POPULATION SUBURBANISATION IN BARCELONA, 1991-2005: IS ITS SPATIAL STRUCTURE CHANGING?

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Summary: This paper presents a static and dynamic study of the spatial structure of the population of the Barcelona Metropolitan Region (BMR) in 1991 and 2005. The aim is to determine whether a process of population suburbanisation exists and, if so, how it is articulated spatially. The results show that polycentric model exists in both years. However, this spatial structure is worsening because of the suburbanisation process, which is affecting both CBD and subcentres. At the same time, transport infrastructures are strengthening their role as a structuring element of the metropolis.

Keywords: Population suburbanisation, urban spatial structure, subcentres, polycentricity, dispersion.

(JEL R14)

*The author is very grateful to Daniel P. McMillen, Ivan Muñiz, and Marta Marot for helpful suggestions.

1 INTRODUCTION

The literature over the last few years has reinforced the idea that the *intrametropolitan spatial structure*, the way in which the metropolitan city is articulated in the territory, generates important *economic, environmental and social* effects. From the environmental perspective, studies by Khan (2000), Nijkamp and Finco (2001), Muñiz and Galindo (2005), Bertaud (2002) and Camagni et al. (2002), emphasise the close relationship that has been established between spatial structure and *environmental sustainability*, whether in terms of land consumed or in energy efficiency and CO_2 emissions. Evans (1976), Rogers (2000), Bertaud (2002) and Camagni et al. (2002) point out the importance of spatial structure in issues relating to *social justice* and *territorial segregation*. From the economic point of view, works such as those by Ciccone and Hall (1996) and Harris and Ioannides (2000) highlight the influence of spatial structure on *productivity*; while Camagni and Salone (1993) associate it with *economic competitiveness*. Finally, works carried out by supranational entities, like the European Union through its *European Spatial Planning* (Ministerial Meeting on Regional Policy and Spatial Planning, 1996) or its *European Spatial Development Perspective* (European Communities, 1999), or by international institutions, such as the World Bank (Bertaud, 2002), maintain that *efficiency in the supply of public services* can only be guaranteed below certain minimum levels of concentration of economic agents in the territory.

This spatial structure has a dynamic nature. At the present time, most large cities in the world are undergoing a process of population suburbanisation and employment decentralisation characterised by the abandonment of the centre of the metropolitan region in favour of more peripheral locations. Suburbanisation/decentralisation can be carried out according to two spatial patterns, dispersed and polycentric, each with its own explanatory factors. With the first, the centre loses population and employment driven by the high price of land, a fall in transport costs and problems of congestion, producing, as a result, a process of occupation of peripheral land in fragmented and non-dense settlements. With the second, the loss of economies of agglomeration[1] in the central areas is compensated by the appearance of peripheral concentrations or subcentres of agents, either in spontaneous or regulated configurations. This polycentrism, however, should not be understood merely as a phenomenon related to the volume of population and employment located in the subcentres, for it is also the influence that these subcentres exercise on the location of the rest of the population and employment[2].

The research proposed in this paper precisely addresses this issue by carrying out an analysis of the spatial structure of the population of the Barcelona Metropolitan Region (BMR) and its evolution between 1991 and 2005. The ultimate aim is to determine whether there is a process of population suburbanisation during these fifteen years and, if this is the case, how it is produced, whether according to the dispersed or polycentric model. The results show that polycentric model existed in 1991 and 2005. However, this spatial structure is worsening because of the suburbanisation process, which is affecting both CBD and subcentres. At the same time, transport infrastructures are strengthening their role as a structuring element of the metropolis. Without considering this latter result, it seems the dispersed model will be the next spatial stage. On the other hand, if the infrastructure role is considered, the next spatial model will be a linear concentration along highways (strip).

The paper begins with Section 2, where a brief presentation of the Barcelona Metropolitan Region (BMR) is made, focusing on its main infrastructure, and land characteristics. In Section 3, the methodologies used in this research are proposed and

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[1] While this concept has been associated almost exclusively with firms, being understood as the advantages obtained from their location in one place, the same concept can be extrapolated to the case of the location of the population and the advantages associated with its location in one place. For example, the formation of large settlements facilitates a sufficient, good-quality supply of public goods.

[2] This is the approach associated with the polycentric models of New Urban Economics. While its main contribution in the past was the Monocentric City Model (Alonso, 1964; Muth, 1969; Mills, 1967; and more recently Richardson, 1977; and Brueckner, 1987), at present more open models are being proposed where monocentrism, polycentrism and dispersion are all possible equilibria which are arrived at depending on the intensity of the centripetal and centrifugal forces that come into play—economies of agglomeration,

explained. In Section 4, the main results are presented. Finally, the principal conclusions of the study are presented.

2. THE BARCELONA METROPOLITAN REGION

The Barcelona Metropolitan Region consists of 164 municipalities that occupy nearly 3,200 km^2 in a radius of roughly 55 km (Figure 1). In addition to being polycentric in nature, the BMR has also been defined as a discontinuous, partially disperse, complex and diverse urban region (Font et al., 1999). The BMR contains a central municipality, Barcelona, which has more than one and a half million inhabitants. Continuing outwards, there is a first metropolitan ring which is extremely dense and urbanised with massive blocks of housing, and a second ring that combines residential use (with density levels significantly lower than in the first ring) with industrial uses. Beyond the second ring can be found a group of medium-sized cities, and some metropolitan corridors where rural and urban uses are mixed. In other words, the BMR includes a central region, Barcelona and its adjacent towns, and six regions that converge in a wedge. Each of these has a central town – a regional capital. Five of these are medium-sized towns that are over one thousand years old, while the other two have been developed recently[3] (Garcia-López and Muñiz, 2008).

