THE EFFECT OF EMPLOYMENT SUBCENTRES ON POPULATION DENSITY IN BARCELONA

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Abstract:

The polycentric models of the New Urban Economics (NUE) predict that population density decreases while increasing the distance to employment centres. In contrast with this, some studies have calculated non-significant gradients or even positive ones, which appear to seriously threaten the usefulness of these theoretical models. Does this mean that we have to give up this theoretical framework in order to understand the decision making process of the actors in a polycentric city and its cumulative effect on the urban structure? Or rather is it a matter of overcoming problems with the appropriate estimating techniques? This study has tested the effect of decentralised and integrated subcentres in the Metropolitan Region of Barcelona on population density in 1991 and 2001. From the preliminary results, it is clear that, in a considerable number of subcentres that have sprung up as employment has decentralised, density increases with distance. It has been detected that this result is due, not so much to the higher value of more distant residential land compared to that nearer the employment subcentres, but to deficiencies in the econometric model used. The problem is that the subcentres belonging to this group are very close together. Once this is resolved, it is demonstrated that, although distance has less effect on decentralised subcentres than integrated ones, in both cases the effect is negative; that is, when distance increases, density is reduced. Therefore, the results obtained are not clearly contrary to the predictions of the theoretical models.

JEL: R12, R14

Keywords: Employment decentralisation, population spatial structure, policentric city, metropolitan integration

INTRODUCTION

Over the last twenty years, the idea that large cities which have various employment centres are the rule rather than the exception has been consolidated. The need to provide theoretical cover for this situation has encouraged a new generation of polycentric theoretical models within the NUE (New Urban Economics). Also, Central Place Theory and its hierarchised areas of influence for cities of different sizes has had to be adapted to the fact that the fall in transport costs has integrated cities of equal or different sizes into the same functional area, creating multinuclear urban regions. The existence of clumps of density shows that the growth of real cities cannot be represented by the metaphor of an oil slick; this has had a strong impact in the world of theory, and explains the appearance of different lines of applied research. The methods for identifying subcentres have become sophisticated, seeking the greatest possible objectivity and replicability. The effect that the subcentres can have on land rents and the distribution of the population and employment has also been addressed.

In the current debate on the process of employment decentralisation, some studies have suggested as an indicator of polycentrism the percentage of jobs located in subcentres compared to the importance of employment distributed in a dispersed way (Gordon and Richardson, 1996; Giuliano and Redfearn, 2005). This is undoubtedly a relevant and useful indicator, but its capacity to capture the effect of subcentres on the location and conditions of population and employment density in the metropolis is limited (Anas et al., 1998; McDonald, 1987; Heikkila et al., 1989; Dowall and Treffeisen, 1991; McDonald and Prather, 1994; Small and Song, 1994). The importance of polycentrism lies not only in the possibility of concentrating jobs in a limited number of areas under conditions of high density, but also in its capacity to structure and hierarchise urban growth as compared to a dispersed model, amorphous and destructured, without anchorages.

Subcentres can have two origins: the decentralisation of employment or the integration of pre-existing centres. In both cases, theory predicts that distance to the subcentre will have a negative effect on population density. However, studies like those by Griffith (1981), McMillen and Lester (2003) and Baumont et al (2004) obtain a "distance to the subcentre" effect which goes against expectations. What is behind this phenomenon, which Griffith (p. 308, 1981) has described as "(…) *nonsense that is actually the missing variable problem of econometrics* (…)"? The aim of this study is to test this prediction for different types of subcentre in Barcelona. To do this, the subcentres are identified using statistical threshold methods and are grouped according to their origins. We will then estimate the effect of distance to the subcentre on population density and examine its development over time. Finally, some explanations are suggested as to why distance to the subcentre could have a positive impact on density and why development over time appears to be going in a direction contrary to the one established in the polycentric models of the NUE.

The results obtained appear to confirm the idea that the effect of distance to subcentres on population density is negative, both for integrated subcentres and for decentralised ones, although the latter show a less steep gradient than the former. The effect of distance on density tends to decrease, contradicting the dynamic predictions of the exogenous polycentric models of the NUE in the case of decentralised subcentres. The study carried out reflects the usefulness, but also the limitations, of abstract models in explaining reality.

This paper is structured in the following manner: Section 2 establishes the theoretical predictions on the behaviour of population density in relation to their distance to employment centres according to the Polycentric Models of the New Urban Economics and the Urban Network approach arising from the Central Place Model. Also, we review the empirical works calculating population density gradients where results contrary to what was expected were obtained. Reasons are specified that have been shown to explain this behaviour. In Section 3 an outline of the Barcelona Metropolitan Region is introduced followed by a reflection on the major changes that took place during the period under study, 1991-2001. Next, the employment subcentres are identified through a methodology based on statistical thresholds, labelled as decentralised or integrated according to the distance to the CBD and its population in 1900. Lastly, they are characterized by ten indicators referring to mobility, density, economic structure and land use criteria. In Section 4 the empirical examination is presented where, parting from a standard regression model, necessary changes are incorporated so that the estimated gradients reflect in the most reliable possible way how the population density is affected by the distance to the employment centres. In Section 5 the principal conclusions of the paper are presented.

2. THE EFFECT OF SUBCENTRES ON POPULATION DENSITY IN BARCELONA

2.1. Decentralised and integrated subcentres and their effect on population density.

Polycentrism has been studied from two different theoretical approaches. The first consists of a reformulation of the *Monocentric City Model*, where the possibility that different employment centres coexist is accepted. Departing from *Central Place Theory,* the second approach analysis how the expansion of market areas allows the functional integration of nearby urban centres which in the past had developed a certain autonomy (Clark and Kuijpers-Linde, 1994; Champion, 2001).

The so-called *Polycentric Models* of the New Urban Economics (NUE) (White, 1999) suggest a more complex theoretical framework than the monocentric one (Alonso, 1960; Muth, 1961; Mills, 1967). The fundamental theoretical piece that comes into play in these models is the existence of economies and diseconomies of agglomeration. Diseconomies of agglomeration (congestion, high land prices, etc.) would act as a centrifugal force that would throw out part of the economic activity that was previously located in the CBD. Whether decentralised employment tends to become concentrated in one or more subcentres, or is distributed in a dispersed way among a large number of possible destinations, critically depends on the possibility of replicating on the periphery some of the economies of agglomeration that existed in the CBD. In such a case, transport costs would prevent the excessive dispersal of employment and population, as in order to enjoy the economies of agglomeration in the subcentres it would be advisable not to move too far from them (White, 1976, 1990; Sullivan, 1986; Hotchkiss and White, 1993; Ross and Yinger, 1995). We call subcentres that appear in employment decentralising context *decentralised subcentres*.

One of the clearest predictions of this kind of model is that population density does not smoothly fall with distance to the CBD – as is shown in monocentric models – but rather tends to increase nearer to the subcentres. It is a valid prediction both for static *Endogenous Polycentric Models*, where the number of subcentres, their location, the behaviour of land rents, salaries and population density are simultaneously determined (Fujita and Ogawa, 1982; Palivos and Wang, 1996; Berliant et al., 2002), and for the so-called *Exogenous Polycentric Models*. The advantage of this second group of models is that, as well as being mathematically simpler, they offer something like a story of the process leading to polycentrism, which can be summarised in the following points: *a)* a sufficient number of businesses decentralise, locating on the periphery of the urban region and forming an employment subcentre; *b)* although population density, like land rents, reduces with distance from the CBD, at a certain point it will start to increase on approaching a subcentre, due to the saving in the cost of commuting; c) the impact of distance to the subcentre on population density grows with the passage of time[1], reflecting a delayed response by the population to the decentralisation of employment (*Fig. 1*).

