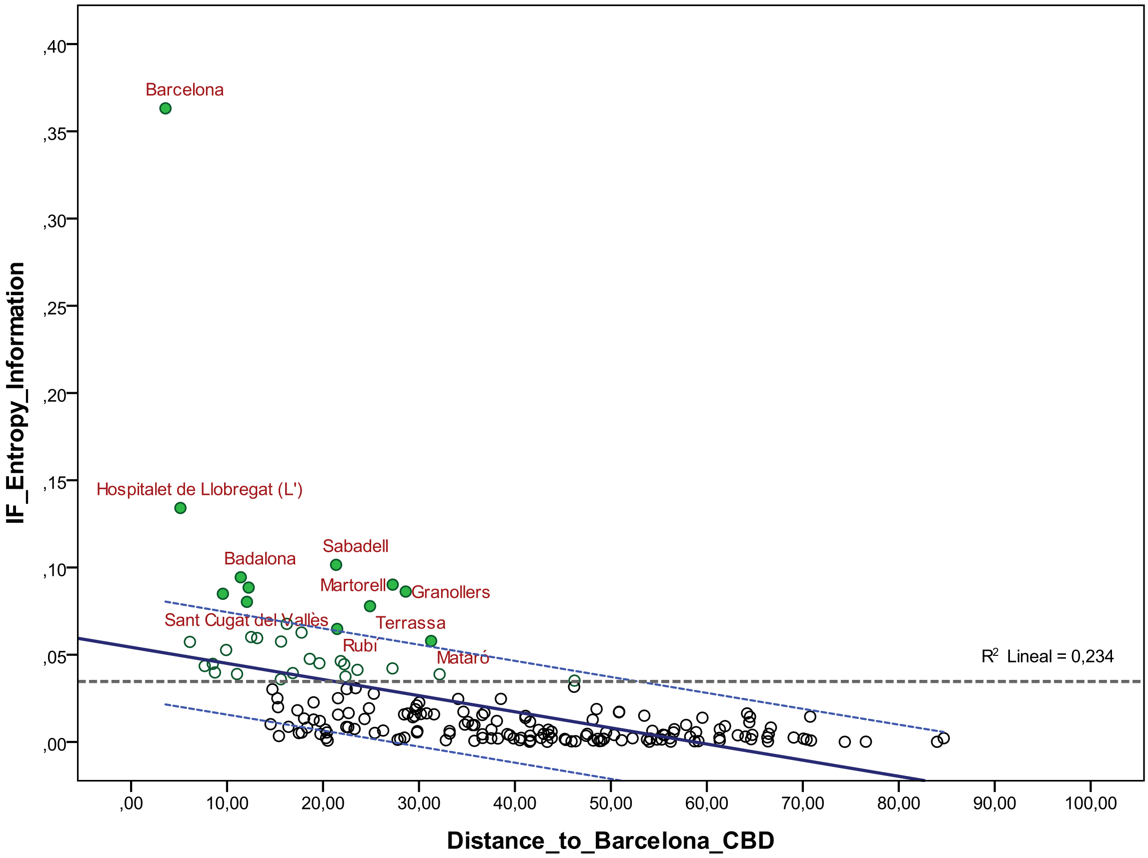
Residuals Statistics[a]

	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	-,013753	,036655	,015483	,0112718	184
Residual	-,0257492	,3175312	,0000000	,0314643	184
Std. Predicted Value	-2,594	1,878	,000	1,000	184
Std. Residual	-,816	10,064	,000	,997	184

a. Dependent Variable: RW_Entropy_Information

Source: Own Elaboration

Figure 35. **Lineal Regression: IF (in-commuting flows) Entropy Information function and Distance to Barcelona. Identifying the positive residuals (municipalities) in 2001**



Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	,054	,005		10,482	,000
	Distance_to_Barcelona_CBD	-,001	,000	-,484	-7,456	,000

a. Dependent Variable: IF_Entropy_Information

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	,051	1	,051	55,599	,000[a]
	Residual	,168	182	,001		
	Total	,220	183			

a. Predictors: (Constant), Distance_to_Barcelona_CBD
b. Dependent Variable: IF_Entropy_Information

