Polycentrism in the Spanish metropolitan system, an analysis for 7 metro areas

Carlos Marmolejo Duarte, Carlos Aguirre Núñez, Jaume Masip Tresserra, Eduardo Chica Mejía & Claudia Pérez Prieto.

Abstract

Polycentrism is becoming one of the dominant structures in contemporary metropolises. Concentrated decentralization and the integration of formerly independent cities by the reduction of travel time are behind of such a process. In this paper, the spatial structure of the seven biggest metro areas in Spain is depicted. By analysing employment density and travel-to-work data the polycentric structure of them is detected at the time that the functional borders are delimited. Results suggest a very heterogeneous image where Barcelona, Valencia and Bilbao emerge as the most polycentric areas at the time that Madrid, Seville and Zaragoza have a structure more orientated towards monocentrism, Málaga is an exception since having few subcentres, their share in employment concentration is important. Clearly a correlation between polycentrism and complexity of the relations among subcentre emerges.

Keywords

Polycentrism, new urban economy, metropolitan structure.

Introduction

Changes in metropolitan areas characterized by the dispersion and concentrated decentralization (Dematteis, 1998) of employment and population have led to a specialized line of research into polycentric urban systems. The topic is of obvious interest because a perfect polycentric system would offer the two major economic advantages of urban systems: the presence of agglomeration economies, which result in increasing returns for companies, and a potential reduction of transport costs (including time), which lead to a reduction in salaries and land rent (McMillen & Smith, 2003; McMillen, 2003a; McDonald, 2009).

Moreover, this urban model would have social and environmental benefits arising from an improvement in transport planning (McMillen, 2001b) and a drop in commuting (Gordon *et al.* 1986) if the network is designed to connect subcentres (McMillen, *Op. Cit*). In theory, polycentric systems offer the benefits of large and medium-sized cities (McMillen and Smith, *Op. Cit*.) by combining the advantages of traditional centralized cities with a decentralized spatial configuration (McMillen, 2003a). The European Spatial Development Perspective (ESDP) agreed in 1999 proposes the promotion of polycentrism as a European Union central policy. At continental scale polycentrism is understand as the promotion of alternative centres, outside of the so called “pentagon”[1], but at regional level, the polycentric notion is associated to a concentrated-decentralization from central cities to emergent ones functionally linked among them, but not necessarily contiguous.

The aim of this study is to evaluate the level of polycentrism in the seven biggest metropolitan systems in Spain. The work reported here constitutes the first steep of a more comprehensive research project, in which the main objective is study the impact of urban structure (i.e. polycentrism level) on the urbanization efficiency (e.g. mobility and land consumption).

The rest of the paper is organized as follows: i) first the theory on formation of polycentric structures is presented, ii) secondly methodology to delimit the metropolitan limits and subcentre identification is discussed, iii) data and case studies are presented, and iv) results of subcentres identification are discussed.

1. Processes that derivate in polycentrism

The standard urban model (SUM) as it was shaped by Alonso (1964), Muth (1969) and Mills (1967) with roots in the pioneering work of Thünen (1826) and Launhardt (1885) is the theoretical framework behind the formation of urban densities. This model, originally conceived for a monocentric city, explains that in achieving locational equilibrium households bid up for land accordingly to expenses saved in commuting. Thus the closer is the residing place to CBD (where all employment is supposed to be) the higher is the rent transferred to land (which capitalizes into higher prices), emerging in that way a land rent gradient. It is the existence of land rent gradients what underlies in density formation in a competitive market scenario. In the monocentric model most of the employment (and services) are located at city centre, and peripheral areas do concentrate housing in low density urban schemes, since the price of unit of land decreases as the distance to CBD increase.

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

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

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

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

2. Methods to identify metropolitan limits and subcentres

2.1 Methods to identify metropolitan limits

The first stage in the study of polycentrism is the delimitation of metropolitan limits. In doing so, two main families (beyond administrative approaches) can be devised: the first based on physical (i.e morphological) criteria like the continuity of urban fabrics, or the existence of contiguous dense spatial units of what can be considered urban (e.g. employment related to central services, manufacturing, etc.), and the second based on functional relations. For evident reasons the dominant family is that based on analysis of functional relations, since it is able to detect metropolitan areas without continuous urbanization. In doing so, travel-to-work data has been seen as an essential element of analysis, since such information reveals the borders, inside which, firms and households make their locative decisions. So by analysing residence-to-work travels it is possible to detect the space of confluence of the two most important urban markets, it is to say the residential and the labour market.

In the US travel to work data has been extensively used to detect metropolitan borders since the census of 1950 (OMB, 2000), as well as in other countries like France, Italy, The United Kingdom, or Canada. In Spain Clusa (1998) and Casado (2001) have detected in Catalonia and in the Comunidad Valenciana respectively, by means of travel-to-work data, Local Labour Markets; although the philosophy behind such a conformation is quite different from that pursue in the delimitation of metropolitan areas[2]. Using data from 2001 national census Roca (2004) delimited 7 Spanish metropolitan areas based on the methodology used by the Bureau of US Census for New England in 1991 (since the urban structure is quite similar), Boix & Veneri (2009) and Feria (2008; 2009) using own algorithms of adscription[3] also have delimited metropolitan borders across the country.

The methodology used by Roca (2004) consist in: 1) detect urban centres, as those municipalities with a population superior to 50,000 people; 2) detect those municipalities that send at least 15% of their working population to the urban centre previously detected; 3) aggregate the centre with the dependent municipalities in one metropolitan belt; 4) repeat the process indicated in 2 and 4, 3 more times. In such a way, by means of 4 iterations, it is possible to detect both Primary Metropolitan Areas (with only one centre) and Consolidated Metropolitan Areas in which the existence of more than one centre is possible. Following this procedure they have detected the borders of seven metro areas: Madrid, Barcelona, Valencia, Bilbao, Seville, Zaragoza and Málaga.

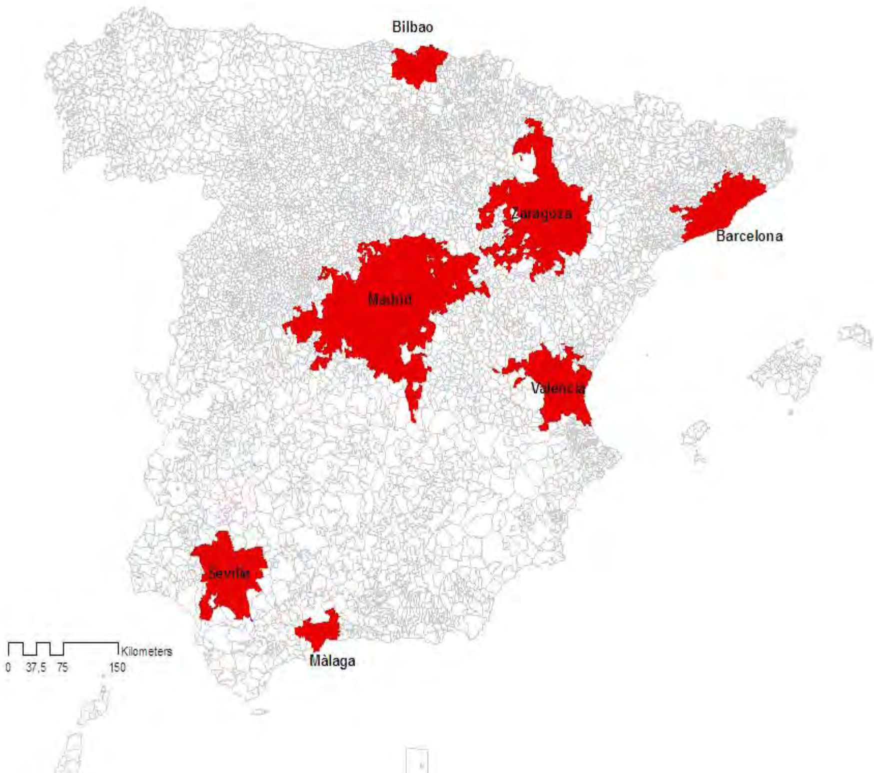
The main problem of such a method is that the 15% limit (without considering any critical mass) tends to integrate in the metropolitan area very small municipalities located in the outskirts in which the 15% threshold can be easily reached (for that reason other authors like Feria, *Op. Cit.,* have tried other thresholds and combined them with critical mass criteria). As direct consequence of that those metropolitan areas located in very low density hinterlands, such a Madrid or Zaragoza, appears enormous as depicted in the lower figure.