The origin of polycentrism studied on the basis of *Central Place Theory* must be found in falling transport costs. From the functional integration of cities of equal or different rank which had been relatively disconnected in the past, the possibility emerges of using the urban system differently. According to the original model, larger centres offer more specialised services, covering more extensive market areas, while smaller ones – greater in number – offer less specialised services within a smaller radius. As transport costs fall, medium-sized centres can specialise in one sector covering a more extensive market area, and achieving localization economies without having to give up the advantages of diversification (urbanisation or network economies) (Camagni, 1993, 1994; Camagni and Salone, 1993; Batten, 1995; Dematteis, 1990, 1991a, 1991b; Emmanuel and Dematteis, 1990). In this analytical framework, the term *multinucleation* is used when similar sized centres are integrated, while the terms *polycentrism* and *subcentres* are used when medium-sized towns and cities end up becoming functionally integrated in a region led by a higher ranking city, which is the case that concerns us[2]. We call subcentres of this kind *integrated subcentres*.

Although the relationship between population and distance to the subcentre has not been accorded particular importance in this kind of approach, the theoretical work by Papageorgiou and Pines (1999) and Wang (1999) clearly predicts that land rents – and consequently population density – should decrease when distance to the subcentre increases. In addition, the absolute value of the gradient, contrary to what would be expected for decentralised subcentres, will tend to reduce with the passage of time (*Fig. 2*). Increasing integration means that the capacity of the subcentres to attract workers living in nearby areas will be lower because of the growing influence of other employment subcentres and the CBD.

Recapitulating, both the polycentric models of NUE and those emerging from *Central Place Theory* predict a fall in population density as the distance to the employment subcentre increases. In addition, it is expected that the value of the gradient tends to decrease for integrated subcentres and increases for decentralised ones.

- Figure 1 -

- Figure 2 -

As for the expected value of the gradient for integrated subcentres compared to decentralised ones, in principle the gradient for decentralised subcentres should be less than the one for integrated subcentres for three reasons: *a)* they are usually nearer the CBD[3] (Fujita, Thisse and Zenou, 1997; Papageorgiou and Pines, 1999); *b)* their creation is more recent and therefore the density conditions are less restricted to transport costs, as studies by Alperovich (1983) and McDonald (1989) analysing the effect of the age of the city on the density gradient would indicate; and *c)* they show a more open labour mobility model than integrated subcentres (Fujita and Ogawa, 1982).

2.2. What does the empirical evidence tell us?

The first surprising thing when reviewing the studies that have compared the effect of employment subcentres on population density is that it is quite common to have obtained gradients with the opposite sign to the one expected (McMillen and Lester, 2003); Baumont et al, 2004) or which are statistically insignificant (Griffith, 1981; Dowall and

Treffeisen, 1991; McDonald and McMillen, 2000). A gradient with a positive sign means a serious breach of the fundamental principle governing bid rent models. Density should decrease as the distance from employment centres increases so that lower land prices compensate for higher transport costs, leading to greater land consumption. A positive gradient appears to reflect a phenomenon that we could call "expulsion". A possible explanation of why the population would value residential areas farther from the employment centres could be that the cost savings from transportation between the place of residence and the workplace would be less than the valuation of the harmful effects that go with proximity to the workplace, for example the decay of urban centres or the presence of groups perceived as troublesome. Nevertheless, most of the papers consulted have proposed less drastic explanations.

There are five alternative arguments to "expulsion" to explain the estimation of positive or statistically nonsignificant gradients: *a)* the fact that the subcentres are too near the CBD can mean that moving away from the subcentre towards the CBD involves an increase in residential density (Baumont et al., 2004); *b)* the gross density of the population is usually low in central areas due to the use of space for offices and shops (Dowall and Treffeisen, 1991; McMillen, 2003; Baumont et al., 2004); *c)* the subcentres do not have sufficient critical mass to affect population density levels (McMillen, 2003; Baumont et al., 2004); *d)* subcentres are a phenomenon strictly linked to employment and not to population

(McMillen and Lester, 2003), and *e)* it will be difficult for the formation of an employment subcentre in a previously developed area to affect the pattern of residential density and, in any case, if it does, this will be a slow process (Dowall and Treffeisen, 1991)[4]. The first two arguments are valid to explain the estimate of a positive gradient or one equal to zero, while the following three are only valid to explain obtaining a statistically insignificant gradient.

In the few studies that have examined the effect of subcentres on population density in dynamic terms, the results are generally contrary to the predictions of exogenous models of the NUE. In decentralised subcentres there should be a trend towards increasing the absolute value of the gradient in as far as the residential location model matches the existence of a new employment centre. However, the results obtained in McMillen and Lester (2003), where it seems that the "expulsion effect" is intensified; in Dowall and Treffeisen (1991), where value for the gradient falls in two of the five subcentres; or in Small and Song (1994), where the value falls in five of the seven subcentres[5], seem to indicate rather the contrary. The fact that the gradient value falls could mean two different things: that the population of the subcentres is decentralising to their periphery, a development that would be expected in the case of integrated subcentres but not in the case of decentralised ones; or that residential location is disconnected from the employment location. To complete this section, it should be noted that – unlike with static approaches – in studies where dynamic estimates have been made, no possible explanations have been suggested as to why the impact of subcentres on population density tends to reduce as the years go by.

3. POLYCENTRISM IN THE BARCELONA METROPOLITAN REGION 1991-2001

3.1. The Barcelona Metropolitan Region

The Barcelona Metropolitan Region (BMR) is made up of 163 municipalities occupying 4,000 Km^2 within an approximate maximum radius of 55 Km.. As well as its polycentric nature, the BMR has also been defined as a discontinuous urban region which is partially dispersed, complex and diverse (Font et al., 1999). The BMR contains a central municipality, Barcelona, which has more than a million and a half inhabitants. Then there is a first metropolitan ring which is extremely dense and urbanised with housing estates and a second ring that combines residential uses – with markedly lower levels of density than in the first ring – and industrial ones. Beyond the second ring appears a set of medium-sized cities in the form of an arc and some metropolitan corridors mixing rural and urban uses (ATM, 1998; Muñiz et al., 2003). The BMR is structured around a markedly radial transport network where the medium-sized cities are connected to the main centre via various railway lines and the metropolitan road network. It must be pointed out that the transport infrastructures have had an important influence on the pattern of urban development (Muñiz et al., 2003; Miralles, 1997).

3.2. Metropolitan dynamics 1991-2001

Before identifying and characterising the employment subcentres, it is convenient to describe the spatial dynamics that have appeared between 1991 and 2001. Firstly, no important population increase has been detected, while the number of jobs has increased very significantly. Secondly, the physical expansion of the region has been considerable, especially in the case of transport infrastructures and housing land. As a result, the net population density has fallen, while the figure for employment has increased. Thirdly, both population and jobs have been decentralised and deconcentrated with similar intensity. Finally, the average weighted distance from employment and population to the nearest road access has reduced, based on two differentiated processes: a) the population has moved closer to the accesses and, b) the accesses have moved closer to the population thanks to a policy that has made it possible to increase their number and to distribute them in a more balanced way around the metropolitan area (*Table 1*).