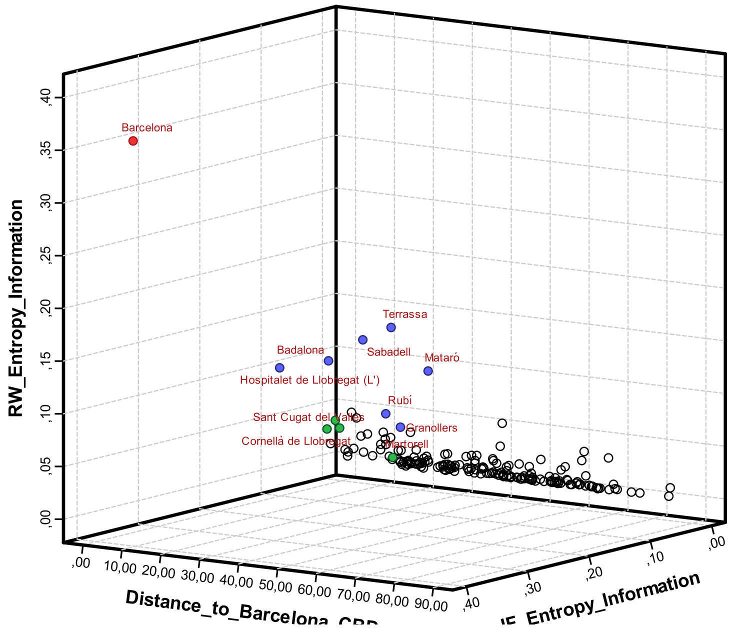
Residuals Statistics[a]

	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	-,024016	,050973	,019476	,0167687	184
Residual	-,0366398	,3121814	,0000000	,0303392	184
Std. Predicted Value	-2,594	1,878	,000	1,000	184
Std. Residual	-1,204	10,262	,000	,997	184

a. Dependent Variable: IF_Entropy_Information

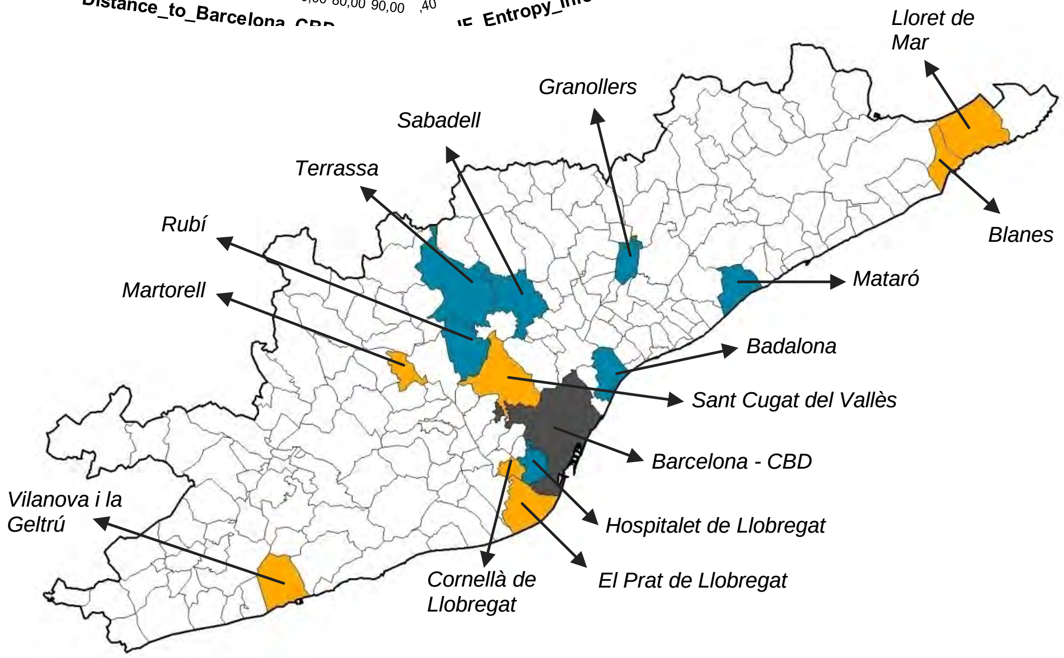
Source: Own Elaboration

Figure 36. **Subcentres and their characterization in “emerging” and “large-consolidated” for the Barcelona Metropolitan System in 2001 by using Masip’s (2012b, 2012c) method**



