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DECENTRALISATION, INTEGRATION AND POLYCENTRISM IN BARCELONA

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Summary: In this study the employment subcentres of the Metropolitan Region of Barcelona are identified using different criteria. Once catalogued according to their nature, i.e. subcentres arising from integration and decentralisation, they are analysed to see whether their impact on population density depends on their origin. The results obtained confirm a greater impact of integrated subcentres in comparison with decentralised ones, amplified in turn by the fact that the former are further from the CBD and present a greater degree of self-containment in the labor market.

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Keywords: Employment decentralisation, policentric city, metropolitan integration.

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1 INTRODUCTION

The growth model of numerous cities in expansion is gradually moving away from monocentrism, forming polycentric structures where different employment centres coexist. Polycentrism may be interpreted as an alternative growth model to dispersion, a phenomenon which is viewed with concern by town planners, ecologists, economists, geographers and, naturally also by the public administrations that have to provide the necessary infrastructure and services. Whatever the truth of the matter, it is clear that polycentrism presents a great theoretical, empirical and political challenge, and it is therefore worth carrying out a research strategy that allows it to be measured reasonably and to analyse in greater depth the factors that bring it about and the effects that it causes.

The question of the different origin (decentralisation or integration) that subcentres belonging to the same urban region may have is a subject that has been little researched, perhaps due to the inconvenience of working with two up until now excessively disconnected theoretical traditions like the Central Place Theory applied to local urban systems and the new developments in the Bid Rent Model. Possibly even more neglected have been the implications that the impact of the subcentres might have on the population distribution in the area depending on its origin. It is nevertheless an important question, given that, knowing the expected effect, it is possible to focus policies of compacting and distribution of public resources in the area more efficiently.

The aim of this study is to identify and characterise the employment subcentres of the Metropolitan Region of Barcelona, and subsequently examine their impact on the intensity of use of residential land. To do so, Section 2 reviews the theoretical literature dealing with the appearance of decentralised and integrated subcentres. Section 3 explains the expected impact of subcentres on the population density level depending on its origin, proximity to the CBD and commuting mobility criterion. Section 4 is devoted to the identification and characterisation of the BMR employment subcentres. Section 5 analyses its impact on population density. Finally, Section 6 sets out the main conclusions of the study.

2 DESCENTRALISATION, INTEGRATION AND POLYCENTRISM IN THE USA AND EUROPE

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

Polycentric decentralisation in North American local urban systems: Theory and empirical evidence

In the United States, polycentrism arises mainly from employment decentralisation: New subcentres appear at the periphery, colonising a space that is either normally empty or occupied by dwellings under low-density conditions. *Edge cities*, industrial districts, technology parks, university campuses, peripheral centres of employment in general, collect that which the CBD expels. Since the mid-eighties there has appeared a substantial amount of literature propounding different methodologies for identifying subcentres that have emerged over time. Gordon et al. (1986), Heikkila et al (1989) Giuliano and Small (1991), Song (1994), Clark and Kuijpers-Linde (1994), Gordon and Richardson (1996) have studied polycentrism in Los Angeles. McDonald (1987), McDonald and McMillen (1990), McDonald and Prather (1994), McMillen and McDonald (1997, 1998) have done the same for Chicago. Other cities that have been the object of analysis of a similar kind are San Francisco (Cervero and Wu, 1997), Cleveland (Bogart and Ferry, 1999), Houston (Craig and Ng, 2001), Baltimore (Dubin and Sung, 1987) or Washington (Garreau, 1991) [1]. The results of this string of applied studies confirm the validity and extension of polycentrism in North American cities, even though the number of subcentres identified in each city may vary considerably depending on the method used or the numerical or statistical reference thresholds.

[1] Other studies have replicated the same identification method for a limited number of cities (Anderson and Bogart, 2001; Shearmur and Coffey, 2002; McMillen, 2001). There are few studies that have used similar

The appearance of the aforementioned applied studies has been complemented by the development of new theoretical approaches which, starting out with the monocentrism associated with the Bid Rent Model (Alonso, 1964; Muth, 1969), have adapted their original hypothesise with the aim of allowing the existence of multiple equilibriums, among which is the appearance of polycentric spatial structures. White (1999) classified polycentric models into two categories: exogenous and endogenous. Exogenous models predetermine the existence of one or various subcentres that have arisen from employment decentralisation, and go on to predict what their effect is on population location, land rent and the commuting mobility model. In this group of studies we find White (1976, 1990), Sullivan (1986), Hotchkiss and White (1993) or Ross and Yinger (1995), among others. In contrast to the exogenous models, endogenous models study the optimal location of firms and workers in a city without history where the possibility of polycentric structures appearing is allowed. The studies by Fujita and Ogawa (1982), Palivos and Wang (1996) or Berliant et al. (2002) are a clear demonstration of this type of model.

Functional integration in European local urban systems: Theory and empirical evidence

European urban systems are becoming increasingly complex. The reduction in the cost of residence-work journeys has blurred some limits that, in the not so distant past, were relatively well established. Although accented during recent years, this process had its origin in the appearance of the industrial city[2]. When industrialisation was accelerating rapidly, the growth of cities also involved intense migratory movements, together with the absorption of smaller-sized nearby centres, which became a part of the expanding metropolis.

Since the middle of the 20th century, regional migratory flows have slowed down in Europe, in such a way that big cities seem to have arrived at a stable population size. This is not however strictly true. The city continues expanding spatially, although not so much by a process of *absorption*, but rather by *integration* (Champion, 2001). Those smaller-sized population and activity centres which in the past were able to resist a trajectory of own

methodologies for non-North American cities, notable among these being that by Griffith (1981) for Toronto, that by Kahimbaura (1986) for Nairobi, and Dowall and Treffeissen (1991) for Bogotá.