---

[2] In local labor markets (LLM) what is pursue is to define the areas where self-containment of resident working populations is enough high (but not the highest possible) to make reasonable decisions about this market like public interventions in terms of unemployment reduction. Metropolitan areas (MAs) are more complex systems, where self-containment is definitely higher to what is usually asked to LLM, at the time that a medium or big MA may contain more than one LLM inside it.

[3] The basic principle consist in identify an urban centre with a population of at least 100,000 people (although the author also incorporates as centres those that having leas of such a threshold, do articulate a metropolitan belt of at least 50,000 people). After identifying centres the process attaches surrounding municipalities that send at least 100 workers to the centre and it is *the biggest outgoing commuter flow*. If the flow is inferior to 1,000 the municipalities must sent 20% of their resident working population to the centre; if the flows are higher than 1,000 the municipalities must send 15% of their resident working population. A surrounding municipality also may be integrated to the centre when the centre send to it the aforementioned flows and % of jobs in such a municipality. It is to say peripheral municipalities may be attached to centre if a given % (and a given critical mass) of their resident working population go to the centre for working, or when a given % (and a given critical mass) of their localized employment is occupied by people living in the centre. In total the delimitation system uses 2 interactions.

Figure 1 Main Spanish Metropolises 2001: metropolitan delimitation using US (1991) criteria according to Roca *et al* 2004

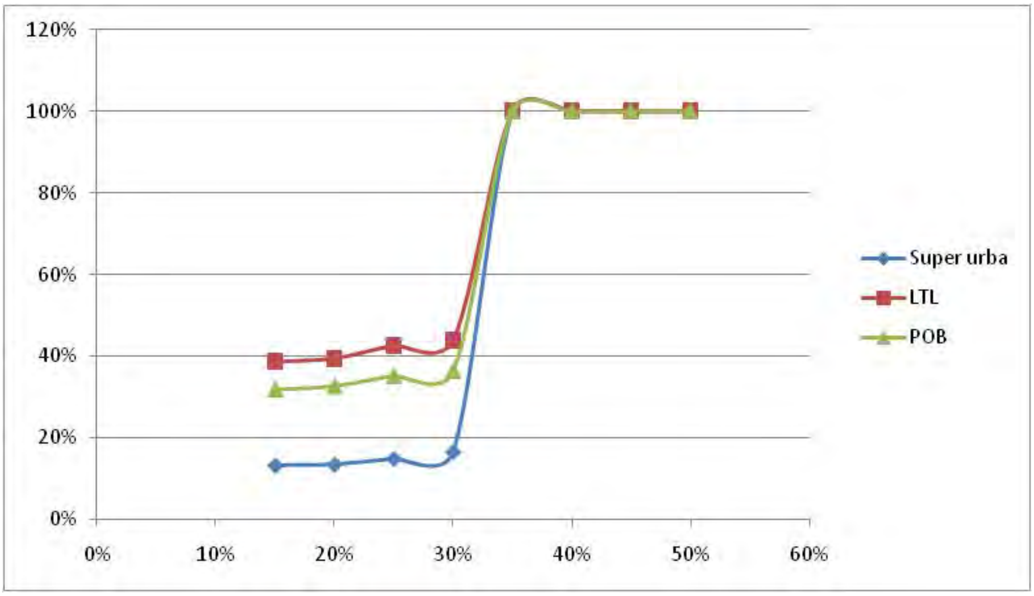


	Number of municipalities	Artificialised land	LTL (working places)	Population	Density
		a	b	c	.=(b+c)/a
Madrid	608	1.080	2.528.229	5.852.524	7.757
Barcelona	229	770	1.907.064	4.548.446	8.386
Valencia	152	315	662.263	1.739.126	7.628
Sevilla	60	243	454.432	1.408.963	7.668
Bilbao	104	99	386.626	1.096.000	14.936
Zaragoza	265	155	312.640	775.479	7.037
Málaga	26	96	244.357	722.019	10.016

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

In order to solve these shortcoming Marmolejo *et al.* (2010a) have modified the method used by Roca (2004) by putting *ad hoc* thresholds for each metropolitan area. The procedure has consisted in calculate the total population, jobs and urbanised land for different thresholds for each metropolitan area, using a precision of 1%; and by means of a dispersion plot, detect after which threshold the increase of the aforementioned indicators becomes in marginal: it is to say, after which limit the inclusion of more municipalities in the metropolitan area does not add significant population, jobs and consumed land in relation to what previously has been integrated. The figure 2depicts the process for Bilbao metropolitan area in which the threshold was fixed in 35%. Nevertheless this methodology has two problems: 1) in a polycentric framework there is the possibility that the hinterlands of subcentres (which may be located at metropolitan outskirts) may not be incorporated in the metropolitan system, which may result in a problem when detecting subcentres, since, as it will be discussed after, one of the validation criteria of subcentre existence is the ability to structure their surroundings, so if such surroundings are not included in the studied area it becomes impossible to test the influence of peripheral subcentres; 2) since only out-to-in (i.e. periphery-to-centre) flows are accounted there is the possibility that periphery municipalities very specialised in economic activity (e.g. manufacturing parks) may not be incorporated into the metropolitan area in the case that their scarce resident working population do not reach the % threshold.

Figure 2 Threshold sensibility analysis for metropolitan area of Bilbao according to Marmolejo *et al* (2010)



For that reason, the methodology used to delimit metropolitan areas in this paper has followed the proposal made by Roca, Marmolejo & Moix (2009) and used by Roca, Arellano & Moix (2011) for the purpose of compare the metropolitan Systems of Barcelona and Madrid. This method is also based in travel-to-work data, having as a particularity that reflexive (transitive) interactions are conjointly considered; it is to say the bidirectional relation between municipalities. By doing so, it is possible to integrate in one municipalities which result complementary including peripheral municipalities specialised in economic activities (i.e. employment agglomerations) in which work people residing in other municipalities. This transitive integration is possible due to the interaction value. As defined by Roca & Moix (2005), following Coombes & Openshaw (1982), the interaction value (IV) between two municipalities can be expressed as follows:

$$IV_{ij} = \frac{f_{ij}^2}{RWP_i LTL_j} + \frac{f_{ji}^2}{RWP_j LTL_i} \qquad (1)$$

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

The first step in detecting metropolitan limits consist in detecting proto-systems as follows:

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

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

The second step in metropolitan delimitation has consisted in aggregate sub-systems according to the interaction value among them. In polycentric metropolitan areas the aggregation is a gradual process: first important subcentres attract peripheral sub-systems before gravitate towards the central protosystem (that in which central municipality is contained in). In our case, the iterative process is stopped in a threshold of an interaction value equivalent to 1/1,000, except in the case of Madrid where stops in the IV of 0.99/1,000, and Seville where stops in the IV of 0.8/1.000.[5]

2.2 Methods to identify subcentres

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

Methods based on density analysis

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

1) The first criterion suggested by McDonald (1987) is based on the identification of employment density "peaks" (the author suggests that a subcentre is the second peak beyond the CBD). This criterion consists of analysing density employment to detect local disruptions with the aid of a geographic information system (GIS). Alternatively, the employment/population ratio can be used to detect the areas that have higher relative concentrations of economic activity. Gordon, Richardson & Wong (1986) restricted the number of subcentres to those areas with high *t-values*; this line of research was continued by McDonald & McMillen (1990) and Craig & Ng (2001).

2) The second approach consists of using upper and lower cutoffs. This line was originally proposed by Giuliano & Small (1991), who considered subcentres to be the contiguous census tracts with a density of more than 10 employees per acre and a total critical mass of at least 10,000 jobs. Therefore subcentres must to meet density and critical mas criteria. The references of this method are Song (1994), Cervero & Wu (1997), McMillen & McDonald (1997), Bogart & Ferry (1999), Anderson & Bogart

[5] In establishing such a stop-value the formation process of all the metropolitan areas (MA) studied in this paper was analyzed in detail. After an interaction value of 1/1.000 it is necessary to wait a significative number of interactions to aggregate more photosystem to each MAs. It is to say, such a threshold, allows for integrate highly linked protosystems.