$$\text{RW(Entropy)Inf.}_x = C + \beta \text{Distance}_{x-CBD}$$

$$\text{IF(Entropy)Inf.}_x = C + \beta \text{Distance}_{x-CBD}$$



Barcelona Metropolitan System 2001	Municipality (name)	RW Entropy Information	IF Entropy Information	Sub-centre Category
	Barcelona	1	1	CBD
	Terrassa	1	1	Large-Consolidated
	Sabadell	1	1	Large-Consolidated
	Mataró	1	1	Large-Consolidated
	Badalona	1	1	Large-Consolidated
	Hospitalet de Llobregat (L')	1	1	Large-Consolidated
	Vilanova i la Geltrú	1	0	Emerging
	Lloret de Mar	1	0	Emerging
	Blanes	1	0	Emerging
	Rubí	1	1	Large-Consolidated
	Granollers	1	1	Large-Consolidated
	Martorell	0	1	Emerging
	Prat de Llobregat (El)	0	1	Emerging
	Cornellà de Llobregat	0	1	Emerging
	Sant Cugat del Vallès	0	1	Emerging
	14 urban sub-centres + CBD	7 "Large-Consolidated" and 7 "Emerging" identified urban sub-centres		

Source: Own Elaboration

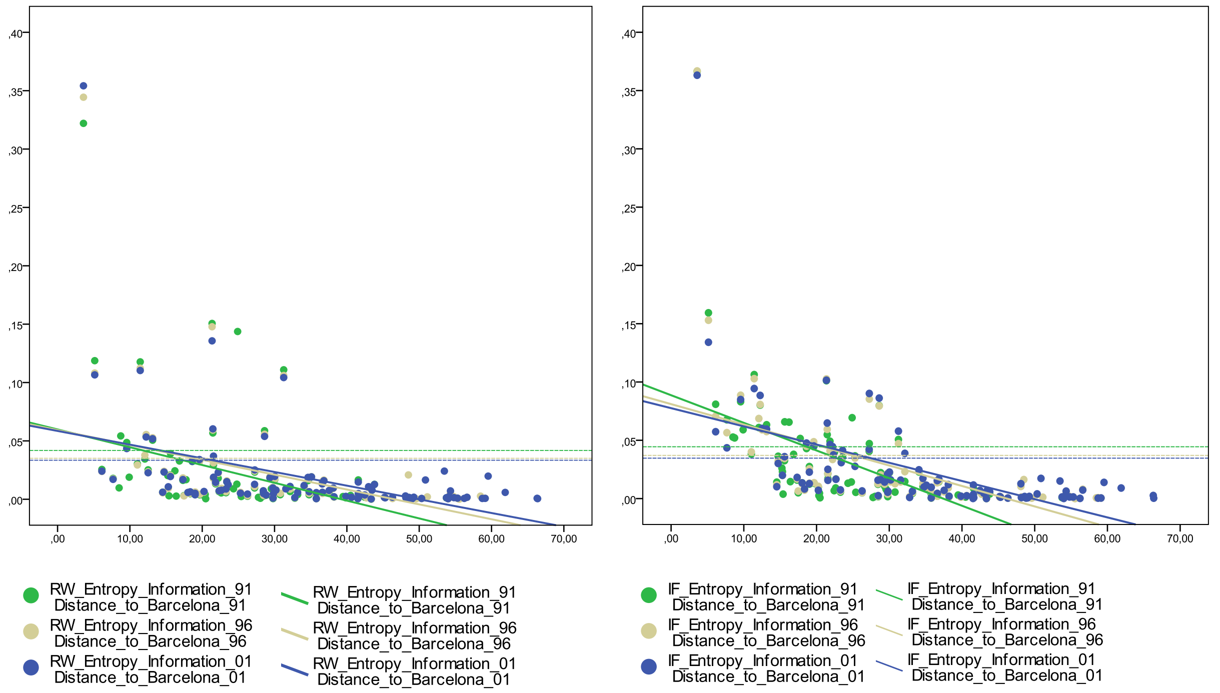
Figure 37. **Summarize of Subcentres identification and their characterization in “emerging” and “large-consolidated” for the Barcelona Metropolitan System in 1991 to 2001 by using Masip’s (2012b, 2012c) method**