- Table 1 –

3.3. Identification of employment subcentres

In a recent study, McMillen and Lester (2003) discuss the suitability of the different methodologies for identifying subcentres depending on the objectives sought in a particular piece of research. The authors indicate that the most suitable criteria to compare policentricity in different metropolitan regions are those based on econometric regressions, given their adaptability to local conditions. By contrast, when the aim of the research is to compare the degree of polycentrism of one city at different points in time, threshold-based methodologies[6] are more appropriate. Instead of specifying fixed numerical values for each year, as is usually done, in this study some fixed statistical values adapted numerically to the conditions each year have been taken as a reference. This is a particularly appropriate methodology when employment growth has been as significant as that in the BMR between 1991 and 2001. After some tests, it has been decided to identify as subcentres municipalities[7] with a gross employment density ($D_{i,t}$) greater than or equal to the average density for the BMR ($\bar{D}_{BMR,t}$) and with a level of employment ($E_{i,t}$) measured at 1% or more of the total for the BMR ($E_{BMR,t}$)

$$D_{i,t} \geq \bar{D}_{BMR,t}$$
$$E_{i,t} \geq 1\% E_{BMR,t}$$

There are 9 municipalities meeting both criteria in 2001 (Fig. 3).

- Figure 3 -

Characterisation of the subcentres

Integrated subcentres

This is a group of medium-sized municipalities (between 28,000 and 180,000 inhabitants) with a medium/high population density and a gross employment density of more than 10 jobs per hectare (except Vilanova). Their historical role as centres supplying services to the nearest municipalities is made clear by the fact that they had considerable populations in 1900. Nowadays these municipalities have a residential sector with a high percentage of urbanised land in the form of old town and 19th century grid plan (*eixample*). They are on the main radial axes (by train and road) at a distance of between 20 and 40 Km. from Barcelona. In general, they have a low *Hirschman-Herfindahl Index*[8] (HH), which means high diversification of production (considering 17 economic sectors). In addition, their Christallerian nature is strengthened by a relative concentration of employment in very specialised services. The indicator used to capture this dimension is the *location coefficient* corresponding to the 10 services with least presence in the municipality, using a classification of 220 subsectors[9]. Although this group of municipalities shows a considerable number of jobs, we cannot characterise them as employment centres only, as the relatively low ratio *of jobs to resident population* indicates that what really characterises them is the mixture of residential and economic functions. A high percentage of the jobs in the municipalities are occupied by the resident population (they show a high *self-containment coefficient*[10]) and they do not require large-scale entry by workers from other municipalities (high *self-sufficiency coefficient*[11])

Decentralised subcentres

The towns in this group are somewhat smaller than the previous group in terms of population (between 20,000 and 50,000 inhabitants). They are municipalities with a high population density and a lower employment density that the previous group. Their recent development has been closely linked to the expansion of Barcelona. A demonstration of this is their small population size in 1900 and a residential fabric characterised by a large percentage of land occupied by housing estates and detached houses, two types of housing which spread from the middle of the 20th century onwards. They are located in Barcelona's second ring (beyond the urban continuum) and nearer to Barcelona than the previous group. They also tend to be more concentrated in the metropolitan area than integrated subcentres[12]. They do not correspond to a Christallerian pattern. Instead they are municipalities where industries have recently been located. With a high HH index, the municipality's activity is concentrated in a few sectors (except Sant Cugat). However, it must be pointed out that they show a concentration of specialised services similar to that shown for the previous group. The *job ratio coefficient* is not significantly different from that in integrated subcentres. Finally, they show low self-containment (the percentage of journeys to Barcelona is extremely high) and low self-sufficiency (many of the recently created jobs are not carried out by the resident population).

- Table 2 -

4. THE EFFECT OF SUBCENTRES ON POPULATION DENSITY

The Population Censuses of 1991 and 2001, with 3,569 and 3,473 observations respectively, provide the data used in this research: area and population at census tract level. A Geographical Information System (GIS) was used to obtain the co-ordinates of the centroids of each census section. These co-ordinates are used to calculate the straight-line distances to the CBD and subcentres. The different proposed models are estimated by Ordinary Least Squares (OLS). To correct the presence of heteroskedasticity in the cross-section samples, the standard errors and the covariance matrix have been calculated using White's method.

The first two columns in *Table 3* show the parameters corresponding to the logarithmic estimate of the monocentric model in the usual terms: gross population density depends on the distance to the CBD following a negative exponential functional form (*Model 1*).

$$\ln D_i = \rho_0 + \rho_1 d_{BCN_i} + \rho_2 d_{INF_i} + \upsilon_i \qquad (1)$$

Both the distance to the CBD and the control variable (distance to the nearest road infrastructure[13]) show the expected sign and are statistically significant. In the next two columns, (*Model 2*) the distances of each census section from each of the nine subcentres already identified are added.

$$\ln D_i = \rho_0 + \rho_1 d_{BCN_i} + \rho_2 d_{INF_i} + \sum_{j=1}^{9} \rho_j d_{SUB_{j,i}} + \upsilon_i \qquad (2)$$

- Table 3 -

When this is done, explanatory capacity increases (R^2), which suggests that the polycentric model reflects the spatial structure of the BMR better than the monocentric one does. In addition, the sign, value and significance of the distance to the CBD and to the nearest road infrastructure remain reasonably stable. As for the effect of distance to the subcentres, while in the case of integrated subcentres all except one (the distance to Sabadell) show the expected sign, in the decentralised ones exactly the reverse happens. Only the distance to Sant Cugat shows a negative sign.

Why does the behaviour of the decentralised subcentres live up to the predictions of the polycentric models of the NUE so poorly? In order to answer that question we review the five possible explanations proposed in Section 2.2.

a) *They are too close to city of Barcelona.* This is a possible explanation of the phenomenon, since going further east from the subcentre implies coming closer to Barcelona, which would bring an increase in density. Nevertheless, there are reasons to think that, despite having some influence, it is not the basic factor. The first is that comparing columns 1 and 2 with 5 and 6 in Table 4, it is observed that the gradient from the distance to Barcelona does not change substantially when adding the group of decentralized subcentres. In addition, a symmetrical test was done to see how the values of gradients of the decentralized subcentres appearing in columns 5 and 6 of Table 4 are affected when the city of Barcelona is taken out of the equation. No significant changes were observed.

b) The gross population density is usually low in central districts due to the presence of offices and businesses. It is a very common phenomenon in North American cities but less so in European ones where residences, offices and businesses are mixed under elevated density conditions. In the case we are dealing with, this effect was contrasted comparing gross population density in the central district of each subcentre with the density of the census sections on the periphery, obtaining in most cases[14] a higher density in the centre than in the periphery.

c) They don't have sufficient critical mass to affect the population. Indeed, the subcentres, in general, have fewer jobs than the integrated ones. Nevertheless, each one of them has more than 15,000 jobs. In addition, although the employment volume can explain why the gradient would be flatter in the decentralized subcentres than in the integrated ones, it is difficult to explain the estimation of positive gradients.

d) The appearance of decentralized subcentres is a phenomenon limited to the behaviour of employment not to that of population. This would imply abandoning a central assumption of all of the spatial models of the New Urban Economics appearing since 1960, which is, that the population and employment have become relatively "independent" of one another due to the fall in transportation costs, but not so much as to think that distance is not important. In fact, the job-ratio of the decentralized subcentres that appear in Table 4 is not very different from that of the integrated ones so it does not seem that this phenomenon can explain the presence of positive gradients.

e) *The formation of the employment subcentres will take time to affect the conditions of residential density.* This argument is based on two different processes. The first takes into account the existence of previous population settlements with some fixed short and medium term density conditions. To readjust densities would imply demolishing buildings and constructing new ones with the delays that this assumes. The second process starts from vacant land surrounding the employment hub which will be developed after adjusting their density levels while being able to draw from the employment subcentre. Logically, if it is a previously urbanised space the adjustment will be slower, and in both cases as time goes by the gradient should better adjust itself to the model. In the case of RMB, the area next to Barcelona is very urbanised so that the adjustment would be show, which could explain the lack of significance of some gradients.

The shorter distance to Barcelona, a smaller amount of employment, its formation as a more recent employment centre and a spatial context already urbanised primarily by houses, can explain why the density gradients of the decentralised subcentres are smaller and less significant than those of the integrated subcentres. However, to explain the presence of positive gradients we need another way. Our proposal consists of examining in more detail the econometric model used.