(2001), Shearmur & Coffey (2002) and Giuliano & Readfearn (2007). In this line, García-López (2007, 2008) and Muñiz & García-López (2009), suggested that subcentres are zones with a density higher than the metropolitan average and at least 1% of metropolitan employment. Pain & Hall (2006) have defined “cores” in their Interreg IIIB Polynet Project, as NUTs 5 with 7 or more workers per hectare, and at least 20,000 workers in either single.

3) From an econometric perspective, there is a third methodology that identifies potential subcentres by analyzing significant residuals in an exponential negative density model discussed in 2.1. McDonald & Prather (1994) suggested several models for detecting subcentres based on the identification of areas with positive residuals that are significant at a 95% confidence level.

4) The fourth approximation (derived from that presented in 3) is based on non-parametric models (e.g., locally or geographically weighted regression –L or GWR-) to detect “peaks” that locally adjust the density function and prioritize the effect of neighboring municipalities on the adjustment process (McMillen, 2001a; Craig & Ng, 2001; Readfearn, 2007). The main advantage of this method is that it enables local gradients of density reduction to be determined across the metropolitan area. Suarez & Delgado (2009) develop a hybrid method, where once that peaks of density have been detected by means of GWR residuals, adjacent census tracks are added to comply with a threshold number of workers and density.

According to McMillen (2001b) approaches based on cutoffs are useful because enables a historical analysis of the subcentre structure. Nevertheless, they excessively rely on local knowledge to calibrate the thresholds of critical mass and density, and this can be a problem when trying to compare different metro areas with different local experts. The work of García-López (2007) seems to give a steep forward by relativizing the critical mass threshold to 1% of metropolitan employment and minimum density to metropolitan average. Nonetheless, such a criterion, in the way operationalized by him, is flawed since the larger the number of spatial units in the metro area, the highest is the difficulty to reach the critical mass criterion, and the most homogeneous is the density function across units, the higher is the probability that a large number of units are above average density. Additionally, cutoffs approach have a more serious defect: they tend to prioritize as subcentres central areas, since they regret what is essential in the standard urban model (i.e. global density is determined by proximity to CBD). Some authors have tried to solve such a problem by manually removing what they consider is the CBD, other have established differentiated thresholds in relation to centrality.

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

$$LnD_x = k + BD_{cx} \tag{2}$$

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

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

While these methodologies has meant a significant advance in understanding the structure of contemporary metropolises, all of them have failed to conceptualize what is really behind employment density. Departing from employment density as it has been calculated in these works there are not warranties that "dense spots[6]" are the random result of urban development or whether they respond to true metropolitan subcentres: municipalities (not census tracts or their grouping) that being employment concentrations with influence on density of neighboring municipalities are at the same time elements of metropolitan structuration able to have population and retain their working population. In this sense Marmolejo, Aguirre & Roca (2010b) have proposed a compound density that integrates basic elements of urban mobility: incoming flows (IF), outgoing flows (OF) and resident workers (RW). By means of DP2 distance they integrate such elements to prioritise as subcentres municipalities where: density is produced by a combination of IF and RW, being the OF low. They are: a) sufficiently attractive in residential terms to have a resident population, b) sufficiently attractive in employment terms to retain part of their working population, and c) sufficiently diverse to attract workers from elsewhere, i.e. to employ people with professional profiles different from those of their own residents.

Methods based on the analysis of functional relations

The second family of methods is based on the understanding that subcentres are not only abnormally dense zones in the metropolitan space, but also structural nodes that can strengthen the functional relationship with their surrounding municipalities. *In that sense, this*

[6] Very dense municipalities may result from employment concentrations without or with very low levels of resident population (e.g. industrial parks); it is difficult to consider such municipalities as metropolitan subcentres; also might be very dense municipalities without relations with their surrounding municipalities (e.g manufacturing colonies where people work and live in); again it is difficult to consider them as subcentres having not interaction with the rest of the system.

approach is closer to the conception that centres in a network of cities function as nodes, without the necessity of being dense spots. The methods based on the analysis of functional interactions were designed to delimit territorial systems (Nel·lo, 2001), including *Travel To Work Areas* in England, *Statistical Metropolitan Areas* in the USA and *Functional Urban Areas*, and some focused on detecting subcentres that structure such territorial systems. References in this field include Bourne (1989), Gordon & Richardson (1996), and the revised literature in section 2.

The methodology proposed by Roca *et al* (2009) and revised in section 2, also allows for detect subcentres. Namely the most important municipality inside of each protosystem, it is to say the municipality with the highest interaction value with the remaining municipalities of a given protosystem.

In this paper 4 ways to detect subcentres has been tested:

1) Using the classical approach, it is to say using the classic density (LTL/a) and functional form explained in (2)
2) Using the compound density proposed by Marmolejo *et al* (2010b) and the functional form explained in (2)
3) Using the cut off approach in the way as has been used by García-López (2007)
4) Considering as candidate to subcentre to those municipalities leading each sub-system as suggested by Roca *et al* (2009).

3. Data & cases study

The data used for analyze in this paper the population and the localized workers is the information of the municipalities using the Census at the date of 2001 because there is no data below the municipal scale.

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

1) As artificialised area the following uses have been considered (in brackets is the Corine-code): continuous urban fabric (11100), discontinuous urban fabric (11210), discontinuous green urban areas (11220), industrial areas (12110), commercial and service areas (12110), port areas (12300), green urban areas (14100), golf courses areas (14210) and rest of sport and leisure facilities (14220).

2) In some cases, the surface of some uses has been considered only partially.In the case of airport areas (12400), the run-ways (and the safety areas around them) has been discarded, since they introduce a bias, in the case of nig airports, in the calculus of employment density. In the case of areas under construction (13300) the surface

destined to highways and railroad networks has been also discarded, since these surfaces are not conceptually included in the artificialised areas imputable only to the municipalities cruised by them.

3) Not taking into account the following artificial surface uses: road and highway networks and associated land (12210), railroad networks (12220), mineral extraction sites (13100) and dump sites (13200).

On the other hand, it's worth mentioning that in some Metropolitan Areas (concretely Barcelona, Bilbao and Madrid) there are municipalities where Corine Land Cover 2000 could not detect its artificial surfaces or detects it in an untrustworthy way. To identified and eliminated these municipalities from the analysis, this study/paper have classified all the municipalities into localized worker ranks[7].

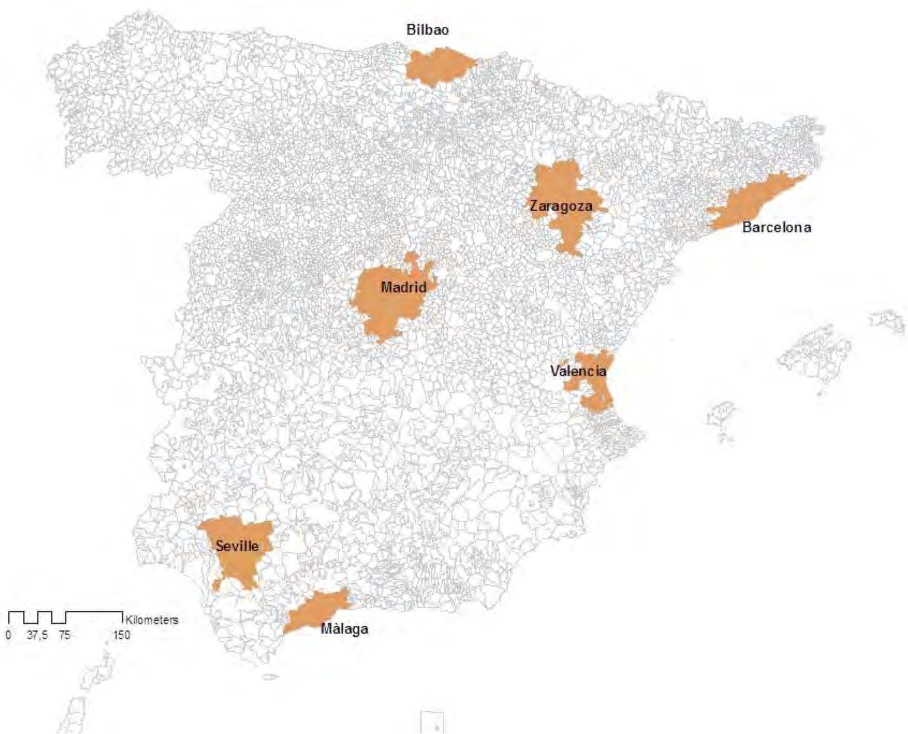
In relation with the case studies (Figure 3), this study has analysed the next Spanish metropolitan areas: Madrid, Barcelona, Valencia, Sevilla, Bilbao, Zaragoza and Málaga[8]. To delimit the urban continuous for each metropolitan area, is used a buffer of 200 metres and taking into account neither crossed rivers nor crossed bridge as an empty space. Related to the delimitation of its core economic continuous, are used tree criteria: the most restrictive based on GEMACA; then the municipalities must accomplish a functional criterion, being within the sub-system of the core city; and finally checking that these municipalities that are accomplishing the previous criterions are also within the core urban continuous.

