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Measuring functional polycentricity for the analysis of structural places: The case of the seven principal metropolitan areas in Spain

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MEASURING FUNCTIONAL POLYCENTRICITY FOR THE ANALYSIS OF STRUCTURAL PLACES. THE CASE OF THE SEVEN PRINCIPAL METROPOLITAN AREAS IN SPAIN

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Keywords: Urban Structure, polycentricity, Structural Places, Metropolitan Areas, Spain.

Abstract

The study of polycentrism is responsible for identifying subcenters that integrate urban systems, as well as measuring the magnitude of the phenomenon in urban reality. This paper presents the analysis of measure of functional polycentricity, applying the functional polycentricity index presented by Green (2007) for seven metropolitan areas in Spain; finding their determinants, incorporating variables of magnitude, territorial balance and complexity to a linear regression model. It was found that from the functional perspective, the studied metropolitan areas of Spain have low levels of polycentricity. In order of magnitude was found to be less polycentric in their subsystems, Zaragoza, Madrid and Seville metropolitan areas; and in contrast Bilbao, Barcelona and Valencia with the largest. Malaga was found as a medium polycentricity level system despite the presence of few subcenters. Was found also that, although the incipient index, the variables that can best explain polycentricity are the size of the subsystem and number of nodes, the specialization and diversity of jobs, and also variables that explain income and mobility within municipalities of the subsystems that conform metropolitan areas in study.

Introduction

The study of polycentrism has been applied along urban territories in order to identify and explain the components of the structure as well as the transformation of cities in metropolitan systems, with their impact on the social, demographic, economic and environmental. It is clear the need to go beyond the paradigm of monocentric city and conveniently to penetrate in the analysis of the current metropolis as large artifacts, composed by a series of settlements which are in fact related to each other. In practical terms, the study of polycentrism is responsible for identifying subcenters that integrate urban systems, as well as measuring the magnitude of the phenomenon in urban reality.

Meanwhile, in regard to the degree of polycentrism of an urban area, can be clearly identified two currents that have been widely studied, almost always independent of one another. The first is related to morphological analysis linked to the analysis of the density and shape of population distribution and employment in their cores and their hinterland. The second trend is related to the functional analysis tied to the study of flows that arise between different cores and their hinterland, linking complementary areas. The separate study of both approaches cannot delve into issues as relevant as

some regions tend to be more functionally polycentric than morphological (Burger and Meijers, 2012). By contrast, integrating both tasks would lead to conclude that the coincidence of morphologic and functional polycentrism would be symptomatic of the existence of places that are not only dense, but also that structure territory and become structural places.

A further development of the measurement of functional polycentrism is presented by Green (2007) proposing the "functional polycentricity" concept, emphasizing the term polycentrism related to the simple morphological polynucleation, from functional related to the network operation of the system. According to Green, functional polycentricity level is not defined by the proximity between nodes but by the relationship between them. Based on the methods of social network analysis, has proposed the indicator of "network density" that attempts to measure how much flows are balanced between the nodes: the more connected they are and such distribution is more uniform, the higher is functional polycentricity level in the system.

The first chapter of this paper reviews the state of the art of the constituent elements of polycentrism studies, the second will examine very closely the study of functional polycentricity, in the third apart is presented the methodology, as well as the scope and sources of information for the study, and finally, the fourth chapter will present the results of measuring polycentricity phenomenon in Spanish metropolitan areas and the exercise of finding the factors that determine their magnitude.

1. State of the Art: morphology and functionality

The empirical study of polycentrism has used different methods of analysis, which may differ, depending on the used criteria, into two spheres almost always independent of each other. The first is the morphological criteria, about the study of the shape and distribution of the population or workers density in the cores that make up a metropolitan area and their respective hinterlands. The second criteria, conceived from the functional sphere is about connectivity relationships, that is to say, the amount and intensity of flows between members that make up the metropolitan phenomenon and complementary relationships created from these. Thus, the terms polynucleation, referring to the morphological approach and polycentricity to the functional, become the pillars of research of modern metropolis transformations, and integrating both approaches lead to a genuine study of polycentrism (for further discussion see Marmolejo et al., 2013).

All approximations already seen respond two fundamental issues in the study of polycentrism: the detection and identification of the cores that make up the area, whether they are called sub-centers in the metropolitan scale or centers in regional; and to measure the magnitude of the phenomenon in territorial dimension and dynamics it involves. What follows is a review of existing literature, taking as reference the criteria which, as we saw, underlying the study of polycentrism.

Morphological approach

From the point of view of the morphology of cities, polynucleation basically refers to the plurality of urban centers in a given territory, and more specifically to the balanced distribution in size and importance of these urban centers and interaction with their areas of influence. Under this perspective, a polycentric development policy can be considered as one aimed at the distribution of the economic functions on space, attempting the territorial balance through the modulation of urban hierarchies (Burger and Meijers, 2012).

Regarding the detection of the components of a polycentric environment it can be said that the element of analysis has been largely associated to density workers and their distribution in space. From this point of view, specialized literature has developed four methods as follows:

a. Employment density peaks which consists in identifying alterations or peaks over surrounding areas by analyzing the spatial distribution of the density function based on Geographic Information Systems tools, being candidates to subcentres those local employment peaks found. This method was used in the first instance by McDonald (1987) and taken up by McDonald and McMillen in 1990.
b. Reference thresholds, which take into account both the density (jobs per square kilometer) and absolute values or critical mass of jobs, of which are highlighted works by Giuliano and Small (1991), McDonald and McMillen (1998) and Garcia-López (2007).
c. A third approximation of density consists of parametric methods that determine subcentres by analyzing the positive residuals on an employment density function, as in the study of McDonald and Prather (1994).
d. Finally, using non-parametric methods to identify local employment density peaks, considering the specific local two-dimensional space through the use of local or geographically weighted regression, where McMillen and McDonald (1997), McMillen (2001) Craig and Ng (2001) and Readfearn (2007) are pioneers.