In *Models 1 and 2*, the effect each subcentre would have on the population density of all the census subsections, from the nearest to the furthest away, has been tested. The density of each census section is therefore assumed to be affected by nine distances – as well as the distance from Barcelona and that from the nearest road infrastructure. However, it is probable that the spatial effect of the subcentres is more limited. One way of incorporating this hypothesis into the model would be to use the inverse of the distance to the subcentre as an explanatory variable. In this way, each census section is affected by all the subcentres, although those which are furthest away have a considerably weaker impact[15]. As they are estimated inversely, the gradient sign reading is the opposite one; that is, if proximity to the subcentre means greater density the sign for the parameter is positive. The results of this estimate appear in columns 5 and 6 of *Table 3*. All the integrated subcentres, without exception, show the right sign and are statistically significant. In the case of the decentralised ones, two of them (Sant Cugat and Cerdanyola) are not significant, two show a changed sign (Martorell and Rubí) and only Granollers behaves in accordance with the established theory. Although in general terms the results are more credible, they are still unsatisfactory.

One way of looking at this idea in depth is to make nine estimates, one per subcentre, for which, as well as the distances to Barcelona and to the road infrastructure, the distance to the subcentre is included, taking as a reference only census sections lying within a radius of 5, 8 and 12 Km. respectively (*Model 3*). The results concerning the effect of distance to the subcentre appear in *Table 4* (the *Appendix* shows all the coefficients estimated).

$$\ln D_i = \rho_0 + \rho_1 d_{BCN_i} + \rho_2 d_{INF_i} + \rho_3 d_{SUB_i} + \upsilon_i \qquad (3)$$

- Table 4 -

- Figure 4 -

For a radius of 5 Km., the effect of distance to the subcentre on density has a negative result in all cases. It is when using greater radiuses that in some cases the resulting sign is contrary to the one expected. With a radius of 8 Km., the distance to two of the decentralised subcentres (Sant Cugat and Cerdanyola) shows a positive sign, and with a radius of 12 Km., this comes to be three – Martorell, Rubí and Sant Cugat – all of them decentralised subcentres. The fact that the estimated gradients do not tend to zero as the distance increases but rather in some cases change sign appears to indicate that the problem is not so much the reduction in effect of the subcentres but rather the overlapping effects due to the short distance separating them. In such a case, moving away from one subcentres involves moving closer to another, so that above a certain distance density would not tend to decrease but rather to increase. *Figure 4* shows that the overlap is stronger when the distance considered is increased, particularly in the case of decentralised subcentres.

A method that has often been used to solve the problem of multicolinearity which appears when a subcentre is too near the CBD or to another subcentre consists of using the distance to the nearest subcentre as an explanatory variable. This method eliminates the overlap effect by not allowing the possibility of assigning one census tracts to two different centres. While in the individualised models appearing in *Table 2* there are census sections assigned to more than one subcentre, in this case each census section comes to be affected by the distance to a single subcentre (*Model 4*).

$$\ln D_i = \rho_0 + \rho_1 d_{BCN_i} + \rho_2 d_{INF_i} + \rho_3 d_{SUB\_Near_i} + \upsilon_i \quad (4)$$

The results of applying this model appear in the first two columns of *Table 5*. The effect of the distance to the nearest subcentre is negative and significant. The same happens with the distance to Barcelona and the distance to the nearest road infrastructure. Population density therefore decreases when distance to Barcelona, to the nearest employment subcentre and to the nearest road infrastructure increases. In general terms, we can state that population density behaves as would be expected in a polycentric metropolis like Barcelona. However, this estimation technique does not allow us to distinguish the possible different effects of distance to integrated subcentres from that of distance to decentralised subcentres. To solve this problem, the sample has been divided into two groups, one composed of census tracts assigned to integrated subcentres and the other by census tracts assigned to decentralised subcentres.

- Table 5 -

The results of this estimate appear in columns 3, 4, 5 and 6 of *Table 5*. In both cases, the effect of distance to the subcentre shows the right sign. The most significant aspect is that the value of the gradient for the integrated subcentres is approximately double that for the integrated ones. This behaviour may be due to: *a)* the decentralised subcentres being nearer to Barcelona than the integrated ones, *b)* the decentralised subcentres having developed more recently than the integrated ones, when transport costs were lower and, *c)* in the case of the decentralised subcentres, their role as employment centres coming after their development as residential centres, so that the location of economic activity has had limited capacity to affect density conditions. Another interesting aspect of *Table 5* is the lack of significance of distance to Barcelona in the sample referring to the integrated subcentres, very probably due to the use of census sections a long way from Barcelona involved in this model.

The dynamics of the effect of distance to the subcentres deserves detailed examination. The value of the coefficients which are significant and have the expected sign in *Table 3* and the three estimates that appear in *Table 5* tend to decrease, which would indicate a population decentralisation process. Although this behaviour would be expected in the case of the integrated subcentres, the same is not the case with decentralised ones. In integrated subcentres, the fall in value of the coefficient is explained due to their growing integration into the dynamics of the metropolitan area. The density conditions of the population living near these subcentres would be less influenced by proximity to the subcentre and more by what was happening in the metropolis as a whole. It is more difficult to explain the apparent population decentralisation indicated by the fall in the coefficient in the case of the decentralised subcentres. According to the polycentric models of the NUE, the value of the gradient should increase as the number of jobs grows until it has sufficient weight to significantly affect residential density conditions (McMillen, 2003; Baumont et al., 2004). In the case of the BMR, it seems to behave in the opposite way to that which might has been expected. In the decentralised subcentres as a whole, employment has increased by 60% and the population by 20%, growth considerably greater than that appearing either in the metropolis as a whole or in the integrated subcentres. We should therefore see an increase in the value of the gradient and not a fall. The only plausible explanation is that the area bounded by the arc where the decentralised subcentres are located has shown a considerable increase in population, both in the subcentres and in the nearest municipalities, which has brought about a converging trend in levels of density between decentralised subcentres, nearby municipalities and Barcelona.

CONCLUSIONS

The effect of subcentres on population density has been directly approached in the exogenous polycentric models of the NUE, as well as in some – but only a few – models in the tradition of *Central Place Theory*. The first theoretical framework would be specially designed for polycentrism stemming from the decentralisation of employment, while the second is applicable to polycentrism deriving from the functional integration of medium-sized centres into the radius of action of a hierarchically superior centre. In both cases, the static theoretical predictions are identical. Greater proximity to an employment subcentre should be translated into greater population density. The expected effect is quite logical, as it would replicate on a smaller scale the logic of a monocentric city according to which greater distance from work would mean lower land rents, which would lead to less intensive use, that is, to lower density.

That population density should behave as indicated by the theory has important consequences. The concentration of population under conditions of high density in subcentres and in the areas nearest to them allows the metropolitan area to be *articulated*. We understand articulation of the area to be the possibility of reducing commuting distances by bringing the population closer to employment centres, the fact that public services are distributed in a balanced way and the viability of a public transport network thanks to being able to have a sufficiently high volume of journeys to guarantee the considerable investment effort required. Polycentrism also makes it possible to offer a greater choice of residential models (large centre, medium-sized centre, high-density dormitory centre, low-density dormitory town) and lower land consumption than a dispersed model.

The result of estimating a polycentric population density model for the case of the Metropolitan Region in 1991 and 2001 are, in principle, favourable to the theoretical predictions in the case of integrated subcentres, but not in decentralised ones. However, it has been shown that these results were largely due to the fact that they were too close together, so that moving away from one meant moving nearer to another one, making the density tend to increase. Once the problem has been solved using an empirical model better adapted to the real situation in the BMR, it is possible to conclude that, both in the case of integrated and decentralised subcentres, density falls with distance, although with the latter the reduction is not so severe.