---

[7] Although, in the case of Barcelona and Madrid these "problematic" municipalities are not strongly relevant (four and three municipalities respectively), in the case of Bilbao these municipalities have a significant weight, being the 27,60% of all the municipalities of Bilbao Metropolitan Area. Classifying these municipalities into ranks of localized workers: Valle de Mena (1000<LW<1200), Etxeberria (800<LW<1000), Sopuerta, Muxika, Gatika, Guriezo (400<LW<600), Izurtza, Gizaburuaga, Gordexola, Galdames, Okonko, Gamiz-Fika (200<LW<400), Dima, Mañaria, Forua, Murueta, Artea, Maruri-Jatabe, Meñaka, Kortezubi, Trucos-Tuitzioz, Artzentales, Moga, Villaverde de Trucios, Arratzu, Ibanangelu, Munitibar-Arbatzegi Gerrikaitz, Mendata, Fruiz, Errigoiyi, Arrieta, Ereño, Nabarniz and Garay (<200 LW).

[8] This paper should mention that in a study which was carried out by Feria (2009), in according to its methodology to delimit metropolitan areas, they identified two more relevant metropolitan areas within the Spanish territory: the metropolitan area formed by Oviedo-Gijón-Avilés and Las Palmas de G.Canaria.

Figure 3 Main Spanish Metropolises 2001: metropolitan delimitation based on criteria suggested by Roca et al (2009; 2011)



	Number of municipalities	Artificialised land	LTL (working places)	Population	Density
		a	b	c	.=(b+c)/a
Madrid	183	859.89	2446400	5542843	9291
Barcelona	184	744.99	1903867	4530164	8636
Valencia	104	308.06	686247	1792375	8046
Sevilla	52	236.99	447849	1381531	7719
Bilbao	123	111.62	445666	1231367	15024
Zaragoza	88	127.22	301860	724335	8066
Málaga	32	193.62	366525	994984	7032

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

4. Results

Results of application of parametric models, using functional expression (2), are contained in the following table. In such a table the models built using the classic density and compound density are contained, the adjusted determination coefficient is reported as well as the B coefficient affecting the density of each municipality according to its position in relation to

CBD[9]. According to the standard urban model, exposed in section 2, the bigger is the distance to CBD the lesser is the density, so the sign of such a coefficient is expected to be negative. In grey are indicated the models and parameters that are not significant at 95% of confidence.

As it can be seen, parametric models do not succeed to explain the spatial distribution of densities using only as independent variable the distance to CBD, since in most of them the models itself or/and the independent variable are not statistical significant. As a matter of fact, just in the case of Madrid, Barcelona, and Valencia it is possible to consider the result of parametric models.

Putting the attention just in Barcelona and Madrid, which are areas relative similar in terms of size (LTL, population and urbanised land), it is possible to see that proximity to CBD explains up to 29% and 36% respectively of the spatial formation of employment density. Also, the gradient of density is higher in the case of Madrid. Those indicators suggest that in Madrid the distance to the CBD is more determinant in the distribution of employment density, what can be interpreted as an indicator of monocentrism. Although Valencia is quite different in terms of size than Madrid and Barcelona, the aforementioned indicators also suggest a polycentric nature, even more than Barcelona.

Table 1 Results of parametric methods

	Parametric methods					
	CL		Dca		DCb	
	R2 adj	B dist CBD	R2 adj	B dist CBD	R2 adj	B dist CBD
Madrid	0,365	-0,041	0,234	-0,037	0,276	-0,044
Barcelona	0,298	-0,034	0,164	-0,029	0,187	-0,033
Valencia	0,231	-0,03	0,139	-0,029	0,151	-0,03
Sevilla	0,046	-0,012	0,01	-0,012	0,021	-0,016
Bilbao	-,009	0,002	-0,008	0,005	0,001	0,001
Zaragoza	0,149	-0,015	0,119	-0,02	0,119	-0,02
Málaga	0,028	-0,007	-0,042	-0,003	-0,022	-0,009

Independent variable LNDLTL

The values in gray are not significant at 95% confidence

[9] For CBD we have used the central municipality of each metropolitan area. In the regressions such a municipality is introduced, since some central municipality can be a dense spot of economic activity beyond to what strictly can be considered CBD. We have also tried to joint all those municipalities conforming the central continuous, and introduce instead of all those central municipalities just the aggregation of them, the results of that approach do not substantially differ in relation to what is presented here in terms of the number of subcentre.

So far, the use of parametric models has been discarded since only proximity to CBD does not succeed in explain the spatial formation of employment densities in all the metropolitan areas. For that reason, the only two methods that allows to make a global "comparison" among MA are those proposed by García-López –GL- (2007), based on cut-offs criteria, and Roca *et al* –JR- (2009) based on functional relations departing from mobility. In the case of the method based in Mobility (JR) only municipalities leading sub-systems with at least 1% of LTL has been considered in order to make the results comparable between two approaches and at the same time discard as subcentre candidates those small. The following table reports the results for the seven metropolitan areas.

Table 2 Subcentre candidate according to cut-off and mobility approach

Municipality	Central employment continuos (CEC)	LTL	Cutt-off GL	Mobility JR
Metropolitan Area of de Madrid				
Madrid	1	1.562.697	1	1
Alcalá de Henares		58.932	0	1
Alcobendas	1	54.787	1	0
Getafe		53.052	1	0
Fuenlabrada		48.836	1	0
Móstoles	1	41.081	1	0
Torrejón de Ardoz		38.325	1	0
Alcorcón	1	37.903	1	0
Guadalajara		27.462	0	1
Coslada	1	27.372	1	0
Tres Cantos		25.166	1	0
	Total nuclei		9	3
	Nuclei beyond CEC		4	2
Metropolitan Area of de Sevilla				
Sevilla	1	281.189	1	1
Utrera		10.789	0	1
Carmona		6.957	0	1
San Juan de Aznalfarache		6.041	1	0
	Total nuclei		2	3
	Nuclei beyond CEC		1	2
Metropolitan Area of de Barcelona				
Barcelona	1	779.296	1	1
Sabadell		69.563	1	1
Terrassa		67.757	1	1
Hospitalet de Llobregat (L')	1	66.668	1	0
Badalona	1	54.998	1	0
Mataró		42.429	1	1
Prat de Llobregat (El)	1	31.863	1	0
Granollers		31.776	1	1
Cornellà de Llobregat	1	27.809	1	0
Rubí		27.640	0	1
Martorell		24.749	1	1
Sant Boi de Llobregat		23.561	1	1
Vilanova i la Geltrú		19.343	0	1
Santa Coloma de Gramenet	1	19.249	1	0
	Total nuclei		12	9
	Nuclei beyond CEC		6	8
Metropolitan Area of de Bilbao				
Bilbao	1	150.063	1	1
Barakaldo	1	24.628	1	0
Leioa	1	11.495	1	0
Zamudio		10.472	1	0
Eibar		10.243	1	1
Durango		8.279	1	1
Portugalete	1	8.091	1	
Mungia		7.555	0	1
Castro-Urdiales		6.675	0	1
Llodio		6.633	0	1
Gernika-Lumo		5.821	1	1
Bermeo		4.874	1	1
	Total nuclei		9	8
	Nuclei beyond CEC		5	7
Metropolitan Area of de Valencia				
Valencia	1	302.770	1	1
Sagunto/Sagunt		20.031	0	1
Torrent		18.047	0	1
Alzira		16.378	1	1
Quart de Poblet		14.074	1	1
Almussafes		12.830	1	1
Aldaia		12.316	1	0
Manises		10.808	1	0
Burjassot	1	9.118	1	0
Silla		8.640	1	1
Alaquàs		8.274	1	0
Algemesí		8.074	1	0
Catarroja		7.991	1	0
Sueca		7.836	0	1
Xirivella		7.372	1	0
Picassent		7.357	0	1
Llíria		6.894	0	1
	Total nuclei		12	10
	Nuclei beyond CEC		10	9
Metropolitan Area of de Zaragoza				
Zaragoza	1	245.681	1	1
Figueruelas		8.563	1	0
	Total nuclei		2	1
	Nuclei beyond CEC		1	0
Metropolitan Area of de Málaga				
Málaga	1	190.550	1	1
Marbella		61.489	0	1
Fuengirola		20.701	1	1
Torremolinos		17.654	1	0
Coín		4.419	1	0
Alhaurín el Grande		4.251	1	0
	Total nuclei		5	3
	Nuclei beyond CEC		4	2