Meanwhile, in terms of dimensioning and measuring the phenomenon of polynucleation at a metropolitan scale, mainly highlights three practices:

a. The rank size distribution used by Hall and Pain (2006) Meijers (2008) and Burger and Meijers (2012) measures the equipotential centers through their demographic size. The flatter the rank-size relationship is more uniform the distribution of the population, which can be interpreted as a higher rate of polycentrism.
b. The analysis of the distribution of employment / population among centers through indicators such as percentage or as integrated indicators as entropy studied by Marmolejo et al (2012) and Masip and Roca (2012).
c. The spatial distribution under the criterion of measurement of the distance of the cores using spatial autocorrelation of density or GINI indicator, introduced by Tsai (2005).

Functional approach

The concept of polycentrism approached from the functional perspective refers to the analysis of flows that for very different reasons occur between the cores and their hinterland linking complementary areas. However, it is implied that a number of prominent flows themselves do not guarantee the polycentric development of an urban or regional area; it is also necessary to have some balance in emerging relationships such connectivity. In this sense the more diverse (ie multidirectional), bidirectional (ie reciprocal) and dense (ie complementary or not self-contained / self sufficient) is the network of flows greater is polycentricity. The polycentricity seems closer to the concept of polycentrism of the ETE which presupposes that such development reinforces the cores own economy by enabling network economies (Boix and Trullen, 2012), complementary to the agglomeration within concentrations of economic activity.

The functional approach is derived from the systems theory of cities (Berry, 1964; Pred, 1977; Dematteis, 1985), which would seem opposed to the central place theory (Christaller, Losch 1933, 1954) but actually as an evolution of the same and thus best inscribed in the field of geography. In recent literature three methods are applied to detect subcenters by route of flow analysis:

a. The attraction ratio (multipurpose travelers attracted / employed people) using the criterion of identifying areas that attract significantly more journeys than others after controlling for the number of jobs on the contributions of Gordon, Richardson & Giuliano (1989), Gordon & Richardson (1996).
b. The spatial interaction models, with criteria for identifying areas where attracted flows are higher than predicted by a gravity model that controls the mass of both the attractor and emitting area and the distance between them as Camagni applications (1994); Trullen & Boix (2000).
c. That of the subsystems under the criteria for identifying areas that structure functional subsystems, understood by them all the areas connected by high values of interaction (VI). The VI is the bidirectional strength of connection of two zones being calculated from flows, once mass controlled, used by Roca & Moix (2005) Roca, Marmolejo & Moix (2009) Roca, Arellano & Moix (2011).

On the other hand, functional methods for the measurement of polycentrism from the functional perspective have been primarily used on a regional scale where the interaction between the different centers is not as obvious as the interaction that arises between the subcenters within a metropolitan area. In Europe, in contrast to North America where the polycentric performance mainly derived from concentrated decentralization of central cities, polycentricity derives priority, although not always, to the incorporation of formerly independent centers, and therefore the emphasis has been the measurement of the functional relationships between the centers attached to the network. The following list briefly describes the three methods developed for this purpose:

a. The spatial distribution that Goei et al. (2010) applies to measure bivariate relationships between centers unexplained by their mass and the distance between them.
b. The indices based on mobility, for example internal centrality index, the rate of relative interaction, dominance, entropy of flows, symmetry index, etc. This family of methods has been used by authors such as Boix (2002); Limtanakool et al. (2007, 2009), Burger and Meijers (2011), Gallo and Garrido (2012); Viñuela et al. (2012).
c. Based on social networks analysis, whose criterion is the measurement of inequality in the distribution of flows among centers, used by Green, N. (2007) and on which we delve into the next chapter, as it represents the body of the present work.

2. Funcional polycentricity in metropolitan areas

Within the family of practices in search of the measurement of polycentricity from a functional perspective, it highlights the contribution of Nick Green (2004, 2005, 2007) who retakes graph theory used in geography (Haggett, 1965; Chorley and Haggett, 1967 and Tinkler, 1977) according to which could be understood regions as formed by cities that act as nodes in a network whose vertices allow to establish complementary relationships of people, matter, energy and information. This perspective allows us to incorporate aspects of the topography of the region, as the number of nodes or zones, and furthermore the level of interlinking (diversity, bidirectionality and complementarity). Therefore, the author considers that this is the appropriate framework for analyzing what he calls "functional polycentricity". Such that different topographies (position of the nodes or zones) can have the same topology (shape, and intensity of connection between them), which is extremely useful when the derived indicator is used to compare urban systems with territorial conditions or different scale.

As with any system, the number of interlinkages may be important, and the difficulty of implementing the functional polycentricity indicator lies not so much in the complexity of estimation, but especially in lack of information. Thus, the interlinking could be measured, among others, by financial flows, emails, online shopping, phone calls, flows of buyers, leisure, medical services or to visit friends, and work trips of course.

For Green it is enough to have more than one node or area in the system and likewise there are links between them to make it possible to calculate the functional polycentricity. The theoretical development of functional polycentricity index can be consulted in the original publications (Hall and Pain, 2006, and Green, 2007). Here we will just simply say that the steps involved in the estimation, in the case of labor mobility are:

1) First, density of network interaction is calculated in terms of commuting Δ_c as follows:

$$\Delta_C = \frac{L}{L_{\max}} \quad (1)$$

Where L is the total number of flows or movements of employed persons in the different nodes/zones in the urban system (metropolitan area in our case); Lmax is the difference between the working population of the system and the resident employed population in the smallest node.

2) With the previous network density is calculated specific index of in-commuting polycentricity or inflows to each zone ($P_{SF\text{-}IC}$) as follows:

$$P_{SF-IC} = 1 - \frac{\sigma_{IC}}{\sigma_{IC\max}}.\Delta_c \quad (2)$$

Where σ_{IC} is the standard deviation for in-commuting of analyzed areas, while σ_{ICmax} is the standard deviation between the largest inflows and zero (since it makes reference to nodal degree of the simplest network with two nodes, where the first takes a value of zero and the second takes the largest in receiving flows).