[2] The primordial economic function of the big city stopped being the providing of more or less specific services, and became the production of non-perishable goods whose market potential extends far beyond the limits previously established according to the personal services supplied. The result is the appearance of a new type of city, in some cases of a size unknown up until then. A city where the economics of agglomeration, externalities of all kinds and linkings of costs, result in a greater efficiency and competitiveness.

growth and were situated far enough away, are being integrated into the field of influence of the main city (Hohenberg and Lees, 1985). Cities like Naples, Marseilles, Toulouse, Turin, Florence, Frankfurt, Helsinki, Stockholm, Oslo, Barcelona or Palermo would be in this group of polycentric cities with an outstanding centre (CEC,1999) [3]. In other cases, cities of a similar size which by their proximity maintain a relationship based on a certain rivalry, have seen how their areas of worker attraction are overlapping, taking on the form of a city of cities without a clear dominant centre. Holland's Randstad (Lambooy, 1998) and the so-called Belgian diamond (Dieleman and Faludi, 1998) are two outstanding examples where similarly ranked cities *merge* (Champion, 2001).

The theoretical framework under which the growing integration of population and employment centres in Europe has been dealt with, has mainly been the re-formulation of the Central Place Model (Christaller, 1933; Lösch, 1940) adapted to local urban systems. The idea is that, as previously disconnected labour market areas become integrated functionally, there arises the possibility that the different centres specialise in certain sectors with the aim of making greatest use of the Marshall-like economies of location. Thus the hierarchic scheme of a system of christallerian-type cities is no longer useful, since the horizontal relationships gain importance in relation to the vertical ones. Expressed another way, it changes the way of using a system of cities, seeking a logic where local advantages are reinforced and extended by introducing the advantages entailed in belonging to a system of cities which all together concentrate a great number of companies, workers and infrastructure. The metaphor of the hierarchic tree gives way to the network of cities (Camagni, 1993, 1994; Camagni and Salone, 1993; Batten, 1995; Dematteis, 1990, 1991a, 1991b; Emmanuel and Dematteis, 1990).

3 THE IMPACT OF SUBCENTRES ON POPULATION DENSITY

There are few examples available where the impact of subcentres on population density is analysed. This apparent lack of interest may be explained by a number of reasons. Beginning with the NEU polycentric theory models, the main problem is that, on complicating the model mathematically, it was thought to be a good idea to prefix some variables to aid their development. The variable chosen has normally been population density (also that of employment). With regard to consumer behaviour, this type of model

[3] In Davoudi (2003) there appears an interesting discussion about the spatial differences starting out from

has analysed the location of the consumer, the area of attraction of workers from the main centre and the subcentres, and the behaviour of land rent; but not population density. Since the appearance of Fujita and Ogawa's model (1982) one can follow said strategy in later theoretical models (Yinger, 1992; Sullivan, 1986; Fujita et al., 1997; Berliant et al., 2002).

The truth is that prefixing a constant density level for certain intervals need not mean an inopportune lack of definition in terms of the expected impact of the employment subcentres on population density. One only has to suppose that the flexibility of compensated housing demand is constant, for the theoretical predictions about the spatial behaviour of land rent – an aspect which has indeed deserved a theoretical development in some of the NEU's polycentric models – to be qualitatively identical to those of population density (Papageorgiou and Pines, 1999). In polycentric models the presence of a subcentre tends to generate a positive impact on the land rent in nearby areas, and one would thus expect the same effect on population density.

With regard to the theoretical studies that have reformulated the Central Place Model, there are a few but nevertheless valuable cases in which elements belonging to the Bid Rent Model have been incorporated, thus permitting dealing with aspects related to land rent or population density which were kept out of the traditional model (Henderson, 1974; Papageorgiou and Casetti, 1971; Fujita and Thisse, 1986; Papageorgiou and Thisse, 1985; Papageorgiou and Pines, 1999; Wang, 1999). The studies by Papageorgiou and Pines (1999) and Wang (1999) are those that deal with the impact of polycentricism on the intensity of residential land use most explicitly. Both studies conclude that the proximity to a subcentre exercises a positive effect on population density.

Finally, the available empirical evidence in this respect is relatively poor. The majority of studies which analyse the impact of subcentres on the degree of density have used employment, not population density, as a depending variable. Breaking with this trend, Dowall and Treffeisen (1991) and McMillen and Lester (2003) find empirical evidence in favour of the existence of a negative relation between residential density and distance to the subcentre, although, in the former case, quantitatively less than that given between land rent and distance to the subcentre. To sum up, theoretical models and empirical evidence

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which intra-urban, inter-urban and regional polycentrism can be studied.

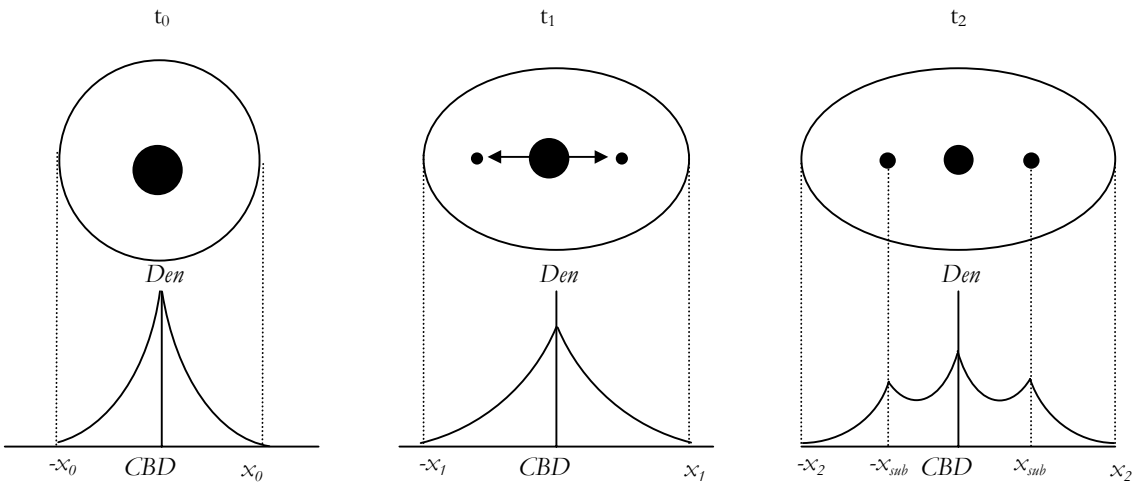
demonstrate, at least provisionally, that the expected effect of proximity to an employment subcentre has a positive impact on population density.