- Figure 1 -

The BMR is structured around a markedly radial transport network, where the principal agglomerations of population and employment are connected with the centre of the city by means of various railway lines and a network of metropolitan highways (A2, C32, C-17, RENFE-suburban trains). More recently, the connections on the southern coastal axis were improved (C-32 south) and the excess radiality has been corrected by adding transversal connections (AP-7, B-30, N-340) (Garcia-López and Muñiz, 2008)

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congestion, internal economies of scale, cost of transport of people and goods, mechanisms for determining wages, etc. (White, 1999).

[3]The Vallès Oriental region contains two towns, Sabadell – the region's capital - and Terrassa.

(Figure 1). The transport infrastructures have had an importance influence on the pattern of urbanisation (Muñiz et al., 2003; Miralles, 1997).

- Table 1 -

In terms of land consumption, the urbanised land[4] increased by some 18,000 hectares between 1992 and 2002. In other words, with a growth rate of 36%, the urbanised area grew from almost 50,000 hectares to 68,000 hectares. Of this land, 11% in 1992 (5,684 ha) and 16.2% in 2002 (11,047 ha) corresponds to land occupied by transport infrastructures. In other words, over these ten years the land used for roads, motorways and freeways almost doubled. In economic terms, with a growth rate of almost 36%, the residential area increased by more than 12,000 hectares, while the land used for economic activity barely grew 700 hectares (Table 1).

This data therefore generally indicates the existence of an urban expansion process in which the main element responsible for the increasing consumption of land is the residential sector, supported by a major increase in the amount of land occupied by transport infrastructures.

3 EMPIRICAL ANALYSIS

3.1 Methodology for identifying population subcentres

Alternative subcentre identification procedures haven proposed by McDonald, (1987), Giuliano and Small (1991), McDonald and Prather (1994), and McMillen (2001, 2003). Among the different proposals available, of particular interest is the one offered by McMillen (2003), in which McMillen (2001) and Giuliano and Small (1991) procedures are combined. Briefly, the principal idea is to estimate an econometric model that defines densities and that is based directly on the monocentric city. The estimated densities

[4] Taken from the *Mapes d'Usos del Sòl*, this land is obtained by adding the land categories associated to "urban nucleuses", "condominium of single and semi-detached houses", "industrial and services zones" and

obtained are subtracted from the corresponding real densities. From among these residuals, the positive ones are chosen and, from among these, those that are statistically different of 0 above a specified level of significance. The groups of selected residuals that surpass a certain threshold (number of agents) are selected as subcentres.

Positive residuals: candidates for subcentres

Positive residuals that are candidates for subcentres are obtained by estimation by *Locally Weighted Regression* (LWR) of a monocentric density function, a linearised negative exponential, in which the gross population density ($\ln D(\bullet)$) is explained by the north/south distance ($d_{CBD_{NS}}$) and the east/west distance ($d_{CBD_{EO}}$) from the CBD. Note that now not one but two distances from the CBD are included. This procedure permits geographical differences to be taken into account, which, in terms of the spatial criteria for population density, can occur in any direction from the city.

$$\ln D\left(d_{CBD_{NS}}, d_{CBD_{EO}}\right) = A - \gamma_1 d_{CBD_{NS}} - \gamma_2 d_{CBD_{EO}} + \varepsilon$$

Once these values have been estimated all that remains is to calculate the residuals and choose those which are positive and significantly different from 0 as candidates for subcentres, that is,

$$\frac{\ln D(\bullet)_i - \ln \widehat{D}(\bullet)_i}{\hat{\sigma}_i} > c$$

where $\hat{\sigma}_i$ is the standard error of the prediction[5] and c is the critical value for a normal distribution.

"infrastructures". The residential land is calculated by adding the "urban nucleuses" land category to "condominium of single and semi-detached houses".

[5] A detailed procedure for calculating this can be found in McMillen (2001) and in Pagan and Ullah (1999).

Positive residuals: the subcentres

Once the observations that surpass the first filter have been obtained, the second filter, from Giuliano and Small's *threshold* methodology (1991), can be applied. Thus, a population subcentre will be an observation or group of observations which, having passed the first filter, presents a number of economic agents equal to or greater than a minimum value. The establishment of this minimum of agents allows those observations to be eliminated as candidates which, even though they have a very high density, have an excessively small number of agents.

The definition of the group of observations that constitute a single subcentre is determined, unlike in Giuliano and Small (1991) and similarly to McMillen (2003), by applying a *proximity criterion*. Specifically, in order for a pair of observations to be considered as being from the same subcentre it is necessary for their associated centroids to be located at a distance below a maximum value. The 'location' of these observations can be determined by means of a simple visual inspection of the map of positive residuals, when there is a small number of them, or as proposed by McMillen (2003) for when there is a very large number of candidates, by using the properties of contiguity matrices. In this case, using only the observations that surpass the first filter, a contiguity matrix (C^1)is created in which the value of 1 appears when there is a distance between two observations of less than the defined maximum, while the rest of the distances between pairs of observations that do not satisfy the criterion are encoded with a 0. This value of 0 is also given to the observation that is the target of the analysis in each row of the matrix, that is, the diagonal of C^1 is made up of zeros.