In the same way is calculated specific index of out-commuting polycentricity or outflows ($P_{SF\text{-}OC}$):

$$P_{SF-OC} = 1 - \frac{\sigma_{OC}}{\sigma_{OC\max}}.\Delta_c \quad (3)$$

3) Then, as a previous step to calculate the General Functional Polycentricity Index, it is necessary to derive a complementarity modifier ϕ (fi), since total resident employed population (REP) equals the total work places (WP) because are only taking into account the flows that start and end within the urban system, and therefore specific indexes are complementary. This modifier is calculated as follows:

$$\phi = 1 - \sigma\left(\frac{\sigma_{OC}}{\sigma_{OC\max}}, \frac{\sigma_{IC}}{\sigma_{IC\max}}\right) \quad (4)$$

4) As a final step is calculated the General Functional Polycentricity Index P_{GF} through the average of specific rates of input and output flows weighted to the extent that are complementary, in the following way:

$$P_{GF=} \frac{\phi \cdot P_{SF-IC} \cdot P_{SF-OC}}{2} \quad (5)$$

Note that the indicator is constructed with flows between zones, excluding those who stay in them. This is consistent with the christallerian original concept of centrality and nodality. To Christaller (1933) the centrality of a place is given by the ability to attract flows (consumers of goods and services), while the nodality for their ability to meet domestic demand and thus is represented by those who live and consumed in the same area, although in practice nodality has been assimilated to the size of the nucleus. Then could be said that a multinuclear paradigmatic system would be the one where the size of the cores is similar (not dominated morphologically by none), while a paradigmatic in terms of polycentricity would be one with a diverse, bidirectional and dense network (no center monopolizes flows that receives or emits), Burger and Meijers (2012).

As seen from the mathematical formulation, the general functional polycentricity index takes values between 0 and 1. If is close to zero means that the system tends to functional monocentrism with an important center in terms of employment, and also that monopolizes the destination of labor flows from other areas. If the indicator approximates one means that the system tends towards functional polycentricity, as there is a more "democratic" or plural distribution of flows between areas, that is, there is no dominating areas as destinations, nor others left behind and therefore isolated.

Using labor flows, Hall and Pain (2006) have found that this indicator in practice goes from 0.02 to 0.19. In their study, based on the analysis of the interlinkage of FUR (Functional Urban Regions) comprising the eight European regional megacities[1], Paris is the less interlinked, while the RhineRur and Randstad are the most interlinked and therefore with the highest rate of polycentricity, as common sense suggests.

3. Methodology, study area and data

The methodology of this work consists mainly of the following:

1) Detect functional subsystems and subcenters of the study area.
2) Delimitate metropolitan areas as the integration of functional subsystems.ç
3) Calculate the level of functional interlinking within each metropolitan area through functional polycentricity indicator of Green (2007) having separately as inner unity of analysis municipalities, subcenters and subsystems that comprise those areas.

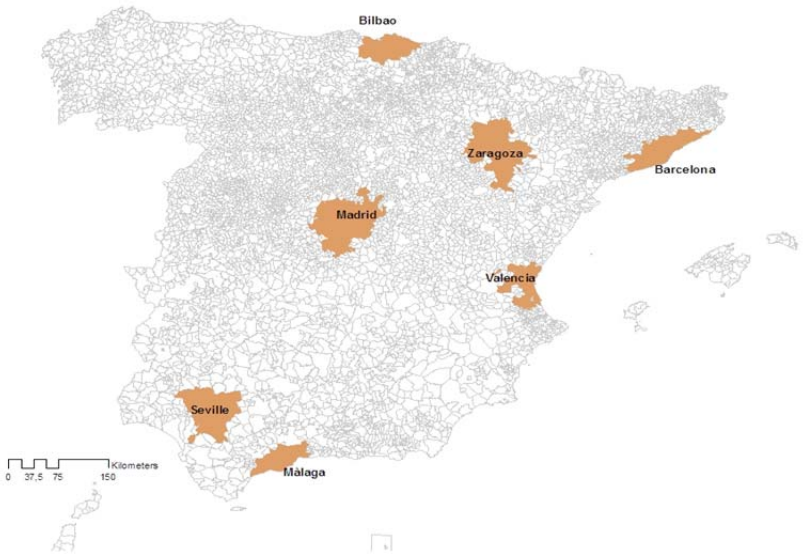
For the detection of functional subsystems and the delimitation of metropolitan areas subject of this study, it's been used the municipal integration method based on the value of interaction proposed by Roca, Moix and Arellano (2012), since it is well suited to our interest because: 1) is based on the analysis of commuting flows by pairs of municipalities and is therefore consistent with the search for the boundaries of the local systems, 2) considers bidirectional center-periphery relations and hence is able to apprehend the complexity of contemporary mobility, 3) ignores the arbitrary thresholding of flows in absolute or relative terms as is common in most of the methods

[1] South East England, Paris Region, Central Belgium, Randstad, RhineRuhr, Rhine-Main, Northern Switzerland EMR and Greater Dublin.

for detecting FUR (functional urban areas). This method allows to find urban subsystems within metropolitan areas that are self-contained by 50%, that is that at least half of employed people living in municipalities are actually working in a municipality of the same subsystem. The authors explain how, through the same interaction value calculated between subsystems, it is possible to find metropolitan areas, and for consistency in this work have been identified likewise the real cities of study.

The scope of the study is limited to the seven major metropolitan areas in Spain: Barcelona, Bilbao, Madrid, Malaga, Seville, Valencia and Zaragoza.

Figure 1. Principal metropolitan areas in Spain



	Municipios	Suelo artificializado (km2)	LTL	Población	Densidad global (LTL+POB/km2)
		a	b	c	.=(b+c)/a
Madrid	183	860	2.446.400	5.542.843	9.291
Barcelona	184	745	1.903.867	4.530.164	8.636
Valencia	104	308	686.247	1.792.375	8.046
Sevilla	52	237	447.849	1.381.531	7.719
Bilbao	123	112	445.666	1.231.367	15.024
Málaga	32	194	366.525	994.984	7.032
Zaragoza	88	127	301.860	724.335	8.066

Source: Corine Land Cover 2000 and Population Census 2001.