The origin of subcentres and their impact on population density.

a) Decentralised subcentres, integrated subcentres and their evolution

The fundamental element to be taken into account when analysing how the different origin of a subcentre conditions the predictions about its impact on the degree of population density, is time. Beginning with the *decentralised subcentres*, it is to be expected that the population changes its location strategy after the formation of the subcentre, generating a greater housing demand in nearby locations with the aim of reducing commuting costs. The bidding mechanism and the need to save space when land is expensive generate a local maximum in the function of population density, which will tend to increase with the passage of time.

FIGURE 1. Decentralised subcentres evolution

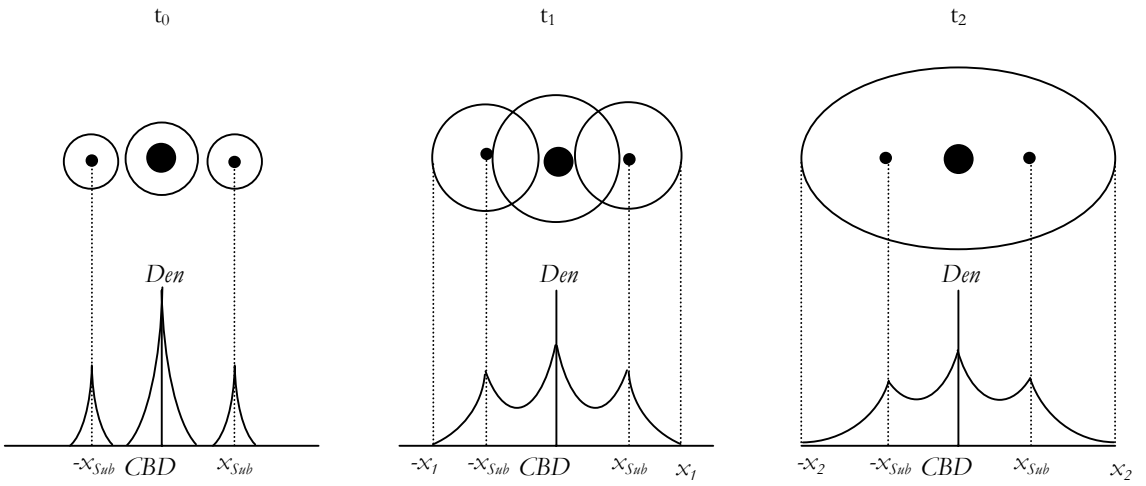


The impulse that generates polycentrism is the existence of agglomeration diseconomies in the centre (high land price, congestion, etc.) and the possibility of agglomeration economies at the periphery.
With the passage of time the weight of the centre is reduced (the black central circle becomes smaller) and new employment centres are created at the periphery (new smaller sized circles situated symmetrically to the right and left of the centre of the region).
The employment polycentric decentralisation makes the real radius of the urban region increase (beyond x, the residential density falls to "rural" levels): $x_0<x_1<x_2$
Population density tends to increase around the employment subcentre originated in t_1 only from t_2 onwards.

In the case of an *integrated subcentre*, the expected impact of the passage of time on the population density gradient is just the opposite. The previous disconnection between the

two centres (the main centre, CBD, and the subcentre) mean the inexistence of overlaps between their respective areas of worker attraction, with the result that each one generates a pattern of population distribution around it separately with a decreasing density from each centre to its periphery, leaving an area between the two devoted to non-urban activities. As the centres tend to become integrated functionally due to more open mobility flows, the intermediate spaces increase in value as the housing demand increases, and the residential density thus increases, with the result that the absolute value of the centre and subcentre density gradients.

FIGURE 2. Integrated subcentres evolution

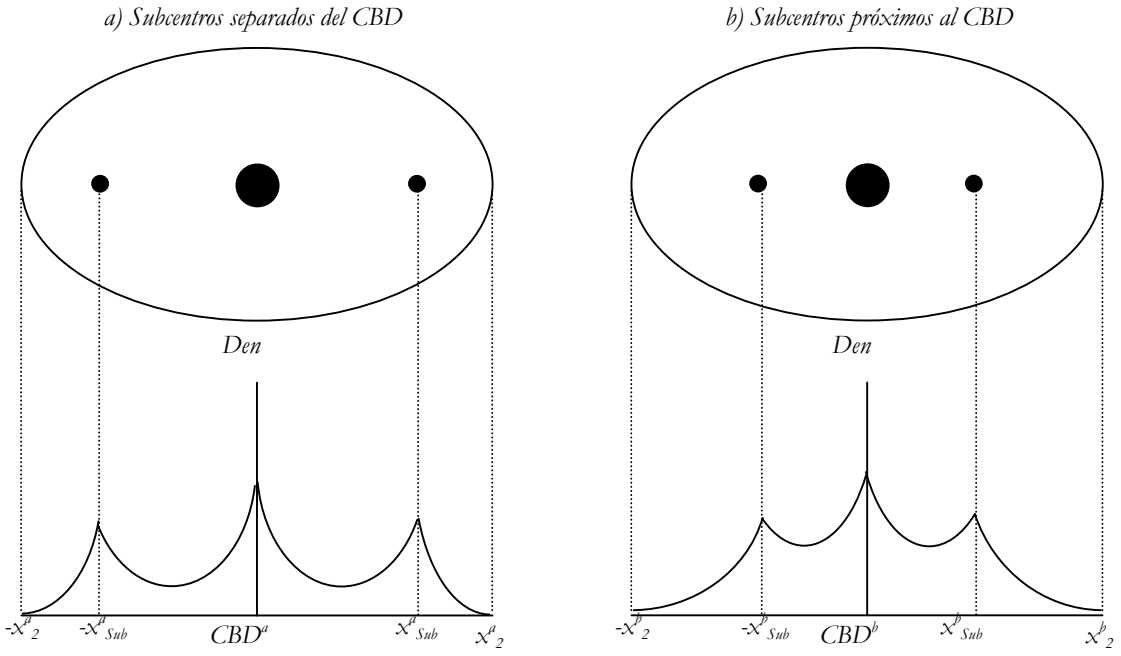


The generating impulse of polycentrism is a fall in the costs of residence-work travel.
The passage of time does not change the relative weight of centre and subcentre, but does so for the real radius of the urban region.
The fall in transport costs produced between t_0 and t_1 generate an overlap in the centre and subcentre work market areas which, on becoming more intense between t_1 and t_2, succeed in totally integrating the centre and subcentre market areas.