Others are calculated on the basis of this matrix, or transformations of it, with which information is obtained about the groups of observations that constitute these subcentres. In the case of C^1, each row associated with an observation indicates other (nearby) observations that are 'just a step away' from the observation that is the target of the analysis. In the squared contiguity matrix ($C^2 = C^1 \times C^1$) the non-nil values provide information about observations that are 'two steps away', and so on, until the observations associated with the non-nil values that appear in successive iterations of the contiguity matrix are not different from the ones that appeared in previous iterations.

In order to take advantage of these properties of the contiguity matrices and simplify the procedure, a simple algorithm can be developed. In the first iteration the diagonal matrix (A^1) is compared with the contiguity matrix (C^1) to form another matrix (B^1) which, by means of a value of 1, indicates which observations with non-nil values of C^1 are not present in A^1 (or are present with a value of 0). In this way, the values of 1 in matrix B^1 indicate which observations show new information, that is, which ones can be achieved in this iteration. In the second and successive iterations, bearing in mind that $A^j = A^{j-1} + B^{j-1}$ and that $C^j = C^{j-1} \times C^1$, A^j is compared with C^j again in order to define B^j. The iterations end when matrix B^j provides no more new information, that is, when all of its elements are zero.

3.2 Methodology for evaluating the influence of population centres

In order to measure the influence of the different population centres, a polycentric spatial structure model has been estimated. McDonald and Prather (1994) show various examples of density functions, and, in our case, we adopt the most commonly used:

$$\ln D\left(d_{CBD}, d_{SUB}, d_{INF}\right) = \alpha - \gamma d_{CBD} + \delta d_{SUB}^{-1} + \mu d_{INF} + \varepsilon$$

in which $D\left(d_{CBD}, d_{SUB}, d_{INF}\right)$ is the population density at a distance d_{CBD} from the CBD, at a distance d_{SUB} from the subcentre, and at a distance d_{INF} from the nearest transport infrastructure[6]; α is the constant of the regression; γ is the density gradient associated with the distance to the CBD[7]; d_{SUB}^{-1} is the inverse of the distance to the nearest subcentre[8], δ its corresponding density gradient; μ is the density gradient associated with the infrastructure, and ε is the error term with the usual properties. While interpretation of the coefficient of the distance to the CBD and to the nearest transport infrastructure can be performed directly, the reading of the estimated coefficient for the inverse of the distance to the nearest subcentre is the opposite, i.e. a positive (negative) coefficient shows that the increase in the population density is less (more) the further away from the population subcentre under consideration. The equation is estimated by ordinary least squares. In order to correct possible problems of heterocedasticity in the cross-section sample, standard errors and the covariance matrix have been calculated using White's method.

Statically, the verification of their expected signs, especially the negative value of the gradient of the CBD and the positive value of the gradient of the nearest subcentre, confirms the existence of a polycentric structure in which population density decreases as the inhabitants move further from the CBD and/or the nearest subcentre. Dynamically, an examination of how the value and the confidence level of the estimated coefficients vary over time enables an analysis to be made of the process of population suburbanisation that may have taken place and its territorial articulation. This latest approach is used in Garcia-López and Muñiz (2008)[9].

When the term suburbanisation is used it is understood that the principal centre of the city, the CBD, is losing population, in relative or absolute terms, in favour of the periphery, in such a way that differences in density are decreasing. Depending on how

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6 In order to control the effect of transport infrastructure, the distance to the nearest transport infrastructure has been included, an aspect which has decisively marked the pattern of urban development and the location of employment (Garcia-López y Muñiz, 2008).

7 The density gradient expresses the percentage change in density due to an increase in the distance.

8 Using an inverted distance permits problems of multicollinearity to be removed (McDonald and Prather, 1994). Other works which use this synthesis variable are those by McMillen (2003, 2004).

these new settlements around existing subcentres are produced, it is possible to define four possible spatial models of suburbanisation:

a) The value of the subcentre gradient and its level of significance increases. The subcentre is playing a greater role in the location of the population because the fall in density as one gets further from it increases (the gradient value increases) and the degree of articulation around this population centre is improving (the t-student increases). A polycentrism with a low radius of action is accentuated (Garcia-López and Muñiz, 2008).
b) The value of the subcentre gradient increases but its level of significance falls. Although the proximity to the subcentre is more important, the degree of articulation around it is worsening. In other words, there is a trend towards polycentrism with a low radius of action and towards dispersion (discontinuity and low density) at the same time (Garcia-López and Muñiz, 2008).
c) The value of the subcentre gradient falls but its significance increases. Although the degree of articulation around the subcentre is improving, the proximity to the subcentre is less important (the fall in density from the subcentre is less than before). There is a trend towards polycentrism with a large radius of action (Garcia-López and Muñiz, 2008). However, if this continues, the influence of the subcentre could come to be null (with a gradient equal to zero), thus implying the disappearance of polycentrism as defined from the perspective of this research.
d) The value of the subcentre gradient and its level of significance falls. The subcentre is losing importance in the location of the population. There is an unmistakable trend towards dispersion (Garcia-López and Muñiz, 2008).