Some of the reasons proposed by previous studies to explain why positive gradients are obtained do not appear valid for the case of the Barcelona Metropolitan Region. The gross population density in the census districts of the subcentres is systematically greater than in the city limits; it has a positive value residing close to the centres, not only due to the cost savings from residence to work trips, but also to the easy access to leisure opportunities and services in general that are concentrated there; and signs of decay are not observed that could lead to the process of expulsion. This has led to a strong link between places of residence and employment. However, the high price of housing in the central zones and the fall in the price of transport costs has driven the decentralisation process that has translated into a fall in the absolute value of the density gradient in the case of the decentralised subcentres as well as the integrated ones.

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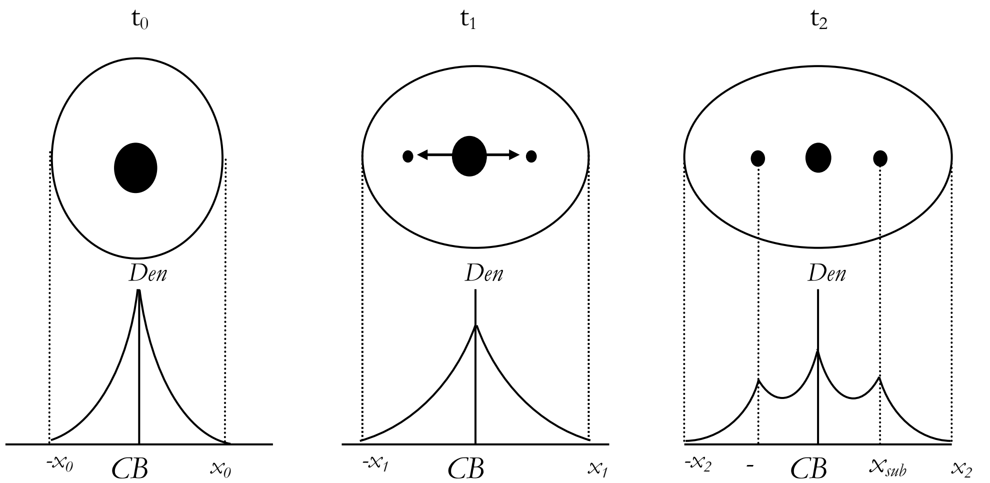
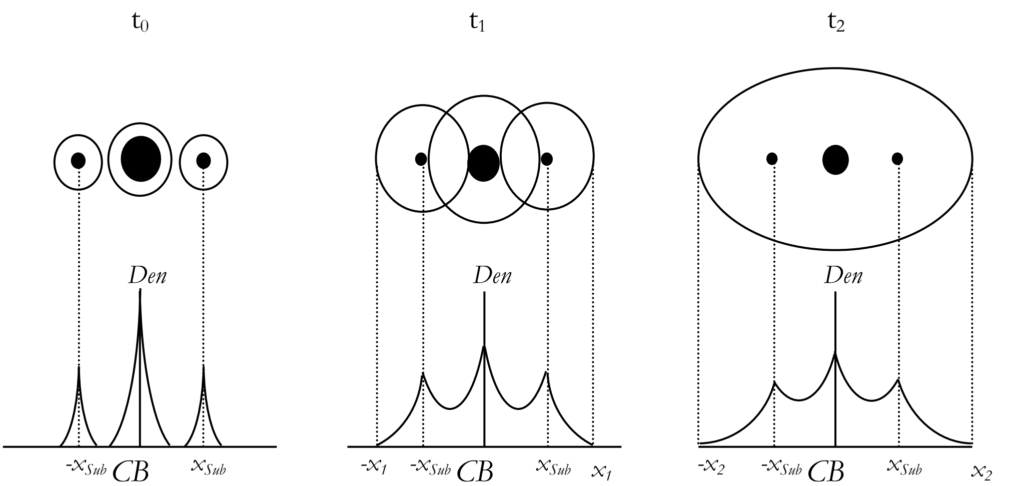
FIGURES AND TABLES

Figure 1: Development of Spatial Structure: Decentralised Subcentres



The weight of the main centre tends to decrease (the central black circle becomes smaller) and new employment centres are created on the periphery (new small circles situated symmetrically on the left and right of the centre of the region). The polycentric decentralisation of employment makes the actual radius of the urban region increase (beyond x, residential density falls to "rural" levels): $x_0<x_1<x_2$. Population density tends to increase around the employment subcentre that originates in t_1 only from t_2 onwards.

Figure 2: Development of Spatial Structure: Integrated Subcentres



The driving force generating polycentrism is a fall in the cost of commuting.
The fall in transport costs occurring between t_0 and t_1 generates an overlap in the job market areas of the centre and subcentres which, as it intensifies between t_1 and t_2, they become fully integrated.