The information sources used are:

1) In terms of demographics and travel-to-work the Population and Housing Census 2001.

2) In terms of data related to consumption and land use the Corine Land Cover 2000.
3) In terms of road network infrastructure the Tele Atlas in 2001 and the network of stations and halts the RENFE and other supra-regional rail services.
4) The optimal distance matrix between subsystems and municipalities calculated from the data of the previous point with the help of a specific transport SIG.
5) Digital Terrain Model with a resolution of 1 pixel = 80 * 80 meters from which has constructed topographic indicators.

4. Polynucleation and polycentricity in the Spanish urban system

As mentioned, the vast majority of studies on polycentrism in Spain have focused on the analysis of polynucleation. Whether analysis methods have been based on morphological criteria, such as the analysis of spatial patterns of employment density, or functional as the detection of nodes that are especially relevant in attracting flows, the common destiny of these studies has been the identification of the polynucleation level. In this work was carried out the analysis of the magnitude of functional polycentricity for the seven major metropolitan areas in Spain. In the first part the calculation was performed for each metropolitan area taking municipalities as the unit of analysis, in the second, the analysis was based on the subcenters identified in previous studies (Roca et al. 2009) and in the third part, the analysis was performed at the level of the subsystems that comprise each metropolitan area. A further work consisted in the study of the determinants of functional polycentricity index, incorporating variables of magnitude, territorial balance and complexity to a linear regression model.

4.1 Mensuration of the phenomenon at a metropolitan scale

The functional polycentricity index was firstly estimated considering commuting flows between all the municipalities of the seven metropolitan areas. It was found a high level of polycentricity in the metropolitan system of Bilbao, a medium level of polycentricity in Barcelona, Valencia and Madrid, and a lower level in systems Seville, Malaga and Zaragoza. The table below warns that urban systems with higher level of polycentricity among their municipalities are obviously those with less self-containment, that is, in these areas there are more flows or connections between the towns, and in turn, there are lower levels of functional polycentricity in systems with higher self-containment levels, as expected.

Table 1. Functional polycentricity between municipalities of the Metropolitan Area

AM	Total Commuting	In-commuting	Self-containment	# municipalities	Pgf
Bilbao	430.056	227.460	47,1%	122	**0,401**
Barcelona	1.854.082	792.564	57,3%	184	**0,346**
Valencia	659.612	264.042	60,0%	103	**0,318**
Madrid	2.328.709	871.477	62,6%	183	**0,306**
Sevilla	427.498	120.237	71,9%	52	**0,187**
Málaga	340.105	67.267	80,2%	32	**0,114**
Zaragoza	283.788	39.473	86,1%	88	**0,101**

Source: INE, 2005.

As a second step it was calculated the level of functional polycentricity between subcenters of the Metropolitan Areas, grouping the municipalities of the CEC (Continuous Economic Center) as the primary subcenter or CBD (Central Business District). The lower table data reveals that in this case the greater polycentricity level are precisely those most polynuclear systems, so is the number of subcenters and their relative importance in terms of metropolitan employment concentration (Subcentrers Commuting (not CEC)). These are Barcelona, Valencia and Bilbao, followed distantly by, Seville, Madrid and Zaragoza. Malaga is a very special case, because having fewer cores, they concentrate a significant amount of economic activity, so that the metropolis would tend more towards the equipotential, since the presence of major tertiary centers such as Marbella and tertiary-industry as Torremolinos or Fuengirola compete with the central city.

Table 2. Functional polycentricity between metropolitan subcenters

MA	Total Commuting	CEC Commuting	Subcenters Commuting (no CEC)	Subcenters	Pgf
Valencia	361.110	256.747	19,8%	18	**0,068**
Barcelona	1.218.005	889.210	21,9%	24	**0,066**
Bilbao	257.557	310.317	15,5%	15	**0,042**
Málaga	241.389	164.442	23,1%	5	**0,022**
Sevilla	229.197	202.710	6,9%	8	**0,013**
Madrid	1.480.448	1.376.415	5,5%	9	**0,011**
Zaragoza	250.943	239.905	4,4%	8	**0,007**

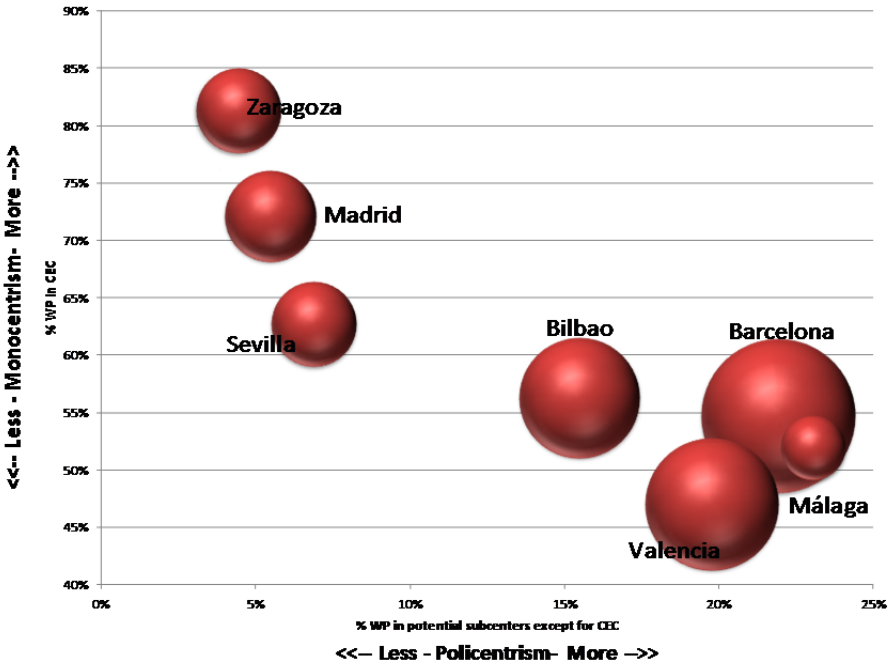
Source: INE, 2005.