[9] In this previous work, we propose this approach to analyse the evolution of the employment spatial

3.3 Statistical sources

Several sources of information were used in this research study. The Population Census of 1991 and the Municipal Register of 2005, with 3,569 and 3,473[10] census sections respectively, provided some data: the area and population of each observation. With these two variables one dependent variable is derived, gross population density, which measures the number of inhabitants per hectare of total land.

Another dependent variable to be used is net population density, which measures the number of inhabitants per hectare of residential land. To be precise, the residential land is calculated using the so-called *Mapes d'Usos del Sòl de Catalunya* of 1992 and 2002. The data used in these maps, produced by the Institut Cartogràfic de Catalunya (ICC), originates from multispectral data taken from the *Thematic Mapper* sensor of the LANDSAT-TM satellite, at a scale of 1:25,000. The minimum mappable unit is 0.36 hectares and presents a classification of twenty-one uses, which include four urban types. The residential land is obtained by adding together the "urban nucleuses" and "condominium of single and semi-detached houses" land categories. Given that these maps are accessible in raster format for Catalonia as a whole, the creation of a map for the Barcelona Metropolitan Region, as well as the calculation of the areas that, on a census level, are associated to each of the uses, was performed using Geographical Information System (GIS) software.

GIS software is also used to obtain the coordinates of the centroids in each census section. With these coordinates the north/south and east/west distances from the CBD are calculated along with the distances between census sections. The latter are used to define the neighbourhood of the census sections and the weightings of the *Locally Weighted Regression*, the contiguity matrix of the BMR (C^1), and the distance from each section to the nearest population subcentres identified.

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distribution at the municipal level between 1986 and 2001.

[10] This number is derived from adapting the number of census sections in 2005, 3486, to the GIS map of 2001, 3473. The GIS map for 2005 is currently being completed.

Calculation of the distance to the nearest transport infrastructure again made use of GIS software and the vectorial archive of the main transport infrastructure of 1997, which was also provided by the Institut Cartogràfic de Catalunya (ICC).

4 RESULTS

4.1 Population subcentres in the BMR

Before applying the two-filter methodology for the identification of population subcentres it is necessary to point out two things. First, the application of the LWR that serves as a reference for the monocentric context requires a definition of neighbourhood (α). Too small a neighbourhood is more susceptible to local effects associated with the object observation and it would therefore be difficult for the LWR estimate to show a negative relationship between density and distance from the centre. On the contrary, as pointed out by McMillen (2001), $\alpha = 0.5$ is more appropriate because it enables the abovementioned negative relationship to be noted, being softer and, therefore, less restrictive than applying a parametric method based on the negative exponential. A neighbourhood of 50% indicates that in each regression 50% of the observations nearest to the target are weighted.

Secondly, it is also necessary to define the significance threshold of the positive residuals (c). In general, studies of the identification of subcentres based on *positive residuals* use 80%, 90% and 95%. Bearing in mind, however, that the lower the threshold the greater the number of candidates for subcentres, in this study a statistical significance of 90% ($c = 1.64$) was required. With this significance threshold the number of census sections presenting positive residuals was 817 in 1991 and 871 in 2005, with 1,275,653 and 1,381,548 inhabitants, respectively, residing in them (Tables 2 and 3).

Using the positive residuals that are 90% statistically significant, the associated contiguity matrix[11] (C^1) is constructed and the algorithm for the second identification filter is applied. For 1991, the algorithm required seven iterations, that is, some of the observations of the positive residuals were only reached after undergoing six observations. In 2005 the number of iterations necessary was fourteen.

Tables 2 and 3 show, for different population thresholds, the number of subcentres identified and the total number of inhabitants found there. Note that the number of subcentres decreases as the second, more restrictive, filter is applied. Consequently, while with no threshold the number of population subcentres is 47 and 44 in 1991 and 2005 respectively, with a threshold of inhabitants of 1% of the total population of the BMR, the numbers decrease to 9 and 7 respectively.

- Table 2 -

- Table 3 -

As regards the population concentrated in the subcentres, the application of a threshold of 10,000 inhabitants implies a drop in population of some 100,000 inhabitants. Considering that these inhabitants are associated with some 21-26 pockets of census sections, they are much too small to be catalogued as candidates for subcentres (Tables 2 and 3). In 2005, moving from a threshold of 10,000 to a threshold of 1% of the BMR would imply the loss of 350,000 inhabitants associated with some 16 candidates for subcentres (Table 3). In this case it would involve a group of subcentres that would include 21,000 inhabitants on average and would, therefore, be of considerable size.

Finally, it must be pointed out that, when using a threshold of 10,000 inhabitants, the population subcentres identified in 1991 and 2005 are practically the same. In the case of a threshold of 1% they drop from 9 to 7 subcentres since, firstly, two subcentres from 1991 would merge into one in 2005 and, secondly, because there is a subcentre in 1991 that

[11] In the first matrix, two sections are near when there is a distance less than or equal to 2 km between them.

disappears as such in 2005 because its population does not quite surpass the second identification filter. Thirdly, in 2005 a subcentre appears that was not identified in 1991.