Figure 3: Employment subcentres in the BMR

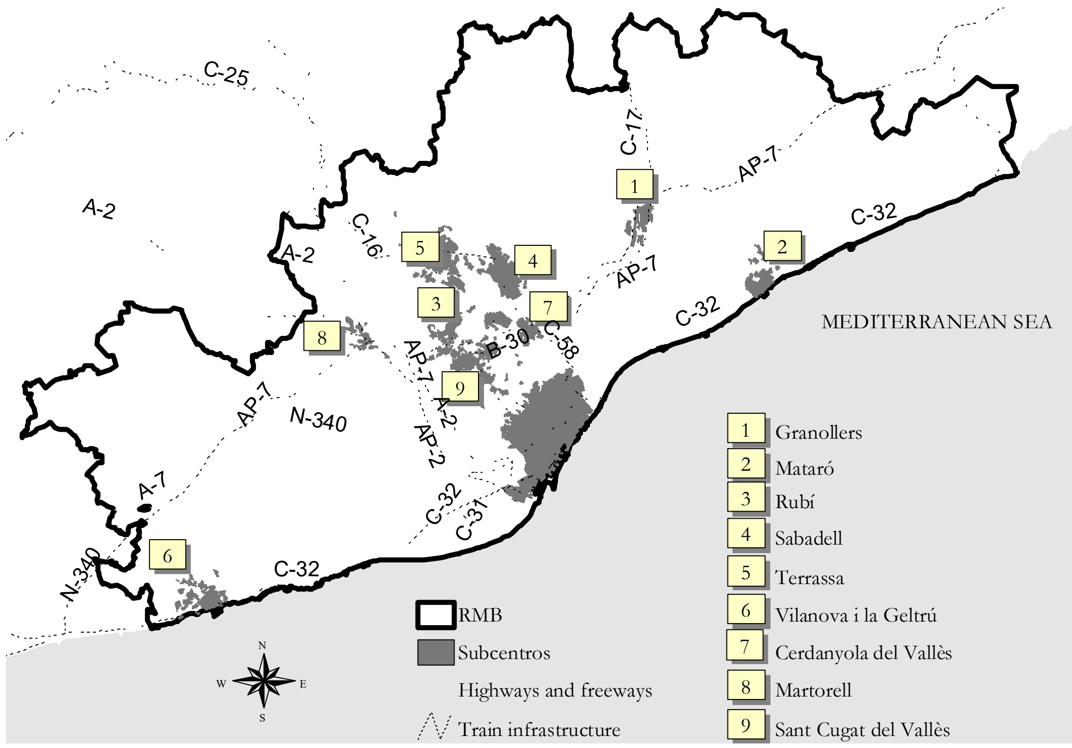


Figure 4: Areas of influence of the subcentres and overlaps between them

5 Km.

8 Km.

12 Km.

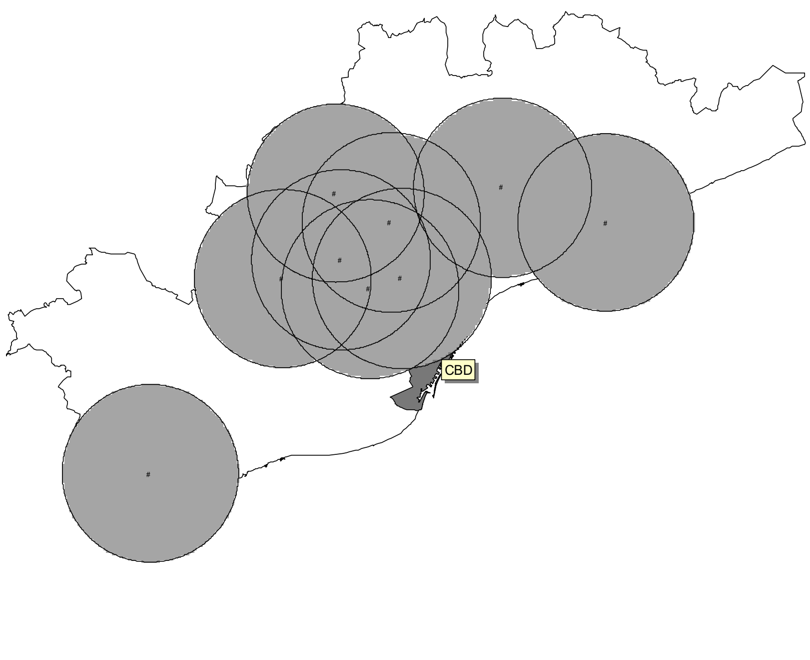


Table 1: Metropolitan dynamics in the BMR 1991-2001

	1991	*2001*	*Variación*
Population	4,264,000	4,390,000	+126,000 (2.95%)
Employment	1,537,000	1,822,000	+285,000 (18.5%)
Urbanized land (ha)	50,000	68,000	+18,000 (36.2%)
Infrastructure Land (ha)	5,680	11,040	+5,360 (94%)
Population Net Density	127	96.2	-24%
Employment Net Density	54.1	67.2	+ 24%
Population Decentralisation (weighted average Barcelona distance – Km.)	10.7	12.15	+1.8 (16.8%)
Employment Decentralisation (weighted average Barcelona distance – Km.)	9.48	11.1	+1.62 (17%)
Population Deconcentration (Gini)	0.83	0.79	-
Employment Deconcentration (Gini)	0.85	0.81	-
Weighted Average Distance from Population to the Nearest Infrastructure Access (Km.)	3.55	2.68	-0.87 (-24%)
Weighted Average Distance from Employment to the Nearest Infrastructure Access (Km.)	3.43	2.64	-0.79 (-23%)

Table 2: Characterisation of the employment subcentres of the BMR

	Population 1996	*Population 1900*	*Distance CBD (Km.)*	*Employment Gross Density 1996*	*Population Net Density 1996*	*% Land Massive Housing Blocks*	*% Land Detached Terrace-Houses*	*HH 1996*	CL_{10s} *1996*	*E 1996*	*Job ratio 1996*	*ACON 1996*	*ASUF 1996*
Integrated Subcentres													
Mataró	102,018	19,704	29.8	14.5	223.6	3.1	10.2	0.20	0.45	32,816	0.46	0.72	0.75
Terrassa	163,862	15,956	15.9	10.2	151.3	9.6	11.5	0.19	0.36	54,915	0.48	0.72	0.74
Sabadell	185,798	23,294	22	16.4	214.9	19.9	6.1	0.16	0.62	59,937	0.46	0.61	0.67
Vilanova	47,979	11,856	41.3	4.5	99.1	4.4	53	0.14	0.99	15,200	0.45	0.67	0.63
Decentralised Subcentres													
Cerdanyola	50,503	928	19.1	5.4	296.9	38.3	19.1	0.14	0.75	17,090	0.45	0.34	0.38
Rubí	54,085	4,400	28.9	6.4	169.5	6.5	24.5	0.33	0.61	20,631	0.53	0.57	0.55
Martorell	17,822	3,221	24.8	14.5	182.1	9.6	8	0.39	0.98	18,730	1.47	0.53	0.19
Sant Cugat	47,210	2,120	20	3.6	310.8	0	49	0.13	0.51	17,667	0.52	0.33	0.36
Granollers	50,951	6,755	29.3	16.5	138	9	18.4	0.18	0.52	24,405	0.68	0.53	0.42

Table 3: OLS estimates of Models 1 and 2

	1	2	3	4	5	6
	1991	2001	1991	2001	1991	2001
Constant	6.812*** (127.16)	6.670*** (134.15)	7.524*** (12.15)	6.896*** (13.67)	6.579*** (65.10)	6.547*** (75.59)
dist Sabadell			0.014 (0.57)	0.009 (0.41)		
dist Mataró			-0.055*** (-4.22)	-0.046*** (-4.13)		
dist Terrassa			-0.205*** (-9.62)	-0.187*** (-10.57)		
dist Vilanova			-0.057*** (-5.47)	-0.043*** (-5.00)		
dist Granollers			0.086*** (4.73)	0.086*** (5.58)		
dist Martorell			0.184*** (4.44)	0.171*** (4.92)		
dist Rubí			0.230** (2.53)	0.160** (2.19)		
dist Sant Cugat			-0.316*** (-3.63)	-0.213*** (-3.20)		
dist Cerdanyola			0.109*** (2.76)	0.081** (2.57)		
1/dist Sabadell					1.620*** (5.41)	1.233*** (4.91)
1/dist Mataró					3.997*** (8.99)	3.507*** (8.61)
1/dist Terrassa					3.358*** (10.82)	3.181*** (11.47)
1/dist Vilanova					5.225*** (11.11)	4.653*** (11.50)
1/dist Granollers					2.149*** (5.94)	1.669*** (5.12)
1/dist Martorell					-4.332*** (-3.11)	-4.123** (-3.52)
1/dist Rubí					-2.878*** (-3.31)	-2.781** (-3.43)
1/dist Sant Cugat					0.485 (0.88)	0.380 (1.00)
1/dist Cerdanyola					0.444 (0.97)	0.085 (0.23)
dist Barcelona	-0.101*** (-32.61)	-0.091*** (-33.41)	-0.088*** (-8.08)	-0.097*** (-10.78)	-0.122*** (-29.08)	-0.10*** (-26.94)
dist infrastructure	-0.272*** (-9.22)	-0.313*** (-10.98)	-0.317*** (-10.23)	-0.378*** (-11.96)	-0.222*** (-7.97)	-0.268*** (-9.79)
Adjusted R^2	0.3901	0.3842	0.4530	0.4543	0.4485	0.4423
Observations	3569	3473	3569	3473	3569	3473