However, polynucleation can also be analyzed from another reading based on the weight of CEC subsystem, as a macrocephalic urban system would have a large share of employment in its center, displacing the rest of the subcenters to a secondary role. In this line of thought, it is possible to rank urban systems in terms of the relative importance of their principal core, thus as a result, Zaragoza would be the most macrocephalic system, with a weight of 95.6% of subcenters commuting, followed by Madrid and Seville, in a second group would Bilbao, Barcelona, Malaga and Valencia

that would be the center with less significance in relation to the whole metropolitan area.

If both forms of reading the urban structure are sorted in a Cartesian plane emerges the image of the figure below, where can be observed very clearly two families of metropolitan systems. The first one consists of Zaragoza, Madrid and Seville where the center tends to dominate at the expense of the number and specific weight of the subcrnters, and the second, consisting of Barcelona, Valencia, Bilbao and Malaga in which the opposite occurs: the center has a lesser importance, compared to a more abundant number of cores and their economic weight.

Figure 2. Polynucleation level of urban systems in Spain



Note: The size of the spheres is representative of the number of cores / subcentres of the metropolitan system.

It is interesting to note how the size of the metropolitan system has little or no influence on the number of cores, as Madrid and Barcelona, which are very similar in terms of population and number of municipalities, are at opposite ends and so it is Malaga in relation to Zaragoza. Instead, the territorial matrix upon which rest the urban systems seems to have an influence on the polynucleation as is evident in the case of Barcelona and Bilbao where the cores follow the valleys or distributed along watersheds.

The table below details the result of applying the Green indicator of functional polycentricity at the level of subsystems that comprise the metropolitan areas, leading to the third set of estimations of this work. As shown, Valencia and Barcelona stand out as the systems with the largest polycentricity of those studied. Bilbao is in an intermediate position, and Malaga is closer to urban systems group with the lowest

level of polycentricity constituted, in this order, by Zaragoza, Madrid and Seville. Therefore, while Malaga has a multinuclear structure that moves toward equipotential in terms of the weight of the economic activity of their cores, is far from the cities where the subsystems denote the highest labor interlinking among them. Instead, we can say that Zaragoza, Seville and Madrid are less polycentric cities both in terms of low level of polycentricity as polynucleation.

Table 3. Functional polycentricity between subsystems of the Metropolitan Area

MA	# subsystems	Self-containment	Subcenters Commuting (no CEC)	psf (in-commuting)	psf (out-commuting)	Pgf
Valencia	18	75,3%	19,8%	0,13	0,13	0,13
Barcelona	24	77,5%	21,9%	0,14	0,13	0,13
Bilbao	15	86,9%	15,5%	0,07	0,07	0,07
Málaga	5	89,4%	23,1%	0,03	0,04	0,03
Sevilla	8	94,9%	6,9%	0,02	0,02	0,02
Madrid	9	93,6%	5,5%	0,03	0,02	0,02
Zaragoza	8	96,5%	4,4%	0,01	0,02	0,01

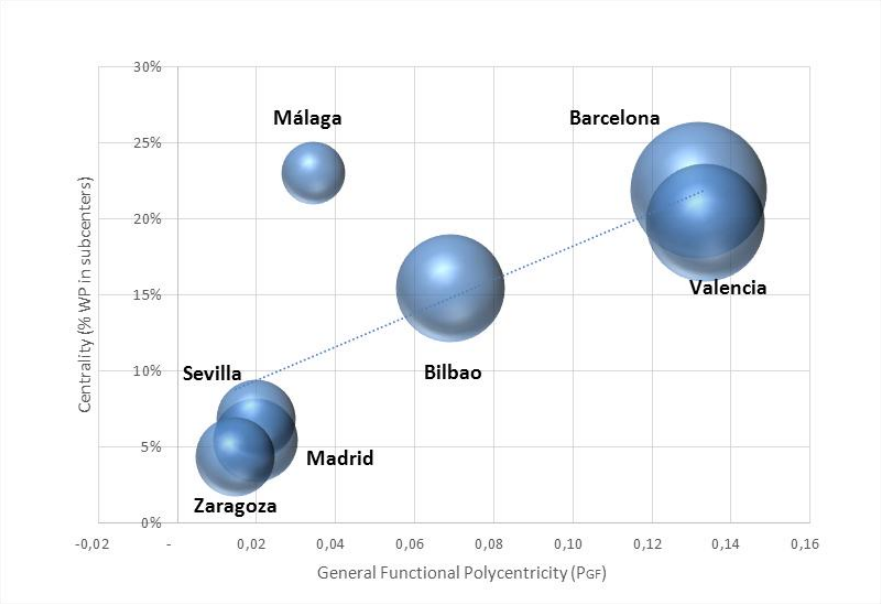
Source: INE, 2005.

Meanwhile the correlation between the average of self-containment of the subsystems constituting each metropolitan area and the general polycentricity index (r = -0.918) confirms that the metropolis formed by self-sufficient systems are those in which there is less interaction within subsystem, as is apparent. This means that the greater the policentricity the higher the density or network opening (measured as the ratio between the flows and work places), more reliance exists, therefore, between the various subsystems that make up the metropolis.

If the above data are analyzed, unfolding the two constituent parts of the general polycentricity, it means, the specific polycentricity of input and output flows, one can see how the larger metropolitan areas tend to have greater polycentricity in their inflows regarding to out commuting. This correlation may be due to that larger cities have bigger subsystems capable of hoard inflows in a more democratic way in relation to emissions of workers.