- Figure 2 -

As regards the location of these population subcentres, Figure 2 shows their geographical position in the BMR with a threshold of 10,000 inhabitants in 2005 (in the box are the municipalities or groups of municipalities that make up the 7 that surpass the threshold of 1%). Note how in the central agglomeration, which includes Barcelona as the centre of the region and its conurbation as its area of influence, population subcentres can be detected such as those associated with the census sections of the municipalities of Viladecans, l'Hospitalet, Sant Boi, Cornellà and Esplugues. The existence of this large high-density concentration of population, as well as the existence of the rest of the conurbation, is due to the migrations of the fifties and sixties that overflowed the central municipality and, with no urban planning, settled in dormitory communities made up of blocks of flats for mass housing (Muñiz et al., 2003).

As far as population subcentres identified outside of the central agglomeration are concerned, part of these correspond to cities of Christallerian origin, like Sabadell, Terrassa and Mataró. With a population of more than 100,000 inhabitants, they also have a high concentration of employment, with an associated municipal density in 2005 of more than 10 jobs per hectare (except for Vilanova). These are cities that in the past grew according to an endogenous model of development. Their urban model, the result of a long period of maturation, is characterised by an urban area largely made up of a historic city centre and an urban expansion area and which, therefore, has a low percentage of single family dwellings and housing developments. Located at a distance of between 20 and 40 km from the city of Barcelona, they show a diversified production structure, although they do still show evidence of a certain specialisation in textiles, a sector which, in the past, enabled them to grow in a relatively independent way. They are also specialised in certain services (equipment rental, wholesaling, health and retailing) due to their role as providers of services to the population and the businesses of the municipality and the nearest small towns (Garcia-López and Muñiz, 2008).

The rest of the subcentres, such as Mollet and Rubí, are an outgrowth of the process of population suburbanisation itself and employment decentralisation. Their development was totally dependent on the expansion of Barcelona during the second half of the 20th century. The urban model here is characterised by a large percentage of area dedicated to housing developments and detached single-family dwellings. These are municipalities located in the second ring of Barcelona (beyond the urban continuum) at a lesser distance from Barcelona than the previous group. They do not correspond to a Christallerian model, but are municipalities where industrial estates have recently been constructed. They are relatively specialised in certain industrial sectors, such as machinery manufacture, chemicals, metallurgy and transport material. To a lesser extent, they also combine services to businesses (machinery rental and wholesaling) and people (retailing and personal activities) (Garcia-López and Muñiz, 2008).

4.2 An approach to analyse changes to spatial structure: Absolute and relative importance of spatial zones

As far as spatial structure and its dynamics are concerned, the division of the BMR into three zones, Barcelona as the centre, the subcentres (all of them) and the rest of the region, provides an initial approach to analysing the process of population suburbanisation[12]. To this end, Table 4 shows the number of inhabitants in each spatial area, its relative importance compared to the whole of the region and the absolute variation and percentage of variation in the fifteen years under consideration. Among the results, of particular note, firstly, is the existence of a process of suburbanisation characterised by the

[12] Following on from the studies by Gordon and Richardson (1996), Giuliano et al. (2005), and Lee (2007), the variation in the weight of each area can be examined to compare the changes in polycentrism as compared to dispersion (Garcia-López and Muñiz, 2008).

loss of the absolute and relative importance of the CBD, leading to a loss of 3% of its population[13]. Secondly, there is population growth in the subcentres, which, in absolute terms, gain more than 100,000 inhabitants (absolute growth), although in relative terms they come to concentrate only 29% of the population of the BMR (relative decrease). Thirdly, the census sections that make up the rest of the region are the ones that have most benefited from the dynamics of the suburbanisation of the centre, as well as from the growth of the region. Thus, this area experienced a population growth of 33%, reaching almost 1,800,000 inhabitants. Finally, it should be pointed out that, since the population of the whole of the BMR increased by 500,000 individuals, the region was affected during this period more by a process of 'suburban growth' than by a process of suburbanisation.

- Table 4 -

These results appear to indicate that the suburbanisation of Barcelona has positively affected both the population subcentres and the rest of the region, with the latter being the area that benefited most. While the subcentres concentrate a percentage of the population which is less than the population in the third spatial area, and their differences increased during the fifteen years analysed, it must also be borne in mind that the number of census sections is appreciably smaller in the subcentres. Pending the analysis of the impact of the subcentres and the centre on the spatial distribution of the rest of the population, this data appears to indicate that in the fifteen years considered, while the subcentres maintained their presence and, therefore, a polycentric spatial structure still exists, the dynamism of the rest of the region might be endangering their future viability.

[13] Using the data from 2001 it can be seen that the process of suburbanisation is more intense in the first 10 years. Thus, in 2001 the population of Barcelona had fallen to 1,427,296 inhabitants, indicating a negative growth rate of 13%. Between 2001 and 2005, however, the population of the centre was subject to growth, probably caused by the international migratory waves of the moment, which would also explain part of the total population growth of the BMR, as well as the gentrification process.

4.3 An alternative approach to analyse changes to spatial structure: The influence of population centres

The results in Table 4 appear to indicate that the population subcentres are losing importance, at least in relative terms, in the spatial structure of the population of the BMR. Nonetheless, as commented earlier, polycentrism should not be understood only as a phenomenon related to the volume of population located in the subcentres, but also as the influence that these subcentres exercise on the location of the rest of population.