b) The effect of the distance from the centre and the commuting mobility flows

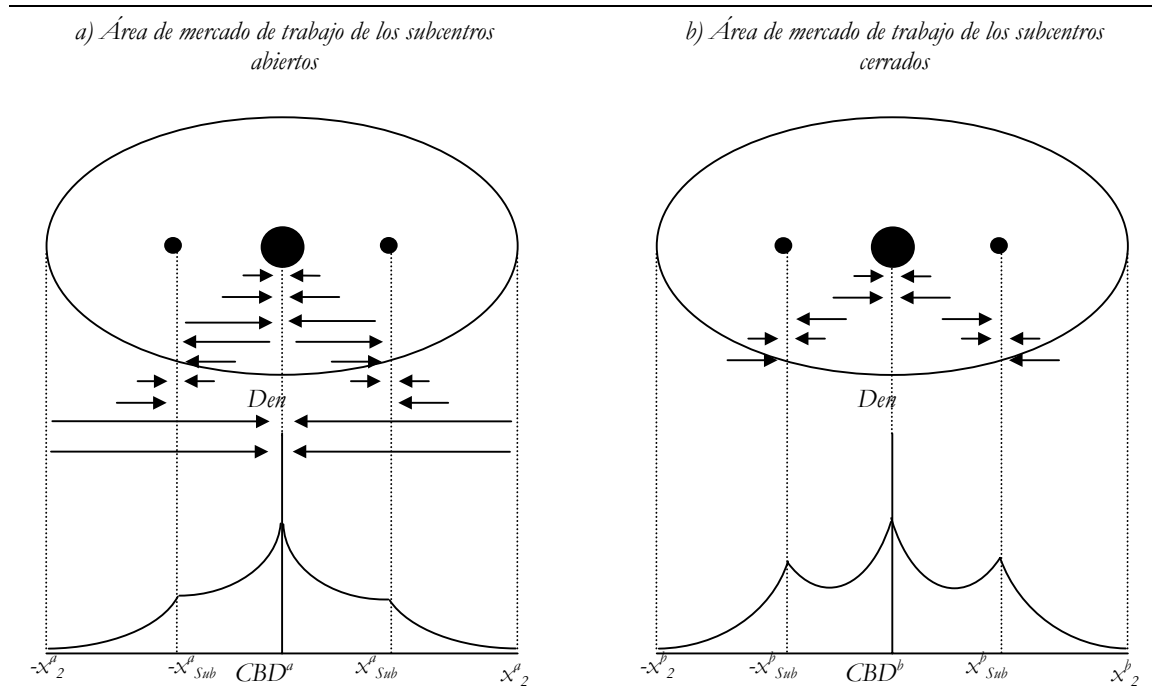
Starting out from a different origin is not the only factor that conditions the intensity of the impact of a subcentre on their population density gradient. The distance separating the subcentre from the CBD is another important aspect to be taken into account. The greater the distance, the greater the expected value of the density gradient. In the case of decentralised subcentres, Fujita, Thissse and Zenou (1997) demonstrate said prediction theoretically, although using land rent rather than population density as a variable. Papageorgiou and Pines (1999) also come to the same conclusion in the case of integrated subcentres.

FIGURE 3. The effect of distance to CBD on population density



$$\left|\delta^a_{Sub}\right| > \left|\delta^b_{Sub}\right| \text{ and } \left|x^a_{Sub}\right| > \left|x^b_{Sub}\right|$$

FIGURE 4. The effect of commuting pattern on population density



$$\left|\delta^a_{Sub}\right| < \left|\delta^b_{Sub}\right|$$

Lastly, Fujita and Ogawa (1982) show how in a three centre configuration (a CBD and two symmetrical subcentres) the effect of the subcentre on the land rent gradient – and therefore also the population density gradient – is as greater as the commuting journey areas are impermeable with respect to the CBD's attraction capacity.

To sum up, *ceteris paribus*, it is expected for the impact of a subcentre on the absolute value of its population density gradient to be greater when either a) the integration process has been recent (in the case of an integrated subcentre) or, the longer the time that has passed since the formation of the subcentre (in the case of decentralised subcentres), b) the more distant is the CBD, and c) the more closed is its commuting travel area.

4 POLYCENTRISM IN THE BARCELONA METROPOLITAN REGION

Identification of subcentres in the BMR

Previous studies that have attempted to identify the subcentres of the BMR are few and far between. There are some studies where, without it being their main objective, some extremely simple criterion has been used, such as a threshold of population (Martori and Suriñac, 2002) or of employment (Asensio, 2000). Somewhat more sophisticated are the studies where subcentres are identified by analysing commuting mobility flows, such as ATM (1998) or Burns et al. (2001), or that of Muñiz et al. (2003), where a *cubic spline* population density function is used to identify the municipalities-subcentre that originate a local maximum in the population density. Although this literature has provided interesting material, it should be remembered using a single threshold is considered an excessively subjective and incomplete method; that the fact of receiving workers from the other municipalities is not a cause, but rather the consequence of concentrating a significant number of jobs; and that using employment density as a criterion is more suitable than that of population. The intention in this section is to use a range of methods to correct the deficiencies of previous studies.

With the total employment and surface area data provided by the 1996 Population Register and from the 1997 Land Use Map, the BMR employment subcentres were begun to be identified using three criteria: the McDonald method (1987), that of Giuliano and Small

(1991), and that of McDonald and Prather (1994). The method proposed in McDonald (1987) consists of choosing those municipalities whose gross employment density is higher than that of adjacent municipalities. The Giuliano and Small (1991) method is based on the use of a number of minimum thresholds for the density and the total number of jobs. Lastly, the McDonald and Prather method (1994) consists of estimating an employment density function subject to the hypothesis of monocentricism so as then be able to identify those municipalities whose real density is significantly greater than that estimated.