Municipality (name)	1991	1996	2001	% Increment LTL (2001-1991) in comparison with their LTLs in 1991	Distance to CBD (Barcelona)
Barcelona	CBD	CBD	CBD	1,06%	-
Sabadell	Large-Consolidated	Large-Consolidated	Large-Consolidated	10,56%	21,36
Terrassa	Large-Consolidated	Large-Consolidated	Large-Consolidated	26,71%	24,90
Mataró	Emerging	Emerging	Large-Consolidated	17,17%	31,26
Badalona	Large-Consolidated	Large-Consolidated	Large-Consolidated	11,16%	8,32
Hospitalet de Llobregat (L')	Large-Consolidated	Large-Consolidated	Large-Consolidated	5,21%	5,14
Granollers	Large-Consolidated	Large-Consolidated	Large-Consolidated	30,36%	28,62
Sant Iscle de Vallalta	Emerging				53,76
Vilanova i la Geltrú		Emerging	Emerging		46,17
Vendrell (El)		Emerging			64,19
Vilafranca del Penedès		Emerging			46,21
Rubí		Emerging	Large-Consolidated	44,80%	21,47
Martorell		Emerging	Emerging	153,16%	27,26
Cornellà de Llobregat		Emerging	Emerging	26,80%	9,56
Prat de Llobregat (El)		Emerging	Emerging	39,72%	12,25
Lloret de Mar			Emerging		70,77
Blanes			Emerging		64,50
Sant Cugat del Vallès			Emerging	87,30%	12,07
	7 urban sub-centres	13 urban sub-centres	14 urban sub-centres	Average (26,36%)	Average (37,64)

*Vilanova i la Geltrú, El Vendrell, Vilafranca del Penedés, Lloret de Mar and Blanes were not within the Barcelona Metropolitan System in 1991