So, is there a relationship between the polynucleation and polycentricity? The simple statistical conjunction suggests that there is, since the correlation between the number of subcenters and general polycentricity is r = 0.918, and the correlation between the relative weight of the subcenters in terms of economic activity and general polycentricity is r = 0.717. As seen in the chart below the correlation is not perfect, since, as was said before, Malaga has a higher polynucleation level than the level of polycentricity, while, according to the trend line, Seville, Madrid and Zaragoza has a higher the level of polycentricity than their level of polynucleation. This same finding was highlighted by Hall and Pain (2006) in his POLYNET project in which the Greater London, markedly monocentric system, was found to have a higher level of polycentricity in relation to their level of polynucleation.

Figure 3. Polynucleation vs. Polycentricity



Note: The size of the spheres is representative of the number of cores / subcentres of the metropolitan system.

In an attempt to bring together the topography (polynucleation) and topology (functionality) of the network in a more general indicator of polycentrism, it has been carried out a factor analysis with the various dimensions of polynucleation (ie number of subcenters,% of WP in subcenters,% WP in the CEC) and polyfunctionality. The result of it is a principal component (able to synthesize the 78% of the information) whose factorial scores are significant of the level of Polycentrism in metropolitan systems. The table below reflects the results of this analysis where are three clear paradigms: polycentric cities (Barcelona and Valencia), moderately polycentric (Bilbao and Málaga) and less polycentric (Seville, Madrid and Zaragoza).

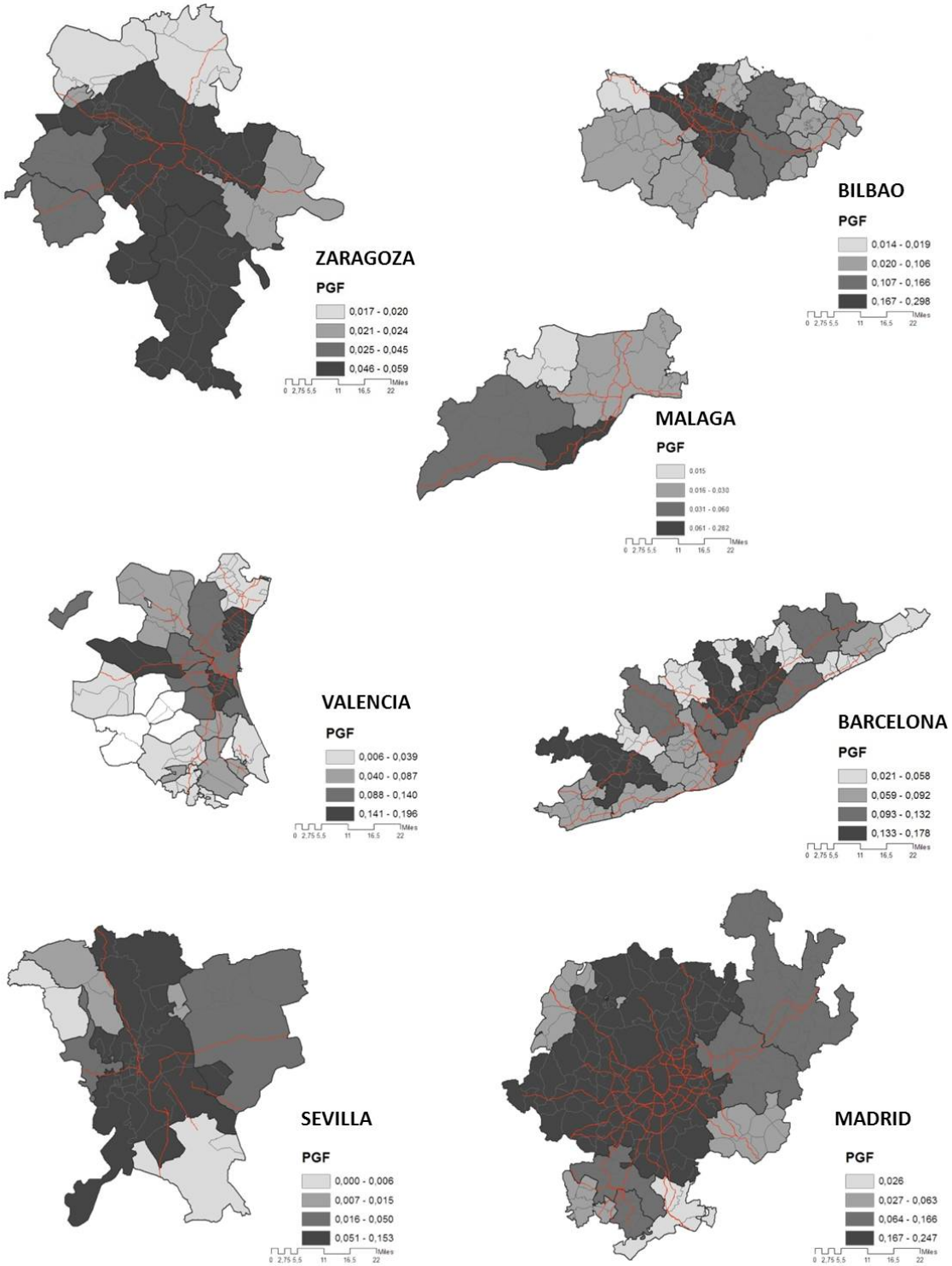
Table 4. Polycentrism in Spanish metropolises

Barcelona	1,285
Valencia	1,169
Bilbao	0,313
Málaga	0,092
Sevilla	-0,693
Madrid	-0,923
Zaragoza	-1,242

Note: Units are factorial scores, the more positive they are, the greater the level of polycentrism (polynucleation and polycentricity).

La figura posterior indica el nivel de policentricidad funcional al interior de los subsistemas que conforman las siete áreas metropolitanas españolas en estudio, a la vez imbricado sobre la infraestructura vial existente.

Figure 4. General Functional Policentricity within subsystems of principal Spanish metropolitan areas



Own elaboration.