TABLE 1. Selected studies on BMR policentricity

Methodology	*Study*	*Criterion*	*Subcentres (municipalities)*
Picks	McDonald (1987)	Gross employment density higher than adjacent municipalities + Employment ≥ 10000	Martorell, Sabadell, Granollers, Vilanova i la Geltrú, Vilafranca del Penedès, Mataró, Premià de Mar, Arenys de Mar, Malgrat de Mar, Castelldefels, Sant Sadurní d'Anoia, Sant Pere de Riudebitlles, Pineda de Mar, Sant Celoni
Thresholds	Giuliano and Small (1991)	4.5 Employment/ha + Employment ≥ 10000	Martorell, Sabadell, Granollers, Vilanova i la Geltrú, Vilafranca del Penedès, Mataró, Terrassa, Montcada i Reixac, Cerdanyola del Vallès, Santa Perpètua de Mogoda, Rubí
Positives Residues	McDonald and Prather (1994)	Employment exponential density function + Employment ≥ 10000	Martorell, Sabadell, Granollers, Vilanova i la Geltrú, Vilafranca del Penedès, Mataró, Terrassa, Montcada i Reixac, Cerdanyola del Vallès, Santa Perpètua de Mogoda, Rubí, Barberà del Vallès
		Job ratio exponential density function + Employment ≥ 10000	Martorell, Sabadell, Granollers, Vilanova i la Geltrú, Vilafranca del Penedès, Mataró, Terrassa, Montcada i Reixac, Cerdanyola del Vallès, Santa Perpètua de Mogoda, Rubí, Barberà del Vallès, Sant Cugat del Vallès

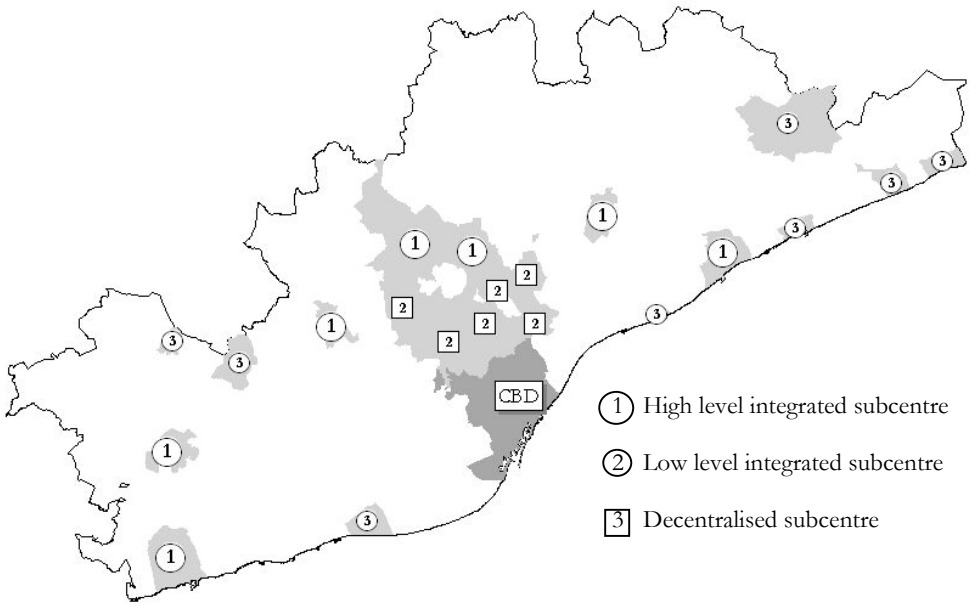
By applying the method proposed in McDonald (1987), a list of fifteen municipalities was obtained. The criteria adopted entails an over-representation of the coastal municipalities and those situated in the region's interior borders, since by definition it is easier to satisfy the requisite of being totally surrounded by municipalities with a lower employment density. The second methodology used, based on the work of Giuliano and Small (1991), demands a total municipal employment of at least 10,000 jobs and a gross employment density of at least 4.5 jobs per hectare[4]. This filter allows a provisional list of 22 municipalities to be obtained, of which 11 are municipalities[5] contiguous to the municipality of Barcelona, with the result that, following the recommendation of Hall et al.

[4] Giuliano and Small (1991) propose a higher employment density (10 jobs per acre, or in other words, 25 jobs per hectare). In our case, the fact of working with the gross municipal employment density requires a significant reducing of the reference threshold.

[5] Hospitalet, Esplugues, Sant Feliu, Sant Joan, Cornellà, el Prat, Sant Boi, Viladecans, Sant Adrià, Santa Coloma and Badalona. This list of municipalities practically coincides with the Barcelona urban continuum.

(1973), they cannot be considered subcentres, but rather the periphery of a centre that goes beyond the administrative borders of the municipality of Barcelona. The third method consists of estimating the residue using a gross employment density negative exponential function. Of the 163 municipalities that make up BMR, 57 present an employment density significantly higher than that estimated. To all appearances this is an excessive number of candidates, so it was decided to take into account only those containing more than 10,000 jobs and not belonging to the Barcelona urban continuum; obtaining as a result a list of 12 municipalities. Using the same criterion and the same filter with a negative exponential function for the job ratio, the same municipalities are identified as in the previous case, plus one additional one. Table 1 and Figure 5 synthesise the results obtained.

FIGURE 5. BMR employment subcentres, 1996



Cataloguing the subcentres

The municipalities identified as subcentres under any of the criteria used may be grouped into three categories: *high level integrated, decentralised subcentres and low level integrated subcentres.* The indicators used to perform this classification are the following: Population in 1900, Coefficient of diversification and Coefficient of Location of the 10 most specialised ("uncommon") services. A high population in 1900 and a high coefficient of diversification and specialisation in this group of services indicates the integrated nature of the subcentre,

given that the data suggests that they were already population and employment centres a century before, and that their role as a christallerian centre is still present in a diversified economic structure that enables the providing of a wide variety of services to their population and to the surrounding municipalities. The population and job volume in 1996 is the criterion by which they are classified as being of first or second order. By contrast, a low level of population in 1900 and a low coefficient of diversification and of specialised services would indicate a totally different origin. In this case they are municipalities that have grown recently specialising in some activity sector, which indicates that their economic base is not explained by an articulating role of the surrounding territory.