Source: Own elaboration

The results the two biggest metropolitan areas is as follows: in Madrid 9 (GL) or 3 (JR) candidates to subcentre were found, but only 4 (Getafe, Fuenlabrada, Torrejon, and Tres Cantos) and 2 (Guadalajara, and Alcalá) are out of the central employment continuous.

Neither of them are simultaneously detected by both methodologies. Monocentris seems to be in Madrid the dominant structure in its metropolitan area. In Barcelona the image is quite different since several municipalities are identified as candidate to subcentres. Namely using cut-off approach (GL) 12 are identified of which 6 are out of central employment continuous (which emphasises the limitations of this methodology derived from its not spatial nature), functional methodology (JR) identifies 9 municipality of which 8 are beyond CEC. What is relevant is the fact that most of the municipalities succeed in both methods as candidates to subcentre like Sabadell, Terrassa, Mataró, Granollers, Martorell and Sant Boi. As seen, Barcelona is undoubtedly a polycentric urban system since both methodologies agree in consider most of the candidate to subcentres.

In the second group of metropolises in terms of employment size we have Valencia, Seville, and Bilbao. The case of Valencia is quite similar to Barcelona, in structure, but not in size. Barcelona as it has been exposed before has 1,9 million LTL and Valencia only 0,7 million. Cut-off approach identifies 12 municipalities of which 10 are not contained in the CEC; at the time that functional methodology suggest 10 of which 9 are beyond CEC. As in the case of Barcelona, in Valencia there are four municipalities considered as candidate to subcentre by both methods, those are: Alzira, Quart de Pobla, Almussafes and Silla. Being selected subcentre by both approaches means that those municipalities do structure the residence-to-work flows in its surroundings (i.e. do structure their hinterland) and at the same time are denser than the metropolitan average in terms of employment and have a critical mass above 1% of metropolitan LTL. Seville denotes a more monocentric structure since only 2 municipalities (1 beyond CEC) are detected as potential subcentre using Cut-off approach, at the time that 3 (2 beyond CEC) using functional perspective. None of them coincide in any municipality. Meanwhile Utrera and Carmona structure their hinterland, they not succeed in terms of minimum density necessary to be considered as potential subcentres by cut-off approach. On the opposite situation is San Juan de Aznalfarache that being quite near from municipality of Seville, and consequently being enough dense to be considered subcentre by cut-off approach, is functionally integrated to Seville to be considered and independent city. The metropolitan structure of Bilbao is nearer to Valencia and Barcelona. In Bilbao cut-off methodology suggest the existence of 9 municipalities (5 beyond CEC) and functional approach 9 (8 beyond CEC). As in Valencia and Barcelona, 4 municipalities are identified as potential subcentres by both methods: Eibar, Durango, Gernika-Lumo and Bermeo. This findings support the idea that Bilbao has a more polycentric nature.

In the last group of metropolises formed by Zaragoza and Málaga, although they are similar in terms of employment size, they differ substantially in their structure. In Zaragoza cut-off methodology suggest that Figueruelas is a potential subcentre, nevertheless its strong functional relations with the municipality of Zaragoza prevent to consider Figueruelas and independent subcentre. In the case of Málaga, 5 municipalities (4 beyond CEC) are considered as potential subcentres by cut-off approach, and 3 (2 beyond CEC) by functional methodology. Only Fuengirola succeeds in structure its near hinterland and terms of functional flows and in reaching the minimum density demanded by cut-off approach. Marbella although has an important capacity to structure its hinterland does not reach the minimum density. In any case Málaga clearly appears as a more polycentric system in relation to Zaragoza.

In the following table a comparison is realised using both methodologies, as well it is depicted the employment share that represent the central employment continuous and the subcentres beyond it. The employment share that represents the central employment continuous can be seen as an indicator or macrocephalia and the employment in subcentres of polycentrism. In terms of macrocephalia Madrid and Zaragoza leads the ranking, and Barcelona, Valencia and Málaga, it is to say the most polycentric metropolises are on the opposite situation, it is to say in these metropolitan systems the distribution of employment is not as monopolised by the centre as in Madrid and Zaragoza.

In terms of employment located at potential subcentres, according to cut-off approaches Valencia and Barcelona are the most polycentric systems in Spain, followed by Málaga and Bilbao. This conclusion is also supported by functional approach based on residence-to-work mobility.

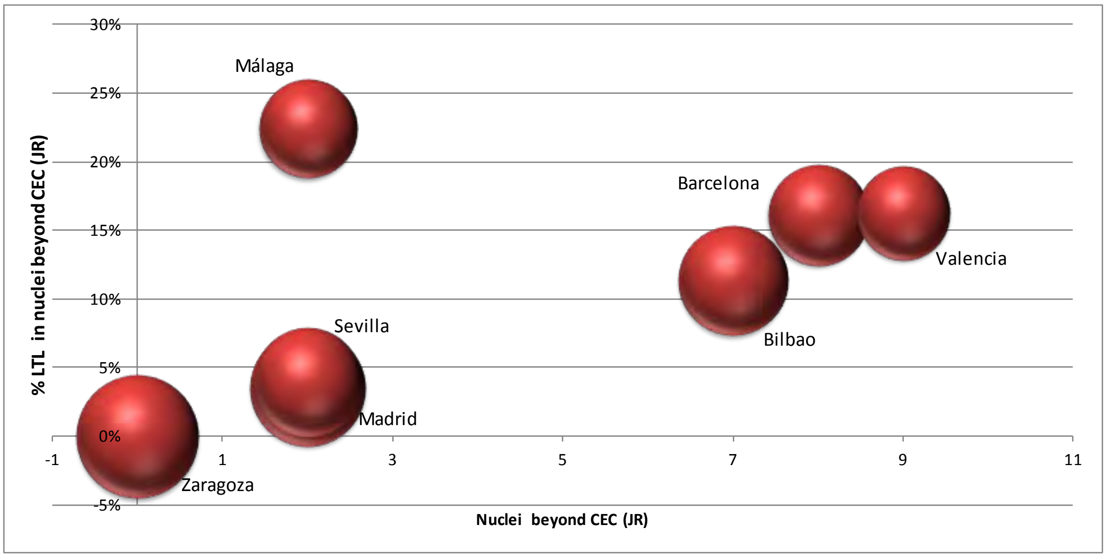
Table 3 Metropolitan structure according to cut-off and functional approaches