4.2 Analysis of the determinants of functional polycentricity

The interconnectivity of the areas that constitute a system fundamentally depends on the level of complementarity between them, ie, the coupling capacity of the different

spaces according to their territorial vocation (on which impact issues such as planning and socioresidencial segregation), and although it also depends on the level of infrastructure, mobility services and income level. In order to find the urban factors behind functionality has been made a regression model, which among other things, is required to have a reasonable number of observations, so that the PGF was recalculated at an urban subsystem level. Therefore, the dependent variable is the level of polycentricity between the municipalities of urban subsystems of the seven metropolitan areas studied. Meanwhile the explanatory variables are:

- *In terms of urban and regional structure:*

    - The percentage of employment in the subcenter municipality in relation to total employment at subsystem, which provides an idea of the "macrocephaly" of the subcenter in relation to the group of municipalities that structure (% subcenter WP).
    - Orographic complexity level[2] as an indicator of the difficulty of overcoming the space within subsystems.
    - The number of subcenters and general polycentricity ($P_{GF\text{-}intersubsistms}$) in the metropolitan area of reference. This variable allows us to see the relationship between polycentricity within and between the subsystems.

- *In terms of the structure of the labor market:*

    - The percentage of specialized jobs[3] in the subsystem (% specialized jobs). It is expected that the more specialized the labor market area, greater the need to import skilled labor from other.
    - The diversity of job offer[4] (employment diversity) in the municipalities of the subsystem. The greater the diversity, the greater the probability that the REP with different professional profiles can find work in the same place in which they live, which reduces mobility with others.
    - The mismatch index between labor supply (sectoral imbalance) that measures how similar is the structure of the REP and WP at a 1 digit disaggregation of the National Classification of Economic Activity. When this index is 0, it means that for municipalities in a subsystem are

[2] This indicator is constructed as follows: in the first instance within each municipality is calculated the amount of land in different ranges of slope (ie <5% between 5 and 10%, between 15 and 20%, etc.) with the help of a GIS. Then, on these figures we calculated the Shannon diversity indicator. The higher the indicator, the greater the entropy of orographic slopes and higher the level of the municipality orographic complexity. Finally, a subsystem indicator has been integrated by using a weighted average, where the weighting is the area of the municipality.

[3] To identify specialized jobs have been analyzed at the level of all Spanish municipalities, the sectors in which working people is moving more. This calculation has consisted of multiply the origin destination matrix of each of the seventeen sectors of the CNAE one digit disaggregation and optimal distance matrix derived from an analysis TransCAD using Tele Atlas map database. Then, using a cluster analysis has identified specialized sectors, which are: Public Administration, Offshore, Financial, Services, and Transport and Telecommunications.

[4] Employment diversity was calculated from the workplace (WP) 17 disaggregated sectors through the Shannon entropy index. Specifically, this index is calculated at the municipal level, and added by subsystem using a weighted average of WP in each municipality.

balanced in terms of the sectoral structure of the labor market, ie, for all sectors there is the same proportion of job offer that demand for it, which could promote self-containment, and hence reduce inter municipal mobility. The closer to 2 is the index means that there is a greater imbalance and hence that labor mobility is necessary.

- *In terms of the provision of transport infrastructure*

    - The provision of inter municipal railway stations per 10,000 inhabitants. This index albeit less to what is desirable, attempts to measure mass transport services within a subsystem.
    - The number of accesses at highways and motorways (auto pis / pathways) per 10,000 inhabitants. The higher this index and the previous, the lower the difficulty of people to overcome the distance between each municipalities, and therefore, *ceteris paribus*, the greater the potential mobility.

- *Regarding the level of income*

    - The socioprofessional[5] structure of the resident employed population, as it is expected to be a relationship between the level of income and mobility (Fac. unqualified).

In the same way, there are controlled issues such as the size of the subsystems and their density.

Of the 87 subsystems that make up the seven metropolitan areas have been considered 82, since five of those denote extreme values of general functional polycentricity[6]. The table below provides the results of the models, presenting only the variables that were significant at the 95% confidence level[7]. In the second column (1a) is constructed with all subsystems at a time, the results indicate that polycentricity should:

1) Decreases to the preponderance of the subcenter that gives structure to the subsystem, since the larger is the header, it is created a monocentric effect in

[5] This structure has been synthesized from a principal component analysis built on the percentage of each of the categories of the National Classification of Occupation to one digit disaggregation. In this analysis factor 1 polarized, positive, areas where live qualified people (eg managers, professionals, technicians upper and middle) and in the negative ones where live less qualified industry workers. Component 2 (Fac unqualified) indicates the places where they live unqualified socio-professional groups. Both factors are able to explain 66% of the variance.

[6] These five subsystems are: Chiva, Fuengirola, Bilbao, Torremolinos and Madrid, in all cases PGF is more than two standard deviations from the mean of the set.

[7] In addition to the models presented, others were calculated separating the MA in accordance with their level of polycentrism (Barcelona and Valencia, Bilbao and Málaga, Seville, Madrid and Zaragoza). The results, however, do not differ in essence with those reported here. However, have not been performed individual models for each MA, because the number of cases would have been insignificant, and therefore unsuitable for this type of multivariate analysis.

the small scale. As Burger and Meijers (2012) indicate the size of the center is positively associated with sectoral diversity while a broader labor market allows for better fit between supply and demand for labor, and consequently reduces the need for mobility.