High level Integrated subcentres. This category is made up of medium-sized municipalities, between 28,000 and 180,000 inhabitants, with a medium/high population density level[6] and an employment density above 10 jobs per hectare (except Vilanova and Vilafranca). They are municipalities that in the past grew under an endogenous development model (except Martorell) - an aspect reflected in the fact that, already by 1900, they had a relevant population size. They are located on the main radial arteries, rail and road, that radiate from Barcelona, at a distance of between 25 and 40 Km. from the CBD. In general, they present a low *Hirschman-Herfindahl*[7] index (except Martorell), which means a high productive diversification (considering 17 economic sectors). In addition, their christallerian nature can be seen to be reinforced by a relative concentration of jobs in specialised services[8]. Although this group presents an important number of jobs, what really characterises it is the mixture of residential and economic functions, i.e. a *Job ratio* coefficient that is not too

[6] 1996 population pattern and 1997 land use map.

[7] The HH index measures the lack of diversity. The higher its value, the less diverse is the employment distribution between different sectors. This is calculated as,

$$HH_j = \sum_{i=1}^{n} \left[\frac{Empl_{i,j}}{Total\ Empl_j} \right]^2$$

where j refers to the municipality and i to the productive sector.

[8] The indicator used to capture this aspect is a location coefficient designed, not for a single sector, but for the 10 services with least municipal presence, using a classification of 220 subsectors.

$$CL_{10\text{sec},j} = \frac{\sum_{i=1}^{10} Empl_{ij} \Big/ Total\ Empl_j}{\sum_{i=1}^{10} Empl_{i,RMB} \Big/ Total\ Empl_{RMB}}$$

The 10 sectors with the least municipal presence are in this order: 1) hiring means of transport, 2) extraterritorial organisms, 3) Research into social sciences and humanities, 4) Trade union activities, 5) Data processing, 6) Activities related to databases, 7) Second hand goods retailing, 8) Computer equipment consultation, 9) Other types of wholesale trading, 10) Car hire. The 5 least common sectors have been dispensed with, space transport, recreational activities, transport by internal communication means, transport by piping and discretional air transport, given the highly reduced number of municipalities where these activity subsectors are sited.

high. Lastly, this group of municipalities presents a high coefficient of Self-containment[9] and of Self-sufficiency[10].

Decentralised subcentres. These are municipalities with a population size somewhat lower than the previous group (between 20,000 and 50,000 inhabitants), a high population density and a medium employment density (lower than the previous group). Their development has been entirely linked to the expansion of the municipality of Barcelona in the second half of the 20th century. This fact can be verified by observing the reduced population size in 1900. They are municipalities which are mainly located in the second ring of Barcelona, beyond the urban continuum, and at a shorter distance from Barcelona than the previous group. They do not respond to a christallerian pattern, but are rather municipalities where industrial estates have recently been sited. With a high HH index, the municipalities' activity is concentrated in only a few sectors (except San Cugat). However, it should be stressed that they present a concentration of specialised services that is similar to that seen in group 1. The Job ratio index is at similar levels as the previous group, which indicates a relevant mixture of population and jobs, but in contrast to the previous group, they present a low self-containment (the percentage of commuting journeys to Barcelona is extremely high) and low self-sufficiency (many recently created jobs are not occupied by the resident population).

Low level integrated subcentres. These are small-sized municipalities in comparison to the other two, with a medium/low population density and a relatively low employment density. The population growth since the beginning of the 20th century has been relatively modest. For the most part they are situated at a distance of between 40 and 60 Km. from Barcelona. A good part of them are to be found on the region's border, following the coastline or the interior limit. They are characterised by a high productive diversity which reflects their christallerian nature. They currently still provide moderately specialised services to the smaller municipalities that surround them. Together they have a modest job volume and a medium Jobs ratio index. They present a Self-containment and Self-sufficiency index which is lower than the first group, but higher than the second one.

[9] Self-containment measures the percentage of the occupied resident population who work in the same municipality in which they live.
[10] Self-sufficiency measures the percentage of local jobs covered by the resident population.

TABLA 2. Subcentres characterisation

		Population 1996	*Population 1900*	*Distance BCN (Km.)*	*Employment Gross Density 1996*	*Employment Net Density 1996*	*Diversity (HH) 1996*	*Specialised "uncommon" Services (CL) 1996*	*Empl. 1996*	*Empl.-Pop. 1996*	*Self-containment 1996*	*Self-sufficiency 1996*
GROUP 1	*Mataró*	102018	19704	29.8	14.5	223.6	0.20	0.45	32816	0.46	0.72	0.75
	Granollers	50951	6755	29.3	16.5	138	0.18	0.52	24405	0.68	0.53	0.42
	Terrassa	163862	15956	15.9	10.2	151.3	0.19	0.36	54915	0.48	0.72	0.74
	Sabadell	185798	23294	22	16.4	214.9	0.16	0.62	59937	0.46	0.61	0.67
	Martorell	17822	3221	24.8	14.5	182.1	0.39	0.98	18730	1.47	0.53	0.19
	Vilafranca del Penedès	28553	7749	40.9	5.7	163.8	0.14	0.64	11269	0.56	0.61	0.61
	Vilanova	47979	11856	41.3	4.5	99.1	0.14	0.99	15200	0.45	0.67	0.63
GROUP 2	*Montcada i Reixac*	27068	1710	14.6	5.4	159.1	0.30	0.19	12699	0.67	0.38	0.27
	Cerdanyola del Vallès	50503	928	19.1	5.4	296.9	0.14	0.75	17090	0.45	0.34	0.38
	Santa Perpètua de Mogoda	18124	1742	22.7	6.8	255.2	0.36	0.26	10749	0.81	0.36	0.23
	Rubí	54085	4400	28.9	6.4	169.5	0.33	0.61	20631	0.53	0.57	0.55
	Barberà del Vallès	25484	1470	19.5	16.2	327.9	0.30	0.79	14241	0.76	0.35	0.24
	Sant Cugat del Vallès	47210	2120	20	3.6	310.8	0.13	0.51	17667	0.52	0.33	0.36
GROUP 3	*Premià de Mar*	24420	2239	21.3	22.7	280.8	0.13	0.51	4357	0.24	0.29	0.58
	Arenys de Mar	11827	4618	43.8	4.9	141	0.10	0	3188	0.41	0.51	0.66
	Calella de Mar	11687	4316	54.3	6.1	108.3	0.12	0.34	4831	0.61	0.62	0.56
	Malgrat de Mar	12707	3738	65.1	4.9	90.4	0.16	0.62	4407	0.5	0.65	0.69
	Castelldefels	38509	2840	23	6.1	153.4	0.10	0.52	7612	0.27	0.40	0.47
	Sant Sadurní d'Anoia	9205	2671	47.9	1.9	71.2	0.29	0.20	3528	0.57	0.68	0.69
	Sant Pere de Ribes	2144	1614	55.7	1	76.6	0.31	0.62	583	0.40	0.5	0.68
	Pineda de Mar	17844	1264	57.2	5.5	96.3	0.18	0.29	5673	0.44	0.56	0.65
	Sant Celoni	12890	2568	51	0.7	77.5	0.24	0	5098	0.57	0.63	0.60