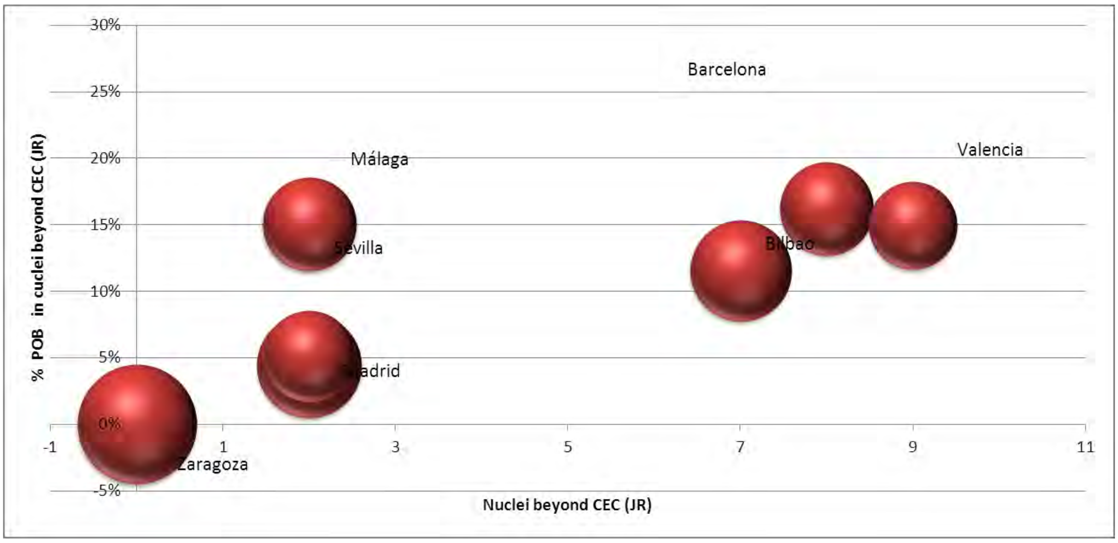
			Cutt-off GL			Mobility JR		
	LTL	LTL in CEC (%)	Total nuclei	nuclei beyond CEC	LTL in nuclei beyond CEC	Total nuclei	nuclei beyond CEC	LTL in nuclei beyond CEC
Madrid	2.446.332	72%	9	4	7%	3	2	4%
Barcelona	1.903.867	55%	12	6	14%	9	8	16%
Valencia	688.711	47%	12	10	16%	10	9	16%
Sevilla	447.849	63%	2	1	1%	3	2	4%
Bilbao	438.382	65%	9	5	9%	8	7	11%
Zaragoza	301.860	81%	2	1	3%	1	0	0%
Málaga	366.525	52%	5	4	13%	3	2	22%

Source: Own elaboration

In the following figure is exposed the position of each metropolis, in the x axis is the number of potential subcentres (beyond the central employment continuous) and in the y axis the share of employment (LTL) contained in such potential subcentres. The size of the sphere represents the share of employment located at the central employment continuous (in the inferior graphic is the same for population). The methodology used is only that originated from the functional linkage of municipalities, which is in our judgment the most coherent method since is able to detected nodes that truly structure their hinterlands by means of the interaction between the labor and residential markets, besides the fact that only municipalities with more than 1% of total employment has been considered, prevents to include nodes of insignificant critical mass in the analysis. In such a figure, the right upper quadrant represents a strong degree of polycentrism; it is to say an important number of potential subcentres concentrating a significant share in the employment distribution. Clearly emerge two groups of metropolises. In the group of most polycentric ones are Barcelona, Valencia and Bilbao; on the group of less polycentric ones are Madrid, Seville and Zaragoza. Málaga is a special case, because although its number of subcentres is small (due the short extension of the metropolitan system) they do concentrate an important share on employment distribution.

Figure 4 Level of polycentrism according to functional approach



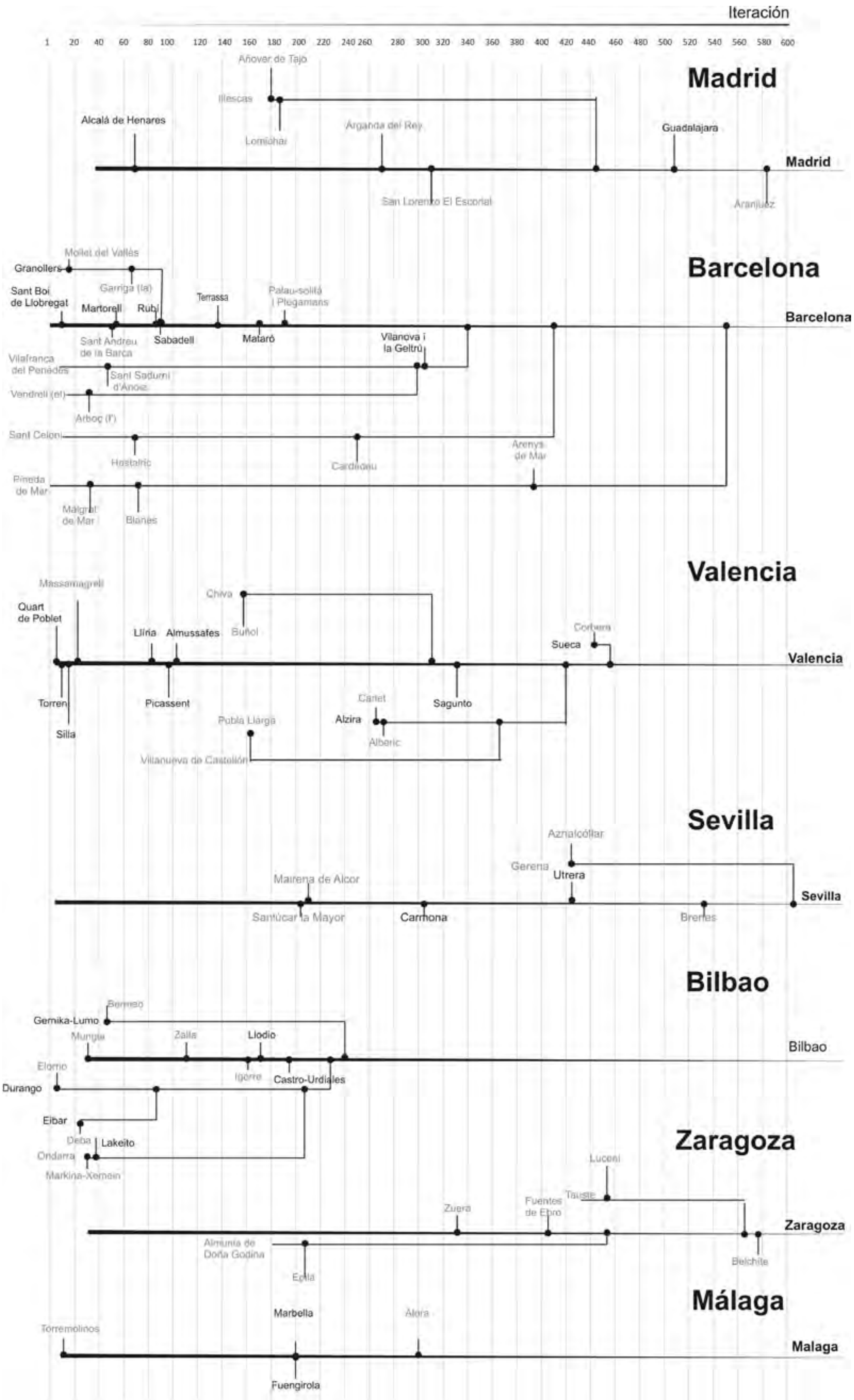


In terms of population distribution the position of each metropolis is quite similar, except for the case of Malaga that approaches to the group of monocentric metropolises. So in Málaga the population share of subcentres beyond CEC is less important than the share of employment, it may suggest the presence of a sprawled residential pattern.

Functional approach also allows studying the complexity in the structuration process of metropolitan areas. It is to say, the way in how sub-systems (the hinterlands structured by potential subcentres) gravitates toward central sub-system (the subsystems in which CBD is contained). In the following figure the functional tree (suggested in Roca *et al* (2005; 2011)) has been reconstructed for the metropolitan areas, the potential subcentres which LTL are superior to 1% are marked in black letters. So the potential subcentres marked in black are those which function as hierarchic subcentres (they are dense and relatively big) and as nodes (they articulate travel-to-work flows); and these potential subcentres marked in grey are those which basically works in a network schema.