For the type of dependent variable, two polycentric density functions are considered, one in which a gross population density is considered (Tables 5 and 6), and the other in which a net population density is used (Tables 7 and 8). While for gross density only topics associated to the location of the population are considered, for net density it is possible to consider this aspect and also the typology of the residential settlements and the consumption of land. In other words, with these two groups of estimates the intention is to determine possible differences in the results when only location matters or when location and land use matters.

According to the subcentres considered, another two types of estimates are made per year, one in which the population subcentres used are the 21-23 identified on establishing, as the second filter, a population threshold of 10,000 inhabitants (Tables 5 and 7), and the other in which the subcentres identified with a population threshold of 1% of the population of the BMR are used, that is, the 9 and 7 subcentres identified in 1991 and 2005 respectively (Tables 6 and 8). With these two groups of estimates the intention is to determine possible differences in the results between the group of exclusively large subcentres (Tables 6 and 8) and the group of subcentres of all sizes (Tables 5 and 7). In addition, in each case, two specifications are considered, one in which the density function is estimated for each year with the subcentres identified in 1991 (specifications (1) and (2) in Tables 5 and 7, and (5) and (6) in Tables 6 and 8), and another where the subcentres used for both years are those identified in 2005 (specifications (3) and (4) in Tables 5 and 7, and (7) and (8) in Tables 6 and 8). Proceeding in this way it is possible to control differences in the results that might be caused by working with a group of subcentres that are different in number and composition for the two years analysed.

Gross population density analysis

The results obtained with each of the specifications considered (Tables 5 and 6) show that the estimated coefficients of all the variables present the expected signs and are significant in all the years. In other words, the negative signs of the density gradients corresponding to the distance to the CBD, γ, and to the nearest infrastructure, μ, and the positive sign of the density gradient of the inverse of the distance to the nearest subcentre, δ, indicate that population density decreases as one gets further from the centre of the region, the infrastructure, and its population subcentres. Statically, these results econometrically verify the existence of a spatial structure associated with the polycentric type of population in 1991 and 2005.

- Table 5 -

- Table 6 -

Moreover, the process of population suburbanisation from the centre of the Barcelona Metropolitan Region is also verified. Thus, the dynamic analysis of the results of the coefficient associated with the CBD indicates that the centre of the region is losing the capacity to influence population location because the differences in density between the CBD and the rest of the region are decreasing, that is, the fall in density as the distance from the CBD increases drops in 2005 (its gradient has a lower absolute value). However, the increase in the degree of individual significance of the gradient would indicate an increase in the articulation capacity of the CBD in the spatial distribution of the population in the rest of the BMR. Following the methodological approach described in the previous section, the BMR population suburbanisation affects the CBD according to the type (c) spatial model.

As regards the effect of the suburbanisation process on the rest of the region, it seems that the transport infrastructure is the protagonist of the new pattern of population location. In this case, both its estimated coefficient and its significance increase over the fifteen years considered, thus imposing the type (a) spatial model.

The subcentre results indicate that there is no clear spatial dynamic outcome associated with these settlements; it depends on both the type and the year of the subcentres considered. Thus, while the group of all subcentres in 1991 (Table 5, specifications (1) and (2)) experiences a decrease in its influence, in its coefficient, and a slight improvement in its degree of articulation, its t-student (spatial model (c)), the 2005 all subcentres group (Table 5, specifications (3) and (4)) experiences an increase in both articulation degree and influence (spatial model (a)). When the group of subcentres identified with a threshold of 1% of the BMR is considered (Table 6), the coefficient and the t-student increase (spatial model (d)) for the 1991 subcentres (specifications 5 and 6), and they increase and decrease respectively (spatial model (b)) for the 2005 subcentres (specifications 7 and 8). In other words, between 1991 and 2005 the polycentrism is clearly improved only in the first subcentre group (threshold of 10,000 inhabitants). This improvement is only due to the new small subcentres emerging in 2005, and the growing saturation of the large ones (with at least 42,000 inhabitants).

To sum up, as regards the population location pattern and the spatial model followed, the results obtained statically show the existence of polycentrism. However, this spatial structure is worsening because of the suburbanisation process, which is mainly saturating all types of subcentres (only two subcentres of at least 10,000 grew between 1991 and 2005). At the same time, transport infrastructures are strengthening their location role as a structuring element of the metropolis. For the moment, without considering this latter result, it seems the dispersed model will be the next spatial stage, at least in location terms.

Net population density analysis

As commented earlier, the net density of the population makes it possible to consider both the population location pattern and the intensity of land use in their settlements. In this case (Tables 7 and 8), a polycentric spatial structure is also verified in 1991 and 2005. However, this urban form is clearly evolving.

-Table 7 -

- Table 8 -

As in the gross density results, the suburbanisation process is affecting the CBD, whose proximity is less important, although its articulation degree is improving (type (c) model). Furthermore, this process also benefits locations close to the transport infrastructure with higher densities around it (type (a) model).