5 THE IMPACT OF SUBCENTRES ON POPULATION DENSITY

In this section we propose to identify those employment subcentres that exercise a statistically significant effect on population density. To do so, we have used the population and surface area data from the 3481 census sections corresponding to the 163 municipalities of the Metropolitan Region of Barcelona for the year 1996.

The typical population density function of a monocentric spatial structure is based on a *Negative Exponential*.

$$D\left(d_{CBD}\right) = D_0 e^{-\gamma d_{CBD} + \varepsilon} \tag{1}$$

where $D\left(d_{CBD}\right)$ is the gross population density at a distance d_{CBD} from the CBD; D_0 is the gross population density in the CBD; γ is the density gradient associated with the distance to the CBD[11]; ε is the error term with the usual properties.

In the case of a polycentric spatial structure, Anas et al. (1998) show different functions of this type resulting from the generalisation of the negative exponential. One of those most commonly used is that known as Multiplicative Negative Exponential which, as its name indicates, is the function that arises from the product of the negative exponential functions associated with the different employment subcentres considered:

$$D\left(d_{CBD}\right) = Ae^{-\gamma d_{CBD}} \prod_{i=1}^{n} e^{-\delta_i d_i + \varepsilon}$$

or (2)

$$D\left(d_{CBD}\right) = Ae^{-\gamma d_{CBD} + \sum_{i=1}^{n} -\delta_i d_i + \varepsilon}$$

where d_i is the distance to the subcentre i and δ_i its density gradient[12].

With the use of (2) it is assumed that the population values its access to all the urban region's employment centres, these being perfect complementaries, and moreover these exercise a

[11] The density gradient expresses the percentage variation of the density against a marginal increase of the distance to the centre. In an exponential function, the gradient is constant for any distance, i.e.,

$$\gamma = \left(\partial D / D\right) / \partial d_{CBD}$$

[12] Note that now, in contrast to (1), the estimated constant A cannot be associated with the central theoretical density, but rather takes on the joint effects of the CBD's central densities and those of the subcentres. (Dowall and Treffeisen, 1991).

strong influence even on the most distant locations. In order to prevent this property and at the same time reduce the problems of multicolineality existing between the distances, some researchers have proposed substituting $-\delta_i d_i$ with $\delta_i d_i^{-1}$, i.e. with the inverse of the distance to the subcentre i (Anas et al., 1998)[13].

In this way, in its linearised version, the finally estimated population density function is the following:

$$\ln D\left(d_{CBD}\right) = \ln A - \gamma d_{CBD} + \sum_{i=1}^{n} \delta_i d_i^{-1} + u \qquad (3)$$

The equation (3) is estimated by Ordinary Least Squares. In order to correct possible problems of heterocedasticity in the cross-section sample, the standard errors and the covariance matrix have been calculated using the White method. In addition to the distance to the centre of Barcelona, column 1 of Table 3 also displays as explicative variables the distance to each and every one of the subcentres previously identified.

Of the 22 subcentres, the majority – 18- present the expected sign, but only 12 have a statistically significant coefficient[14]. The overall explicative capacity of the model is 43.85%.

Column II only includes the 7 high level integrated subcentres that the majority of studies about the RMB identify as such. In this case, the model's explicative capacity is affected, falling to 41.13%, which at first glance, supports the idea that it is advisable to broaden the list of subcentres, although the municipalities to be added correspond to employment centres of a lower hierarchic order or have been formed as a result of recent decentralising trends.

Finally, column III only includes as an explicative variable the distance to the centre of Barcelona, with the model's explicative capacity falling to 36.52%. The important influence of the distance with respect to the centre of Barcelona is undeniable when it comes to explaining

[13] Note that working with a direct distance in the case of the CBD (Barcelona) and an inverted distance in the case of the nearest subcentre, implies recognising that the spatial influence of the CBD is greater than that of the subcentres for long distances. In addition, whereas the interpretation of the coefficient of the distance to the CBD can be made 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. indicates that the growth of employment density is less (greater) as we move away from the employment subcentre under consideration.

the population density differentials, but the model improves significantly on including other alternative employment subcentres to the CBD, which confirms the hypothesis that the RMB's polycentrism influences the intensity of residential land use significantly.

With the aim of verifying the hypothesis that in order to explain population density levels conveniently, one should take into account a broad list of subcentres, against the alternative hypothesis that it is only necessary to include the distance to Barcelona (monocentrism hypothesis) or a limited list of seven subcentres (restricted polycentrism), Table 3 also displays the results of the Wald test calculations for each estimated specification (I, II and III).

The Wald test allows the different specifications to be compared as long as they are added, i.e. when they are the result of adding additional variables to a simpler or more restricted model, giving rise to a more complex or non-restricted model

$$F = \frac{\left(SSR^r - SSR^u\right)/q}{SSR^u/\left(n-k\right)}$$

where SSR^r and SSR^u are the sum of the squares of the restricted and the non-restricted model residues respectively; n is the size of the sample; k is the number of estimated parameters in the non-restricted model; and q is the number of restrictions[15] (McDonald and Prather, 1994). The significativity of the value F implies the rejection of the restricted model in favour of the non-restricted model.