***, ** and *: Variables significant at 99%, 95% and 90%, respectively.

Table 4: OLS estimates of Model 3

	1	2	3	4	5	6
	1991	1991	1991	2001	2001	2001
	5 Km.	8 Km.	12 Km.	5 Km.	8 Km.	12 Km.
Sabadell	-0.439***	-0.066***	-0.109***	-0.431***	-0.044**	-0.103***
	(-3.56)	(-2.40)	(-5.43)	(-4.27)	(-2.04)	(-6.13)
Mataró	-0.871***	-0.531***	-0.273***	-0.684***	-0.423***	-0.232***
	(-3.46)	(-7.09)	(-7.82)	(-3.62)	(-6.47)	(-7.40)
Terrassa	-0.478**	-0.066	-0.173***	-0.630***	-0.192***	-0.171***
	(-2.28)	(-0.48)	(-6.87)	(-4.05)	(-2.75)	(-7.46)
Vilanova i la Geltrú	-0.988***	-0.727***	-0.513***	-0.774***	-0.521***	-0.404***
	(-6.32)	(-5.04)	(-6.36)	(-4.43)	(-4.87)	(-7.16)
Granollers	-1.208***	-0.327***	-0.137***	-1.025***	-0.293***	-0.120***
	(-5.11)	(-4.99)	(-4.01)	(-4.75)	(-6.21)	(-4.41)
Martorell	-0.346	-0326***	0.017	-0.234	-0.245**	0.013
	(-0.72)	(-2.71)	(0.33)	(-0.58)	(-2.18)	(0.32)
Rubí	-1.055***	-0.117	0.176	-0.747***	-0.108	0.138***
	(-4.47)	(-1.47)	(1.30)	(-3.44)	(-1.64)	(4.78)
Sant Cugat del Vallès	-0.193	0.174***	0.123***	-0.146	0.125***	0.116***
	(-1.16)	(2.63)	(5.78)	(-1.18)	(2.68)	(6.83)
Cerdanyola del Vallès	-0.005	0.140***	-0.081***	-0.069	0.108***	-0.056***
	(-0.06)	(3.97)	(-4.51)	(-0.91)	(3.73)	(-3.50)

***, ** and *: Variables significant at 99%, 95% and 90%, respectively.

Table 5: OLS estimates of Model 4

	1	2	3	4	5	6
	1991	2001	1991	2001	1991	2001
Constant	7.295*** (69.38)	6.999*** (76.21)	5.477*** (19.32)	5.398*** (23.78)	7.727*** (67.31)	7.424*** (73.94)
dist Subcentre	-0.051*** (-6.23)	-0.035*** (-5.09)				
dist Integrated Subcentre			-0.111*** (-7.44)	-0.094*** (-8.03)		
dist Decentralised Subcentre					-0.068*** (-7.36)	-0.049*** (-6.15)
dist Barcelona	-0.105*** (-29.36)	-0.093*** (-30.67)	-0.014 (-1.32)	-0.012 (-1.39)	-0.150*** (-32.86)	-0.137*** (-35.08)
dist infrastructure	-0.243*** (-8.63)	-0.290*** (-10.42)	-0.605*** (5.96)	-0.594*** (-6.67)	-0.171*** (-6.37)	-0.218*** (-8.16)
Adjusted R^2	0.405	0.39.6	0.3624	0.3390	0.4086	0.4236
Observations	3569	3473	559	655	3010	2818

***, ** and *: Variables significant at 99%, 95% and 90%, respectively.

ANNEX

Table A1: OLS estimates of Model 3: Integrated Subcentres samples

	Sabadell						*Mataró*					
	1991			*2001*			*1991*			*2001*		
	5 Km.	*8 Km.*	*12 Km.*	*5 Km.*	*8 Km.*	*12 Km.*	*5 Km.*	*8 Km.*	*12 Km.*	*5 Km.*	*8 Km.*	*12 Km.*
Constant	12.401***	4.864***	5.423***	11.868***	4.750***	5.277***	11.84*	9.730***	7.772***	8.268*	8.861***	7.702***
	(5.84)	(10.22)	(14.61)	(6.39)	(13.15)	(16.93)	(1.90)	(4.99)	(9.76)	(1.80)	(5.30)	(11.19)
dist Subcentre	-0.439***	-0.066***	-0.109***	-0.431***	-0.044**	-0.103***	-0.871***	-0.531***	-0.273***	-0.684***	-0.423***	-0.232***
	(-3.56)	(-2.40)	(-5.43)	(-4.27)	(-2.04)	(-6.13)	(-3.46)	(-7.09)	(-7.82)	(-3.62)	(-6.47)	(-7.40)
dist Barcelona	-0.337***	0.003	0.002	-0.313***	0.004	0.004	-0.199	-0.126**	-0.063**	-0.087	-0.101*	-0.063***
	(-3.46)	(0.15)	(0.14)	(-3.69)	(0.26)	(0.32)	(-0.98)	(-1.92)	(-2.39)	(-0.59)	(-1.82)	(-2.79)
dist infrastructure	0.951***	0.024	-0.477***	0.916***	0.038	-0.366***	0.742	-0.302	-0.969***	0.737	-0.338	-0.888***
	(3.59)	(0.16)	(-3.52)	(3.95)	(0.34)	(-3.32)	(1.34)	(-1.00)	(-5.77)	(1.35)	(-1.27)	(-6.60)
Adjusted R^2	0.1091	0.0044	0.0830	0.1270	0.0001	0.0801	0.2106	0.4519	0.4448	0.2147	0.3422	0.3999
Obs.	160	293	470	187	340	553	75	97	134	82	112	157

	Terrassa						*Vilanova*					
	1991			*2001*			*1991*			*2001*		
	5 Km.	*8 Km.*	*12 Km.*	*5 Km.*	*8 Km.*	*12 Km.*	*5 Km.*	*8 Km.*	*12 Km.*	*5 Km.*	*8 Km.*	*12 Km.*
Constant	-1.858	6.543	9.815***	2.667	10.311***	9.416***	11.650*	21.259*	13.324***	7.699	15.308***	12.609***
	(-0.42)	(1.41)	(12.78)	(0.77)	(4.16)	(14.19)	(1.76)	(3.69)	(5.18)	(1.39)	(3.91)	(6.67)
dist Subcentre	-0.478**	-0.066	-0.173***	-0.630***	-0.192***	-0.171***	-0.988***	-0.727***	-0.513***	-0.774***	-0.521***	-0.404***
	(-2.28)	(-0.48)	(-6.87)	(-4.05)	(-2.75)	(-7.46)	(-6.32)	(-5.04)	(-6.36)	(-4.43)	(-4.87)	(-7.16)
dist Barcelona	0.292*	-0.062	-0.174***	0.123	-0.199**	-0.157***	-0.149	-0.387***	-0.198***	-0.050	-0.239**	-0.181***
	(1.85)	(-0.36)	(-6.34)	(0.98)	(-2.19)	(-6.59)	(-0.92)	(-2.74)	(-3.18)	(-0.37)	(-2.52)	(-3.96)
dist infrastructure	-0.838***	-0.092	-0.183	-0.351*	0.159	-0.170	0.305	-0.361	-0.574**	-0.347	-1.002	-0.720***
	(-3.36)	(-0.33)	(-1.30)	(-1.72)	(0.89)	(-1.44)	(0.51)	(-0.45)	(-2.59)	(-0.49)	(-1.54)	(-3.69)
Adjusted R^2	0.2684	0.0013	0.1760	0.3069	0.0531	0.1897	0.5036	0.4209	0.5930	0.3437	0.2858	0.5332
Obs.	114	200	353	131	238	415	37	45	54	46	58	70