The most important differences between the gross and net results are found in the subcentres. While the results previously depended on the typology of subcentres and the year that they were identified, in the net results there is full coincidence between them. Specifically, the reduction in the estimated coefficient and lower t-student indicate that the type (d) spatial model is the one that is acting: the subcentres are losing importance in the location of the population, and there is an unmistakable trend towards dispersion.

With all of these results, like in the results of Section 4.2[14], it seems the dispersed model will be the next spatial stage, at least in terms of CBD and subcentre influence. The question to be asked is whether this location model in which the population moves away from the CBD and the subcentres, but which is increasingly closer to the transport infrastructure, can be catalogued exactly as being a disperse model or whether it is a new model in which location continues to be concentrated but in a linear (strip) pattern. In fact, these results are not exclusive to either the population or the city under study, but rather this seems to be a spatial pattern that is being imposed in other spatial realities and that affects other economic agents. In Lang's study (2003) the same has been observed for employment in the American metropolis.

5 CONCLUSIONS

Various studies have shown that the spatial structure of a city generates economic, environmental and social effects of different types. Reinforcing the positive ones and reducing the negative ones must include the application of policies that will bring about a redirection of the city and its territorial articulation. The knowledge of the reality to be altered and its evolution over time is a necessary step prior to formulating these policies

In this respect, the experience of the last few years shows that changes in the spatial structure of the cities occur in accordance with two possible models of suburbanisation (or suburban growth) of the population. The first, dispersed, is characterised by an occupation of peripheral land by means of fragmented non-dense settlements. In the second, polycentric, the occupation of peripheral land is accomplished through large concentrations of population, either in spontaneous or regulated formations.

In the case of the Barcelona Metropolitan Region between 1991 and 2005 suburban growth of the population occurred in which its centre lost absolute and relative importance in favour of more peripheral locations, locations which, furthermore, are outside of the population subcentres identified in this study. These subcentres, however, are not simply large concentrations of population located beyond the CBD, but are additionally able to articulate metropolitan territory, that is, the peripheral location of the population outside the subcentres is not left to chance, but is articulated around these subcentres, constituting

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[14] The results do not necessarily always have to coincide. In fact, in the case of Garcia-López and Muñiz

local maximums of density and, therefore, confirming the existence of a polycentric type spatial structure. However, the dynamic results indicate that this structure is worsening. The suburbanisation process is affecting both the CBD and subcentres, which are losing influence on population location. Only transport infrastructures are strengthening their location role as a structuring element of the metropolis. It seems the next spatial stage will be the dispersed model or, at least, a linear model (strip).

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(2008) the results do not fully coincide.

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TABLE 1
Land consumption in the BMR, 1992-2002:
Absolute (hectares) and relative importance of land uses

	1992	2002	1992-2005
Urbanised land*	49,917 (15.39%)	67,999 (20.97%)	18,082 (36.22%)
Other land uses*	274,363 (84.61%)	256,284 (79.03%)	---
Residential land**	33,605 (67.32%)	45,623 (67.09%)	12,018 (35.76%)
Industrial and services zones land**	10,628 (21.29%)	11,329 (16.66%)	701 (6.60%)
Transport infrastructure land**	5,684 (11.39%)	11,047 (16.25%)	5,363 (94.35%)

* Percentage of land with respect to the total land in brackets.
** Percentage of land with respect to the urbanised land in brackets.

TABLE 2
Population subcentres in 1991

Threshold	Number	Population
No threshold	47	1,275,653
10,000	21	1,177,338
1% BMR (42,644)	9	945,684

TABLE 3
Population subcentres in 2005

Threshold	Number	Population
No threshold	44	1,381,548
10,000	23	1,294,810
1% BMR (47,701)	7	943,154

TABLE 4
Population suburbanisation, 1991-2005:
Absolute and relative importance of the spatial zones

	1991	2005	1991-2005
BMR	4,264,422	4,770,180	505,758
Barcelona	1,643,542 (38.54%)	1,593,075 (33.40%)	-50,467 (-3.07%)
Subcentres (no threshold)	1,275,653 (29.91%)	1,381,548 (28.96%)	105,895 (8.30%)
Rest of the region	1,345,227 (31.55%)	1,795,557 (37.64%)	450,330 (33.48%)

TABLE 5
Gross population density in the BMR:
Influence of the centres (Threshold of 10,000 inhabitants)

	Subcentres 1991		Subcentres 2005	
	(1) 1991	(2) 2005	(3) 1991	(4) 2005
α	6.503* (123.86)	6.405* (134.62)	6.515* (123.49)	6.408* (134.31)
γ	-0.100* (-31.75)	-0.087* (-31.84)	-0.100* (-32.05)	-0.087* (-32.36)
δ	0.216* (9.93)	0.198* (9.94)	0.199* (8.17)	0.209* (9.08)
μ	-0.219* (-7.06)	-0.265* (-9.08)	-0.220* (-7.05)	-0.260* (-8.85)
$\bar{R}^2$	0.3790	0.3686	0.3745	0.3683

* Variables 99% significant.