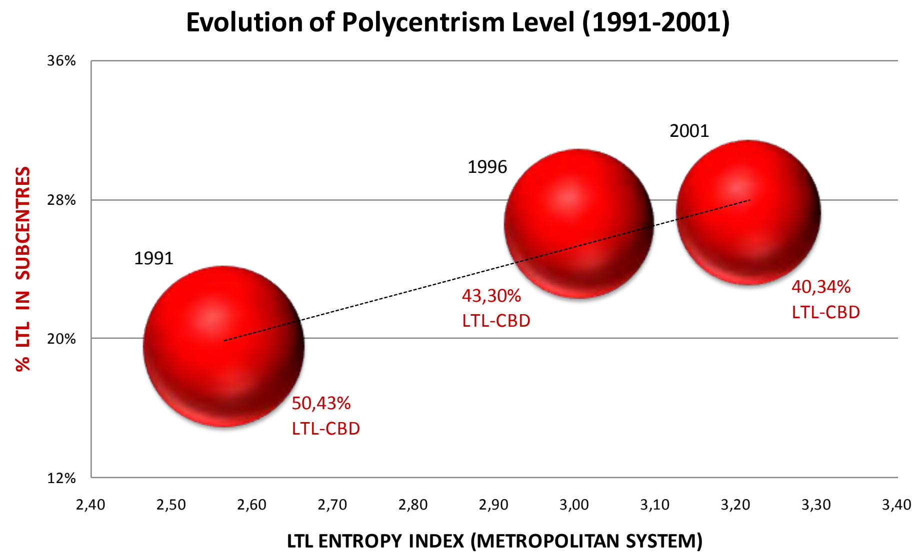
Source: Own Elaboration

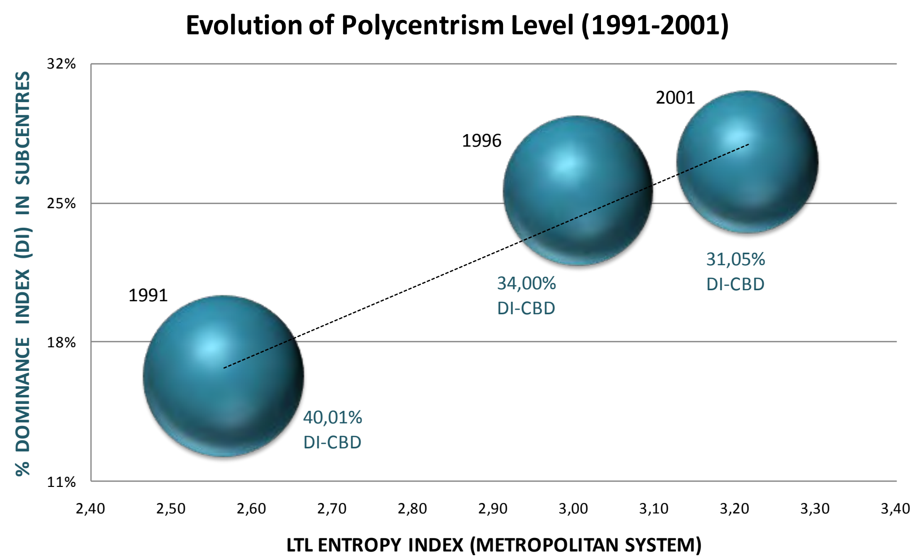
Figure 38. **Regression Models: Dynamics of IF (in-commuting flows) and RW (resident workers) Entropy Information in functions and Distance to Barcelona from 1991 to 2001 for the Barcelona Metropolitan System by using Masip’s (2012b, 2012c) method**

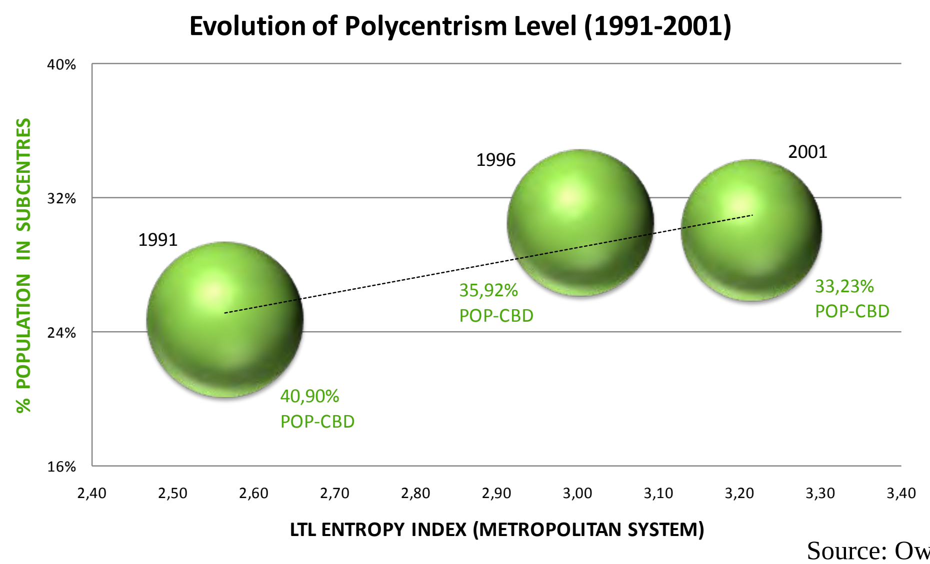


Source: Own Elaboration

Figure 39. **Measuring the polycentricity level at Municipality territorial scale from 1991 to 2001 for the Barcelona Metropolitan System by using the morphological and functional indicators proposed by Masip (2011a, 2011b, 2011b)**