***, ** and *: Variables significant at 99%, 95% and 90%, respectively.

Table A2: OLS estimates of Model 3: Decentralised Subcentres samples

	Granollers						*Martorell*						*Rubí*					
	1991			*2001*			*1991*			*2001*			*1991*			*2001*		
	5 Km.	*8 Km.*	*12 Km.*	*5 Km.*	*8 Km.*	*12 Km.*	*5 Km.*	*8 Km.*	*12 Km.*	*5 Km.*	*8 Km.*	*12 Km.*	*5 Km.*	*8 Km.*	*12 Km.*	*5 Km.*	*8 Km.*	*12 Km.*
Constant	3.852	7.357***	8.231***	2.501	6.638***	7.713***	11.336*	7.442***	5.608***	9.121**	6.287***	5.476***	8.354*	5.593***	2.782***	8.172***	5.753***	3.075***
	(0.66)	(5.29)	(11.19)	(0.49)	(6.08)	(13.21)	(2.01)	(5.35)	(7.78)	(2.21)	(4.56)	(8.74)	(1.84)	(5.27)	(5.66)	(2.88)	(6.58)	(8.00)
d Sub	-1.208***	-0.327***	-0.137***	-1.025***	-0.293***	-0.120***	-0.346	-0326***	0.017	-0.234	-0.245**	0.013	-1.055***	-0.117	0.176	-0.747***	-0.108	0.138***
	(-5.11)	(-4.99)	(-4.01)	(-4.75)	(-6.21)	(-4.41)	(-0.72)	(-2.71)	(0.33)	(-0.58)	(-2.18)	(0.32)	(-4.47)	(-1.47)	(1.30)	(-3.44)	(-1.64)	(4.78)
d BCN	0.076	-0.070	-0.114***	0.117	-0.049	-0.098***	-0.299	-0.141***	-0.093***	-0.198	-0.085*	-0.073***	-0.032	-0.037	0.021***	-0.066	-0.045	0.023*
	(0.40)	(-1.45)	(-4.83)	(0.69)	(-1.31)	(-5.31)	(-1.51)	(-2.98)	(-4.23)	(-1.46)	(-1.70)	(-3.76)	(-0.14)	(-0.68)	(4.81)	(-0.50)	(-1.02)	(1.76)
d infra	-0.306	-1.068***	-1.115***	-0.420	-0.808***	-0.985***	-0.644	-0.553**	-1.202***	-0.877**	-0.588***	-1.114***	-2.591***	-1.235***	-0.649***	-1.983***	-0.970***	-0.563***
	(-0.30)	(-3.08)	(-8.24)	(-0.47)	(-3.42)	(-9.32)	(-0.74)	(-2.45)	(-7.07)	(-2.71)	(-2.96)	(-7.52)	(-4.12)	(-4.21)	(-4.86)	(-4.91)	(-3.77)	(-5.19)
Adj. R^2	0.5541	0.4375	0.4281	0.5637	0.4303	0.4191	0.0703	0.3559	0.3090	0.2437	0.2716	0.3091	0.4319	0.1287	0.1007	0.4117	0.1142	0.0955
Obs.	53	87	149	57	100	179	18	40	126	24	52	162	36	99	436	46	121	522

	Sant Cugat						*Cerdanyola*					
	1991			*2001*			*1991*			*2001*		
	5 Km.	*8 Km.*	*12 Km.*	*5 Km.*	*8 Km.*	*12 Km.*	*5 Km.*	*8 Km.*	*12 Km.*	*5 Km.*	*8 Km.*	*12 Km.*
Constant	-3.877	3.355***	5.107***	-3.143**	3.987***	5.040***	3.922***	6.367***	7.444***	3.810***	6.331***	7.071***
	(-1.54)	(3.11)	(18.97)	(-2.00)	(4.19)	(23.04)	(4.98)	(20.63)	(32.37)	(5.02)	(23.58)	(34.77)
dist Sub	-0.193	0.174***	0.123***	-0.146	0.125***	0.116***	-0.005	0.140***	-0.081***	-0.069	0.108***	-0.056***
	(-1.16)	(2.63)	(5.78)	(-1.18)	(2.68)	(6.83)	(-0.06)	(3.97)	(-4.51)	(-0.91)	(3.73)	(-3.50)
dist BCN	0.516***	-0.002	-0.076***	0.475***	-0.015	-0.070***	0.079*	-0.123***	-0.118***	0.088*	-0.112***	-0.107***
	(3.65)	(-0.04)	(-11.92)	(5.64)	(-0.31)	(-12.62)	(1.73)	(-9.65)	(13.32)	(1.89)	(-9.94)	(-14.16)
dist infra	0.071	0.222	0.068**	0.213	0.142	0.056*	-0.899*	-0.210***	-0.005	-0.704*	-0.211***	-0.029
	(0.12)	(1.13)	(2.09)	(0.41)	(0.74)	(1.78)	(-1.86)	(-2.94)	(-0.16)	(-1.78)	(-2.75)	(-0.79)
Adj. R^2	0.1984	0.0724	0.2302	0.2480	0.0520	0.2384	0.0610	0.2028	0.2065	0.0605	0.1895	0.2141
Obs.	59	275	2178	80	300	2036	124	658	1939	139	634	1777

***, ** and *: Variables significant at 99%, 95% and 90%, respectively.

NOTES

[1] At least while the number of jobs is increasing in the subcentre, which represents an on-going maturing process.

[2] The Randstad in Holland is usually presented as a representative example of a multinucleated urban space based on the integration of two cities of similar size – Amsterdam and Rotterdam – and other smaller towns. In Europe there are other metropolises which, like Barcelona, are polycentric, with a principal outstanding centre. This is the case with the urban regions of Naples, Toulouse, Turin, Florence, Frankfurt, Helsinki, Stockholm, Oslo, Barcelona and Palermo (CE, 1999); Bologna (Ceccarelli and Cavalcoli, 2004), Milan (Morandi and Pucci, 2004), Valencia (Giménez and Temes, 2004), Marseille and Montpellier (Borruey and Bosc, 2004).

[3] See McDonald and McMillen (2000) for the case of Chicago; Cervero and Wu (1997) for San Francisco and Muñiz et al. (2003) for Barcelona.

[4] This would support an alternative location model where the population does not follow employment, but rather the reverse. The studies by Cooke (1978), Mills and Price (1984) and, more recently, Boarnet (1994), Giuliano (1991), and Small and Song (1994).

[5] In an alternative model that only takes 4 subcentres into account, the gradient falls in 3 of them.

[6] Most studies consider a double threshold, one for the number of jobs and another for the density of employment (Giuliano and Small, 1991; Song, 1994; Cervero and Wu, 1997; McMillen and McDonald, 1997; Bogart and Ferry, 1999; Anderson and Bogart, 2001).

[7] The 12 municipalities contiguous with Barcelona and with no gap in the urbanised land are excluded.

[8] $HH_i = \sum_s \left(E_{i,s} / E_i \right)^2$, concerning i the municipality and s each productive sector considered. The HH index measures lack of diversity. The greater its value, the less diverse the distribution of employment between the different sectors.

[9] $CL_{10s,i} = \sum_{s=1}^{10} \left(E_{i,s} / E_i \right) \Big/ \sum_{s=1}^{10} \left(E_{BMR,s} / E_{BMR} \right)$. The 10 sectors with lowest municipal presence are, in the following order: 1) transport hire, 2) extraterritorial bodies, 3) social sciences and humanities research, 4) trade union activities, 5) data processing, 6) database-related activities, 7) trade in second-hand goods, 8) computer equipment consulting, 9) other types of wholesaling, 10) car hire. The 5 least common sectors have been dispensed with: space transport, recreational activities, transport by internal communication routes, pipeline transport and discretionary air transport, given the very small number of municipalities where these subsectors of activity are located.

[10] $ACON_i = \left(\frac{Employment\ in\ i\ occupied\ by\ residents\ en\ i}{Employed\ population\ resident\ in\ i} \right)$

[11] $ASUF_i = \left(\frac{Employment\ in\ i\ occupied\ by\ residents\ en\ i}{Employment\ in\ i} \right)$

[12] As McMillen (2003) indicates for the case of the metropolitan regions of Atlanta, Baltimore-Washington, Boston, New York and Philadelphia.

[13] This variable is obtained for both years from SIMCAT, a piece of GIS software for carrying out simulations on Catalonia's road infrastructure commissioned from the consultancy Mcrit S.L. by the Department of Regional Planning Policy and Public Works (DPTOP) of the Catalan government.

[14] The exception was found in some massive housing developments on the periphery of municipalities identified as decentralized subcentres.

[15] This is quite a common way of proceeding which allows a partial correction of possible problems of multicolinearity.