TABLE 6
Gross population density in the BMR:
Influence of the centres (Threshold of 1% of the BMR)

	Subcentres 1991		Subcentres 2005	
	(5) 1991	(6) 2005	(7) 1991	(8) 2005
α	6.520* (121.89)	6.431* (132.14)	6.517* (120.46)	6.418* (130.75)
γ	-0.096* (-30.72)	-0.083* (-30.75)	-0.096* (-30.61)	-0.083* (-30.69)
δ	0.174* (7.07)	0.148* (6.17)	0.190* (6.40)	0.191* (6.01)
μ	-0.237* (-7.58)	-0.283* (-9.58)	-0.235* (-7.48)	-0.278* (-9.37)
$\bar{R}^2$	0.3687	0.3556	0.3678	0.3576

* Variables 99% significant.

TABLE 7
Net population density in the BMR:
Influence of the centres (Threshold of 10,000 inhabitants)

	Subcentres 1991		Subcentres 2005	
	(1) 1991	(2) 2005	(3) 1991	(4) 2005
α	6.364* (182.31)	6.399* (177.26)	6.370* (182.23)	6.403* (177.06)
γ	-0.057* (-32.95)	-0.052* (-31.93)	-0.057* (-33.22)	-0.052* (-32.41)
δ	0.116* (9.31)	0.097* (8.19)	0.110* (7.22)	0.096* (6.97)
μ	-0.113* (-5.45)	-0.179* (-8.04)	-0.113* (-5.43)	-0.178* (-7.95)
$\bar{R}^2$	0.3231	0.3059	0.3202	0.3044

* Variables 99% significant.

TABLE 8
Net population density in the BMR:
Influence of the centres (Threshold of 1% of the BMR)

	Subcentres 1991		Subcentres 2005	
	(5) 1991	(6) 2005	(7) 1991	(8) 2005
α	6.370* (179.71)	6.408* (174.90)	6.363* (177.71)	6.405* (173.78)
γ	-0.055* (-32.06)	-0.050* (-31.04)	-0.054* (-31.95)	-0.050* (-31.03)
δ	0.102* (6.75)	0.082* (5.28)	0.123* (5.87)	0.095* (4.77)
μ	-0.122* (-5.86)	-0.187* (-8.35)	-0.120* (-5.74)	-0.185* (-8.27)
$\bar{R}^2$	0.3164	0.2996	0.3170	0.2998

* Variables 99% significant.

FIGURE 1

Land use and transport infrastructure in the Barcelona Metropolitan Region

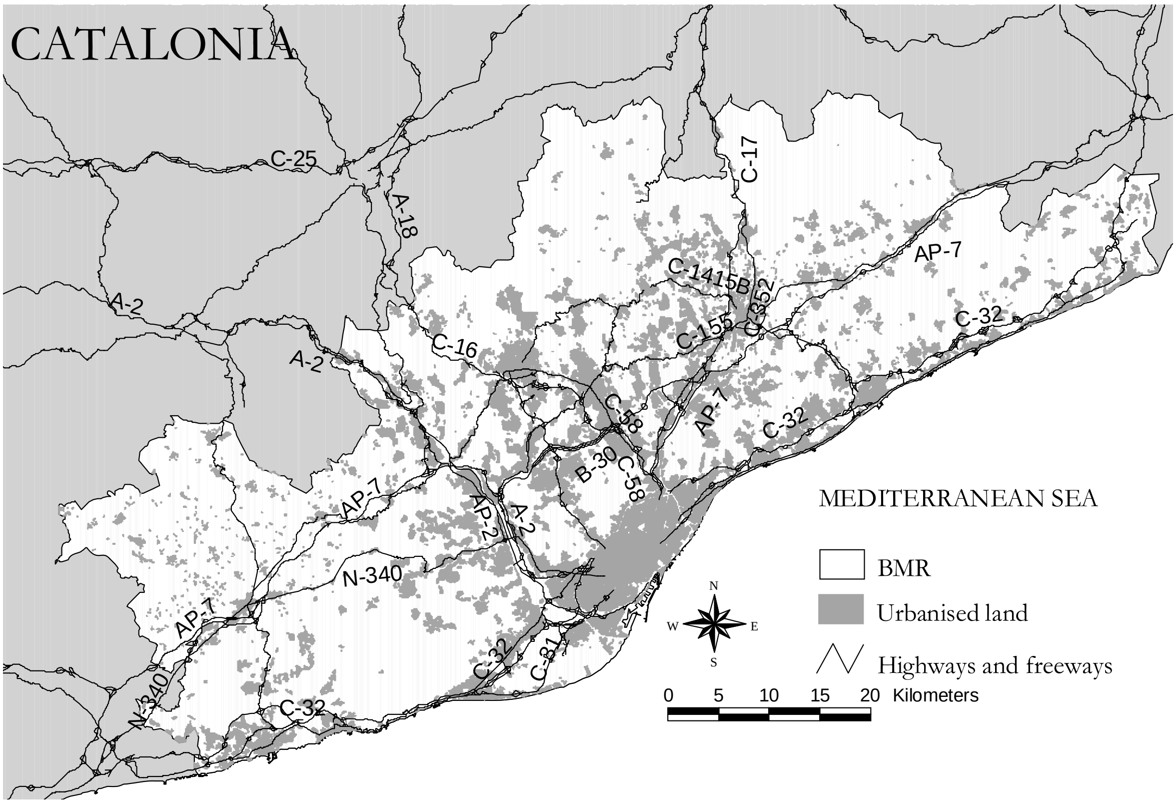

FIGURE 2

Population subcentres in 2005: Location