In the group of more polycentric metropolises (Valencia, Barcelona and Bilbao) clearly Barcelona stands out as the most complex polycentric system. Such a conclusion is derived not only from the number of potential subcentres (sub-systems) but also from the arrangement with shape of tree branches that they form in the process of integration, and finally because some of those branches are the latters in integrate into the metropolitan system (which is representative of its autonomy and resilience to integrate to the CBD).

Figure 5 Analysis of complexity of metropolitan areas by means of the analysis of integration departing from sub-systems



In Valencia the complexity is similar to Barcelona, if the size difference in terms of size is considered. In Bilbao although stands as well as a complex system, all of their sub-system integrate into the system quickly (in the interaction 239 all of them are integrated with the centre).

In the group of more monocentric systems (Seville, Madrid and Zaragoza), Seville and Madrid have similar structure (despite the fact they are enormously different in terms of employment size). Zaragoza in not quite different, but any of its candidates to subcentre succeed in having more than 1% of metropolitan LTL.

In Málaga metropolitan system, Fuengirola and Marbella are incorporated almost simultaneously to the metropolitan area. Fuengirola is first incorporated and immediately after Marbella, which is representative that this latter is a little bit more independent.

Conclusions

Changes in metropolitan areas characterized by the dispersion and concentrated decentralization of employment and population have led to a specialized line of research into polycentric urban systems. The topic is of obvious interest because a perfect polycentric system would offer the two major economic advantages of urban systems: the presence of agglomeration economies, which result in increasing returns for companies, and a potential reduction of transport costs (including time), which lead to a reduction in salaries and land rent. In this paper we have explored the level of polycentrism of 7 metropolitan areas in Spain: Madrid, Barcelona, Valencia, Sevilla, Bilbao, Zaragoza and Málaga.

In the first part of the paper the delimitation of such metropolitan areas is discussed. After revising different methods of delimitation, it has been used that proposed by Roca, Marmolejo & Moix (2009) and used by Roca, Arellano & Moix (2011) in the delimitation of Madrid and Barcelona. Such a methodology, using residence-to-work data, allows for integrate into small subsystem those municipalities that according to commuting flows are highly interlinked. Such residence-to-work integrated areas are called by the aforementioned authors “sub-systems”. The peculiarity of this method in relation to other based on functional relations (e.g. GEMACA, US Census Bureau, etc.) are: 1) that not thresholds of interaction or critical mass are a priori established; 2) reflexive interactions are considered into and not only one-way commuting flows (using the “interaction value”). This latter peculiarity allows detecting sub-systems in complex metropolitan areas in which there is not one economic centre, and firms do locate both in the CBD, subcentres and in the sprawled hinterland articulated by them. After having delimited sub-systems departing from municipalities, metropolitan areas are assembled by means of the stepwise-join of sub-systems using the “interaction value” among them. As a result of such a methodology Madrid appears with 183 municipalities concentrating 5.5 million persons and 2.4 million jobs in 860 sq km of urbanised land; Barcelona is quite near with 184 municipalities, 4.5 million persons and 1.9 million jobs in 745 sq km. After the biggest metro areas appear a group of tree conformed by Valencia (1.7 million persons; 0.6 million jobs), Seville (1.3; 0.4) and Bilbao (1.2;0.4). In a final group are the smallest metro areas studied here Zaragoza (0.7; 0.3) and Málaga (0.9; 0.3). As seen, metro areas are quite different in terms of size, and also in land consumption. Bilbao stands out as the denser area (in terms of land consumed for employment and residential purpose)[10]; quite fare is the rest of the metropolitan areas which average density starts in 7.032 for Málaga (jobs+pob/sq km) and ends 9.291 for Madrid (jobs+pob/sq km).

In order to detect subcentres two families of methods used in literature has been implemented. From the perspective of employment density analysis econometric models using "classic density" (that only considers employment without considerate mobility) and that "compound density" (that analyses the formation of density considering mobility) proposed by Marmolejo *et al* (2010b) has been used; as well as cut-off approach as it has been used by García-López (2007). From the perspective of mobility analysis subcentres has been detected by analysing the densest municipality inside each protosystem having the most intense functional relations with the remaining municipalities in the sub-system. Meanwhile econometric approach failed to found significant models in five of the seven metropolitan areas studied, cut-off and mobility approach succeed in depict the structure of all the areas. Cutt-off approach detects dense and relatively big municipalities (without regarding their paper as nodes in the articulation of urban life). In and mobility approach detects nodes that articulate travel-to-works area (without regarding their density and size). So cut-off approaches is more orientated to detect top-hierarchy areas (although there is not guarantee that dense and big municipalities exert any influence on their hinterland) and mobility approach is more orientated to detected nodes inside network systems. Municipalities that are detected as potential subcentres by both methods are: dense, big and nodes in the articulation of metropolitan systems.

In the first group of big metropolises Madrid and Barcelona, the first do not have any municipality that simultaneously succeed in subcentre detection, and in the second case there a 6 municipalities detected as potential subcentres.

In the second group of metropolises Valencia has 4 municipalities detected as potential subcentres by both methods; Seville as Madrid does not have any municipality that succeeds in both methods and Bilbao has as well as Valencia 4 municipalities detected as potential subcentres by the density and functional approach.

---

[10] Despite the fact that we have found serious problems in Euskadi in the Corine Land Cover data base. And although that 34 small municipalities (less than 2,000 LTL) has been excluded from analysis because the evident undervaluation of urbanized land, there are not guaranties that the rest of the municipalities have the same level of accuracy in the measurement of urbanized land.

In the third and last group formed by Zaragoza and Málaga, although that any of them have municipalities that succeed in both methods, clearly Málaga denotes a bigger level of polycentrism if the results of the methods are analysed independently.

In order to quantify the level of polycentrism the share of employment and population located at subcentres beyond the central economic continuous has been calculated. As a conclusion there are two groups of metropolitan areas. In the group of most polycentric ones are Barcelona, Valencia and Bilbao; on the group of less polycentric ones are Madrid, Seville and Zaragoza. Málaga is a special case, because although its number of subcentres is small (due the short extension of the metropolitan system) they do concentrate an important share on employment distribution

Mobility approach also allows for measuring the complexity of polycentrism. By analysing in detail the process by means of which sub-system integrate among them to conform the metropolitan area it is possible to detect the level of complexity of the subjacent structure. Simple structures are formed by the direct incorporation of peripheral protosystem to the central one. Complex structures are formed by the formation of branches in which medium-important protosystem capture others before gravitate towards the central protosystem in which the metropolitan CBD is contained in. In the group of more polycentric metropolises (Valencia, Barcelona and Bilbao) clearly Barcelona stands out as the most complex polycentric system. Such a conclusion is derived not only from the number of potential subcentres (sub-systems) but also from the arrangement with shape of tree branches that they form in the process of integration, and finally because some of those branches are the latters in integrate into the metropolitan system (which is representative of its autonomy and resilience to integrate to the CBD). In Valencia the complexity is similar to Barcelona, if the size difference in terms of size is considered. In Bilbao although stands as well as a complex system, all of their sub-systems integrate into the system quickly (in the interaction 239 all of them are integrated with the centre). In the group of more monocentric systems (Seville, Madrid and Zaragoza), Seville and Madrid have similar structure.

Results suggest that the biggest is the level of polycentrism the more complex is the structure and hierarchical integration of potential subcentres into the central one.

Acknowledgments

The authors would like to acknowledge the financial support received from the Spanish Science Ministry in the framework of the project CSO 2009 7218. We also want to thank to Josep Roca and Montserrat Moix for allowing us use their software to delimit protosystems, sub-systems and functional metropolitan areas, and for their suggestions and critics to this work.

References

Alonso, W. (1964), *Location and Land Use*, Cambridge, Mass., Harvard University Press.

Anderson, N.B. & Bogart, W.T. (2001): The Structure of Sprawl. Identifying and Characterizing Employment Centers in Polycentric Metropolitan Areas , *Journal of Economics and Sociology*, 60, pp. 147-169.