2) It increases with the size of the subsystem, measured as the sum of the optimal distance between all municipalities that comprise it. This result is consistent with the intra-metropolitan scale analysis (inter subsystems) of the previous section where those polycentric metropolis have larger subsystems (excluding the CEC). That is, the less dominant central subsystem is more importance (and extension) have subordinates, which in turn has, internally, a higher polycentricity because their subcenters are capable of structure vigorously their surroundings.
3) It increases with sectoral imbalance. The more out supply and demand for labor, the greater the interaction between the municipalities within the subsystems. This finding is very important because it stresses that the lack of coordination in shaping urban land use has indeed an impact on mobility patterns. To encourage self-containment is not necessary just having a certain balance between the roof (land) for housing and economic activity (measured in employed people not in m2), but also, and above all, that there is a correspondence between the socio-professional profile of employment and the type of housing that can be accessed depending on their income level.
4) Increases with the polynucleation of the metropolitan system. That is, there is a relationship between metropolitan polynucleation and functionality within subsystems[8]. The process appears to take a fractal effect.
5) Finally, the 1a model emphasizes that infrastructure provision of high capacity and speed roads, such as highways and motorways also promotes the interlinking between the municipalities of the subsystems. This conclusion is detrimental to the assumption of many local authorities in the sense of assuming that this type of infrastructure is more a burden than a benefit because they understand it as long distance service and therefore "in passing". By contrast, our finding suggests that highways and motorways also have a key role in shaping territorial structures in the small scale, and even more, that the role of the streets has been replaced by motorways, and therefore that their architectural design as daily elements of contemporary cities requires further attention.

In Model 2a have been removed central subsystems (CEC) to check how far the polycentricity in subordinated subsystems continue being explained through these urban factors. The results show that the specialized employment rate variable and diversity replaced the role of sectoral imbalance. Specifically, the higher the percentage of qualified jobs in the subsystem is greater the interaction between the municipalities that comprise it, which is consistent with the fact that this type of scarcer employment requires more territorial area producing greater mobility. As Emeritus Professor Paul

[8] In fact, was also tried to introduce the general index of polycentricity instead of the number of cores, however this second variable was not significant.

Cheshire reminded during his last visit to Barcelona: "My wife and I, of equal level of qualification, we could only live and work in a job market like London". This greater disposition / possibility to travel were verified by Schwanen and Dijst (2002).

Table 5. Models to explain the functional polycentricity within subsystems

	Model			
Independent Variable	**(1a)**	**(1b)**	**(2a)**	**(2b)**
Constant	0,003	0,223	0,245	0,225
	0,129	3,993	5,003	4,184
% WP in the subcenter	-0,058		-0,037	
	-2,775		-1,718	
Sum dist intrasubsystem	0,000		0,000	
	3,161		1,733	
% specialized employment		0,626	0,607	0,788
		5,772	3,763	6,009
Diversity of jobs		-0,139	-0,148	-0,152
		-4,014	-4,668	-4,477
Sectoral imbalance	0,153			
	3,183			
Number of subcenters	0,003		0,002	
	3,719		2,259	
Highways / roads	0,004			
	2,069			
Fac. unqualified		-0,009		-0,009
		-1,783		-1,690
PGF inter-subsystems		0,198		0,192
		2,405		2,316
R2	0,39	0,44	0,49	0,49
R2 (adjusted)	0,35	0,41	0,45	0,46
σ (estimated)	0,04	0,04	0,04	0,04
Durbin-Watson	0,79	0,70	0,98	0,84
Sample size	82	82	77	77

Dependient variable: polycentricity general functional (P_{GF})
Input method: stepwise

The negative sign of the diversity indicator allows reinforcing the idea that the more complex the sector supply of jobs, the lower inter municipal mobility because the probability of finding a job that matches the skills of the employed population is greater. The loss of explanatory power of the provision of high-capacity road infrastructure suggests less weight in the explanation of the internal mobility of the peripheral systems.

B models reproduce the A ones, except for the fact that has been offered to the model the introduction of income level indicators. As seen, Fac unqualified variable enters

with a negative sign, which is indicative of a relationship between the level of income (and occupations) and the level of mobility within the municipalities of subsystems. Finally to highlight that this indicator ejects the level of preponderance of central municipality of the model, since the size of the subsystem and the number of subcenters is replaced by the polycentricity between subsystems.

5. Conclusions

This work attempts the analysis of measure the level of functional Polycentricity for seven metropolitan areas in Spain, applying the functional polycentricity index presented by Green (2007). It was found that from the functional perspective, policentricity is incipient in all areas, and less in Zaragoza, Madrid and Seville than in Bilbao, Barcelona and Valencia the largest. In addition, it was found that there is a strong relationship between polynucleation (defined as the number of sub-centers and their relative weight) and polycentricity (understood as the level of functional interlinking among subsystems structured by subcenters), however, this correlation is not perfect. In this regard the case of Malaga is paradigmatic, as long as its functional interlinking level is lower than suggests by its high level of multicentric equipotentiality in the morphological way. Basically, functional analyzes have shown that almost every metropolitan area has a strong monocentric component, being the policentrism an emerged stadium at most of them, derived from the integration of former originally independent cores, than the appearance of new ones as polycentrism in North America. However, in some areas like in Bilbao, and especially in Barcelona, evidence strongly suggests of functional polycentric relationships between subcenters that would justify the creation or enhancement of road /rail systems promoting complementary relationships historically created.

On the other hand, the analysis of the variables that could determine the policentricity index, found that those that can best explain it are the size of the subsystem and number of nodes, the specialization and diversity of jobs, and also variables that explain income and labor mobility within municipalities of the subsystems that conform metropolitan areas in study. In this regard, we would ask ourselves: is the polyfunctionality, it means, functional polycentrism, something desirable? The answer depends on what is being analyzed. In the case of labor mobility, as studied here, the level of functional interlinking is positive, as it enables territorial complementarity by the flow of human capital that benefits companies, and provides more job opportunities for people; but could also be harmful to the extent that mobility has an environmental and social cost when travel time is detrimental to reproductive activities. In this latter sense, our analyzes suggest the important role that has, in the containment of mobility, the urban coordination in configuring land uses to encourage a coherent balance between socio-professional profiles of economic activity and the type of housing they can access according to their income level. Also show that the large highways around our cities have an important role in the local structure, and therefore, should have a more architectural design consistent to their urban role, despite the apathy of planners. Understand that planning that infrastructure is a sectorial topic instead of urbanistical, is anachronistic in light of empirical evidence.

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