Source: Own Elaboration

Table 21. Urban structure dynamics in Barcelona Metropolitan System 1991-2001

Urban Structure (Barcelona Metropolitan System)		1991	1996	2001
LTL Entropy Index (Metropolitan System)		2,56466	3,00484	3,21571
	Mean	0,02565	0,01832	0,01748
	Median	0,01339	0,00696	0,00731
	Std.Desv.	0,04251	0,03582	0,03386
Population Entropy Index (Metropolitan System)		2,82137	3,21005	3,44081
	Mean	0,02821	0,01957	0,01870
	Median	0,01156	0,00759	0,00837
	Std.Desv.	0,04817	0,03861	0,03571
RW Entropy Index (Metropolitan System)		2,21876	2,60821	2,84885
	Mean	0,02219	0,01590	0,01548
	Median	0,00899	0,00517	0,00590
	Std.Desv.	0,04183	0,03510	0,03342
IF Entropy Index (Metropolitan System)		3,01530	3,37984	3,58361
	Mean	0,03015	0,02061	0,01948
	Median	0,01457	0,00790	0,00784
	Std.Desv.	0,04446	0,03705	0,03466
OF Entropy Index (Metropolitan System)		3,47958	3,84786	4,08631
	Mean	0,03480	0,02346	0,02221
	Median	0,01689	0,01058	0,01174
	Std.Desv.	0,04970	0,03804	0,03394
IF Entropy Index - OF Entropy Index (difference)		-0,46428	-0,46802	-0,50269
Dominance Index		100	164	184
	Mean	1	1	1
	Median	0,24192	0,19202	0,21359
	Std.Desv.	4,02645	4,44981	4,31867
BARCELONA (Municipality - CBD of the Metropolitan System)		**METHOD TO IDENTIFY SUB-CENTRES: RW & IF Entropy Inf.**		
	Dominance Index	40,01323	55,75913	57,13453
	% Dominance Index	40,01%	34,00%	31,05%
	LTL Entropy Information	0,34522	0,36244	0,36622
	% LTL Entropy Information	13,46%	12,06%	11,39%
	LTL in CBD	740.037	639.981	747.905
	% LTL in CBD	50,43%	43,30%	40,34%
	Population in CBD	1.643.542	1.508.805	1.505.325
	% Population in CBD	40,90%	35,92%	33,23%
	Population Entropy Information	0,36566	0,36778	0,36610
	% Population Entropy Information	12,96%	11,46%	10,64%
SUBCENTRES (within the Metropolitan System)		**METHOD TO IDENTIFY SUB-CENTRES: RW & IF Entropy Inf.**		
	Number of Subcentres	7	13	14
	Dominance Index	16,26938	41,91980	49,75492
	% Dominance Index	16,27%	25,56%	27,04%
	LTL Entropy Information	0,66002	0,98869	1,03052
	% LTL Entropy Information	25,74%	32,90%	32,05%
	LTL in subcentres	286.214	393.104	503.941
	% LTL in subcentres	19,51%	26,59%	27,18%
	Population in subcentres	992.666	1.281.860	1.361.763
	% Population in subcentres	24,70%	30,51%	30,06%
	Population Entropy Information	0,76247	1,05757	1,07808
	% Population Entropy Information	27,02%	32,95%	31,33%
REST OF THE METROPOLITAN SYSTEM		**METHOD TO IDENTIFY SUB-CENTRES: RW & IF Entropy Inf.**		
	Dominance Index	43,71738	66,32107	77,11055
	% Dominance Index	43,72%	40,44%	41,91%
	LTL Entropy Information	1,55942	1,65371	1,81898
	% LTL Entropy Information	60,80%	55,03%	56,57%
	LTL beyond nuclei	441.070	445.069	602.236
	% LTL beyond nuclei	30,06%	30,11%	32,48%
	Population beyond nuclei	1.381.891	1.410.332	1.663.166
	% Population beyond nuclei	34,39%	33,57%	36,71%
	Population Entropy Information	1,69324	1,78471	1,99663
	% Population Entropy Information	60,01%	55,60%	58,03%

Source: Own Elaboration

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