Bogart, W.T. & Ferry, W.C. (1999): Employment Centres in Greater Cleveland: Evidence of Evolution in a Formerly Monocentric City , *Urban Studies*, 36, pp. 2099-2110.

Boix, R.; Veneri,P. (2009): Metropolitan Areas in Spain, IERMB Working Paper in Economics, nº 09, 01, March 2009.

Bourne, L. S. (1989): Are new urban forms emerging? Empirical tests for Canadian urban areas, *The Canadian Geographer*, 4, pp. 312–328.

Casado, J.M. (2001): Los mercados laborales locales de la Comunidad Valenciana. Trabajo y Territorio. Publicaciones Universidad de Alicante.

Cervero, R. & Wu, K-L. (1997). Polycentrims, Commuting and Residential Location in the San Francisco Bay Area , *Environment and Planning A*, 29, pp. 865-886.

Champion, A.K. (2001): Changing demographic regime and evolving polycentric urban regions: consequences for the size, composition and distribution of city populations, Urban Studies, 38(4), 657-677

Christaller, W.(1933) Die Zentralen Orte in Suddeutschland", Gustav Fischer Verlag,Jena ; trad. It: le località centrali della Germania medridionale,Milán,1981.

Craig, S.G. & Ng, P.T. (2001): Using Quantile Smoothing Splines to Identify Employment Subcenters in a Multicentric Urban Area , *Journal of Urban Economics*, 49, pp. 100–120.

Coombes, M. & Openshaw, S. (1982): The use and definition of travel-to-work areas in Great Britain: some comments , *Regional Studies*, 16, 141–149.

Dematteis, G. (1998). Suburbanización y periurbanización. Ciudades anglosajonas y ciudades latinas , en *La ciudad dispersa*, Editado por F. J. Monclús, Centro de Cultura contemporánea Barcelona, Barcelona.

Feria, J.M. (2008): Un ensayo metodológico de definción de las áreas metropolitanas de España a partir de la variable residencia-trabajo. Investigaciones Geográficas, Instituto Universitario de Geografía, Universidad de Alicante, nº46; 49-68.

Feria, J.M. (2009). La delimitación y organización espacial de las areas metropolitanas españolas: una perspectiva desde la movilidad residencia-trabajo. Ciudad y Territorio – Estudios Territoriales, pp. 189-210.

García-López, M.A. (2007). Estructura Espacial del Empleo y Economías de Aglomeración: El Caso de la Industria de la Región Metropolitana de Barcelona, *Architecture, City & Environment*, 4, pp. 519-553.
García-López, M.A. (2008). Manufacturas y servicios en la RMB, cambios en la estructura espacial de su empleo; *Revista de Estudios Regionales*, 83, pp 197-224.

Giuliano, G. & Small, K.A. (1991). Subcenters in Los Angeles Region, *Regional Science and Urban Economics*, 21, 163-182.

Giuliano G. ; Redfearn C.L. (2007). Employment concentrations in Los Angeles, 1980–2000 , *Environment and Planning A*, 39 (12),pp. 2935–2957.

Gordon, P., Richardson, H.W. & Wong, H.L. (1986). The distribution of population and employment in a polycentric city: the Case of Los Angeles, *Environment and Planning A*, 18, pp. 161-173.

Gordon, P. & Richardson, H.W. (1996): Beyond Polycentricity: the Dispersed Metropolis, Los Angeles 1970-1990, *Journal of American Planning Association*, 62, pp. 289-295.

Henderson,V; Shalizi,Z.; Venables,A. (2000). Geography and Development; WP World Bank, WP2456.

Launhardt, 1885. W. Launhardt , Mathematisch Begrundung der Volkswirtschaftslehre. , Teubner, Leipzig (1885).

Marmolejo, C.; Aguirre,C.; Ruiz,M.; (2010a). ¿Hacia un sistema de metrópolis españolas policéntricas?: caracterización de su estructura metropolitana?. 6CTV Mexicali 2010.

Marmolejo, C.; Aguirre,C.; Roca,J. (2010b): Revisiting employment density as a way to detect metropolitan subcentres: an analysis for Barcelona & Madrid. Congreso de la European Regional Science Association (ERSA), 1-24

McDonald, J.F. (1987). The Identification of Urban Employment Subcenters, *Journal of Urban Economics*, 21, pp. 242-258.

McDonald, J.F. (2009). Calibration of a monocentric city model with mixed land use and congestion *Regional Science and Urban Economics*, Volume 39, Issue 1, January 2009, pp. 90-96

McDonald, J.; McMillen, D. (1990). Employment Subcenters and Land Values in a Polycentric Urban Area: the Case of Chicago, *Environment and Planning A*, 22, pp. 1561-1574.

McDonald, J.; Prather, P. (1994). Suburban employment centres: The case of Chicago , *Urban Studies*, 31, pp. 201-218.

McMillen, D.; McDonald, J.F. (1997). A Nonparametric Analysis of Employment Density in a Polycentric City , *Journal of Regional Science*, 37, pp. 591–612.

McMillen, D. (2001a). Non-Parametric Employment Subcenter Identification, *Journal of Urban Economics*, 50, pp. 448-473.

McMillen,D. (2001b). The centre restored: Chicago's Residential price gradients reemerges *Economic Perspectives*, 2Q/2002.

McMillen,D. (2003a). Employment subcentros in Chicago: Past, Present and future *Economic Perspectives*, 2Q/2003

McMillen, D. (2003b). The return of centralization to Chicago: Using repeat sales to identify changes in house price distance gradients, *Regional Science and Urban Economics*, 33, 287-304.

McMillen, D.; Smith, S. (2003). The number of subcenters in large urban areas, *Journal of Urban Economics nº* 53, pp. 321-338.

Mills, E. (1972). *Studies in the Structure of the Urban Economy* . London, John Hopkins Press.

Muñiz, I.; García-López, M.A (2009). Policentrismo y sectores intensivos en información y conocimiento, *Ciudad y Territorio Estudios Territoriales*, 160

Muth, R. (1969). *Cities and Housing*. Chicago: Chicago University Press.

Nel·lo, Oriol (2001). *Ciutat de ciutats* . Barcelona, Ed. Empúries.

OMB (2000). Office of Management and Budget. Part IX. Standards for Defining Metropolitan and Micropolitan Stadistical Areas; Notice, Federal Register.

Pain,K; Hall,P. (2006). The Polycentric Metropolis. Learning from mega-city regions in Europe. Earthscan.

Redfearn, C.L. (2007). The Topography of Metropolitan Employment: Identifying Centers of Employment in a Polycentric Urban Area , *Journal of Urban Economics*, 61, pp. 519-561.

Roca, J (2004): La explosión urbana: presente y futuro de las metropólis. Ciudad y Territorio. Estudios Territoriales, nº 141-2; pp. 501-503.

Roca, J.; Moix, M. (2005). The Interaction Value: Its Scope and Limits as an Instrument for Delimiting Urban Systems , *Regional Studies*, 39, pp. 359-375.

Roca, J.; Marmolejo, C.; Moix, M. (2009). Urban Structure and Polycentrism: Towards a redefinition of the sub-centre concept, *Urban Studies, volume 46* (Forthcoming)

Roca, J.; Arellano,B.; Moix,M. (2011-forthcoming): Estructura urbana, Policentrismo y Sprawl, los ejemplos de Madrid y Barcelona. Ciudad y Territorio, Estudios Territoriales.

Shearmur, R.; Coffey, W.J. (2002). A Tale of Four Cities: Intrametropolitan Employment Distribution in Toronto, Montreal, Vancouver, and Ottawa-Hull, 1981-1996 , *Environment and Planning A*, 34, pp. 575-598.

Suarez,M.; Delgado, J. (2009). Is Mexico City Polycentric? A trip attraction capacity approach, *Urban Studies*, Volume 46(10), P 2187-2211.

Thünen, von J. (1826): Der Isoliete in Beziehung auf Landwirtschat und nationalökonomie. Hamburgo, Puthes.

White, M.J. (1976): “Firm Suburbanization and Urban Subcenters”. Journal of Urban Economics, 3, pp. 323.