In our case, the most complex or general model is that corresponding to specification I, in which all the subcentres appear previously identified, with the rest of the specifications being those corresponding to restricted models. In all the cases, specification I is the best indicated, if the existence of a polycentric spatial structure in the distribution of the population is compared with the model corresponding to column III; and if the greater explicative capacity of a broad polycentric model is compared with column II, against one that is restricted to seven subcentres.

[14] The bilateral correlations obtained between the different distances used in this more general specification, at no time exceed 31%, with the majority of them adopting values lower than 10%.

[15] In our case, to pass for instance from the specification that includes all of the employment subcentres identified in this study, column I, to the specification that only includes the traditionally considered subcentres, column III, we establish 15 restrictions, $q = 15$.

TABLE 3. CBD and subcentre distance effect on population density (ln)

	I	II	III
Constant	6.238***	6.305***	6.361***
	(120.45)	(165.88)	(186.63)
d Barcelona	-0.121***	-0.107***	-0.093***
	(-31.34)	(-29.70)	(-30.98)
1/d Martorell	-0.723***	-1.173***	
	(-3.11)	(-2.87)	
1/d Sabadell	0.636***	0.585***	
	(5.11)	(5.08)	
1/d Granollers	0.863***	0.767***	
	(7.69)	(7.40)	
1/d Vilanova i la Geltrú	1.743***	1.459***	
	(7.35)	(7.63)	
1/d Vilafranca del Penedès	0.935*	0.431	
	(1.71)	(1.28)	
1/d Mataró	1.155***	1.124***	
	(4.41)	(4.41)	
1/d Terrassa	1.231***	0.971***	
	(6.52)	(6.34)	
1/d Premià de Mar	0.209		
	(0.96)		
1/d Arenys de Mar	1.026***		
	(3.57)		
1/d Calella de Mar	0.642**		
	(2.20)		
1/d Malgrat de Mar	1.459**		
	(2.04)		
1/d Castelldefels	-0.078		
	(-0.54)		
1/d Sant Sadurní d'Anoia	-0.353		
	(-1.19)		
1/d Sant Pere Riudebitlles	0.024		
	(0.17)		
1/d Pineda de Mar	1.504***		
	(4.62)		
1/d Sant Celoni	1.068***		
	(4.69)		
1/d Montcada i Reixac	0.112		
	(1.27)		
1/d Cerdanyola del Vallès	0.071		
	(0.51)		
1/d Santa Perpètua de Mogoda	0.021		
	(0.15)		
1/d Rubí	-0.975***		
	(-2.77)		
1/d Barberà del Vallès	0.443***		
	(3.70)		
1/d Sant Cugat del Vallès	0.019		
	(0.25)		
Adjusted R^2	0.4385	0.4113	0.3652
F Stat	119.183***	304.959***	2002.802***
Wald Test I vs.	---	6.6192***	10.2038***

***, **, *: significant at the 1%, 5% and 10% levels, respectively.

Lastly, returning to the results obtained, why is it that despite having a considerable employment volume, the subcentres that emerge from the decentralising process do not manage to influence significantly the levels of population density? We consider there to be three fundamental reasons.

1. The concentration of employment in this group of municipalities is a fairly recent phenomenon. In 1986 they presented a total of 65 percent fewer jobs, which gives us an idea of the extent to which their consolidation as an employment subcentre has been a recent phenomenon[16]. As set out in the second section, being recently created *decentralised subcentres*, one should expect a reduced density gradient value, given that the residential location decisions have not had enough time to be properly adjusted. This situation also contrasts with the significant impact of *integrated subcentres* on the population density. In this case they are municipalities that have gone beyond the barrier of 15% commuting journeys to the central agglomeration relatively recently[17] - one of the criteria used by the North American Census Office to delimit metropolitan areas (CPSV, 2000). Their recent integration in the system, combined with their christallerian past, should translate into a notably greater density gradient impact than in the case of the second group. The results obtained seem to confirm the expected differential impact.

2. The majority of these new employment centres have not been covered by the resident population, but rather originate a commuting pattern that is very different to that observed in the seven traditional subcentres, where the level of self-containment is significantly greater and the average distance commuted to the subcentre is less. They are therefore very open job market areas in comparison with the first group, with the result that the expected effect on the density gradient is less.

3. The third element to take into account is that most of them are situated at a shorter distance from the CBD than the integrated subcentres, and therefore the expected effected on the density gradient is also less.

[16] Unfortunately we do not have the data on municipal employment prior to 1986.

6. CONCLUSIONS

In this study we have analysed the differing impact employment subcentres can have on population density depending on its origin, distance from the CBD and the commuting mobility pattern. In order to do so, the BMR subcentres have been identified using different criteria. Once properly catalogued, the empirical evidence indicates that the subcentres that have an integrated origin can be seen to exercise an impact on the population density of nearby areas that is greater than the subcentres that have arisen from decentralisation. The reasons that explain this result are: a) The fact that the subcentres corresponding to groups I and III have functionally integrated recently and that the decentralised subcentres, group II, have not for their part had enough time to generate important changes in the patterns of residential location; b) the fact that the integrated subcentres are relatively distant from the CBD in comparison with the decentralised ones; and c) because the integrated subcentres have a mobility characterised by a high level of self-containment and self-sufficiency in contrast to the opening up of decentralised subcentres job market area.

Although the impact of subcentres on the density gradient is markedly different depending on the group to which they belong, it is also true that, with the passage of time, the strongest likelihood is that they tend to converge, with subcentres from groups I and II reducing their impact and those from group II increasing theirs. This result can be sped up or slowed down depending on the planning decisions adopted. If the aim is to promote a polycentric urban system that preserves a certain compactness, at the same time as a mobility based on short distances and the use of public transport, it would be necessary to match the job profiles better with those of the resident population of the area where the decentralised subcentres are concentrated, as well as preserving the high self-containment of the integrated subcentres. This can only be achieved by suitably regulating the land and housing market and carrying out a consistent transport policy.

[17] Sabadell and Premià in 1981; Martorell and Granollers in 1986; Terassa, Mataró and Arenys de Mar, in 1991; finally, Vilanova, Calella, Malgrat, Sant Sadurní, Sant Pere, Pineda and Sant Celoni, in 1996. (CPSV, 2000).

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